Physical Activity Is Associated with Attention Capacity in Adolescents

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ABSTRACT

OBJECTIVE: To assess the relationship between physical activity (PA), measured objectively, and attention capacity among 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 PA. The d2 Test of Attention was administered to assess attention capacity. Multivariate analyses were used to study the association of attention capacity with each PA parameters. Receiver operating-characteristic (ROC) analysis was performed to determine thresholds that best discriminated between low and good attention capacity.

RESULTS: After controlling for potential confounding variables (age, sex, BMI, parental educational level, fat mass, aerobic fitness and center), adolescents' attention capacity test performances were significantly positively associated with longer time spent in moderate or moderate-to-vigorous PA in free-living conditions ($P < 0.05$). ROC analyses revealed that the PA thresholds that best discriminated between low/good attention capacities were ≥ 41, ≥ 12, and ≥ 58 min.day^{-1} for moderate, vigorous, and moderate-to-vigorous PA, respectively.

CONCLUSIONS: These findings suggest that promoting moderate-to-vigorous PA might be beneficial to attention capacity, an important component of cognition, in adolescents.

Introduction

Physical activity (PA) is an important determinant of health throughout the whole lifespan. Engaging in regular moderate-to-vigorous PA (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.[1-3]

The two important parameters of cognition in children and adolescents are attention and concentration because they are indispensable elements in comprehension and learning processes.[4-6] Attention is the behavioral and cognitive process of selectively concentrating on one aspect of the environment while ignoring other things.[5-6] Sibley and Etnier performed a meta-analysis on PA and cognition in children.[2] They concluded that there is a significant positive relationship between PA and cognitive function in children.[2] However, this only included studies conducted to investigate the effects of exercise type on cognitive functions. Moreover, in this meta-analysis eight categories of cognitive assessment tools were used: perceptual skills, intelligent quotient, 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 has been included in the meta-analysis. Some interventional studies showed that the type[4,7], the duration[8-9] or the intensity of PA 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.[7-9,11-13] All these studies examined the improvement of the attention ability after an acute challenge intervention. [7-9,11-13] However, to our knowledge, there is no study examining the baseline attention capacity with respect to adolescent PA patterns.

Therefore, the primary aim of this study was to investigate the relationship of PA, measured objectively, with the attention capacity of European adolescents. The secondary aim was to establish the optimal PA intensity cut-off that best discriminated between low and good attention capacities.

Methods

Study design

This is an ancillary study of the HELENA project (Healthy Lifestyle in Europe by Nutrition in Adolescence; 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 the Ghent University) for almost all cities (except for Pecs and Athens, where schools were locally selected due to local administrative constraints). Details about the selection criteria for schools and classes were previously reported.[14] The inclusion criteria in the study were: (*i*) Male and female subjects aged [12.5–17.5] years old; (*ii*) Schooling in one of the participating classes; (*iii*) Informed consent form signed by the parents and/or the legal guardian; (*iv*) Subject was not participating simultaneously in another similar study. Each participating center was asked to include about 150 male and female adolescents per age stratum (12.5-14; 14-15; 15-16; 16–17.5 years).

In total, 3528 adolescents (1844 girls and 1684 boys) meeting the inclusion criteria completed all examinations. A detailed description of the HELENA study methodology and sampling has been published elsewhere.[15-16] For the purposes of the present study, all participants with valid data on PA, anthropometric characteristics, aerobic fitness and attention ability were included into the analysis (n= 273) (Figure 1). Data were obtained from six countries: France (Lille), Spain (Zaragoza), Austria (Vienna), Germany (Dortmund), Hungary (Pecs), and Greece (Athens).

The aims and objectives were carefully explained and written consents were obtained from the adolescents and their parents. The local ethics committee for each country approved the HELENA study, and all procedures were performed in accordance with the ethical standards of the Helsinki Declaration of 1975 (as revised in 2008) and the European Good Clinical Practice Guidelines.[17]

Measurements

Participants' Characteristics

Weight was measured in light clothes, without shoes, to the nearest 0.1 kg using an electronic scale (SECA 871; SECA, Hamburg, Germany). Height was measured without shoes to the nearest 0.1 cm using a telescopic height-measuring instrument (SECA 225; SECA). Body mass index (BMI) was calculated as weight (kg)/height^2 (m^2). The nutritional status was assessed by the International Obesity Task Force scale.[18]

Total fat and fat free mass were assessed using bioelectrical impedance analysis (AKERN®; BIA101 AKERN, Pontassieve, Italy). Following a 5-min rest, subjects were placed in a supine position with arms and legs in abduction between 30 and 40° 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]

