

ONLINE FIRST

Active Commuting to School and Cognitive Performance in Adolescents

The AVENA Study

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Objective: To examine the associations between active commuting to school and cognitive performance in adolescents.

Design: Cross-sectional study.

Setting: Five cities (Granada, Madrid, Murcia, Santander, and Zaragoza) in Spain.

Participants: A total of 1700 adolescents (892 girls) aged 13 to 18.5 years.

Main Exposures: Mode and duration of transportation to school and participation in extracurricular physical activity were self-reported.

Main Outcome Measures: Cognitive performance (verbal, numeric, and reasoning abilities and an overall score) was measured by the Spanish version of the SRA Test of Educational Ability.

Results: Active commuting to school was associated with better cognitive performance (all $P < .05$) in girls but not in boys, independent of potential confounders including participation in extracurricular physical activity. In addition, adolescent girls who spent more than 15 minutes actively commuting to school had better scores in 3 of the 4 cognitive performance variables (all $P < .05$) than those who spent less time actively commuting to school (≤ 15 minutes) as well as better scores in all of the cognitive performance variables (all $P < .001$) than girls in actively commuting.

Conclusion: Active commuting to school and its duration may positively influence cognitive performance in adolescent girls.

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A GROWING BODY OF LITERATURE supports the beneficial effect of physical activity on cognition in youth.¹⁻⁴ During adolescence, the brain shows noteworthy changes in both structure and function. Several studies showed that physical activity may be a positive stressor providing plasticity and flexibility to the brain.⁵ Findings from the AVENA (Alimentación y Valoración del Estado Nutricional de los Adolescentes Españoles [Food and Assessment of the Nutritional Status of Spanish Adolescents]) study suggested that extracurricular physical activity might have a positive influence on cognitive performance in Spanish adolescents.⁶ These results highlighted the need for increasing extracurricular physical activity opportunities in adolescence to improve not only physical health but also brain health.

There is compelling evidence regarding the effects of curricular and extracurricular physical activity on cognition,¹⁻⁴ but to our knowledge, to date there is no study investigating the influence of active commuting to school (ACS) on cognitive or academic outcomes in adolescents. Active commuting is a good opportunity to accumulate physical activity in adolescence, and its benefits seems to extend beyond this. For example, several studies showed an association between ACS and lower levels of body fat as well as between ACS and physical fitness in adolescents.⁷ It is likely that the physical activity that takes place immediately before school might also play a role in cognition, effective learning, and academic performance. In this study, we examined the associations between ACS and cognitive performance (including verbal, numeric, and reasoning abilities and an overall score) in Spanish adolescents.

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Group Information: The AVENA Study Group members are listed at the end of this article.

STUDY DESIGN AND PARTICIPANTS

Participants were part of the AVENA study, which was primarily designed to assess the nutritional status of a representative sample of urban Spanish adolescents aged 13 to 18.5 years.⁸ Data collection took place from November 6, 2000, to June 28, 2002, in 5 Spanish cities (Granada, Madrid, Murcia, Santander, and Zaragoza). A total of 2859 adolescents participated in the AVENA study. The present study comprised 808 boys and 892 girls (n = 1700; participation rate = 60%) with complete data on height, weight, extracurricular physical activity, patterns of commuting to school, and cognitive performance. Socioeconomic status was parent-reported and defined by the educational achievement of the mother (primary school, secondary school, and university). In the final sample, socioeconomic status data were available in 87% of adolescents (83% in boys and 90% in girls). Parents and guardians were informed about the nature and aims of the AVENA study, and they gave their written informed consent. The AVENA study protocols were approved by the Review Committee for Research Involving Human Subjects from Marques de Valdecilla University Hospital, Santander, Spain.

TYPE OF SCHOOL

The schools involved in the AVENA study were classified into 2 groups. Public schools were defined as those funded by the national government. Private schools were defined as not being funded by the national government.

