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ABSTRACT

Purpose: To examine the prospective associations of physical activity at 11, 15 and 18 years of age with cognitive performance in young adulthood in a large birth cohort study from Brazil. **Methods:** Participants were part of a large birth cohort study in Pelotas, Brazil (n = 3235 participants). Physical activity was self-reported at 11, 15 and 18 years and also was objectively measured at 18 years. Cognitive performance was assessed using an adapted Brazilian version of the short form of the Wechsler Adult Intelligence Scale (WAIS-III) at 18 years. **Results:** At 11 years, participants in the middle tertile of self-reported physical activity presented a significantly higher cognitive performance score as compared to the lowest tertile. Physical activity at 15 years of age was unrelated to cognitive performance at 18 years. Self-reported physical activity was cross-sectionally positively associated with cognitive performance at 18 years ($p<0.001$). Data from objectively measured physical activity at 18 years showed that those in the highest moderate to vigorous physical activity tertile presented lower cognitive performance scores at 18 years as compared to those in the lowest tertile (-2.59; 95%CI: -3.41; -1.48). Analyses on changes in tertiles of physical activity showed that maintaining an intermediate physical activity level from 11 to 18 years and from 15 to 18 years was associated with higher cognitive performance score of 2.31 (95%CI: 0.71; 3.91) and 1.84 score (95%CI: 0.25; 3.42), respectively. **Conclusion:** Physical activity throughout adolescence is associated with cognitive performance before adulthood. Adolescents who are active at moderate levels, specifically those who maintain these levels of physical activity, tend to show higher cognitive performance. However, high levels of physical activity might impair cognitive performance.

Keywords: Cognitive performance, physical activity, early adulthood, prospective study.

INTRODUCTION

Cognition, a wide term to refer to cognitive and academic performance, is an important marker of health (11,13). Lower cognitive levels during adolescence have been associated with greater morbidity and mortality, mental disorders, coronary heart disease and some cancers later in life (11,15,18,20,21). Since physical activity stimulates some factors involved in brain plasticity, such as brain-derived neurotrophic factor, being physically active may have beneficial effects on brain development, which in turn may play a key role in cognitive performance (4). However, scientific evidence from observational studies is unclear to confirm these potential benefits at the population level.

A recent systematic review found that most studies that examined the association between physical activity and cognitive performance in adolescents have a cross-sectional design and use self-reported measures of physical activity (10). These limitations likely contribute to the mixed findings. Observations from cross-sectional studies have mainly found positive associations between self-reported physical activity and cognitive indicators (i.e. the BADYG Battery, SRA Test of Educational Ability, d2 test of attention, CANTAB tests) (23,24,28,30,35). Specifically, Syväoja et al found discrepancies when using self-reported and objective measures of physical activity in relation to cognitive performance (35). One prospective study found a negative association between sport participation and cognitive performance among 12th-grade students (22). Intervention studies performed in physical education settings found that vigorous-intensity physical activity was related to higher cognitive performance (Math Task and Terra Nova standardized tests) (5,29). A better understanding of the association between physical activity and cognitive performance in adolescents is required. Indeed, examining this association is particularly important during adolescence because the magnitude of decline in physical activity during this period is greater than during any other period throughout life (8) in combination with the brain's profound plasticity during adolescence (27).

The 1993 Pelotas (Brazil) Birth Cohort Study is a unique data set with the opportunity to address this issue due to the availability of (i) physical activity measures at 11-, 15- and 18 years, including accelerometry at 18 years, and (ii) cognitive performance at 18 years of age. We examined the prospective associations of physical activity at 11, 15 and 18 years of age with cognitive performance in young adulthood in a large birth cohort study from Brazil.

