



## Original research

## Is adherence to 24-Hour Movement Guidelines associated with a higher academic achievement among adolescent males and females?

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## ABSTRACT

**Objectives:** This study aims to examine the independent and combined associations of 24-Hour Movement Guidelines for physical activity, screen time, and sleep duration with academic achievement in adolescent males and females.

**Design:** Cross-sectional study.

**Methods:** 1290 Spanish adolescents (565 females), aged 11 to 16 years ( $13.06 \pm 0.84$ ), participated in this study. Self-reported physical activity, screen time, and sleep duration questionnaires were assessed. Academic achievement was calculated as an average score of the adolescents' grades in first language (Spanish), first foreign language (English), and mathematics subjects. A multiple linear regression model was used to examine the association between meeting 24-Hour Movement Guidelines and academic achievement. Covariates included age, sex, socioeconomic status, body mass index, and cardiorespiratory fitness.

**Results:** Not meeting any of the three 24-Hour Movement Guidelines was associated with lower academic achievement in the whole sample ( $p < 0.001$ ). Meeting physical activity and sleep duration guidelines, both independently and together, was associated with higher academic achievement in the whole sample ( $p < 0.001$ ). Meeting at least two recommendations was associated with higher academic achievement in males ( $p < 0.01$ ). However, trend analysis revealed that participants who met two or three recommendations had higher academic achievement compared to those who met one or none of these recommendations ( $p < 0.05$ ). All these results were similar for males and females.

**Conclusions:** Our findings suggest the importance of promoting more than one 24-Hour Movement Guidelines, mainly physical activity and sleep duration, which seems to contribute positively to increased academic performance in adolescents.

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## Practical implications

- Not meeting any of the three 24-Hour Movement Guidelines was associated with lower academic achievement in both sexes.
- Meeting physical activity guidelines was associated with higher academic achievement in the whole sample but not in both sexes.
- Meeting sleep duration guidelines and meeting both physical activity

and sleep duration were associated with higher academic achievement in the whole sample and both sexes.

- Meeting two recommendations was associated with higher academic achievement in males.
- Meeting all three 24-Hour Movement Guidelines was not related to higher academic achievement.

## 1. Introduction

Academic achievement among students refers to their degree of success in achieving educational goals, and can be measured by their grade-point average, as a cluster of achievement test, or by using a specific test

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for assessing reading or arithmetic skills such as reading speed, fluency and comprehension, and the ability to solve logical/arithmetic problems.<sup>1</sup> Academic achievement has been associated with work opportunities in adulthood and some positive health indicators such as self-esteem and subjective well-being.<sup>2</sup>

Although there are multiple factors associated with higher academic achievement, the adoption of a healthy lifestyle has been shown to be one of the most important correlates of brain development processes and cognitive function.<sup>3</sup> Previous systematic reviews and meta-analysis have shown that higher physical activity levels,<sup>4</sup> lower levels of sedentary behaviors (mainly recreational screen time),<sup>5</sup> and optimal sleep duration<sup>6</sup> have been positively and independently related to academic achievement in children and adolescents. Physical activity has been shown to be more strongly associated with academic achievement among females than males<sup>7</sup>; however, the few existing studies that have examined sex differences in the relationship between screen time<sup>8</sup> or sleep duration<sup>9</sup> and academic achievement have found inconsistent results. Therefore, further studies that examine the relationship of sleep duration and screen time with academic achievement in both males and females are required.

A large body of knowledge has found that these movement (physical activity) and non-movement (sedentary time and sleep duration) behaviors are co-dependent across the entire day (24-hour period) and should therefore be considered simultaneously.<sup>10</sup> It is well known that meeting 24-Hour Movement Guidelines (i.e.,  $\geq 60$  min/day of moderate-to-vigorous physical activity and muscle and bone strengthening activities should each be incorporated at least 3 days per week,  $\leq 2$  h/day of recreational screen time, and 8–10 h/night of sleep duration) has been associated with many positive health indicators (e.g., health-related quality of life, adiposity, and fitness) in adolescents.<sup>11</sup> Given most previous studies have examined the relationship between these 24-Hour Movement Guidelines and academic achievement in isolation, little is known about how the different possible combinations of these recommendations are related to academic achievement.