ANTHROPOMETRY

The harmonized anthropometric protocols in the AVENA study were described elsewhere.⁹ Body height and weight were measured with the adolescents having bare feet and wearing light underclothes. Height was measured to the nearest 1 mm and body weight to the nearest 0.05 kg using a standard beam balance with a stadiometer (SECA 861; SECA, Hamburg, Germany). Body mass index was calculated as body weight in kilograms divided by height in meters squared. Overweight (including obese) adolescents were classified according to age- and sex-specific body mass index cutoffs proposed by Cole et al.¹⁰

EXTRACURRICULAR PHYSICAL ACTIVITY

Participation in extracurricular physical activity was self-reported and determined by the following question: "Do you practice any type of physical sports activity after school?"⁶ The possible answers were no and yes.

MODE AND DURATION OF COMMUTING TO SCHOOL

Patterns of commuting to school were also self-reported.¹¹ Two questions were asked about the mode and duration of commuting to school: (1) "how do you usually travel to school?" and (2) "how long does it usually take you to travel from home to school?" Response options to the first question were walking, biking, car, bus or subway, motorcycle, and others. Response options to the second question included 15 minutes or shorter, from 15 to 30 minutes, from 30 to 60 minutes, and longer than 60 minutes. Adolescents were classified as inactive commuters (car, bus or subway, or motorcycle [non-ACS]) or active commuters (walking or biking [ACS]) according to the mode of traveling to school. Additionally, the ACS

group was classified into 2 groups (≤ 15 minutes and > 15 minutes) according to the time spent commuting to school. Descriptive characteristics of commuting to school in the AVENA study were presented in a previous article.¹¹

COGNITIVE PERFORMANCE

Cognitive performance was assessed using the Spanish version of the SRA Test of Educational Ability.¹² This standardized questionnaire provides general and multifactorial measures of intelligence and basic skills to learn. The SRA Test of Educational Ability evaluates verbal (command of language), numeric (speed and precision in performing operations with numbers and quantitative concepts), and reasoning (the ability to find logical ordination criteria in sets of numbers, figures, or letters) abilities. Direct scores ranging from 0 to 33 are obtained for each of these specific abilities. Finally, an overall cognitive performance score ranging from 0 to 99 is calculated by summing the scores obtained from the 3 abilities. The SRA Test of Educational Ability test battery may be collectively administered and has 3 levels, level 1 (administered at ages 8-12 years), level 2 (administered at ages 11-14 years), and level 3 (administered at ages 14-18 years), that require 26, 42, and 27 minutes, respectively.

Owing to the age range of our adolescent sample, only levels 2 and 3 were used. The psychometric properties of level 2 showed internal consistency reliabilities of $\alpha = .78$ for verbal ability, $\alpha = .83$ for numeric ability, $\alpha = .88$ for reasoning ability, and $\alpha = .92$ for overall cognitive performance. Concerning level 3, internal consistency reliabilities were $\alpha = .74$ for verbal ability, $\alpha = .87$ for numeric ability, $\alpha = .77$ for reasoning ability, and $\alpha = .89$ for overall cognitive performance.

STATISTICAL ANALYSIS

Statistical analyses were performed using SPSS version 15.0 statistical software for Windows (SPSS Inc, Chicago, Illinois). In all analyses, statistical significance was set at $P < .05$. Sex differences were analyzed by 1-way analysis of variance and Pearson χ^2 test for continuous and nominal variables, respectively.

The association between mode of commuting to school (non-ACS or ACS) and extracurricular physical activity (no or yes) was analyzed by binary logistic regression after controlling for age, type of school (public or private), and weight status (nonoverweight or overweight).

