

Physical Activity Is Associated with Attention Capacity in Adolescents

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 [Healthy Lifestyle in Europe by Nutrition in Adolescence \(HELENA\) Study Group](#)

Objective

To assess the relationships among physical activity, measured objectively, and attention capacity in European adolescents.

Study design

The study included 273 adolescents, aged 12.5-17.5 years, who participated in the Healthy Lifestyle in Europe by Nutrition in Adolescence Study. Participants wore a uniaxial accelerometer for 7 days to measure physical activity. The d2 Test of Attention was administered to assess attention capacity. Multivariate analyses were used to study the association of attention capacity with each measure of physical activity. Receiver operating characteristic analysis was performed to determine thresholds that best discriminate between low and good attention capacity.

Results

After controlling for potential confounding variables (age, sex, body mass index, parental educational level, fat mass, aerobic fitness, and center), adolescents' attention capacity test performances were significantly and positively associated with longer time spent in moderate or moderate-to-vigorous physical activity (MVPA) in free-living conditions ($P < .05$). Receiver operating characteristic curve analyses revealed that the physical activity thresholds that best discriminated between low/good attention capacities were ≥ 41 min·day⁻¹ for moderate, ≥ 12 min·day⁻¹ for vigorous, and ≥ 58 min·day⁻¹ for MVPA.

Conclusion

These findings suggest that promoting MVPA may have a beneficial effect on attention capacity, an important component of cognition, in adolescents.

[AUC](#) (Area under the receiver operating characteristic curve), [BMI](#) (Body mass index), [d2T](#) (d2 Test of Attention), [HELENA](#) (Healthy Lifestyle in Europe by Nutrition in Adolescence), [ISCED](#) (International Standard Classification of Education), [MVPA](#) (Moderate-to-vigorous physical activity), [ROC](#) (Receiver operating characteristic)

Physical activity is an important determinant of health throughout the lifespan. Engaging in regular moderate-to-vigorous physical activity (MVPA) has important health benefits, especially in the treatment of metabolic syndrome-related disorders such as obesity, heart and pulmonary diseases, bone and joint diseases, cancer, depression, asthma, and in cognitive function.^{1, 2, 3}

The 2 important measures of cognition in children and adolescents are attention and concentration because they are indispensable elements in comprehension and learning processes.^{4, 5, 6} Attention is the behavioral and cognitive process of selectively concentrating on one aspect of the environment while ignoring other things.^{5, 6} Sibley and Etnier² performed a meta-analysis on physical activity and cognition in children and concluded that there is a significant positive relationship between physical activity and cognitive function in children; however, their analysis included only studies conducted to investigate the effects of exercise type on cognitive function. Moreover, in this meta-analysis, 8 categories of cognitive assessment tools were used: perceptual skills, IQ, achievement, verbal tests, math tests, memory, developmental level, and academic readiness. Although there could be overlap between IQ testing and some aspect of attention, no specific study assessing attention capacity was included in the meta-analysis. Some interventional studies showed that the type,^{4, 7} duration,^{8, 9} or intensity of physical activity positively influenced cognitive functions.¹⁰ Indeed, studies have suggested that short bouts of exercise on coordinative skills or a single and acute bouts of MVPA might have an impact on attention capacity in adolescents.^{7, 8, 9, 11, 12, 13} All of these studies examined the improvement of the attention ability after an acute challenge intervention.^{7, 8, 9, 11, 12, 13} However, to our knowledge, no previous study has examined baseline attention capacity with respect to adolescent physical activity patterns.

The primary aim of the present study was to investigate the relationship of physical activity, measured objectively, with the attention capacity in European adolescents. The secondary aim was to establish the optimal physical activity intensity cutoff that best discriminates between low and good attention capacities.