To our knowledge, only three studies have examined the association between meeting the overall 24-Hour Movement Guidelines and academic achievement among children<sup>12</sup> and adolescents.<sup>13,14</sup> Howie et al.<sup>13</sup> showed that adolescents who met screen time recommendations and at least two 24-Hour Movement Guidelines behaviors had higher academic achievement. However, this study also suggested that meeting these two recommendations was not necessarily better than just meeting screen time recommendations in terms of academic achievement. A limitation of the study of Howie et al.<sup>13</sup> is that the four possible combinations of the 24-Hour Movement Guidelines (i.e., physical activity + screen time, physical activity + sleep duration, screen time + sleep duration, and physical activity + screen time + sleep duration) were not calculated; therefore, it is not possible to know what combination of these three 24-Hour Movement Guidelines could be related to higher academic achievement. In the study of Lien et al.,<sup>14</sup> the three 24-Hour Movement Guidelines were not independently associated with academic achievement; however, adolescents who met the combination of screen time and sleep duration guidelines or the three 24-Hour Movement Guidelines had a higher academic achievement than those who met one or none of these recommendations. Moreover, Watson et al.<sup>12</sup> reported that meeting all three 24-Hour Movement Guidelines or the combination of screen time and sleep duration guidelines was related to higher literacy achievement, while meeting physical activity guidelines in any combination was associated with higher numeracy achievement. Therefore, two of the three existing studies suggest that meeting more 24-Hour Movement Guidelines might have additional benefits in terms of academic achievement.<sup>12–14</sup> However, neither study examined sex differences in the association between 24-Hour Movement Guidelines and academic achievement among adolescents.<sup>13,14</sup> Knowing which combination of 24-Hour Movement Guidelines is associated with academic

performance in adolescent males and females may be of great interest to develop sex-specific strategies.

This study aims to expand current knowledge regarding the association between the meeting of different possible combinations of the 24-Hour Movement Guidelines and academic achievement in adolescents. Moreover, to fill the gap regarding sex differences in this relationship, a secondary aim of this research is to examine possible differences between males and females.

## 2. Method

The baseline data were collected before the COVID-19 pandemic, from March 2018 to June 2019, in south-western Spain. A total of 2217 participants from 22 high schools participated in the study, using a simple random sample. Out of the total number of adolescents, 940 were excluded because they had missing values on academic achievement ( $n = 233$ ), physical activity ( $n = 7$ ), sedentary screen time ( $n = 452$ ), sleep duration ( $n = 104$ ), cardiorespiratory fitness (CRF [ $n = 143$ ]), and body mass index (BMI [ $n = 1$ ]). A final sample of 1277 adolescents, aged 11 to 16 years, and consisting of 712 males ( $13.13 \pm 0.91$  years old) and 565 females ( $13.06 \pm 0.86$  years old), participated in the study (see Fig. 1 for a flow chart on inclusion criteria). This study was conducted in accordance with the Declaration of Helsinki and this research was approved by the Ethics Committee of the main author's University (89/2016).

**Physical activity.** Physical activity was measured using the Spanish version of a self-reported questionnaire called Physical Activity Questionnaire for Adolescents (PAQ-A). The PAQ-A is a valid (the PAQ-A correlation with total physical activity [ $r = 0.39$ ] and moderate and vigorous physical activity [ $r = 0.34$ ] assessed by accelerometer) and reliable ( $\alpha = 0.79$  and Intraclass Correlation Coefficient [ICC] = 0.71) measure to assess physical activity levels in Spanish young people aged 12 to 17 years.<sup>15</sup> In the present study, Cronbach's alpha on this scale was 0.88. This scale comprises nine questions that assess the frequency of participation in physical activities in the last 7 days at different moments, including during physical education, during school breaks, during lunchtime, after school, evenings, and weekends. Each answer is scored on a 5-point scale ranging from 1 to 5. The physical activity score was calculated as the average value of all responses. Higher scores indicate higher levels of physical activity. Physical activity guidelines were categorized as either "meeting" or "not meeting" based on a cut-off score of 2.75 in the PAQ-A.<sup>16</sup>

**Recreational screen time.** Recreational screen time was measured using the Youth Leisure-Time Sedentary Behaviour Questionnaire (YLSBQ). The YLSBQ is a valid ( $r = 0.36$ ) and reliable (ICC = 0.75) measure to assess sedentary recreational screen time among Spanish young people aged 8 to 18 years.<sup>17</sup> In the present study, however, four different screen-based behaviors were measured (i.e., TV, videogames, computer, and mobile phone). The daily average time spent on each screen-based behavior was calculated by weighing weekday and weekend day times at a ratio of 5:2 (i.e., [daily screen time on weekdays  $\times 5$ ] + [daily screen time on weekend days  $\times 2$ ] / 7). Total daily recreational screen time was measured by the sum of different daily screen-based behaviors.

