

Objectively measured physical activity and academic performance in school-aged youth: The UP&DOWN longitudinal study

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To examine the longitudinal relationships between objectively measured total volume and specific intensities of physical activity (PA) with academic performance in a large sample of youth aged 6-18 years. A longitudinal study of 1046 youth (10.04 ± 3.10 years) from Spain was followed over 2 years. PA (volume and intensity) was measured by accelerometry. Academic performance was assessed through grades reported on the transcript at the end of the academic year (Mathematics, Language, an average of these two core subjects, and grade point average [GPA]). Longitudinal relationships between PA and four indicators of academic performance were examined using covariance and regression analyses, adjusted for a variety of confounders. Youth Quartile 2 for PA volume at baseline obtained better scores than those who participated in Quartiles 1 or 4 volumes of PA in GPA 2 years later ($p = 0.006$). There were generally no longitudinal associations between specific PA intensities and any of the academic performance indicators (all $p > 0.170$). However, a change in light PA over 2 years was inversely associated with three academic indicators in youth (β_{range} , -0.103 to -0.090 ; all $P < 0.040$). Findings suggest that participants in Quartile 2 volume of PA had a better GPA in comparison with Quartiles 1 and 4 volumes of PA during youth,

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but there was no association with changes in PA volume over time. PA intensity was generally unrelated to academic performance during youth. However, there was an inverted u-shape relationship between light PA changes and GPA.

KEYWORDS

academic achievement, adolescents, children, motor activity, school performance

1 | INTRODUCTION

The physical health benefits of physical activity (PA) for youth are widely acknowledged,¹ yet PA also benefits brain health.^{2–6} Academic performance is a consequence of brain function and has been a cornerstone of the advances achieved by humans.⁷ According to the WHO–UNICEF–Lancet Commission the evidence is clear, early investments in children's education have benefits that compound throughout the child's lifetime, for their future, and society as a whole.⁸ In this sense, growing evidence has been amassed over the past two decades that PA is considered as one of the more promising and cost-efficient methods to enhance brain function and thus succeeding academically during youth.^{3,4,9–24} However, the evidence from these systematic reviews and meta-analytic investigations has documented positive or null effects of either chronic and acute effect PA on academic performance with small-to-moderate effect sizes.^{9,14,18,20,22} A common conclusion of this vast amount of evidence is that many aspects of the causality of the objectively PA on academic performance, such as PA characteristics (ie, volume and/or intensity), remain unclear.

The current PA guidelines for youth recommends children and adolescents aged 5–17 years achieve a minimum of 60 minutes of moderate-to-vigorous PA (MVPA) daily to benefit academic performance.²⁵ However, it is still unknown if there is a maximum threshold of PA volume from which may not be longer benefits or even null consequences for youth's academic performance.^{26,27} In addition, some methodological weaknesses and specific gaps in the field point to the need to explore this further. For instance, much of the previous studies have assessed PA volume with subjective measures.²⁸ In this sense, inconsistent relationships between objective and subjective measured PA and academic achievement have been encountered.¹⁸ Additionally, previous investigations researching this association have mainly considered the PA volume measure as counts per minute.²⁹ Therefore, further investigation on how others PA volume measures affect this aspect is warranted. Concerning past epidemiological studies, only a few investigations have focused on the study of PA volume and academic performance

relationship, which all of them are cross-sectional designs. The results of these previous studies have been inconclusive, reporting null or mediated association (cardiorespiratory fitness).^{30–32} Two of these three investigations assessed academic performance using standardized tests and one with academic indicators. Collectively, the past evidence raises some questions for future research on PA volume, such as the use of objective methods to PA assessment, the need for longitudinal designs, the consideration of different academic indicators, and/or the study of different PA measures.