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

Attention capacity

Attention capacity was assessed by the d2 Test of Attention (d2T).[20] The choice to use the d2T was made because it is low cost, easily and rapidly administered, and enables large numbers of people to be tested simultaneously. It was developed to measure sustained attention and concentration under stress induced by a completion time. The principle of this test is to assess performance in terms of visual perceptual speed and concentrative capacities by assessing an individual's ability to selectively focus on certain relevant aspects in a task while ignoring other irrelevant ones, as well as doing so quickly and accurately. This principle reflects three components of attentional/concentration behavior:

(*i*) speed/velocity by quantity of work in a period of time, (*ii*) concentration by quality of work (*iii*), and performance quality by assessing the relationship between speed/velocity and work quality.

The d2T is a paper-and-pencil letter-cancellation test comprising 14 different lines, each one containing 47 randomly-mixed letters ("p" and "d"), for a total of 658 letters. Letters "p" and "d" appear with one or two dashes above or below each letter. The test subject has to carefully check if each letter "d" has two dashes either above or below it, at a rate of 20 s per line. The complete duration of the test is 4 min and 30 seconds. Testing using d2T was carried out in a classroom under the supervision of an HELENA fieldworker during the morning. All d2T were performed before the PA assessment. A low error rate indicates high-quality performance. The reliability of the d2T has a range between 0.95 and 0.98, and the validity coefficient is 0.47.[20]

The attention capacity was calculated by the formula: number of correct guesses, this is, number of correct relevant elements –commissions, number of irrelevant elements marked. Percentiles (%ile) of attention capacity were determined by using the norms given in the test manual, according to sex and age through raw data. Percentiles of attention capacity could be divided into two categories: 1. Low attention capacity (%ile < 25), normal to high attention capacity (%ile ≥ 25 and 75).

Physical Activity

The ActiGraph® Monitor (ActiGraph GT1M®; ActiGraph, Pensacola, FL, USA) was used to assess the physical activity in free-living conditions.[21] This is a uniaxial accelerometer that measures 51 × 41 × 15 mm and weighs 43 g. This device has been validated against oxygen consumption and heart rate to assess physical activity.[22] The inter-instrument reliability of this device is high for both sedentary and vigorous activities. The epoch interval for the ActiGraph® monitor was set at 15 s. The adolescents wore the accelerometer on the lower back with an elastic belt and adjustable buckle. They were instructed to remove the accelerometer during swimming, showering, and bathing. The accelerometers recorded activity for 7 consecutive days and were taken off at night.

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 recording with a minimum of 8 hours of activity per day were excluded from the analyses. Zero activity periods of 20 min or longer were interpreted as "not worn time," and these periods were removed from the summation of activity. Moderate-to-vigorous physical activity levels of the adolescents were assessed using the 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 cut-off ranges of 0–500, 501–1999, 2000–2999, and > 2999 counts·min^{-1}, respectively.

Statistical analysis

Categorical data are expressed as percentages and continuous data are expressed as mean and standard deviations (SD). Normality of the distribution was tested by Shapiro-Wilk test. Statistical testing was conducted at the 2-tailed α level of 0.05. Data were analyzed with SAS software version 9.3 (SAS Institute Inc., Cary, NC, USA) (2013).

The association of each PA parameters with attention capacity were investigated in 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).[25-27] Since nutritional status was based on BMI, we included only BMI into 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 association between PA parameters and attention capacity across sex by including the corresponding interaction term into multivariable regression models.

In order to assess the linearity of relationship between attention capacity and PA parameters, further analyses were done after categorization of PA according to quartiles using analysis of covariance; linear contrasts were used to perform trend tests.

Receiver operating-characteristic (ROC) curves were used to calculate the optimal physical activity cut-off points for moderate, vigorous, and moderate-to-vigorous PA that best discriminated between low and good attention capacity categories. The area under the 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 cut-off points, the test can be: non informative/test 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 a perfect discriminatory test (AUC = 1.0).[28] Cut-off points were selected for those scores optimizing the sensibility–specificity relationship.

Results

A descriptive analysis of the study population is reported in Table 1. One hundred thirty adolescents (47.6%) performed more 60 min.day^{-1} of moderate-to-vigorous PA.

Insert Table 1

In multivariate analyses, time spent in moderate or moderate-to-vigorous PA in free-living conditions were significantly associated with an increase adolescents' attention capacity after adjustment for the level of education of the father and mother, age, sex, BMI, center, fat mass and aerobic fitness level ($P < 0.05$) (Table 2). In addition to PA parameters, only mother's education level and center remained independently associated with attention capacity in any of multivariate analyses (data not shown). We found no significant heterogeneity in the association of each PA parameters and attention capacity across sex (P for all interaction>0.80).