**Sleep duration.** Sleep duration was measured using a Spanish translation of a self-reported sleep questionnaire.<sup>18</sup> We evaluated the sleep period as recommended by a previous systematic review with meta-analysis. Adolescents self-reported their usual bedtime and wake-up time for school days and non-school days. Daily sleep duration was calculated by weighing weekday and weekend day amounts at a ratio of 5:2 (i.e., [daily sleep duration on weekdays  $\times 5$ ] + [daily sleep duration on weekend days  $\times 2$ ] / 7). These questions have been shown as a valid ( $r = 0.45$ – $0.90$ ) and reliable (ICC = 0.71–0.99) measure to assess sleep duration in children aged 9 to 12 years old.<sup>18</sup>

**Academic achievement.** School grades were provided at the end of the academic year by each high school. Consistent with most previous studies, academic achievement was measured using the average score of

three subjects: first language (Spanish), first foreign language (English), and mathematics.

Covariates included in our models were age (in years), sex (male/female), socio-economic status (SES), BMI, and CRF. Students self-reported age and sex. SES was obtained according to the level of average income per family unit in each of the cities/villages of the Region of Extremadura. Weight and height were used to calculate BMI (kg/m<sup>2</sup>). CRF was measured with the 20-meter shuttle run test as described by Leger. Before the analysis, the final score, computed as the number of stages completed, was converted into ml/kg/min.

The research team contacted the principal at each school to conduct this study. Parents were informed on the nature and purpose of the study by letter. Written informed consent was required from both adolescents and their parents/legal guardians. The paper-and-pencil questionnaire was administered in a regular classroom by one member of the research team. Students' health-related behaviors were assessed before anthropometric measurements were taken. After completing the questionnaires, the children were measured and weighed individually in a private room by a researcher of the same sex as the child. Finally, the 20-meter shuttle run test was performed in the school's playground. All measures were collected in approximately 60 min.

Descriptive statistics are presented as means and standard deviations or number of subjects and percentages (%).

The multilevel approach was not supported given the low level-2 variability (intraclass correlation coefficient lower than 0.08 for all indicators),<sup>19</sup> therefore, the multilevel analysis was not supported.<sup>20</sup> Multiple linear regression analyses (method: forced entry) were used to examine the associations between physical activity, screen time, sleep duration, and academic achievement. The assumptions of outliers, collinearity, independent errors, random normal distribution of errors, homoscedasticity and linearity, and non-zero variances were tested, and all of these conditions were met. Relationships between meeting

24-Hour Movement Guidelines for moderate-to-vigorous physical activity (≥60 min/day), recreational screen time (≤2 h/day), and sleep duration (8–10 h/night) with academic achievement were assessed using a one-way covariance analysis (ANCOVA). Each 24-Hour Movement Guideline and all possible combinations were examined. Participants were classified into one of the following categories (i.e., not meeting recommendations, meeting exclusively physical activity, meeting exclusively screen time, meeting exclusively sleep duration, meeting physical activity + screen time, meeting physical activity + sleep duration, meeting screen time + sleep duration, and meeting all three recommendations [see Table 2]). Meeting at least only one or two 24-Hour Movement Guidelines was also calculated. Since previous studies have pointed out that age, sex, SES, BMI, and CRF are confounding variables in these relationships, all analyses were adjusted by these variables.<sup>21</sup> Finally, an ANCOVA between not meeting any of these recommendations, meeting at least one, meeting at least two, or meeting the three 24-Hour Movement Behaviours and academic achievement was conducted (see Fig. 1), after adjusting for age, sex, BMI, and CRF. Since a preliminary analysis showed a significant interaction by sex in the association between 24-Hour Movement Guidelines and academic achievement (all  $p < 0.01$ ), sex-separately analyses were conducted. This analysis is also justified because some previous studies have indicated that the relationship of these behaviors, especially physical activity,<sup>7</sup> could be related in different ways to academic performance in men and women. All statistical analyses were conducted using SPSS version 23.0 for Windows (IBM, Armonk, New York) and the level of significance was set at  $p < 0.05$ .

### 3. Results

Descriptive characteristics and 24-Hour Movement Guidelines of the participants are presented in Table 1 according to sex. For the adherence