Unlike PA volume, the association between specific PA intensities and academic performance in youth has been studied more thoroughly. The evidence from randomized controlled trials has generally reported greater benefits on academic performance for higher PA intensities, with the MVPA intensity the most endorsed.^{14,20} Regard to observational data, this fact is less clear and needs further study. Briefly, the past research is mix and inconclusive, wherein some investigations found a positive relationship between some PA intensities (vigorous or MVPA) to academic performance,^{33–36} others showed that association mediated via other variables,^{31,37} others found no association^{30,38–42} or even a negative link.^{43,44} Additionally, some studies have considered the joint effect of the MVPA,^{29,35,38,40,42,45} and others have distinguished between different PA intensity levels.^{34,36,43,46} However, only three longitudinal studies examined this association and were unable to produce consistent conclusions.^{28,29,46} Additionally, none of the three longitudinal studies investigated the association of all PA intensities (light PA, moderate PA, vigorous PA, and MVPA) with academic performance in the same report. In addition to these discrepancies and weaknesses in the literature, there is a need to further research this association with a wide age range of participants. Taken all together, deciphering the dose-response effect of each PA intensity on academic performance, as well as, the consistency and magnitude of its effects over time, still as a current debate.³ Therefore, this study aimed to examine the longitudinal associations between objectively measured total volume and specific intensities of PA with academic performance in a large sample of Spanish youth aged 6–18 years.

2 | METHODS

Data were taken from the UP&DOWN study, which is a 2-year longitudinal study with a convenience sample of 2225 youth aged 6 to 18 years from Spanish schools. In total, 23 schools from Cadiz (1188 children aged 6 to 11) and 22 schools from Madrid (1037 adolescents aged 11 to 18) participated.⁴⁷ Baseline data were collected from September 2011, through June 2012, and 2-year follow-up data were collected from September 2013, through June 2014. From the total UP&DOWN sample, 1780 school-aged youth had valid data at baseline, while 1046 had valid data at a 2-year follow-up (Figure S1 flow chart of study participants).

Before participating in the UP&DOWN study, written informed consent was obtained from parents and participants. The Bioethics Committee of the National Research Council (Madrid, Spain), the Ethics Committee of the Hospital Puerta de Hierro (Madrid, Spain), and the Committee for Research Involving Human Subject at the University of Cádiz (Cádiz, Spain) approved the study protocols.

Objectively measured PA was obtained by the ActiGraph accelerometer models GT1M, GT3X, and GT3X+ (Actigraph TM; LLC, Pensacola, FL, USA). The data from the vertical axis were downloaded and analyzed using the ActiLife software to compare data between different accelerometer models (v.6.6.2 Actigraph TM, Pensacola, FL, USA).⁴⁸ Each participant wore the accelerometer at the lower back for seven consecutive days, removing it during sleep and water-based activities. To be included, youth were required to provide activity monitor data of at least 10h per day for 3 days⁴⁹. Non-wear time was defined as a period of 60 min of zero counts and an allowance of up to two consecutive minutes < 100 counts per minute (cpm) with the up/downstream 30 min consecutive of zero counts for detection of artifactual movements.⁵⁰ Before analyses, data were reintegrated into 10-sec epochs. PA was estimated using cut-points of 100–1999, 2000–3999, and >4000 cpm for light PA, moderate PA, and vigorous PA, respectively.^{43,51} The PA variables included in this study were percentages per day at light PA, moderate PA, vigorous PA and MVPA, and total volume of PA in minutes (light + MVPA). Quartiles of the objective measured the total volume of PA at baseline and at 2-year follow-up were created based on sex-specific and age-specific cutoff points. Quartiles of specific PA intensities at both time points were calculated based on the percentage (%) that each intensity accounted for the total volume of PA. For example: % light PA = (light PA [min/day]/total volume of PA [min/day]) x 100, in which the total volume of PA was the sum in min/day of the three specific PA intensities (light plus MVPA intensity).

The academic performance of each participant was assessed through grades reported on the transcript at the end of the academic year during both time points. Academic performance was based on four indicators: Mathematics, Language, an average of these two core subjects, and grade point average (GPA) score. GPA score was calculated as a single average for the examinable subjects in each grade. For analytic purposes, individual letter grades at baseline and 2-year follow-up were converted to numeric data as follows: A = 5, B = 4, C = 3, D = 2, and F = 1.

Information on age, sex, city (Madrid/Cadiz), maternal education level, physical fitness, accelerometer wear time, and each academic indicator were used as confounders. Height and weight were measured with participants having bare feet and wearing light under-clothes. Height was measured to the nearest 1 mm and weight to the nearest 0.05 kg using a standard beam balance with a stadiometer (SECA 701; SECA, Hamburg, Germany). Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared (kg/m²). Maternal educational level was reported as elementary school, middle school, high school, or university completed. For analyses, maternal educational level responses were dichotomized as university level or below university level.