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Methods

This is an ancillary study of the Healthy Lifestyle in Europe by Nutrition in Adolescence (HELENA) Study (www.helenastudy.com) performed in European adolescents (2006-2007). The aim of the HELENA Study was to obtain a broad range of standardized, reliable, and comparable nutrition- and health-related data from a random sample of European adolescents aged 12.5-17.5 years. The random selection of schools and classes was performed centrally (by Ghent University) for all cities except Pecs and Athens, where schools were selected locally owing to local administrative constraints. Details of the selection criteria for schools and classes were reported previously.¹⁴ The inclusion criteria were male or female aged 12.5-17.5 years, schooling in 1 of the participating classes, consent form signed by parent and/or legal guardian, and no concurrent participation in another similar study. Each participating center was asked to include approximately 150 male and female adolescents per age stratum (ie, aged 12.5-14, 14-15, 15-16, and 16-17.5 years).

A total of 3528 adolescents (1844 girls and 1684 boys) meeting the inclusion criteria completed all examinations. A detailed description of the HELENA Study methodology and sampling is available elsewhere.^{15, 16} For the purpose of the present study, all participants with valid data on physical activity, anthropometric characteristics, aerobic fitness, and attention ability were included in the analysis (n = 273) ([Figure 1](#); available at www.jpeds.com). Data were obtained from 6 countries: France (Lille), Spain (Zaragoza), Austria (Vienna), Germany (Dortmund), Hungary (Pecs), and Greece (Athens).

The aims and objectives were explained in detail, and written consent was obtained from each participant and a parent or legal guardian. The local Ethics Committee for each participating institution approved the HELENA Study, and all procedures were performed in accordance with the ethical standards of the Declaration of Helsinki (as revised in 2008) and European Good Clinical Practice Guidelines.¹⁷

Weight was measured with the subject wearing light clothing, without shoes, to the nearest 0.1 kg using an electronic scale (model 871; Seca, Hamburg, Germany). Height was measured without shoes to the nearest 0.1 cm using a telescopic measuring instrument (model 225; Seca). Body mass index (BMI) was calculated as weight (kg)/height² (m²). Nutritional status was assessed based on the International Obesity Task Force scale.¹⁸

Total fat and fat-free mass were assessed using bioelectrical impedance analysis (model BIA101 body composition analyzer; Akern, Pontassieve, Italy). After a 5-minute rest, the subject was placed supine with the arms and legs in abduction between 30 and 40 degrees from the trunk. Electrode tape, conductivity gel, and current electrodes were placed on the dorsal surfaces of the right hand and foot at the distal metacarpals and metatarsals, respectively.¹⁹

Parental educational level was classified into 1 of 4 categories using a specific questionnaire, adapted from the International Standard Classification of Education (ISCED) (<http://www.uis.unesco.org/Library/Documents/isced97-en.pdf>): 1, primary education (level 0 and 1 in the ISCED classification); 2, lower secondary (level 2 in the ISCED classification); 3, higher secondary (level 3 and 4 in the ISCED classification); or 4, tertiary (level 5 and 6 in the ISCED classification).

Attention capacity was assessed using the d2 Test of Attention (d2T).²⁰ Developed to measure sustained attention and concentration under stress induced by a completion time, the d2T was used because it is low cost, easily and rapidly administered, and enables testing of large numbers of people simultaneously. The d2T assesses performance in terms of visual perceptual speed and concentrative capacities by assessing an individual's ability to selectively, quickly, and accurately focus on certain relevant aspects in a task while ignoring other irrelevant aspects. This test reflects 3 components of attentional/concentration behavior: speed/velocity, based on quantity of work performed in a given period; concentration, based on quality of work; and performance quality, based on the relationship between speed/velocity and concentration. The d2T is a paper-and-pencil letter-cancellation test comprising 14 different lines, each containing 47 randomly mixed letters ("p" and "d"), for a total of 658 letters. The letters "p" and "d" appear with 1 or 2 dashes above or below each letter. The test subject has to carefully check whether each letter "d" has 2 dashes either above or below it, at a rate of 20 seconds per line. The complete duration of the test is 4 minutes and 30 seconds. The d2T was administered in a classroom under the supervision of an HELENA fieldworker during the morning. All tests were performed before the physical activity assessment. A low error rate indicates high-quality performance. The documented reliability of the d2T ranges from 0.95 to 0.98, with a validity coefficient of 0.47.²⁰

Attention capacity was calculated using the following formula: number of correct guesses (ie, number of correct relevant elements) – commissions (ie, number of irrelevant elements marked). Percentiles of attention capacity were determined using the norms given in the test manual, according to sex and age from raw data. Percentiles of attention capacity could be divided into 2 categories: low attention capacity (<25th percentile) and normal to high attention capacity (≥25th-75th percentile).