METHODS

Design and participants

Participants selected for the present study were enrolled in the 1993 Pelotas (Brazil) Birth Cohort. Detailed description about the cohort methods is available elsewhere (12,32,33). In brief, this birth cohort included 5,249 of the 5,265 newborn children (99.7%) in the calendar year of 1993 in Pelotas, a city in Southern Brazil. This study used data from the follow-ups that were carried out when participants were aged 11, 15 and 18 years. Of the 5,249 participants of the cohort, we were able to include data on 3,235 (61.6%) for this study. Of the 2,014 non-participants, 164 (3.1%) were known to have died between birth and 18 years of age, 974 (18.6%) were not located and 876 (16.7%) did not provide valid physical activity data in at least one of the three follow up visits. Before participating in the study, written parental consents were obtained. The study protocols were approved by the Ethics Committee of the Medicine School from the Federal University of Pelotas.

Physical activity measures

Self-reported physical activity during leisure time (min/week) was assessed using two validated questionnaires. Both questionnaires have shown a good reliability and adequate validity to assess physical activity in youth and adults from Brazil when compared with pedometer measurements (1,6). The questionnaire used at 11 and 15 years included a list of physical activities typically practiced by youth in the region with the possibility to include other activities not listed previously. Participants reported the frequency (days per week) and the mean duration (hours and/or minutes per day) that they engaged in each activity over the last 7 days (1). For calculating the time spent in leisure time physical activity, we firstly multiplied the number of days by the average daily duration of each activity, and we then summed the values across different activities. The questionnaire used at 18 years was the leisure-time section of the long version of the International Physical Activity Questionnaire (IPAQ) (6). Participants were asked about the frequency and duration that they spent in walking, moderate-intensity and vigorous-intensity physical activity over the past week. Time spent in leisure time physical activity at 18 years was derived by summing the minutes engaged per week in each category.

Objectively measured physical activity was obtained by the GENEActive accelerometer (ActivInsights, Kimbolton, UK) at 18 years of age. The GENEActive is a waterproof and triaxial accelerometer capable of measuring accelerations from -8 to 8*g* with a sampling frequency set at 85.7 Hz. Data are stored directly as sampled from the MEMS chip (unfiltered data) and expressed in units milligrams (1000m*g* =*1g* = *9*.81 m/s^2) (7). Each participant wore the accelerometer at their non-dominant wrist for 4–7 free-living days including at least one weekend day. A recent validation study confirmed that there is a strong agreement for the vector magnitude of wrist acceleration (m*g*) between GENEActiv and Actigraph accelerometers (16).

The inclusion criteria were an activity monitor recording of at least 2 days. Accelerometers were set up and downloaded using the GENEActiv software. The data were analyzed in binary format with R-package GGIR [http:/cran.r-project.org] (31).

Moderate to vigorous physical activity (MVPA) was estimated using an intensity threshold of 100m*g* based on 5-s epoch data with minimum bout duration of 10 minutes, where > 80% of the data points are equal to or above the threshold. The intensity threshold was based on a recent methodological study in children and adults wearing a GENEActiv accelerometer on their wrist while performing standardized activity types (16). Further information about accelerometer procedures is available elsewhere (7). The physical activity variable used for this analysis was based on minutes per week at MVPA.

Covariates

The main confounding variables included were sex, body mass index (BMI), birth weight and two indicators of socioeconomic status: maternal schooling at birth and family income at birth.

Cognitive performance

Cognitive performance was assessed at 18 years of age using an adapted Brazilian version of the short form of the Wechsler Adult Intelligence Scale (WAIS-III). The WAIS-III is a subsequent revision of the WAIS and the WAIS-R. The WAIS-III short form included four selected WAIS-III subtests (the arithmetic, digit symbol, similarities, and picture completion subtests) (19). This test is designed for adults and older adolescents aged 16 to 89 years. The main adaptations for the Brazilian version were regarding to the content of some items of the verbal scale, the order of items presentation, the time limit and bonus concession, the criteria to start and discontinue the application and the establishment of norms for age. This test was administered by a psychologist in a clinic. An overall cognitive performance score was calculated by summing the score for each subtest and then applying a specific Brazilian weighting (25).

