OPEN

# Physical Activity throughout Adolescence and Cognitive Performance at 18 Years of Age

IRENE ESTEBAN-CORNEJO[1], PEDRO C. HALLAL[2], GRÉGORE I. MIELKE[2], ANA M. B. MENEZES[2], HELEN GONÇALVES[2], FERNANDO WEHRMEISTER[2], ULF EKELUND[3,4], and AIRTON J. ROMBALDI[2]

[1]*Department of Physical Education, Sports, and Human Movement, Autonomous University of Madrid, Madrid, SPAIN;* [2]*Postgraduate Program in Epidemiology, Federal University of Pelotas, Pelotas, BRAZIL;* [3]*Department of Sport Medicine, Norwegian School of Sport Sciences, Oslo, NORWAY; and* [4]*Medical Research Council Epidemiology Unit, University of Cambridge, Cambridge, UNITED KINGDOM*

**ABSTRACT**

ESTEBAN-CORNEJO, I., P. C. HALLAL, G. I. MIELKE, A. M. B. MENEZES, H. GONÇALVES, F. WEHRMEISTER, U. EKELUND, and A. J. ROMBALDI. Physical Activity throughout Adolescence and Cognitive Performance at 18 Years of Age. *Med. Sci. Sports Exerc.*, Vol. 47, No. 12, pp. 2552–2557, 2015. **Purpose**: This study aimed to examine the prospective associations of physical activity at 11, 15, and 18 yr 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 yr and was also objectively measured at 18 yr. Cognitive performance was assessed using an adapted Brazilian version of the short form of the Wechsler Adult Intelligence Scale at 18 yr. **Results**: At 11 yr, participants in the middle tertile of self-reported physical activity presented a significantly higher cognitive performance score as compared with the lowest tertile. Physical activity at 15 yr of age was unrelated to cognitive performance at 18 yr. Self-reported physical activity was cross-sectionally positively associated with cognitive performance at 18 yr ($P < 0.001$). Data from objectively measured physical activity at 18 yr showed that those in the highest moderate-to-vigorous physical activity tertile presented lower cognitive performance scores at 18 yr as compared with those in the lowest tertile (−2.59; 95% confidence interval (CI), −3.41 to −1.48). Analyses on changes in tertiles of physical activity showed that maintaining an intermediate physical activity level from 11 to 18 yr and from 15 to 18 yr was associated with a higher cognitive performance score of 2.31 (95% CI, 0.71–3.91) and 1.84 score (95% CI, 0.25–3.42), respectively. **Conclusions**: 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.
**Key Words:** COGNITIVE PERFORMANCE, PHYSICAL ACTIVITY, EARLY ADULTHOOD, PROSPECTIVE STUDY



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, CHD, and some cancers later in life (11,15,18,20,21). Because 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. (35) found discrepancies when using self-reported and objective measures of physical activity in relation to cognitive performance. 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,

Address for correspondence: Irene Esteban-Cornejo, Ph.D., Department of Physical Education, Sports, and Human Movement, Autonomous University of Madrid, Ctra de Colmenar km 15, 28049 Madrid, Spain; E-mail: irene.esteban@uam.es.
Submitted for publication January 2015.
Accepted for publication May 2015.

0195-9131/15/4712-2552/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/MSS.0000000000000706

examining this association is particularly important during adolescence because the magnitude of decline in physical activity during this period is greater than that 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 because of the availability of 1) physical activity measures at 11, 15, and 18 yr, including accelerometry at 18 yr, and 2) cognitive performance at 18 yr of age. We examined the prospective associations of physical activity at 11, 15, and 18 yr 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 descriptions about the cohort methods are available elsewhere (12,32,33). In brief, this birth cohort included 5249 of the 5265 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 age 11, 15, and 18 yr. Of the 5249 participants of the cohort, we were able to include data on 3235 (61.6%) for this study. Of the 2014 nonparticipants, 164 (3.1%) were known to have died between birth and 18 yr 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$\cdot$wk$^{-1}$) 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 yr 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 (d$\cdot$wk$^{-1}$) and the mean duration (h and/or min$\cdot$d$^{-1}$) that they engaged in each activity over the last 7 d (1). For calculating the time spent in leisure time physical activity, we first 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 yr was the leisure time section of the long version of the International Physical Activity Questionnaire (6). Participants were asked about the frequency and duration that they spent in walking and in moderate-intensity and vigorous-intensity physical activity over the past week. Time spent in leisure time physical activity at 18 yr was derived by summing the minutes engaged per week in each category.