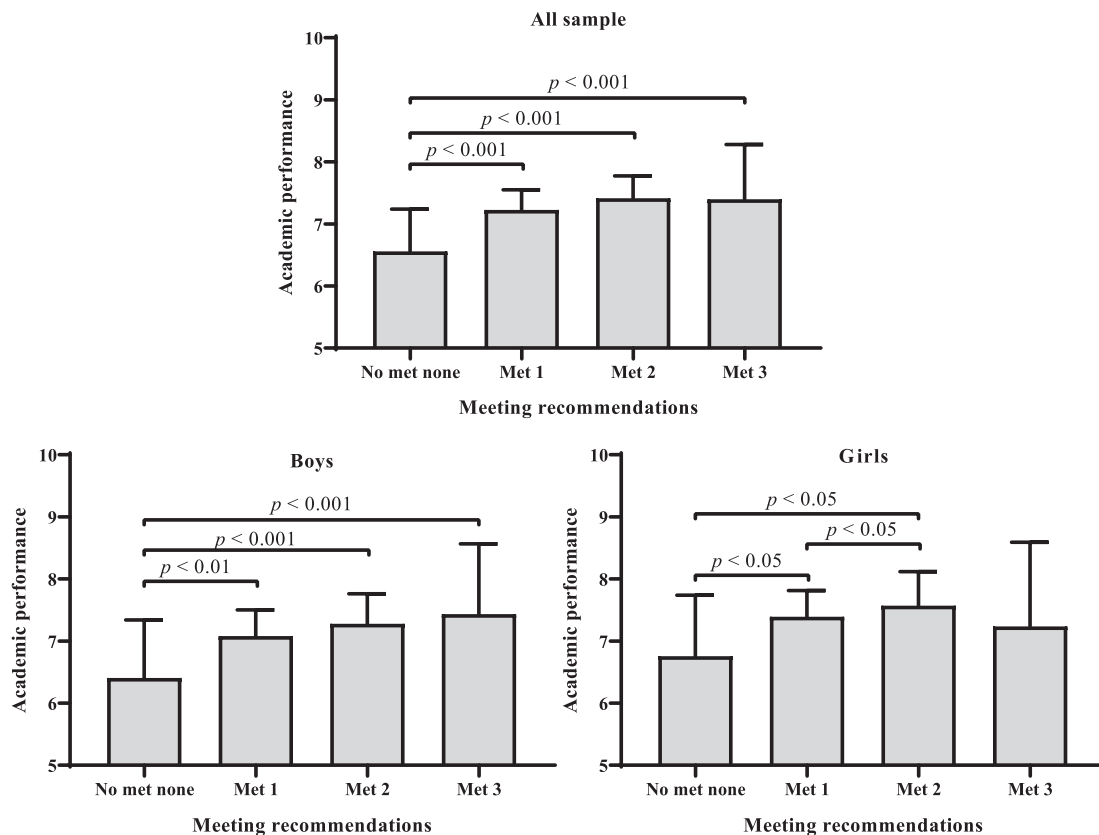


Fig. 1. Differences between students that met none, met one, met two or met three guidelines and academic performance. Note. Covariates included were age, sex, socioeconomic status, and cardiorespiratory fitness.

**Table 1**  
Descriptive characteristics of the participants and prevalence of 24-Hour Movement Guidelines in whole sample and by sex.

Study variables	Total	Males	Females
	M ± SD	M ± SD	M ± SD
n (%)	1277 (100.00)	712 (55.80)	565 (44.20)
Age (years old)	13.06 ± 0.84	13.08 ± 0.86	13.04 ± 0.81
Socioeconomic status (€)	20,554.84 ± 2986.25	20,601.18 ± 2946.28	20,496.45 ± 3037.48
Body mass index (kg/m <sup>2</sup> )	21.14 ± 3.76	21.24 ± 3.88	21.03 ± 3.61
Cardiorespiratory fitness (ml/kg/min)	42.70 ± 5.97	44.79 ± 6.25	40.07 ± 4.34
Physical activity (1–5)	2.54 ± 0.60	2.30 ± 0.51	2.12 ± 0.47
Screen time (h/day)	4.51 ± 2.25	4.61 ± 2.19	4.40 ± 2.32
Sleep duration (h/night)	8.67 ± 0.90	8.67 ± 0.95	8.68 ± 0.48
Academic achievement (0–10)	6.98 ± 1.79	6.83 ± 1.82	7.17 ± 1.74
Not meeting recommendations n (%)	124 (9.60)	70 (9.80)	54 (9.50)
Physical activity recommendations (≤60 min/day) n (%)			
Not meeting	792 (62.00)	392 (54.90)	511 (70.80)
Meeting	485 (38.00)	320 (45.10)	165 (29.20)
Screen time recommendations (≤2 h/day) n (%)			
Not meeting	1077 (82.70)	612 (81.00)	465 (84.80)
Meeting	200 (15.70)	100 (14.10)	100 (17.70)
Sleep duration recommendations (8–10 h/day) n (%)			
Not meeting	222 (17.30)	136 (19.00)	86 (15.20)
Meeting	1055 (82.70)	576 (81.00)	479 (84.80)
Meeting at least one recommendation n (%)	637 (50.0)	331 (46.60)	306 (54.20)
Physical activity + screen time recommendations n (%)			
Not meeting	1191 (93.30)	658 (92.40)	533 (94.30)
Meeting	86 (6.70)	54 (7.60)	32 (5.70)
Physical activity + sleep duration recommendations n (%)			
Not meeting	891 (67.80)	462 (62.40)	429 (74.50)
Meeting	386 (32.20)	250 (37.60)	136 (25.50)
Screen time + sleep duration recommendations n (%)			
Not meeting	1117 (87.10)	633 (88.70)	484 (85.00)
Meeting	160 (12.90)	79 (11.30)	81 (15.00)
Meeting at least two recommendations n (%)	440 (34.50)	263 (37.00)	177 (31.30)
Meeting three recommendations (PA + ST + SD) n (%)	1203 (94.20)	666 (93.50)	537 (95.00)

Note. PA: physical activity; ST: screen time; SD: sleep duration.

to the 24-Hour Movement Guidelines, a larger proportion of males met recommendations for physical activity, screen time, sleep duration, and the combinations of physical activity + sleep duration and screen time + sleep duration.