Statistical analysis

Descriptive characteristics are presented as means ± SD and differences between sexes were assessed by t-test. Preliminary analyses showed no significant interactions among sex and physical activity variables (all P > .10); thus, all analyses were performed sex combined.

Participants were classified according to their time spent in physical activity at 11, 15 and 18 years based on sex-specific tertiles (low, middle and high). We evaluated the prospective association between physical activity at 11 and 15 years and cognitive performance at 18 years using linear regression adjusting for sex, BMI at baseline, BMI at 18 years, birth weight, family income at birth and maternal schooling at birth. We also examined the cross-sectional association of objectively and self-reported physical activity with cognitive performance at 18 years, including the same confounding variables.

The differences in cognitive performance by changes in tertiles of physical activity (consistently low, decreasing, consistently middle, increasing, consistently high) from 11 to 18 years and 15 to 18 years were examined by multiple linear regression adjusted for sex, change in BMI from baseline (11 or 15 years) to 18 years, birth weight, family income at birth and maternal schooling at birth. All analyses were conducted using SPSS version 18.0 for Windows (IBM, Armonk, New York), with significance set at $P<0.05$.

RESULTS

Table 1 presents the characteristics of the sample at age 18 years. **Table 2** describes the tertiles of self-reported and objectively measured physical activity used in the analyses. At 11, 15 and 18 years, girls were less active than boys. From 11 to 15 years of age, boys in the lowest tertile increased their physical activity, while boys in the highest tertile decreased their physical activity. Among girls, there was a decline of the mean self-reported physical activity for all three tertiles. At 18 years of age, boys were more active than girls, both in terms of self-reported and objectively measured physical activity. Based on accelerometry, the lowest tertile accumulated on average 109 min/wk and 36 min/wk of MVPA in boys and girls, respectively.

In **table 3**, we display the associations between physical activity at 11, 15 and 18 years of age and cognitive performance at 18 years. At 11 years, participants in the middle tertile of physical activity had 1.03 score (95%CI for the difference: 0.08; 1.98) higher than those in the lowest tertile. Physical activity at 15 years of age was unrelated to cognitive performance at 18 years. Self-reported physical activity at 18 years of age was cross-sectionally positively associated with cognitive performance at 18 years, but only the intermediate tertile continued to present higher cognitive performance scores in the adjusted analyses (+1.30; 95%CI for the difference: 0.33; 2.27). However, data from objectively measured PA suggested that higher amounts of MVPA were associated with lower cognitive performance. Both in the crude and in the adjusted analysis, those in the upper MVPA tertile presented lower cognitive performance scores as compared to those in the bottom tertile (-2.59; 95%CI for the difference: -3.41; -1.48). Analyses were also performed including total PA instead of MVPA, and results were virtually similar (data no shown).

Table 4 shows the effects of trajectories of self-reported physical activity throughout adolescence on cognitive performance at 18 years of age. Findings for the periods 11 to 18 years and 15 to 18 years were notably consistent. Those who were consistently active at moderate levels – i.e. categorized in the intermediate tertile – presented significantly higher cognitive performance scores than those who were consistently inactive. Maintaining an intermediate physical activity level from 11 to 18 years and from 15 to 18 years was associated with higher cognitive performance score of 2.31 (95%CI: 0.71; 3.91) and 1.84 score (95%CI: 0.25; 3.42), respectively.

DISCUSSION

The main finding from this study was that being consistently moderately physically activity throughout adolescence was significantly associated with cognitive performance at age 18 years. This observation was similar in both prospective and cross-sectional analyses using self-reported physical activity. However, data from our cross-sectional analysis using objectively measured physical activity by accelerometry suggested that high physical activity levels might impair cognitive performance. Our results contribute to the current knowledge by suggesting that intermediate levels of physical activity may have the greatest benefit on cognitive performance.