Physical fitness was measured using cardiorespiratory and motor fitness tests according to the ALPHA Fitness Test Battery.⁵² Specifically, the cardiorespiratory fitness was assessed by the 20-m shuttle run test. The score was the number of stages completed. Motor fitness was assessed with the 4 × 10m shuttle-run test of speed of movement, agility, and coordination. The test was performed twice, and the fastest time was recorded in seconds. The individual score of each test (cardiorespiratory fitness and motor fitness) was standardized as follows: z-standardized value = (value - mean)/SD. A single physical fitness score was calculated as the mean of the two z-standardized scores and used for analyses as a covariate. We included these two components as we found those to be associated with academic performance in a previous paper with the present sample.⁴³

The characteristics of participants are presented as means (SD) or percentages at both time points. Differences between time points were tested by the t test and chi-square tests for continuous and nominal variables, respectively. Since no significant interactions were found for sex or age groups according to age and sex (all *p* > 0.1), all analyses were performed on the whole sample. Analyses were adjusted by sex, age, city, maternal education, physical fitness score, accelerometer wear time, and the academic indicator at baseline. All the analyses were repeated without adjusting for physical fitness score and the results did not change (data not shown). The analyses included 1046 participants who had valid data at both baseline and

2-year follow-up on objectively measured PA, academic performance, and potential confounders. It is important to note that no differences between included vs. excluded participants were observed in studied variables nor at the sociodemographic level.

An analysis of covariance was used to determine whether the quartiles of the total volume of PA at baseline was related to academic performance (each academic indicator per separate) at a 2-year follow-up. We also examined the associations of groups of PA volume change with academic performance at a 2-year follow-up. Thus, the academic performance at a 2-year follow-up was entered as the dependent variable and the groups of PA volume change (from baseline to 2-year follow-up) as an independent variable. The groups of PA volume change were computed as follows: youth who remained in quartiles 1 or 2 at both time points were classified as “persistent low” and those who dropped from an upper quartile at baseline to a lower quartile at follow-up were classified as “decreasing” (from quartiles 3 or 4 to 1 or 2). The other categories were “persistent high” (quartile 3 or 4 at both time points) and “increasing” (those who changed from a lower quartile at baseline to an upper at follow-up, from quartiles 1 or 2 to 3 or 4).

For each PA intensity, we performed an analysis of covariance to determine whether the specific intensities of objectively measured PA at baseline (ie., light PA, moderate PA, vigorous PA, and MVPA) were related to academic performance (each academic indicator) at 2-year follow-up. Also, we examined the associations of groups of PA intensity change with academic performance at a 2-year follow-up. Changes in PA volume within each intensity (light, moderate, vigorous, and MVPA) were also placed into groups resulting in four categories: persistent low, decreasing, persistent high, and increasing.

Linear analysis models were conducted with the Restricted Maximum Likelihood Estimation Method, specifically, the Logarithm of Likelihood -2 ($-2LL$) to ascertain the effects of school clustering on the dependent variables. The “school” variable did not prove statistically significant ($p > 0.05$) for any dependent variable, so analyses, therefore, did not adjust for clustering at the school level. Linear and quadratic regression models were used to examine the potential linear and curvilinear associations between PA variables (min/day) and academic performance outcomes at a 2-year follow-up. The academic performance indicators were included as dependent variables and PA variables as independent variables. Each independent variable was analyzed in a separate regression model for each dependent variable adjusting for confounders.

All statistical analyses were performed using IBM SPSS Statistics for Windows, Version 24.0 (IBM Corp), and the level of significance was set at $p < .05$.