Table 2 presents the associations between (non)movement behaviors and academic achievement in the whole sample and by sex. Physical activity, screen time, and sleep duration were associated with academic achievement in the whole sample ( $\beta = 0.18$ ; 95% confidence interval [CI]: 0.36, 0.65;  $p < 0.001$ ;  $\beta = -0.07$ ; 95% CI:  $-0.01, 0.00$ ;  $p = 0.014$ ;  $\beta = 0.20$ ; 95% CI: 0.27, 0.46;  $p < 0.001$ ), as well as for only males ( $\beta = 0.13$ ; 95% CI: 0.16, 0.57;  $p < 0.001$ ;  $\beta = -0.07$ ; 95% CI:  $-0.02, 0.00$ ;  $p = 0.041$ ;  $\beta = 0.17$ ; 95% CI: 0.18, 0.43;  $p < 0.001$ ) and only females ( $\beta = 0.30$ ; 95% CI: 0.62, 1.06;  $p < 0.001$ ;  $\beta = -0.05$ ; 95% CI:  $-0.02, 0.00$ ;  $p = 0.217$ ;  $\beta = 0.24$ ; 95% CI: 0.30, 0.61;  $p < 0.001$ ), unadjusted for covariates. In addition, a negative association between screen time and academic achievement was found only in males ( $\beta = -0.06$ ; 95% CI:  $-0.02, 0.00$ ;  $p = 0.041$ ). After the results were adjusted by covariates, similar statistics were found in all analyses, except in the relationship between screen time and academic achievement in the whole sample ( $\beta = -0.04$ ; 95% CI:  $-0.01, 0.00$ ;  $p = 0.066$ ), for males ( $\beta = -0.06$ ; 95% CI:  $-0.02, 0.00$ ;  $p = 0.071$ ) and for females ( $\beta = -0.02$ ; 95% CI:  $-0.01, 0.01$ ;  $p = 0.463$ ). The individual association between movement behaviors and the assessed subjects can be found in the Supplementary material 1.

The associations between meeting each of the 24-Hour Movement Guidelines and all together and academic achievement in the whole sample and by sex are shown in Table 3. Before the results were adjusted for covariates, meeting exclusively physical activity ( $\beta = 0.27$ ; 95% CI: 0.09, 0.46;  $p < 0.01$ ) and sleep duration ( $\beta = 0.90$ ; 95% CI: 0.66, 1.13;  $p < 0.001$ ) recommendations, as well as meeting both recommendations ( $\beta = 0.47$ ; 95% CI: 0.28, 0.67;  $p < 0.001$ ) were positively associated with academic achievement. However, meeting physical activity recommendations ( $\beta = 0.22$ ; 95% CI:  $-0.01, 0.47$ ;  $p = 0.066$ ) was

not associated with academic achievement in males. Similar results were found after the covariate adjustment in both sexes, except for the relationship between physical activity recommendations and academic achievement in females, which was not significant ( $\beta = 0.23$ ; 95% CI:  $-0.04, 0.50$ ;  $p = 0.103$ ).

Finally, Fig. 1 reveals the differences in academic achievement according to the number of 24-Hour Movement Guidelines met. Adolescents who meet one, two, or the three recommendations obtained higher academic achievement than those who did not meet any of these recommendations (in the whole sample, in females, and in males, all  $p < 0.05$ ). Females who met one or two recommendations had higher academic achievement than those who did not meet any recommendations (all  $p < 0.05$ ).

#### 4. Discussion

This study aimed to examine the independent and combined associations of all three recommendations for physical activity, screen time, and sleep duration with academic achievement in adolescent males and females. The main findings of this study are that: 1) meeting sleep duration guidelines and meeting both physical activity and sleep duration guidelines were positively associated with greater academic achievement in both males and females, while meeting only physical activity guidelines was associated with higher academic achievement in the overall sample but not in males and females; and 2) meeting two recommendations was related to higher academic achievement in males compared to those who met only one or none of these recommendations.

Firstly, it must be noted that not meeting any 24-Hour Movement Guidelines was associated with lower academic achievement among adolescents. This could be because (non)movement behaviors have been related to brain development processes and cognitive function.<sup>3</sup> In our study, the adolescents who met physical activity

**Table 2**

Associations between each of the three movement behaviors (physical activity, screen time, and sleep duration) and academic achievement in the whole sample and by sex.