Insert Table 2

Quartile analysis of each PA parameters confirmed the linearity of association of attention capacity with the time spent in moderate or moderate-to-vigorous PA (Figure 2). Those adolescent with moderate-to-vigorous PA more 60 min.day^{-1} had a mean score of attention capacity test at 48.7 (± 30.0) while those are sedentary (<60 min.day^{-1}) had a mean score of 40.9 (± 29.8) ($P < 0.05$). As shown in figure 2, any of the PA levels really influence attention capacity suggesting that duration of moderate to vigorous PA is the main contributor to increase attention capacity score.

Insert Figure 2

ROC analysis showed that PA levels discriminate good from low attention capacity in adolescents are presented in Table 3.

Insert Table 3

Discussion

This study is the first to investigate the potential impact of PA, measured objectively, on adolescents' attention capacity. Our findings revealed a significant positive correlation between moderate-to-vigorous PA and underlying attention capacity.

The association between PA levels and attention capacity, taking into account age, BMI, sex, educational level of parents, center, fat mass and aerobic fitness levels, supports the hypothesis that there is a positive effect of PA on attention capacity in adolescents. These associations were independent of sex, but we caution that we lacked of adequate statistical power to detect significant interaction. Due to the cross sectional design of our study we however cannot exclude that those adolescents who have a high underlying attention ability are those capable of the increased attention necessary to perform moderate-to-vigorous activity regularly, whereas the others are not. The effects of PA on cognitive functions could be due to physiological changes, such as increased levels of brain-derived neurotrophic factor (BDNF). BDNF facilitates learning and maintains cognitive functions by improving synaptic plasticity, acting as a neuroprotective agent, increasing brain circulation and improving neuroelectric functionality.[10] Previous studies on the attention capacity and PA were intervention studies using a pre and post test, with an intervening acute challenge.[4,8,10-13] Our study is the first to examine the baseline, general attention performance with respect to adolescent PA patterns levels. Our findings suggest that increasing PA in free living conditions might be a helpful method for adolescent to reach a higher performance level during teaching lessons or other cognitive tasks.

One interesting finding of our study is that moderate, but not vigorous, PA had a significant positive effect on the attention capacity test (Table 2). Shephard has suggested that involvement in the PA may have induced an immediate arousal and relief from boredom, with the result that the adolescents paid better attention capacity.[29] As suggested Coe et al, it is possible that a threshold level of activity may be needed to produce these potentially desirable effects.[30] This may explain why high attention capacity is associated with moderate activity and not with vigorous PA in our present study. Indeed, vigorous PA might lead to an increase the fatigue compared to moderate PA, and therefore to a decline of the attention capacity. While teachers in Western countries have reported increasing difficulty in maintaining adequate attention and concentration levels in children and adolescents, our results suggest to reinforce the necessity to offer regular physical education lessons with exercise at a moderate intensity in order to improve these two components of cognitive function and help the learning process. However, future research is needed to investigate PA intensity effects on attention capacity using an intervention study with a control group.

A secondary outcome of our study was to establish the optimal physical activity time at moderate and high PA intensities to “obtain” good attention capacity in adolescents. The current physical activity recommendation of at least 60 min·day^{-1} of moderate-to-vigorous physical activity intensity has been based on obesity prevention or other health outcomes.[1] We found similar results in our study; i.e. spending more than 58 min·day^{-1} in moderate to vigorous physical activity intensity would be associated with better attention capacity. These findings support the use of the current physical activity recommendations for preventive purposes related to a good attention capacity in adolescents, but have to be taken with caution because of the low accuracy of PA cut-offs. Due to its cross-sectional design, the observed associations cannot be interpreted to reflect causal relationships. In addition, the lack of assessment of further neuropsychological functions beyond performance on the d2T may limit the interpretation of the results of our study. However, the use of standardized procedures that are strictly adhered to across different centers is a remarkable strength of the HELENA study.[14-15] Harmonization and reliability of anthropometric and PA assessment techniques were carefully assessed throughout the study.[31] Another strength of this study is the inclusion of several confounding factors in the statistical analyses.

Conclusions

The results from this study show a positive association between physical activity and attention capacity in European adolescents. Moderate-to-vigorous PA might play a role in improving attention capacity in adolescents, which is an important component of cognitive function. The data obtained from this study contribute to develop a better understanding of the link between PA and attention capacity in youth. However, future research should be performed using an experimental design (i.e control and experimental groups with subjects randomization) in order to confirm the results of this present observational study.

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Legends

Figure 1. Final sample size flowchart (online only).