Volume of physical activity

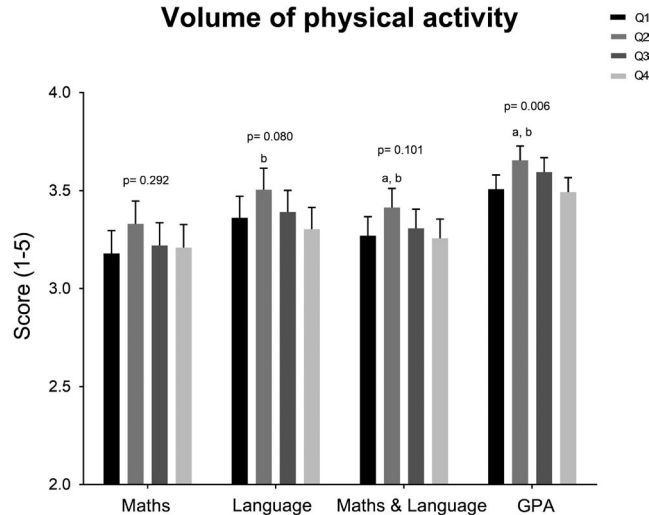


FIGURE 1 Differences in 2-year follow-up academic performance according to the baseline quartiles of the total volume of PA in youth ($n = 1046$). Values are mean (\pm SD). Q1 (lowest), $n = 260$; Q2, $n = 263$; Q3, $n = 264$; Q4 (highest), $n = 259$. PA, physical activity; GPA: grade point average. Q: quartile. Analyses were adjusted by sex, age (years), city (Cadiz/Madrid), the academic indicator at baseline (score), maternal education (university level/below university level), accelerometer wear time at baseline, and physical fitness score (z-score values computed from cardiorespiratory and motor fitness tests). The total volume of physical activity was the sum in min/day of the three specific physical activities intensities at baseline (light, moderate, and vigorous). ^aSignificant differences between Q2 and Q1 ^bSignificant differences between Q2 and Q4

3 | RESULTS

Table S1 Shows the characteristics of the participants. The total volume of PA and specific PA intensities were significantly lower at 2-year follow-up compared to baseline (all $p < 0.001$), except for vigorous PA ($p = 0.075$). Participants had better scores in all academic indicators at baseline in comparison with a 2-year follow-up (all $p < 0.001$). Minutes and percentages of PA outcomes according to quartiles at baseline and 2-year follow-up are shown in Table S2. The flow chart of study participants in the UP&DOWN study is shown in Figure S1.

Figure 1 presents differences in 2-year follow-up academic performance according to the baseline quartiles of the total volume of PA (ie, light PA plus MVPA in min/day). There were significant differences between the total volume of PA and GPA, ($p = 0.006$), and after a Bonferroni adjustment, pairwise significant differences were found when comparing quartile 2 vs 1 (mean difference score: 0.147; $p = 0.006$) and quartile 2 vs 4 (mean difference score: 0.162; $p = 0.002$). However, there were no other significant differences between the total volume of PA and the remaining academic indicators. Figure S2 shows

differences in 2-year follow-up academic performance according to groups of PA volume change (from baseline to 2-year follow-up). There were no significant differences in any academic performance indicator between groups of PA volume change.

Table 1 presents differences in 2-year follow-up academic performance according to baseline quartiles of specific PA intensities. There were no significant differences in any academic performance indicator between quartiles of light PA, moderate PA, vigorous PA, and MVPA. Table 2 presents differences in the 2-year follow-up of academic performance according to groups of PA intensity change. There were no significant differences in any academic performance indicator between groups of PA intensity change.

Table S3, S4 show linear and quadratic regressions between PA intensities at baseline and PA intensity changes with academic performance at a 2-year follow-up in youth. There were no associations between any of the PA intensities nor the total volume of PA at baseline either in

changes with academic performance indicators [(except for quadratic regression in light PA changes with Maths, Maths & Language, and GPA (β_{range} , -.103 to -.090; all $p < .040$)]. The negative coefficients from the quadratic regression suggest an inverted u-shape association.

4 | DISCUSSION

The current study investigated the longitudinal associations between objectively assessed total volume and specific intensities of PA with academic performance among Spanish school-aged youth. The findings indicate that: (a) youth in quartile 2 of PA volume at baseline obtained greater GPA scores than those who participated in other PA volumes, however, changes in PA across different volume groups were unrelated to any of the academic indicators; (b) no longitudinal differences were encountered in specific PA intensities across academic performance indicators; and (c) a curvilinear association was found

TABLE 1 Differences in 2-year follow-up academic performance according to baseline quartiles of specific PA intensities in youth (n = 1046)