Models	All sample		Males		Females	
	β (95% CI)	p	β (95% CI)	p	β (95% CI)	p
<b>Unadjusted</b>						
Physical activity	0.18 (0.36, 0.65)	<0.001	0.13 (0.16, 0.57)	<0.001	0.30 (0.62, 1.06)	<0.001
Recreational screen time	−0.07 (−0.01, 0.00)	0.014	−0.07 (−0.02, 0.00)	0.041	−0.05 (−0.02, 0.00)	0.217
Sleep duration	0.20 (0.27, 0.46)	<0.001	0.17 (0.18, 0.43)	<0.001	0.24 (0.30, 0.61)	<0.001
<b>Adjusted</b>						
Physical activity	0.16 (0.29, 0.59)	<0.001	0.10 (0.09, 0.49)	<0.01	0.22 (0.40, 0.84)	<0.001
Recreational screen time	−0.04 (−0.01, 0.00)	0.066	−0.06 (−0.02, 0.00)	0.071	−0.02 (−0.01, 0.01)	0.463
Sleep duration	0.14 (0.17, 0.63)	<0.001	0.13 (0.10, 0.35)	<0.001	0.17 (0.18, 0.48)	<0.001

Note. The reported β values are standardized coefficients.

Covariates included were age, sex, socioeconomic status (€), body mass index (kg/m<sup>2</sup>), and cardiorespiratory fitness (ml/kg/min).

recommendations reported higher academic achievement. Most of the previous studies conducted among adolescents also found a positive association between meeting physical activity recommendations and academic achievement.<sup>4,21</sup> Although the possible mechanisms that explain this association have not been examined in this study, it is well known that physical activity improves variables related to cognition such as executive function and skills, metacognition, inhibition, and memory, which may in turn, have a positive relationship with academic achievement.<sup>22</sup> The effect of physical activity on the brain could be the result of several factors such as increased cerebral blood flow, oxygen to the brain, synaptic plasticity activity, and neurotransmitter secretion levels, resulting in increased levels of arousal, attention, and effort, which positively impact cognitive task performance immediately after physical activity.<sup>22</sup>

Moreover, consistent with previous studies among adolescents,<sup>23</sup> results of this study indicated that meeting sleep duration guidelines was associated with higher academic achievement among males and females. It is well known that quantity and quality of sleep are related to cognitive improvements such as better memory, attention, and executive control, all of which can contribute to higher academic achievement.<sup>23</sup> Many studies have highlighted that sleep is an active rather than a passive state that optimizes the storage process of acquired or learned information.<sup>24</sup> This process allows the brain to integrate all acquired information into memories that we can access at any

time.<sup>24</sup> The reproduction and integration of memories into long-term memory and the optimization of synaptic connections through synaptic consolidation are promoted when people sleep.<sup>24</sup> Therefore, meeting sleep recommendations has a positive effect on the ability of adolescents to encode and retain learned information, making it accessible in the long term.<sup>24</sup> Given that most teachers in Spain use memory tests to evaluate students, Spanish adolescents who sleep the recommended number of hours may retain information more effectively and, consequently, get better grades.<sup>25</sup> However, all of the mechanisms that explain the relationship between sleep time recommendations and academic achievement are not yet known; therefore, more studies are needed to investigate the mechanisms that explain this possible relationship among young people.

Unlike the other two behaviors, this study did not show a significant relationship between recreational screen time recommendations and academic achievement. Although our findings are in line with a recent systematic review with meta-analysis that found that the amount of time spent on overall screen media use was not associated with academic achievement,<sup>5</sup> most previous research has found opposite results.<sup>26</sup> These inconsistent results between studies can be explained by the type of screen-based behavior assessed in each study (e.g., TV, videogame, computer, mobile phone, and tablets), the purpose (e.g., social communication, online networking, and playing games), and the context in which the screen media is used (e.g., educational:

**Table 3**

Associations between meeting each of the 24-Hour Movement Guidelines and all together and academic achievement in the whole sample and by sex.