A physical activity monitor (model GT1M; ActiGraph, Pensacola, Florida) was used to assess physical activity in free-living conditions.²¹ This small, lightweight uniaxial accelerometer has been validated against oxygen consumption and heart rate measurements for assessing physical activity.²² Its inter-instrument reliability is high for both sedentary and vigorous activities. The device's epoch interval was set at 15 seconds. The subject wore the accelerometer on the lower back with an elastic belt and adjustable buckle, and was instructed to remove the device before swimming, showering, or bathing and at night before sleep. The accelerometer recorded activity for 7 consecutive days.

Data were uploaded from the monitor to a computer after the completed registration period (7 days). Participants who did not record at least 3 days of activity with a minimum of 8 hours of activity per day were excluded from the subsequent analyses. Zero activity periods of 20 minutes or longer were interpreted as “not worn time” and were deleted from the summation of activity. MVPA levels were assessed based on thresholds reported in previous studies of adolescents.^{23, 24} The assessment of time spent in sedentary, light, moderate, and vigorous physical activity was based on cutoff ranges of 0-500, 501-1999, 2000-2999, and >2999 counts·min⁻¹, respectively.

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Statistical Analyses

Categorical data are expressed as percentages, and continuous data are expressed as mean ± SD. The normality of distribution was tested using the Shapiro-Wilk test. Statistical analyses were conducted at a 2-tailed α level of 0.05. Data were analyzed with SAS version 9.3 (SAS Institute, Cary, North Carolina).

The association of each physical activity variable with attention capacity was investigated in a separate multivariate linear regression analysis including the potential confounding factors associated with attention capacity (age, sex, BMI, nutritional status, parental educational level, fat mass, aerobic fitness level, and center).^{25, 26, 27} Because nutritional status was based on BMI, we included only BMI in regression models; similar results were found when multivariable regression models were refit replacing BMI with nutritional status (data not shown). We assessed the heterogeneity in associations between physical activity variables and attention capacity across sex by including the corresponding interaction term into multivariable regression models.

To assess the linearity of relationship between attention capacity and physical activity variables, we conducted further analyses after categorization of physical activity according to quartiles using ANCOVA, and used linear contrasts to perform trend tests.

We used receiver operating characteristic (ROC) curves to calculate the optimal cutoff points for moderate, vigorous, and MVPA that best discriminated between the low and good attention capacity categories. The area under the ROC curve (AUC) was determined by plotting sensitivity vs 1 – specificity of a test as the threshold varies over its entire range. Taking into account the suggested cutoff points, the test can be noninformative/equal to chance (AUC = 0.5); less accurate (0.5 < AUC ≤ 0.7), moderately accurate (0.7 < AUC ≤ 0.9), highly accurate (0.9 < AUC < 1.0), or perfectly discriminatory (AUC = 1.0).²⁸ Cutoff points were selected for those scores optimizing the sensibility–specificity relationship.

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Results

A descriptive analysis of the study population is reported in [Table I](#). One hundred thirty adolescents (47.6%) performed more 60 min·day⁻¹ of MVPA. In multivariate analyses, time spent in moderate or MVPA in free-living conditions was significantly associated ($P < .05$) with an increase in the adolescents' attention capacity after adjustment for the father's and mother's educational levels, age, sex, BMI, center, fat mass, and aerobic fitness level ([Table II](#)). Besides physical activity variables, only mother's education level and center remained independently associated with attention capacity in any of the multivariate analyses (data not shown). We found no significant heterogeneity in the association of each physical activity variable and attention capacity across sex ($P > .80$ for all).