Figure 2. Unadjusted and adjusted means of attention capacity according to the quartiles of PA patterns.

Standard errors of mean and adjusted p for trend are reported. Adjustments were done for age sex, mother's and father's educational level, BMI, center, fat mass and aerobic fitness level.

Table 1. Characteristics of the population studied (147 girls and 126 boys).

Table 2. Association between each PA levels and attention capacity adjusted for potential confounding factors.

Table 3. Physical activity cut-off points to predict good attention capacity in adolescents by ROC analysis.

Table 1. Characteristics of the population studied (147 girls and 126 boys)

	Mean ± SD (unless stated otherwise)	Range
Age (yr)	14.2 ± 1.1	12.5–16.9
Height (cm)	165.3 ± 8.7	143.8–189.4
Body mass (kg)	58.4 ± 12.6	35.4–105.7
BMI (kg·m^{-2})	21.3 ± 3.7	15.4–35.1
Fat mass (%)	23.4 ± 9.5	7.6–56.8
Aerobic fitness (ml.kg.min^{-1})	41.4 ± 7.2	28.3-59
Nutritional status (UW/NW/OW/O) (%)[a]	5/70/19/6	- - - -
Father's education level (I/II/III/IV) (%)[b]	7/31/25/37	- - - -
Mother's education level (I/II/III/IV) (%)[b]	10/24/32/34	- - - -
Attention capacity (%ile)[c]	44.6 ± 30.1	16–99
Attention capacity (I/II) (%)[d]	31/69	
Sedentary activities (min)	528.9 ± 90.0	287.8–966.4
Light activities (min)	175.8 ± 41.5	83.2–343.0
Moderate activities (min)	43.3 ± 14.6	16.7–100.7
Vigorous activities (min)	20.1 ± 13.0	1.3–63.2
MVPA (min)	63.3 ± 24.0	20.4–155.65
Mean counts (counts·min^{-1})	466.4 ± 157.4	204.9–1047.4

[a] Nutritional status: underweight (UW), normal weight (NW), overweight (OW), obese (O). [b] Education level: lower education (I); lower secondary education (II); higher secondary education (III); higher education or university degree (IV). [c] Attention ability expressed in percentile. [d] Attention ability: low ability (I), normal to high ability (II).
MVPA: moderate-to-vigorous physical activity.

Table 2. Association between each PA levels and attention capacity adjusted for potential confounding factors

PA levels	**β ± SE**	**P***	***Partial coefficient determination***
Sedentary PA	0.01 ± 0.02	0.4472	0.002
Light PA	0.01 ± 0.04	0.8471	0.0001
Moderate PA	0.30 ± 0.13	0.0195	0.016
Vigorous PA	0.17 ± 0.15	0.2439	0.004
Moderate to Vigorous PA	0.17 ± 0.08	0.0352	0.013

β indicates regression coefficients; SE = Standard Error

* P-value adjusted for confounding factors : age, sex, BMI, educational level of parents, center, fat mass and aerobic fitness level

Table 3. Physical activity cut-off points to predict good attention capacity in adolescents by ROC analysis

	Minutes/day	Sensitivity	Specificity	AUC
Moderate PA	41	0.524	0.570	0.53
Vigorous PA	12	0.690	0.453	0.58
MVPA	58	0.540	0.593	0.56

PA: physical activity, MVPA: moderate-to-vigorous physical activity; AUC: area under the curve.