	Q1 (lowest) Mean \pm SD		Q2 Mean \pm SD		Q3 Mean \pm SD		Q4 (Highest) Mean \pm SD		P
Light PA (%)									
Maths (1-5)	3.31	1.38	3.28	1.28	3.17	1.28	3.18	1.35	0.871
Language (1-5)	3.41	1.27	3.40	1.29	3.42	1.24	3.33	1.33	0.773
Maths & Language (1-5)	3.36	1.25	3.34	1.20	3.30	1.18	3.25	1.26	0.906
GPA (1-5)	3.60	1.01	3.61	0.94	3.53	0.97	3.51	0.99	0.947
Moderate PA (%)									
Maths (1-5)	3.19	1.32	3.17	1.34	3.30	1.29	3.29	1.34	0.230
Language (1-5)	3.35	1.28	3.33	1.29	3.39	1.30	3.48	1.26	0.632
Maths & Language (1-5)	3.27	1.21	3.25	1.22	3.35	1.23	3.38	1.22	0.359
GPA (1-5)	3.50	0.97	3.53	0.99	3.57	1.01	3.66	0.94	0.214
Vigorous PA (%)									
Maths (1-5)	3.19	1.30	3.12	1.31	3.25	1.32	3.37	1.35	0.766
Language (1-5)	3.36	1.33	3.35	1.29	3.40	1.25	3.44	1.27	0.324
Maths & Language (1-5)	3.28	1.23	3.24	1.21	3.33	1.20	3.41	1.24	0.571
GPA (1-5)	3.55	0.97	3.51	0.97	3.56	0.98	3.63	0.99	0.512
MVPA (%)									
Maths (1-5)	3.17	1.35	3.19	1.28	3.27	1.28	3.32	1.38	0.872
Language (1-5)	3.33	1.33	3.43	1.25	3.38	1.29	3.43	1.27	0.861
Maths & Language (1-5)	3.25	1.26	3.31	1.18	3.33	1.20	3.37	1.25	0.913
GPA (1-5)	3.51	0.99	3.54	0.98	3.60	0.94	3.61	1.01	0.935

Note: Values are mean (\pm SD).

Abbreviations: Q, quartile; PA, physical activity; MVPA, moderate-to-vigorous PA; GPA: grade point average.

Analyses were adjusted by sex, age (years), city (Cadiz/Madrid), maternal education (university level/below university level), physical fitness score (z-score values computed from cardiorespiratory and motor fitness tests at baseline), accelerometer wear time at baseline, and the academic indicator at baseline (score).

TABLE 2 Differences in 2-year follow-up academic performance according to groups of PA intensity change (from baseline to 2-year follow-up) in youth (n = 1046)

	<i>Persistent low</i> Mean \pm SD		<i>Decreasing</i> Mean \pm SD		<i>Persistent high</i> Mean \pm SD		<i>Increasing</i> Mean \pm SD		P
Light PA (%)									
<i>n</i>	365		163		152		366		
Maths (1-5)	3.30	1.35	3.22	1.33	3.13	1.30	3.27	1.31	0.569
Language (1-5)	3.45	1.32	3.41	1.31	3.24	1.28	3.40	1.24	0.414
Maths & Language (1-5)	3.38	1.26	3.31	1.25	3.18	1.19	3.34	1.19	0.474
GPA (1-5)	3.61	0.99	3.57	1.00	3.48	0.96	3.57	0.96	0.722
Moderate PA (%)									
<i>n</i>	377		223		123		323		
Maths (1-5)	3.09	1.34	3.30	1.31	3.19	1.39	3.27	1.29	0.303
Language (1-5)	3.27	1.26	3.45	1.24	3.36	1.36	3.41	1.31	0.667
Maths & Language (1-5)	3.18	1.20	3.38	1.19	3.27	1.32	3.34	1.23	0.392
GPA (1-5)	3.45	0.97	3.62	0.96	3.54	0.99	3.58	1.00	0.172
Vigorous PA (%)									
<i>n</i>	354		164		177		351		
Maths (1-5)	3.07	1.30	3.28	1.34	3.36	1.30	3.21	1.32	0.943
Language (1-5)	3.18	1.39	3.38	1.27	3.55	1.22	3.41	1.27	0.269
Maths & Language (1-5)	3.13	1.24	3.33	1.23	3.46	1.19	3.31	1.21	0.770
GPA (1-5)	3.43	1.00	3.57	0.99	3.66	0.98	3.56	0.96	0.919
MVPA (%)									
<i>n</i>	365		154		163		364		
Maths (1-5)	3.13	1.32	3.28	1.30	3.29	1.37	3.20	1.32	0.510
Language (1-5)	3.25	1.29	3.41	1.23	3.44	1.32	3.41	1.31	0.445
Maths & Language (1-5)	3.19	1.20	3.35	1.18	3.37	1.27	3.30	1.24	0.471
GPA (1-5)	3.49	0.98	3.58	0.95	3.60	1.00	3.56	1.00	0.633

Note: Values are mean (\pm SD).