Objectively measured physical activity was obtained by the GENEActive accelerometer (ActivInsights, Kimbolton, United Kingdom) at 18 yr of age. The GENEActive is a waterproof and triaxial accelerometer capable of measuring accelerations from $-8g$ to $8g$ ($g$ = 9.81 m$\cdot$s$^{-1}$) with a sampling frequency set at 85.7 Hz. Data are stored directly as sampled from the Microelectromechanical Systems chip (unfiltered data) (7). Each participant wore the accelerometer on their nondominant wrist for four to seven 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 criterion was an activity monitor recording of at least 2 d. Accelerometers were set up and downloaded using the GENEActiv software. The data were analyzed in binary format with R-package GGIR (http://www.cran.r-project.org) (31).

Moderate-to-vigorous physical activity (MVPA) was estimated using an intensity threshold of 100 m$g$ based on 5-s epoch data with minimum bout duration of 10 min, 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 yr 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 age 16–89 yr. The main adaptations for the Brazilian version were regarding to the content of some items of the verbal scale, the order of item 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 $P > 0.10$); thus, all analyses were performed sex combined.

Participants were classified according to their time spent in physical activity at 11, 15, and 18 yr on the basis of sex-specific

TABLE 1. Descriptive characteristics of the sample at age 18 yr.

| | 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** |
| BMI (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 (yr) | 6.7 ± 3.5 | 6.8 ± 3.4 | 6.7 ± 3.5 | 0.700 |
| MVPA by accelerometry (min·wk$^{-1}$) | 297.0 ± 289.4 | 400.7 ± 331.4 | 198.9 ± 198.4 | **<0.001** |
| Physical activity by questionnaire (min·wk$^{-1}$) | 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 presented as mean ± SD. Statistically significant values are set in bold.

tertiles (low, middle, and high). We evaluated the prospective association between physical activity at 11 and 15 yr and cognitive performance at 18 yr using linear regression adjusting for sex, BMI at baseline, BMI at 18 yr, 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 yr, 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 and 15 to 18 yr were examined by multiple linear regression adjusted for sex, change in BMI from baseline (11 or 15 yr) to 18 yr, birth weight, family income at birth, and maternal schooling at birth. All analyses were conducted using SPSS version 18.0 for Windows (IBM, Armonk, NY), with significance set at $P < 0.05$.

## RESULTS

Table 1 presents the characteristics of the sample at age 18 yr. Table 2 describes the tertiles of self-reported and objectively measured physical activity used in the analyses. At 11, 15, and 18 yr, girls were less active than boys. From 11 to 15 yr of age, boys in the lowest tertile increased their physical activity whereas 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 yr of age, boys were more active than girls, both in terms of self-reported and objectively measured physical activity. On the basis of accelerometry, the lowest tertile accumulated on average 109 min·wk$^{-1}$ and 36 min·wk$^{-1}$ of MVPA in boys and girls, respectively.

In Table 3, we display the associations between physical activity at 11, 15, and 18 yr of age and cognitive performance at 18 yr. At 11 yr, participants in the middle tertile of physical activity had a 1.03 score (95% confidence interval (CI) CI for the difference, 0.08–1.98) higher than those in the lowest tertile. Physical activity at 15 yr of age was unrelated to cognitive performance at 18 yr. Self-reported physical activity at 18 yr of age was cross-sectionally positively associated with cognitive performance at 18 yr, but only the intermediate tertile continued to present higher cognitive performance scores in the adjusted analyses