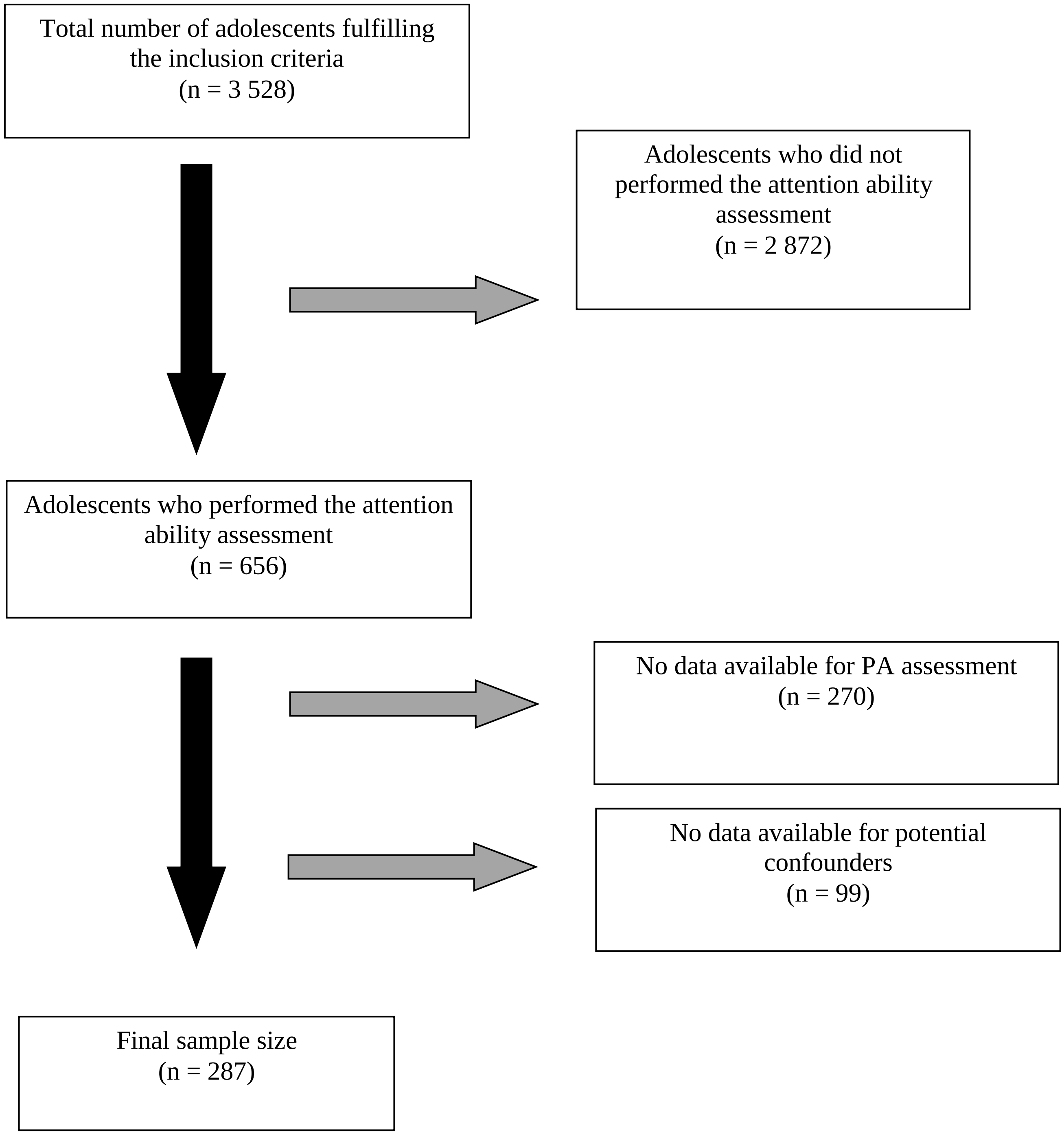

Figure 1. Final sample size flowchart (online only).