To examine the associations between mode of commuting to school (non-ACS or ACS) and cognitive performance levels, we conducted analysis of covariance after controlling for age, type of school, and weight status (model 1). We performed a second model further including extracurricular physical activity as a confounding variable to examine whether the associations between commuting to school and cognitive performance are independent of participation in extracurricular physical activity (model 2). Finally, we conducted an additional analysis of covariance to examine the association between the duration of ACS (≤ 15 minutes and > 15 minutes) and cognitive performance.

RESULTS

The characteristics of the participants are shown in **Table 1**. Overall, 25% of the adolescent boys and 17% of the adolescent girls were categorized as overweight ($P < .001$), and a higher percentage of adolescent boys than girls studied in private schools (11% vs 5%, respectively; $P < .001$). Among the adolescent boys and girls,

Table 1. Characteristics of Study Sample^a

Characteristic	All (N=1700)	Boys (n=808)	Girls (n=892)
Physical characteristic			
Age, mean (SD), y	15.4 (1.3)	15.3 (1.2)	15.4 (1.3)
Weight, mean (SD), kg	59.8 (11.6)	64.0 (12.4)	56.0 (9.2) ^b
Height, mean (SD), cm	166.2 (8.6)	171.1 (161.7)	161.7 (6.1) ^b
BMI, mean (SD)	21.6 (3.3)	21.8 (3.5)	21.4 (3.1) ^c
Overweight + obesity, %	21	25	17 ^b
Education in private schools, %	8	11	5 ^b
Pattern of physical activity, %			
Extracurricular physical activity	66	82	52 ^b
Non-ACS	34	36	32
ACS ≤15 min	54	55	54
ACS >15 min	11	9	13
Cognitive performance score			
Verbal ability ^d	20.82 (6.28)	21.49 (6.42)	20.20 (6.08) ^b
Numeric ability ^d	14.01 (5.08)	15.14 (5.22)	12.99 (4.73) ^b
Reasoning ability ^d	18.19 (5.68)	17.50 (5.97)	18.81 (5.34) ^b
Overall cognitive performance ^e	53.10 (14.16)	54.26 (14.71)	52.04 (13.56) ^f

Abbreviations: ACS, active commuting to school; BMI, body mass index (calculated as weight in kilograms divided by height in meters squared).

^aPercentages may not total 100 owing to rounding.

^bStatistically significant difference between the sexes at $P < .001$.

^cStatistically significant difference between the sexes at $P = .04$.

^dOn a scale of 0 to 33.

^eOn a scale of 0 to 99.

^fStatistically significant difference between the sexes at $P = .001$.

82% and 52%, respectively, participated in extracurricular physical activity ($P < .001$). A similar percentage of boys (64%) and girls (67%) reported ACS ($P = .08$). Boys had higher scores than girls in verbal ability ($P < .001$), numeric ability ($P < .001$), and overall cognitive performance ($P = .001$), whereas girls had higher scores than boys in reasoning ability ($P < .001$).

Binary logistic regression showed that boys in the ACS group had increased odds of being engaged in extracurricular physical activity (odds ratio=1.50; 95% confidence interval [CI], 1.03-2.18) after adjusting for age, type of school, and weight status. However, ACS was not significantly associated with participation in extracurricular physical activity in girls (odds ratio=0.93; 95% CI, 0.70-1.23).

Table 2 shows the associations between mode of commuting to school and cognitive performance. In boys, cognitive performance was similar in the ACS and non-ACS groups. However, girls in the ACS group had significantly higher scores in 3 of the 4 cognitive performance variables than girls in the non-ACS group after adjusting for age, type of school, and weight status (all $P < .05$). After further adjusting for extracurricular physical activity, ACS was positively associated with all of the cognitive variables (all $P < .05$).