Several mechanisms may yield the effect of physical activity on brain function from early ages to even adulthood (4,14). Exercise increases the formation of new neurons and concentrations of brain-derived neurotrophic factor, improves cerebral blood flow and oxygen availability in the brain as well as enhances activity-dependent synaptic plasticity. This set of physiological changes is related to (i) attention, (ii) information processing, storage, and retrieval and (iii) concentration. Therefore, it might lead to improved cognitive performance in adolescents (17). Importantly, adolescence is the period of life when the brain has profound plasticity which offers high possibilities to stimulate cognitive function (27). Contradictorily, this period also experiences the greatest decreases in physical activity levels (8). Hence, adolescents who are physically inactive might be losing an important stimulus to improve learning and cognitive performance.

Our results in a large birth cohort showed that adolescents who were in the middle tertile of self-reported physical activity at 11 years and 18 years had higher cognitive performance at 18 years compared to those in the lowest tertile. Additionally, continued moderate levels of self-reported physical activity throughout adolescence were associated with higher cognitive performance before adulthood. For example, maintaining in the intermediate tertile from 11 and 15 years to 18 years was associated with +2.33 score and 1.96 score in cognitive performance compared to those who maintained in the lowest tertile, respectively. Taken together, our results suggest that maintaining a regular active lifestyle might appear more strongly associated with cognitive performance compared with changing levels of physical activity during adolescence (e.g. being too inactive at a given age and too active at other age). Hence, the earlier start to engage in moderate levels of physical activity, the higher improvement on cognitive performance before adulthood.

To date, a limited number of prospective and interventional studies have examined whether increases in physical activity are associated with better cognitive performance (3,5,22,29).Two fairly small interventional studies including 48 and 232 adolescents, respectively from Greece and the United States found that being active at vigorous intensity during physical education classes was associated with increases in cognitive performance (5,29). Whereas, these studies suggest that a "threshold intensity", specifically vigorous intensity, may be necessary to produce beneficial cognitive effects, our results support the hypothesis that a "threshold amount" of physical activity (i.e. moderate levels) may be enough to enhance cognitive performance. However, it is important to take into account that these intervention studies were focused on physical education classes, but our prospective results were based on leisure-time physical activity. Further prospective and experimental studies in adolescents are necessary to examine the threshold hypothesis within different settings.

Another finding from the present study regarding to cross-sectional analysis with accelerometry was that adolescents at 18 years who engaged in high levels of physical activity (~600 min/week) had lower cognitive performance compared to the least active group. Marsh & Kleitman also showed that sport participation at early adolescence was negatively associated with cognitive performance at grade 12 (22). Indeed, similar results to ours and those from Marsh & Kleitman have been previously showed when examining the association of physical activity with regard to academic performance (2,9,26). It is possible that those with lower cognitive score are those who start working earlier, who in turn, at working place they are more physically active. To test this hypothesis, we carried out a post hoc analysis using information on working status. When including working status as a covariate, the results were virtually the same and there was no evidence of a modifying effect of working status (i.e. p for MVPA*working status interaction >0.1) on the association between MVPA and cognitive performance. Another explanation could be that, although adolescents who are highly active have the biologically benefit of physical activity, they also may displace time that would usually be spent doing schoolwork, reading for pleasure, or engaging in other educational activities, which in turn, may detract cognitive performance.

Surprisingly, we found discrepancies in cross-sectional findings when using self-reported and objective measures of physical activity in relation to cognitive performance. Similar results have been previously showed from Syväoja et al (34,35). A possible explanation is that self-reported physical activity assesses specific domains of physical activity, such us extracurricular physical activity, physical education or leisure-time, whereas accelerometry covers almost the complete range of physical activity in which adolescents are involved (i.e. except cycling or swimming activities). Thus, the association between physical activity and cognitive performance might depend on which specific component of total physical activity is measured. This reason could partially explain why our findings using self-reported physical activity showed positive associations with cognitive performance, while findings with objective measures of physical activity showed negative associations.