Figure 2A. Sedentary physical activity

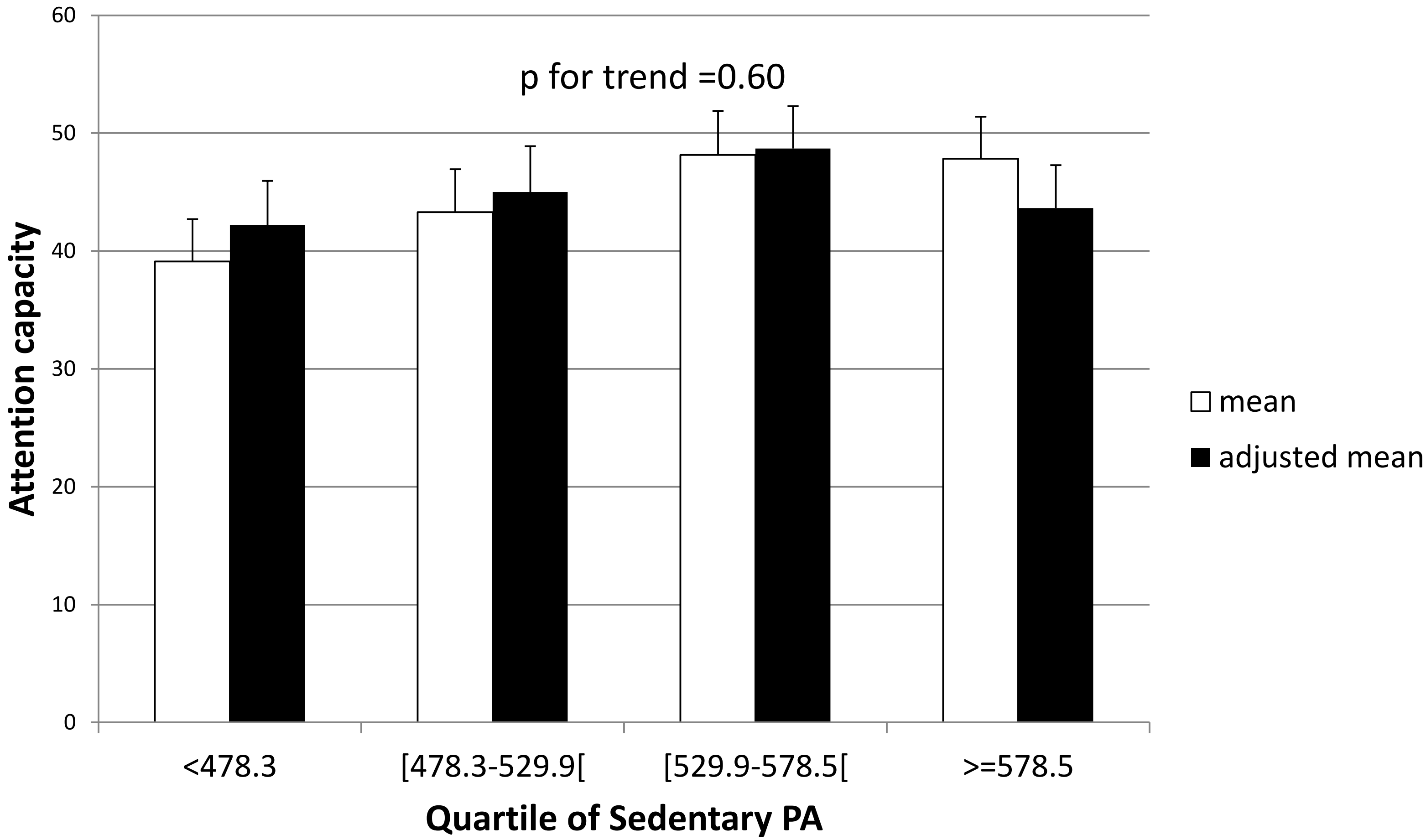

Figure 2B. Light physical activity