Abbreviations: PA, physical activity; MVPA, moderate-to-vigorous PA; GPA, grade point average.

Analyses were adjusted by sex, age change (from baseline to 2-year follow-up in years), city (Cadiz/Madrid), maternal education (university level/below university level), physical fitness score (z-score values computed from cardiorespiratory and motor fitness tests change from baseline to 2-year follow-up), accelerometer wear time change (from baseline to 2-year follow-up), and the academic indicator at baseline (score).

between light PA intensity changes and three academic performance indicators.

Our findings indicate that adolescents who engaged in just under 250mins/day of total PA (all PA intensities combined) had a better academic performance (specifically for GPA) 2 years later compared to those who engaged in higher or lower PA volumes at baseline. Our data indicate that youth in quartile 2 showed greater scores in comparison with quartiles 1 and 4 in all the academic performance indicators, but only significant for GPA. Recent systematic reviews of randomized controlled trials showed a significant and positive impact of PA on academic performance in youth.^{53–55} However, the optimal volume of PA to achieve academic performance benefits is still unknown. Some studies have demonstrated that the combination of higher PA intensities and higher volumes

lead to greater improvements for academic performance^{56,57} Additionally, several cross-sectional studies have examined the associations between total objectively measured PA and academic performance but the evidence is mixed and inconclusive.^{30,31,41,42} For instance, a study with 1271 school-age children found that those reporting less than 2 hours of weekly scheduled exercise had significantly lower performance in three academic indicators than those reporting more than 4 hours.⁵⁸ Collectively, the findings from these previous studies suggest that the total volume of PA during youth may be related to academic performance somehow. Although it is not in the scope of the current study, some hypotheses could explain our findings. For instance, high PA volumes could displace other out-of-school activities associated with enhanced academic performance, such as recreational reading⁵⁹

or art school activities (eg., music instruments, singing, dance, and drama).⁶⁰ While the deleterious effect of low PA volumes could be due to the longer time spent using a smartphone or playing video games, however, this hypothesis is not consistent across the literature.^{61,62} Our results together with previous evidence seem to indicate that a certain threshold of weekly PA time is required to produce positive effects on academic performance. Nonetheless, further longitudinal studies and randomized controlled trials should examine the displacement effects of behaviors considering both the quality and the quantity of these behaviors to confirm or refute these hypotheses.

Our longitudinal findings showed that a PA volume change pattern over 2 years appeared unrelated to academic performance prospectively. Additionally, our data showed an inconsistent pattern of associations between changes in PA and all academic indicators which makes it difficult to conclude from our results. Certainly, there are other factors not captured by our measures that could explain these findings. For instance, parental expectations about how much time youth are allowed to devote to PA or study time may partially explain these inconsistent findings.⁶³

In our study, we did not find any dose-response longitudinal associations of PA in specific intensities across academic performance indicators during youth. Also, our data are inconsistent with the findings provided by the only two longitudinal studies, which did find a positive relationship between MVPA and academic performance.^{29,46} Some differences in study design (eg., sample size, age range, and accelerometer models) could partially explain this variation. Booth et al., (2014) included a sample size four times larger than the present study and had a longer follow-up period (5 years). Lima et al., (2019) included participants younger than in our study ($n = 902$, age range = 7 to 12) with a 3-year follow-up. The main methodological difference between these previous studies and the present study is we used MVPA based on the percentage of the total volume of PA, however, the previous studies did not. Additionally, the lack of a significant finding in our study corresponds with some cross-sectional studies.^{35,38–40} Nevertheless, while the current evidence coming from randomized controlled trials suggests a beneficial effect of MVPA on academic performance, most of them are short term and therefore longer interventions are warranted.^{3,9,12,14,22,64–66}