The strengths of this study include the relative large sample size from a birth cohort, its prospective design, the use of accelerometers to assess physical activity and the substantial time interval between measurements. However, the study also has limitations. Changes in the main outcome were not available because cognitive performance data were not collected in previous waves, which preclude drawing conclusions with regard to causality. Likewise, other confounding factors (i.e. pubertal status, physical fitness, parental cognitive status or ethnicity) were not available, so results should be interpreted with caution. In addition, prospective analyses were based on self-reported physical activity. Future research using repeated measures of both objectively measured physical activity as well as different types of physical activity (active commuting, physical education, recess physical activity) and cognitive performance may provide further insights on this association.

In conclusion, our results suggest that physical activity throughout adolescence is associated with cognitive performance (referring to measures of intellectual quotient) before adulthood. Adolescents who are active at moderate levels, specifically those who maintain these levels of physical activity, tend to show higher cognitive performance. However, high levels of physical activity may be detrimental to cognitive performance.

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CONFLICT OF INTEREST

The authors have declared that no competing interests exist

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Table 1. Descriptive characteristics of the sample at age 18 years.

	All	Boys	Girls	P for sex
N	3235	1573	1662	
Height (cm)	167.2±9.3	173.8±7.0	160.9±6.4	**<0.001**
Weight (kg)	65.7±14.4	70.6±14.1	61.1±13.1	**<0.001**
Body mass index (kg/m^2)	23.4±4.5	23.3±4.2	23.6±4.8	0.125
Birth weight (kg)	3.2±0.5	3.3±0.5	3.1±0.5	**<0.001**
Maternal schooling at birth (years)	6.7±3.5	6.8±3.4	6.7±3.5	0.700
MVPA by accelerometry (min/week)	297.0±289.4	400.7±331.4	198.9±198.4	**<0.001**
Physical activity by questionnaire (min/week)	390.1±566.2	564.2±676.7	225.3±367.2	**<0.001**
Cognitive performance (score)	97.0±12.5	96.6±13.3	97.3±11.7	0.081

Values are mean ± standard deviation. MVPA, Moderate-to-vigorous physical activity. Statistically significant values are in bold.

Table 2. Descriptive of physical activity by sex-specific tertiles at 11, 15 and 18 years.

Tertile	*n*	Physical activity by questionnaire (min/week) Mean (95%CI)	Range	*n*	MVPA by accelerometry (min/week) Mean (95%CI)	Range
Boys	1573			1573		
11 years						
Low	551	53.2 (48.7; 57.6)	0 to 150		_	_
Middle	504	290.6 (283.1; 298.0)	155 to 450		_	_
High	518	991.2 (936.8; 1045.6)	460 to 4680		_	_
15 years						
Low	553	70.0 (64.6; 75.4)	0 to 180		_	_
Middle	494	356.2 (347.2; 365.3)	190 to 540		_	_
High	526	510.8 (1086.0; 1184.8)	550 to 4500		_	_
18 years						
Low	516	48.1 (43.5; 52.7)	0 to 160	525	109.3 (103.6; 115.0)	0 to 225.6
Middle	540	373.0 (362.0; 384.1)	170 to 600	535	335.2 (329.3; 341.0)	225.8 to 467.1
High	517	1278.9 (1214.3; 1343.4)	615 to 4800	513	767.4 (739.7; 795.0)	468.1 to 3492.6
Girls	1662			1662		
11 years						
Low	556	8.0 (6.8; 9.1)	0 to 45		_	_
Middle	539	122.1 (117.9; 126.3)	50 to 210		_	_
High	567	607.9 (567.7; 648.2)	215 to 5230		_	_
15 years						
Low	586	0.0 (0.0; 0.0)	0 to 0		_	_
Middle	531	100.2 (95.8; 104.5)	10 to 180		_	_
High	545	521.8 (488.9; 554.65)	190 to 2640		_	_
18 years						
Low	726	0.0 (0.0; 0.0)	0 to 0	560	36.3 (34.0; 38.6)	0 to 87.6
Middle	387	96.2 (91.3; 101.2)	10 to 180	552	150.9 (147.5; 154.3)	87.8 to 227.5
High	549	614.2 (579.0; 649.4)	200 to 3360	550	412.5 (395.5; 429.6)	277.6 to 2307.7

MVPA, Moderate-to-vigorous physical activity.