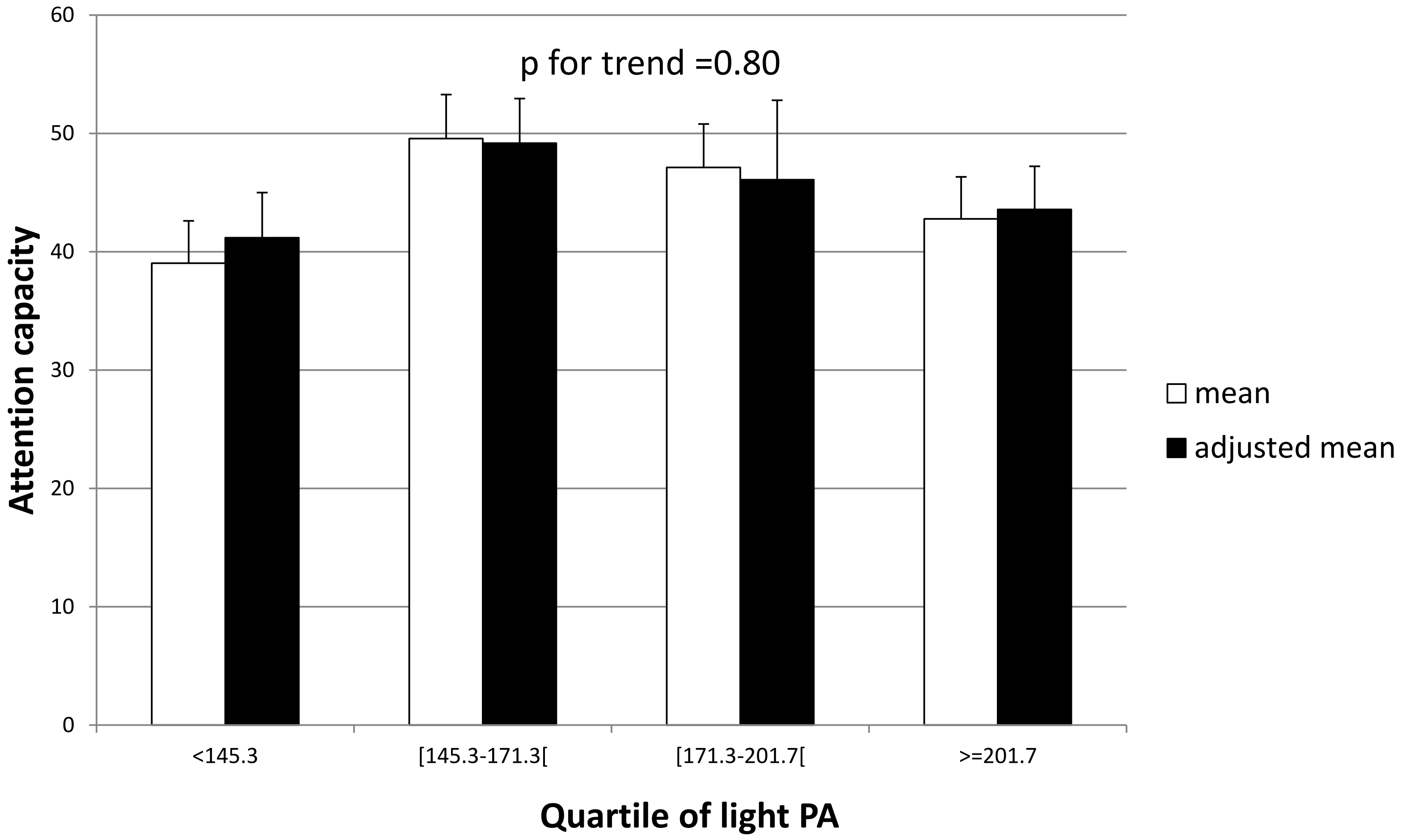

Figure 2C. Moderate physical activity

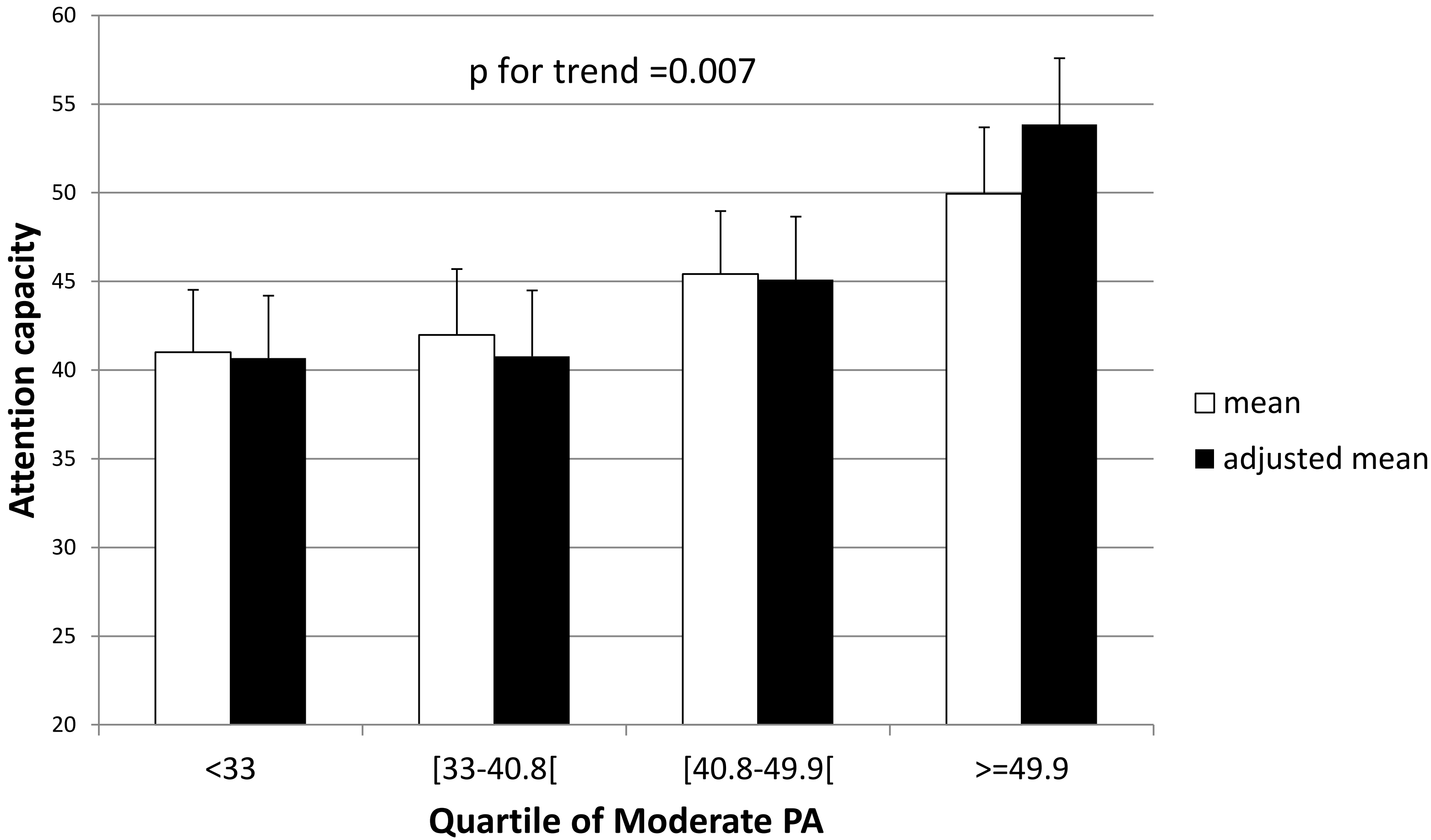