Table I Characteristics of the study population (n = 147 girls, n = 126 boys)	
Characteristics	Value
Age, y, mean ± SD (range)	14.2 ± 1.1 (12.5-16.9)
Height, cm, mean ± SD (range)	165.3 ± 8.7 (143.8-189.4)
Body mass, kg, mean ± SD (range)	58.4 ± 12.6 (35.4-105.7)
BMI, kg·m ⁻² , mean ± SD (range)	21.3 ± 3.7 (15.4-35.1)
Fat mass, %, mean ± SD (range)	23.4 ± 9.5 (7.6-56.8)
Aerobic fitness, mL·kg·min ⁻¹ , mean ± SD (range)	41.4 ± 7.2 (28.3-59)
Nutritional status, UW/NW/OW/O, % ⁻	5/70/19/6
Father's education level, I/II/III/IV, % [†]	7/31/25/37
Mother's education level, I/II/III/IV, % [†]	10/24/32/34
Attention capacity, percentile, mean ± SD (range) [‡]	44.6 ± 30.1 (16-99)
Attention capacity, I/II, % [§]	31/69
Sedentary activities, min, mean ± SD (range)	528.9 ± 90.0 (287.8-966.4)
Light activities, min, mean ± SD (range)	175.8 ± 41.5 (83.2-343.0)
Moderate activities, min, mean ± SD (range)	43.3 ± 14.6 (16.7-100.7)

Vigorous activities, min, mean \pm SD (range)	20.1 \pm 13.0 (1.3-63.2)
MVPA, min, mean \pm SD (range)	63.3 \pm 24.0 (20.4-155.65)
Mean counts, counts \cdot min ⁻¹ , mean \pm SD (range)	466.4 \pm 157.4 (204.9-1047.4)

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*Nutritional status: underweight (UW), normal weight (NW), overweight (OW), obese (O).

†Educational level: lower education (I), lower secondary education (II), higher secondary education (III), higher education or university degree (IV).

‡Attention ability expressed in percentile.

§Attention ability: low ability (I), normal to high ability (II).

Table II Association between physical activity level and attention capacity, adjusted for potential confounding factors

Physical activity level	$\beta \pm SE$	<i>P</i> value [*]	Partial coefficient determination
Sedentary	0.01 \pm 0.02	.4472	0.002
Light	0.01 \pm 0.04	.8471	0.0001
Moderate	0.30 \pm 0.13	.0195	0.016
Vigorous	0.17 \pm 0.15	.2439	0.004
Moderate to vigorous	0.17 \pm 0.08	.0352	0.013

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β , regression coefficient.

**P* values adjusted for confounding factors: age, sex, BMI, parent educational level, center, fat mass, and aerobic fitness level.

Quartile analysis of each physical activity variable confirmed the linearity of association of attention capacity with the time spent in moderate or MVPA ([Figure 2](#)). The mean attention capacity test score was 48.7 ± 30.0 in adolescents with MVPA >60 min \cdot day⁻¹, compared with 40.9 ± 29.8 for sedentary (<60 min \cdot day⁻¹) adolescents ($P < .05$). All of the physical activity levels had an influence on attention capacity, suggesting that duration of MVPA is the main contributor to increasing attention capacity scores ([Figure 2](#)). The results of ROC analyses showing that physical activity levels discriminate good and low attention capacity in adolescents are presented in [Table III](#).

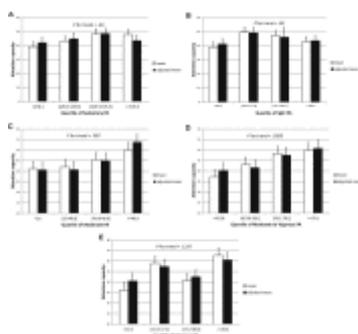


Figure 2

Unadjusted and adjusted means of attention capacity according to quartile of physical activity patterns. **A**, Sedentary physical activity. **B**, Light physical activity. **C**, Moderate physical activity. **D**, MVPA. **E**, Vigorous physical activity. SEM and adjusted *P* values for trend are reported. Adjustments were made for age sex, mother and father educational level, BMI, center, fat mass, and aerobic fitness level.