Adolescents were also divided into 3 groups according to the duration of commuting to school (non-ACS, ACS ≤15 minutes, and ACS >15 minutes). The analysis of covariance with Bonferroni adjustment for age, type of school, weight status, and extracurricular physical activity showed

that girls in the group with ACS longer than 15 minutes had significantly higher scores in numeric ability (score +1.28; 95% CI, 0.13-2.43), reasoning ability (score +1.90; 95% CI, 0.61-3.19), and overall cognitive performance (score +4.48; 95% CI, 3.57-10.55) than the group of girls in the group with ACS for 15 minutes or shorter (all $P < .05$) (**Figure**). In addition, girls in the group with ACS longer than 15 minutes also had significantly higher scores in verbal ability (score +2.75; 95% CI, 1.18-4.32), numeric ability (score +1.94; 95% CI, 0.71-3.17), reasoning ability (score +2.19; 95% CI, 0.81-3.57), and overall cognitive performance (score +7.06; 95% CI, 3.57-10.55) than girls in the non-ACS group (all $P < .001$) (**Figure**). All of the analyses were repeated to examine whether the associations of commuting to school with cognitive performance were modified after further controlling for socioeconomic status (maternal education), but the main results did not substantially change (data not shown).

COMMENT

The main findings of this study suggest that ACS is positively associated with cognitive performance in adolescent girls, independent of potential confounders including extracurricular physical activity. Indeed, the associations between ACS and cognitive performance were stronger in those girls who spent more time in ACS. In contrast, ACS did not seem to be associated with cognitive performance in adolescent boys. These novel results contribute to a growing body of evidence indicating that physical activity may have a beneficial influence on cognition in youth.

Experimental evidence in neuroscience supports the positive association between physical activity and cognition.¹³ Long-term exercise increases the formation of new neurons and concentrations of brain-derived neurotrophic factor, enhances neuronal transmission in the hippocampus, and stimulates gene expression of important nerve growth factors related to nervous influx (eg, insulin-like growth factor and fibroblast growth factor 2). Several reviews also concluded that physical activity improves cerebral blood flow, general circulation, mood, concentration, memory, and classroom behavior, and hence it might lead to better academic performance in school-aged children.¹⁻⁴ During adolescence, the plasticity of the brain makes this an opportune period to stimulate cognitive function.⁵ Paradoxically, adolescence is the period of life with the greatest decline in physical activity levels.¹⁴ Therefore, inactive adolescents might be losing an important stimulus to improve learning and academic performance.

The school curriculum offers a great chance to promote physical activity through physical education; therefore, health organizations aim to increase the proportion of adolescents who participate in daily school physical education.¹⁵ However, educational institutions often argue that adding more physical education to the school curriculum displaces the time devoted to other academic subjects. Extracurricular physical activity does not affect the school curriculum time. We previously observed that extracurricular physical activity might have a positive influence on cognitive performance in Spanish adolescents with-

Table 2. Associations Between Mode of Commuting to School and Cognitive Performance in Spanish Adolescents

Cognitive Performance	Mean (SD)		ACS vs Non-ACS, Mean Difference (95% CI)	P Value ^a	P Value ^b
	Non-ACS	ACS			
Boys					
No.	292	516			
Verbal ability ^c	21.22 (6.07)	21.64 (6.62)	0.42 (-0.51 to 1.34)	.15	.19
Numeric ability ^c	15.10 (5.00)	15.16 (5.35)	0.06 (-0.69 to 0.81)	.93	.82
Reasoning ability ^c	17.91 (5.96)	17.27 (5.96)	-0.65 (-1.50 to 0.21)	.36	.23
Overall cognitive performance ^d	54.24 (13.78)	54.27 (15.22)	0.03 (-2.08 to 2.15)	.64	.84
Girls					
No.	287	605			
Verbal ability ^c	18.90 (5.88)	20.82 (6.08)	1.92 (1.08 to 2.77)	<.001	<.001
Numeric ability ^c	12.36 (4.28)	13.28 (4.91)	0.92 (0.25 to 1.57)	.01	.008
Reasoning ability ^c	18.32 (5.17)	19.05 (5.41)	0.73 (-0.02 to 1.47)	.06	.049
Overall cognitive performance ^d	49.61 (12.24)	53.20 (14.01)	3.59 (1.70 to 5.48)	<.001	<.001

Abbreviations: ACS, active commuting to school; CI, confidence interval.