Our regression analyses showed an inverted u-shaped association between light PA changes with all academic indicators, except for Language. This finding suggests that positive changes in light PA (to a point) over 2 years may be important for academic performance. The objective measurement of light PA does not distinguish between the type of activity, such as sitting studying, or playing

darts. In this sense, the PA can be light but the cognitive engagement is high and therefore have some effects on the brain function which in turn might impact the academic performance. To highlight, the aim of our research was to investigate the physical activity pattern in relation to academic performance and not to include sedentary behavior. Accelerometer data are unable to discriminate between the different components of sedentary time (standing, screen time, non-screen-based sedentary time, sitting, reclining, lying, etc.), and thus, it is not possible to know the types of sedentary behavior that children were engaged in.⁶⁷

The desirable pattern might be children or adolescents who perform recommended levels of MVPA and low levels of sedentary time; therefore, further studies should include the 24h movement and non-movement behavior and use temporal or compositional analyses to confirm these hypotheses. Either way, we suggest that for academic performance, practitioners and physical education teachers should promote students' engagement doses of light PA, as well as higher intensities of PA as per public health recommendations until further studies provide more evidence.

Despite having a relatively large sample size, our findings may not be generalizable to other geographic locations nor a wider sociodemographic spectrum. Our analyses were based on quartiles of PA created based on sex- and age-specific cut-points for a specific sample. Since PA levels and academic performance in youth vary across countries, such differences in quartiles might influence the results. The high attrition rate in our study limits the generalizability of study findings. The accelerometer does not capture water-based and weight-bearing activity impeding capture of all types of PA, which could be considered another limitation. The academic indicators used for the current study are most probably different from other educational systems and partly rely on teacher's perceptions and both facts may also affect the data interpretation. The recruitment by a convenience sample may have introduced bias. Key strengths of the current study were that it is the first longitudinal study to investigate the total volume of PA and specific PA intensities. This study had a relatively large sample size using objective measures with two different time points.

5 | CONCLUSION

This longitudinal study suggests that engaging in approximately 250 mins/day (quartile 2) of total PA volume at baseline was associated with a better academic performance 2 years later, specifically with GPA. Although specific PA intensities were not generally related to

participants' academic performance, we found an inverted u-shape association between light PA changes over 2 years and three academic indicators in youth. However, no other associations were seen in terms of specific PA intensities. The modification of PA volume and intensity across childhood and adolescence might be considered as a changeable PA element to influence academic performance across childhood and adolescence.

6 | PERSPECTIVE PARAGRAPH

Our results showed that being in Quartile 2 volume of PA was related to a better GPA in comparison with Quartiles 1 and 4 volumes of PA during youth, but there was no relationship with changes in PA volume. Also, we did not see a clear relationship between specific PA intensities and academic performance during youth was found. However, an inverted u-shape relationship was found for the association between change in light PA and GPA during youth. Collectively, our results suggest that practitioners and physical education teachers should promote students engagement in optimal volumes of PA, but the benefits of higher volumes of PA on academic performance need further exploration. The modification of PA intensity across childhood and adolescence might be used as a changeable PA element to influence academic performance across childhood and adolescence; however, more evidence is required.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the youth, parents, and teachers who participated in this study. The UP&DOWN Study was supported by the DEP 2010-21662-C04-00 grant from the National Plan for Research, Development, and Innovation (R + D + i) MICINN. DM-G is supported by a 'Ramon y Cajal' contract (RYC-2016-20546). IE-C is supported by the Spanish Ministry of Economy and Competitiveness (RTI2018-095284-J-100). AM-M was a recipient of a José Castillejo Fellowship from the Spanish Ministry of Science, Innovation, and Universities (CAS19/00265). JS is supported by a Leadership Level 2 Fellowship, National Health and Medical Research Council Australia (APP 1176885). This research was partially funded by "Convocatoria extraordinaria de ayudas a la investigación. Preparación, ejecución y transferencia de conocimiento (convocatoria 2020) de l'Institut de Recerca i Innovació Educativa (IRIE)".

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

How to cite this article: Muntaner-Mas A, Martínez-Gómez D, Castro- Piñero J, et al. Objectively measured physical activity and academic performance in school-aged youth: The UP&DOWN longitudinal study. *Scand J Med Sci Sports.* 2021;31:2230–2240. <https://doi.org/10.1111/sms.14036>