Models	All sample			Males			Females		
	β (95% CI)	p	η <sup>2</sup>	β (95% CI)	p	η <sup>2</sup>	β (95% CI)	p	η <sup>2</sup>
<b>Unadjusted</b>									
Not meeting recommendations	−0.95 (−1.25, −0.65)	<0.001	0.03	−0.97 (−1.37, −0.57)	<0.001	0.03	−0.93 (−1.37, 0.49)	<0.001	0.03
Meeting at least one recommendation	0.95 (0.65, 1.25)	<0.001	0.03	0.97 (0.57, 1.37)	<0.001	0.03	0.93 (0.49, 1.37)	<0.001	0.03
PA only	0.27 (0.09, 0.46)	<0.01	0.00	0.22 (−0.01, 0.47)	0.066	0.00	0.47 (0.19, 0.76)	<0.001	0.01
ST only	0.03 (−0.21, 0.28)	0.777	0.00	0.16 (−0.18, 0.51)	0.344	0.00	−0.13 (−0.48, 0.20)	0.429	0.00
SD only	0.90 (0.66, 1.13)	<0.001	0.04	0.86 (0.56, 1.16)	<0.001	0.04	0.91 (0.55, 1.27)	<0.001	0.04
Meeting at least two recommendations	0.41 (0.23, 0.59)	<0.001	0.01	0.40 (0.16, 0.64)	<0.001	0.01	0.48 (0.21, 0.76)	<0.001	0.02
PA + ST only	0.21 (−0.14, 0.57)	0.242	0.00	0.44 (−0.01, 0.89)	0.058	0.00	−0.11 (−0.68, 0.46)	0.706	0.00
PA + SD only	0.47 (0.28, 0.67)	<0.001	0.01	0.45 (0.20, 0.71)	<0.001	0.01	0.62 (0.31, 0.92)	<0.001	0.02
ST + SD only	0.20 (−0.06, 0.47)	0.137	0.00	0.22 (−0.16, 0.60)	0.261	0.00	0.15 (−0.22, 0.52)	0.433	0.00
Meeting all three recommendations	0.25 (−0.12, 0.64)	0.184	0.00	0.41 (−0.08, 0.90)	0.102	0.00	0.06 (−0.54, 0.67)	0.838	0.00
<b>Adjusted</b>									
Not meeting recommendations	−0.67 (−0.92, −0.41)	<0.001	0.02	−0.73 (−1.09, −0.37)	<0.001	0.02	−0.57 (−0.93, −0.21)	<0.01	0.01
Meeting at least one recommendation	0.76 (0.47, 1.05)	<0.001	0.02	0.77 (0.47, 1.05)	<0.001	0.02	0.68 (0.26, 1.09)	<0.001	0.01
PA only	0.18 (0.01, 0.36)	0.046	0.00	0.14 (−0.09, 0.38)	0.245	0.00	0.23 (−0.04, 0.50)	0.103	0.00
ST only	−0.04 (−0.28, 0.18)	0.680	0.00	0.13 (−0.20, 0.46)	0.447	0.00	−0.26 (−0.58, 0.05)	0.105	0.00
SD only	0.75 (0.53, 0.97)	<0.001	0.03	0.76 (0.46, 1.05)	<0.001	0.03	0.73 (0.39, 1.06)	<0.001	0.03
Meeting at least two recommendations	0.29 (0.12, 0.47)	<0.001	0.00	0.33 (0.33, 0.12)	<0.010	0.01	0.22 (−0.03, 0.48)	0.091	0.00
PA + ST only	0.13 (−0.20, 0.47)	0.449	0.00	0.37 (−0.07, 0.81)	0.099	0.00	−0.29 (−0.82, 0.24)	0.281	0.00
PA + SD only	0.36 (0.17, 0.55)	<0.001	0.01	0.37 (0.12, 0.62)	<0.01	0.01	0.31 (0.02, 0.60)	0.038	0.00
ST + SD only	0.10 (−0.15, 0.36)	0.423	0.00	0.17 (−0.20, 0.54)	0.370	0.00	0.02 (−0.33, 0.37)	0.912	0.00
Meeting all three recommendations	0.16 (−0.20, 0.52)	0.382	0.00	0.33 (−0.14, 0.80)	0.169	0.00	−0.16 (−0.73, 0.40)	0.569	0.00

Note. The reported β values are standardized coefficients; CI: confidence interval; η<sup>2</sup>: square stage.

PA: physical activity, ST: screen time, and SD: sleep duration.

Covariates include were age, sex, socioeconomic status (€), body mass index (kg/m<sup>2</sup>), and cardiorespiratory fitness (ml/kg/min).

doing homework, studying, etc. or recreational: playing video games).<sup>5</sup> For example, the systematic review of Adelantado-Renau et al.<sup>5</sup> only found that television viewing and video game playing were negatively associated with academic achievement. The fact that we assessed in our study not only the use of TV and videogames, but also computer and mobile phone usage, may explain the lack of association. Therefore, these results suggest that each screen-based behavior should be analyzed independently to understand its association with academic achievement. Given the lack of screen time recommendations for each screen-based device, however, we chose to combine all of the screen-based behaviors to calculate the recreational screen time recommendations<sup>11</sup> for this study.