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Table III Physical activity cutoff points to predict good attention capacity in adolescents by ROC analysis				
	Min/d	Sensitivity	Specificity	AUC
Moderate physical activity	41	0.524	0.570	0.53
Vigorous physical activity	12	0.690	0.453	0.58
MVPA	58	0.540	0.593	0.56

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Discussion

The association between physical activity levels and attention capacity, taking into account age, BMI, sex, parents' educational level, center, fat mass, and aerobic fitness level, supports the hypothesis that there is a positive effect of physical activity on attention capacity in adolescents. This association was independent of sex; however, we caution that this study lacked adequate statistical power to detect a significant interaction. Owing to the study's cross-sectional design, we cannot exclude the possibility that those adolescents with a high underlying attention capacity are those capable of the increased attention necessary to perform moderate-to-vigorous activity regularly, whereas others are not. The effects of physical activity on cognitive function could be related to physiological changes, such as increased levels of brain-derived neurotrophic factor, a protein that facilitates learning and maintains cognitive function by improving synaptic plasticity, acting as a neuroprotective agent, increasing brain circulation, and improving neuroelectric function.¹⁰

Previous studies on the attention capacity and physical activity were intervention studies using a pretest and a posttest, with an intervening acute challenge.^{4, 8, 10, 11, 12, 13} Our study examined the baseline, general attention performance with respect to adolescent physical activity patterns levels. Our findings suggest that increasing physical activity in free living conditions might be associated with higher performance levels during lessons or other cognitive tasks.

Moderate, but not vigorous, physical activity had a significant positive effect on the attention capacity test ([Table II](#)). Shephard²⁹ has suggested that involvement in physical activity may induce immediate arousal and relief from boredom, resulting in improved attention capacity. As suggested by Coe et al.,³⁰ it is possible that a threshold level of activity may be needed to produce these potentially desirable effects. This idea may explain why high attention capacity is associated with moderate activity and not with vigorous physical activity in our study. Indeed,

vigorous physical activity might lead to greater fatigue, and thus to decreased attention capacity. Teachers in Western countries have reported increasing difficulty in maintaining adequate attention and concentration levels in children and adolescents, and our results suggest that offering regular physical education lessons with exercise at a moderate intensity might improve these 2 components of cognitive function and enhance learning. Further research using an interventional design is needed to investigate the effect of physical activity intensity on attention capacity.

A secondary outcome of our study was establishing the optimal duration of physical activity at moderate-to-vigorous intensity to obtain good attention capacity in adolescents. The current recommendation of at least 60 min·day⁻¹ of MVPA intensity has been based on obesity prevention or other health outcomes.¹ We found similar results in our study; that is, spending more than 58 min·day⁻¹ in MVPA intensity was associated with better attention capacity. These findings support the use of the current physical activity recommendations, but must be considered with caution because of the low accuracy of physical activity cutoffs. Owing to the study's cross-sectional design, the observed associations cannot be interpreted to reflect causal relationships. In addition, the lack of assessment of other neuropsychological function beyond performance on the d2T may limit the interpretation of our results. The use of standardized procedures across different centers is a strength of the HELENA study, however.^{14, 15} Harmonization and reliability of anthropometric and physical activity assessment techniques were carefully assessed throughout the course of the study.³¹ Another strength of this study is the inclusion of several confounding factors in the statistical analyses.

The data obtained from this study contribute to develop a better understanding of the link between physical activity and attention capacity in youth. Future research should be performed using an experimental design to confirm the results of this observational study.

Appendix.

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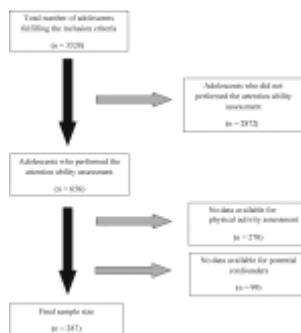


Figure 1

Final sample flowchart.

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*List of HELENA Study Group members is available at www.jpeds.com ([Appendix](#)).

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