^aAnalysis adjusted for age, type of school, and weight status.

^bAnalysis adjusted for age, type of school, weight status, and extracurricular physical activity.

^cOn a scale of 0 to 33.

^dOn a scale of 0 to 99.

out displacing the time spent studying and doing homework.⁶ We also showed that sedentary behaviors, physical fitness, and weight status were not associated with cognitive performance in this adolescent population.⁶

Active commuting to school is a near-daily routine that increases physical activity and improves health.⁷ Also, both educational and public health institutions agree to promote modes of ACS. In this study, we observed that ACS (that is, the potential physical activity before school) was positively associated with cognitive abilities and an overall cognitive performance score. However, this influence showed a sex effect, and only girls in the ACS group had higher values in all of the cognitive indicators, independent of participation or nonparticipation in extracurricular physical activity. We also observed that the duration of ACS is of relevance as adolescent girls in the group with ACS longer than 15 minutes had significantly higher cognitive levels than girls in the group with ACS for 15 minutes or shorter and girls in the non-ACS group.

To our knowledge, this is the first study showing the associations between commuting to school and cognitive performance, which hampers comparisons with other studies. Overall, almost all studies that examined associations between physical activity and cognitive or academic variables in youth showed their results with boys and girls together.¹⁻⁴

The sex-specific effect observed in our study concurs with that in other studies.¹⁶ Kwak et al¹⁶ showed that vigorous physical activity was associated with academic achievement only in Swedish adolescent girls. The reasons explaining why ACS might improve cognitive performance only in adolescent girls cannot be elucidated in our study, yet 2 mechanisms might be speculated. First, in addition to the decline in physical activity levels in adolescence, numerous studies have shown that adolescent boys are more active than girls.¹⁷ For example, our study showed that ACS was associated with extracurricular physical activity in boys but not in girls. Consequently, the relatively short duration of ACS might not influence cognitive performance in boys because it represents a small

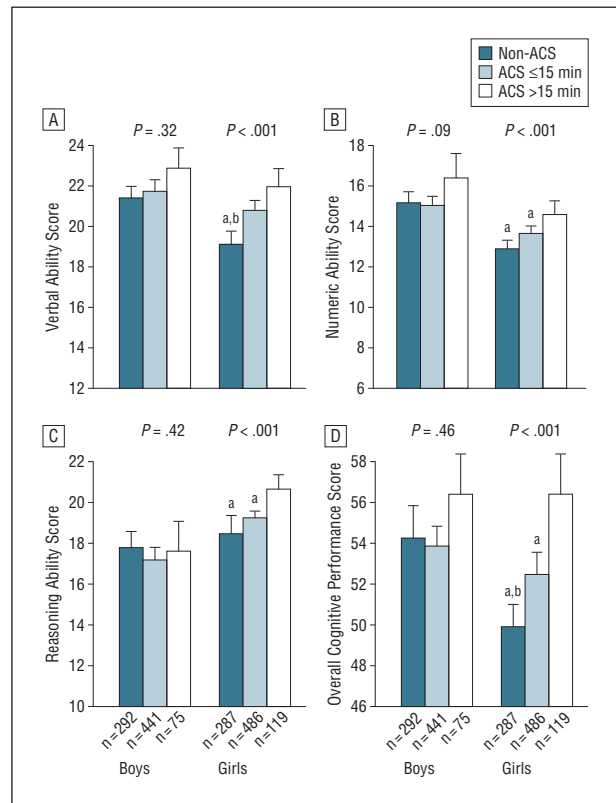


Figure. Mean values of verbal ability (A), numeric ability (B), reasoning ability (C), and overall cognitive performance (D) by groups of Spanish adolescents commuting to school; ACS indicates active commuting to school; error bars, 95% confidence intervals. ^aSignificantly different from the group with ACS longer than 15 minutes. ^bSignificantly different from the group with ACS for 15 minutes or shorter.