While meeting both physical activity and sleep duration guidelines was related to higher academic achievement, meeting all three recommendations was not significantly associated with academic achievement, thus confirming previous studies on adolescents.<sup>13,14</sup> However, a previous study conducted by Walsh et al.<sup>27</sup> found a higher cognitive development in children who met all three 24-Hour Movement Guidelines than those who exclusively met any, one or two recommendations. Moreover, a previous study conducted by Watson et al.<sup>12</sup> among children also reported that meeting all three 24-Hour Movement Guidelines or the combination of screen time and sleep duration guidelines was related to higher literacy achievement compared to those who met one or none of these recommendations.

The trend analysis conducted in our study revealed that adolescents meeting one, two or three 24-Hour Movement Guidelines reported higher academic achievement than those who met none of these recommendations. Although the trend analysis revealed a positive tendency, these results should be interpreted with caution, as no statistically significant differences in academic achievement were found among adolescents who met two or three recommendations. Therefore, meeting more than two 24-Hour Movement Guidelines does not appear to promote higher academic achievement in this study. These findings suggest that efforts should be taken to promote 24-Hour Movement Guidelines, particularly physical activity and sleep duration recommendations, not only for its physical and social benefits,<sup>27</sup> but also for its impact on academic achievement among adolescents. Given that the proportion of adolescents that met all three 24-Hour Movement Guidelines ranged from 1.6% to 9.7%,<sup>28</sup> promoting these movement behaviors should be a public health priority to obtain a higher academic achievement.

Finally, although there were no differences between males and females in most of the relationships examined, it should be noted that meeting two recommendations was associated with higher academic achievement in males only. Our results could be explained by pubertal development and physical activity. On the one hand, previous studies have found that gray matter density increases dramatically between the ages of 10 and 15, especially in females.<sup>29</sup> During this period, females experience a maturation of gonadal hormones, which generates an increase in brain neuroplasticity and neurotrophic factors in the brain, enhancing cognitive ability.<sup>30</sup> As a consequence of this maturational development, we might expect females to develop better academic skills during early adolescence, which may slightly mask the positive effects of physical activity and sleep duration on academic achievement. On the other hand, a positive relationship between CRF and academic achievement has been demonstrated due to increased angiogenesis in the motor cortex and increased blood flow in the brain. These benefits occur especially in males because their cardiorespiratory capacity is higher than females as a result of more intense physical activity.<sup>31</sup> Therefore, taking into account that females may start with a higher academic level due to maturational development, it could be expected that the benefits of these two health-related behaviors may be more noticeable in males, which would help to explain the differences found in our study.

This study has some limitations. Firstly, this research used a cross-sectional design, which does not allow conclusions to be drawn from the cause and effect of the associations. Future longitudinal studies are

required to confirm the findings of this study. Secondly, although all the questionnaires used to assess all three 24-Hour Movement Guidelines were valid and reliable, they were self-reported. Future studies should use device-based measures to assess physical activity and sleep duration. Another future study should more closely analyze the relationship between each screen-based behavior (e.g., TV, videogames, computer, mobile phone, etc.) and academic achievement. Moreover, examining the relationship between weekend and weekday 24-Hour Movement Guidelines and academic performance should be a new avenue of research. Thirdly, the physical activity recommendations were only calculated based on moderate-vigorous physical activity, without considering muscle-strengthening activity. Therefore, future research should consider both moderate-to-vigorous physical activity and muscle-strengthening activity when calculating physical activity recommendations. Finally, there were significant differences between responder vs. non-responder adolescents in academic achievement, mainly in male participants. Therefore, the results should be interpreted with caution.

The study also has some strengths that should be highlighted. SES, sex, age, BMI, and CRF were introduced as covariates in the analyses, which increased the strength of the results. In addition, this is one of the first studies that examined the association between meeting all three 24-Hour Movement Guidelines and academic achievement in adolescents and the first to examine this relationship in terms of sex.

## 5. Conclusions

The present study showed a positive association between the independent meeting for physical activity and sleep duration guidelines with academic achievement in Spanish adolescents. However, a significant association between meeting recreational screen time recommendations and academic achievement was not found. Moreover, it appears that the adolescents who met both physical activity and sleep duration recommendations obtained higher academic achievement compared to those who did not meet any of these recommendations. Especially, in males, those who met two 24-Hour Movement Guidelines reported a higher academic achievement. Finally, although a significant relationship between meeting all three 24-Hour Movement Guidelines and academic achievement was not found, it appears that academic achievement may increase as more 24-Hour Movement Guidelines were met. Overall, results suggest meeting the recommendations for physical activity and sleep duration seems to contribute positively to increased academic performance in adolescents.

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## Declaration of interest statement

The authors declare that they have no conflict of interest.

## Confirmation of ethical compliance

That Mr. Pedro Antonio Sánchez Miguel has submitted the necessary documentation for the Bioethics and Biosafety Commission of the

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