Figure 2D. Moderate to vigorous physical activity

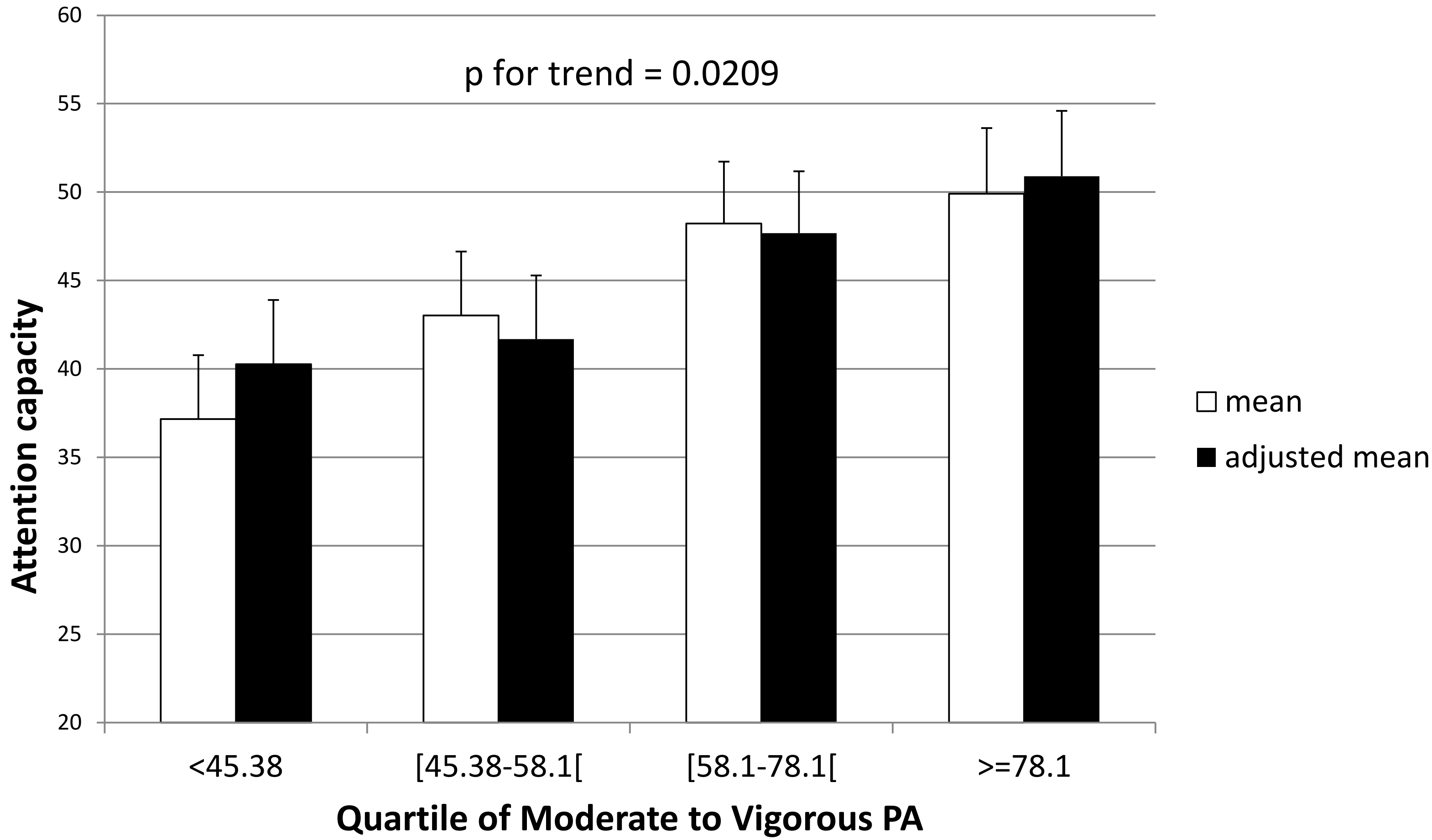

Figure 2E. Vigorous physical activity