amount of their daily physical activity. In contrast, any mode and duration of physical activity might generate a beneficial effect on cognition in girls. This reason could partially explain the observed association between ACS and cognitive performance in girls, independent of extracurricular physical activity. A second mechanism might

be related to sex differences observed in the neurotrophic hypothesis of depression.¹⁸ This hypothesis states that the loss of brain-derived neurotrophic factor may contribute to a major vulnerability for depression and disrupts neuroplasticity. Experimental studies using male and female mice exposed to long-term stress showed that brain-derived neurotrophic factor may have a role in mediating depression in females but not in males.^{19,20} During puberty, adolescents have new biological, psychological, and social challenges that could act as potential stressors. Indeed, adolescent girls tend to show twice as much anxiety and depression as boys.²¹ A study in a large sample of 12- to 15-year-old adolescents showed that several school factors such as grades, teacher support, and school stress are important correlates of depressive symptoms in adolescent girls but not in boys.²² Taken together, ACS might improve the brain-derived neurotrophic factor concentration and as a result may reduce anxiety and stress in girls before they arrive at the school environment with its stressors.

Lambiase et al²³ recently showed the effect of ACS on cardiovascular stress reactivity in children aged 10 to 14 years exposed to a cognitive stressor similar to what children might experience during school. This controlled study performed a simulated ACS in laboratory settings. Children assigned to the active commute group performed a 1.6-km walk on a treadmill at a self-selected pace while images from a real walk through a pleasant neighborhood were projected in front of them. Children assigned to the inactive commute group watched the same images but sat in a chair. After a 20-minute recovery period, children completed a computerized cognitive test. The study showed that active commuters (mean walking duration = 22 minutes) had lower levels of heart rate, blood pressure, and perceived stress than the control group. Another study in laboratory settings showed that 20 minutes of walking on a treadmill increased attention and academic performance in preadolescent children.²⁴ Given that the intensity during ACS in adolescents is usually light or moderate, these and our findings suggest a role of these types of intensities on cognitive performance. Previous studies suggested that only vigorous activities might have a crucial role in improving cognitive function and memory.^{16,25} However, different forms of physical activity apparently have distinctive effects on brain functions.²⁶ Therefore, further prospective and experimental studies in youths are necessary to examine the potential physiological and psychological benefits of ACS and its duration on cognitive and academic performance. Likewise, future studies should clarify the mechanisms that induce the sex effect found in our study.

The strengths of this study are the inclusion of a relatively large and heterogeneous adolescent sample, the use of a standardized test to assess cognitive performance, and analyses including potential confounders (mainly participation in extracurricular physical activity). However, the study has several limitations. Our cross-sectional design limits the ability to draw conclusions with regard to the causality of our findings. We cannot clarify whether ACS improves cognitive performance in girls or whether adolescent girls with higher levels of cognitive performance

chose walking or biking to school. A second limitation is that physical activity variables were self-reported (mode and duration of commuting to school, and extracurricular physical activity); therefore, our findings must be interpreted with caution. Further studies using objective measures of commuting to school (eg, accelerometry and online route planners) may provide more information on the relationships we have found. Additionally, other measures of physical activity in school settings (eg, physical education and recess) could be not controlled in our analyses to examine the independent association between ACS and cognitive performance.¹ Therefore, this issue should be explored in future studies.

In summary, the results of this study suggest that ACS is positively associated with cognitive performance in adolescent girls, so that the ACS group had better cognitive performance. Furthermore, girls in the ACS group who spent more time (>15 minutes) in commuting to school had higher levels of cognitive performance than both less active girls in the ACS group (≤ 15 minutes) and girls in the non-ACS group.

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