Table 3. Association of physical activity at 11, 15 and 18 years with cognitive performance at 18 years.

	Tertile	*n*	Cognitive performance (score)	
			Crude	Adjusted [a]
Physical activity by questionnaire				
11 years [b]				
	Low	1107	Reference	Reference
	Middle	1043	**1.56 (0.50; 2.62)***	**1.03 (0.08; 1.98)***
	High	1085	0.13 (-0.91; 1.18)	0.09 (-0.71; 1.17)
	P		**0.006**	0.848
15 years [c]				
	Low	1139	Reference	Reference
	Middle	1025	0.50 (-0.56; 1.56)	0.32 (-0.64; 1.28)
	High	1071	0.14 (-0.91; 1.18)	0.20 (-0.76; 1.15)
	P		0.637	0.902
18 years				
	Low	1242	Reference	Reference
	Middle	927	**1.88 (0.82; 2.95)***	**1.30 (0.33; 2.27)***
	High	1066	**2.23 (1.20; 3.25)***	0.49 (-0.44; 1.43)
	P		**< 0.001**	0.448
MVPA by accelerometry				
18 years				
	Low	1085	Reference	Reference
	Middle	1087	-0.91 (-1.96; 0.13)	-0.14 (-1.09; 0.81)
	High	1063	**-4.43 (-5.47; -3.38)***	**-2.59 (-3.41; -1.48)***
	P		**< 0.001**	**< 0.001**

Values are mean differences (95% confidence interval). MVPA, moderate-to-vigorous physical activity. [a] Analyses were adjusted for sex, birth weight, BMI at 18 years, family income at birth and maternal schooling at birth. [b] Additionally adjusted for BMI at 11 years. [c] Additionally adjusted for BMI at 15. *P* for heterogeneity. * Significantly different from the low tertile (all $P<0.05$). Statistically significant values are in bold

Table 4. Changes in physical activity from 11 and 15 years to 18 years and cognitive performance at 18 years

Changes in tertile	*n*	Cognitive performance (score) Crude	Adjusted [a]
11 to 18 years [b]			
Consistently low	483	Reference	Reference
Decreasing	1062	0.33 (-1.02; 1.67)	0.64 (-0.56; 1.85)
Consistently middle	312	**3.38 (1.60; 5.16)***	**2.31 (0.71; 3.91)***
Increasing	977	**1.92 (0.55; 3.28)***	0.83 (-0.39; 2.06)
Consistently high	401	**1.73 (0.07; 3.38)***	0.43 (-1.06;1.91)
15 to 18 years [c]			
Consistently low	518	Reference	Reference
Decreasing	1023	0.19 (-1.13; 1.51)	0.58 (-0.63; 1.78)
Consistently middle	1321	**2.66 (0.92; 4.40)***	**1.84 (0.25; 3.42)***
Increasing	954	**2.16 (0.82; 3.49)***	1.12 (-0.10; 2.34)
Consistently high	419	**2.78 (1.17; 4.39)***	1.26 (-0.21;2.73)

Values are mean differences (95% confidence interval). [a] Analyses were adjusted for sex, birth weight, BMI at 18 years, family income at birth and maternal schooling at birth. [b] Additionally adjusted for changes BMI from 11 to 18 years. [c] Additionally adjusted for changes BMI from 15 to 18 years. *Significantly different from the consistently low group (all *P*<0.05). Statistically significant values are in bold.