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

| | | Physical Activity by Questionnaire (min·wk$^{-1}$) | | | MVPA by Accelerometry (min·wk$^{-1}$) | |
|---|---|---|---|---|---|---|
| Tertile | *n* | Mean (95% CI) | Range | *n* | Mean (95% CI) | Range |
| Boys | 1573 | | | 1573 | | |
| 11 yr | | | | | | |
| Low | 551 | 53.2 (48.7–57.6) | 0–150 | | — | — |
| Middle | 504 | 290.6 (283.1–298.0) | 155–450 | | — | — |
| High | 518 | 991.2 (936.8–1045.6) | 460–4680 | | — | — |
| 15 yr | | | | | | |
| Low | 553 | 70.0 (64.6–75.4) | 0–180 | | — | — |
| Middle | 494 | 356.2 (347.2–365.3) | 190–540 | | — | — |
| High | 526 | 510.8 (1086.0–1184.8) | 550–4500 | | — | — |
| 18 yr | | | | | | |
| Low | 516 | 48.1 (43.5–52.7) | 0–160 | 525 | 109.3 (103.6–115.0) | 0–225.6 |
| Middle | 540 | 373.0 (362.0–384.1) | 170–600 | 535 | 335.2 (329.3–341.0) | 225.8–467.1 |
| High | 517 | 1278.9 (1214.3–1343.4) | 615–4800 | 513 | 767.4 (739.7–795.0) | 468.1–3492.6 |
| Girls | 1662 | | | 1662 | | |
| 11 yr | | | | | | |
| Low | 556 | 8.0 (6.8–9.1) | 0–45 | | — | — |
| Middle | 539 | 122.1 (117.9–126.3) | 50–210 | | — | — |
| High | 567 | 607.9 (567.7–648.2) | 215–5230 | | — | — |
| 15 yr | | | | | | |
| Low | 586 | 0.0 (0.0–0.0) | 0–0 | | — | — |
| Middle | 531 | 100.2 (95.8–104.5) | 10–180 | | — | — |
| High | 545 | 521.8 (488.9–554.65) | 190–2640 | | — | — |
| 18 yr | | | | | | |
| Low | 726 | 0.0 (0.0–0.0) | 0–0 | 560 | 36.3 (34.0–38.6) | 0–87.6 |
| Middle | 387 | 96.2 (91.3–101.2) | 10–180 | 552 | 150.9 (147.5–154.3) | 87.8–227.5 |
| High | 549 | 614.2 (579.0–649.4) | 200–3360 | 550 | 412.5 (395.5–429.6) | 277.6–2307.7 |

TABLE 3. Association of physical activity at 11, 15, and 18 yr with cognitive performance at 18 yr.

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

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

(+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 with 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 not shown).

Table 4 shows the effects of trajectories of self-reported physical activity throughout adolescence on cognitive performance at 18 yr of age. Findings for the periods 11–18 and 15–18 yr 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 yr and from 15 to 18 yr was associated with a 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 active throughout adolescence was significantly associated with cognitive performance at age 18 yr. 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 1) attention, 2) information processing, storage, and retrieval, as well as 3) 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 and 18 yr had higher cognitive performance at 18 yr compared with those in the lowest tertile. In addition, 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 15–18 yr was associated with a +2.33 score and a 1.96 score in cognitive performance compared with those who maintained in the lowest tertile, respectively. Taken together, our results suggest that maintaining a regular active lifestyle might seem 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

TABLE 4. Changes in physical activity from 11 and 15–18 yr and cognitive performance at 18 yr.

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

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

active at other ages). Hence, the earlier to 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 yr who engaged in high levels of physical activity (approximately 600 $min \cdot wk^{-1}$) had lower cognitive performance compared with the least active group. Marsh and Kleitman (22) also showed that sport participation at early adolescence was negatively associated with cognitive performance at grade 12. Indeed, similar results to ours and those from Marsh and Kleitman (22) have been previously shown when examining the association of physical activity with regard to academic performance (2,9,26). Those with lower cognitive score might be those who start working earlier, who in turn, are more physically active at their working place. 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 shown 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, whereas 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 and 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.

I. E. C. received a scholarship from the Santander Bank for a brief stay in the Federal University of Pelotas, Brazil. The cohort study is supported by the Wellcome Trust. The initial phases of the cohort were funded by the European Union and the Brazilian National Program for Centers of Excellence (PRONEX), National Research Council (CNPq), and Ministry of Health. None of these organizations influenced the study design, the collection, analysis, and interpretation of data, the writing of the report, or the decision to submit the article for publication.

The authors have declared that no competing interests exist.

The results of the present study do not constitute endorsement by the American College of Sports Medicine.

## REFERENCES

1. Bastos JP, Araujo CL, Hallal PC. Prevalence of insufficient physical activity and associated factors in Brazilian adolescents. *J Phys Act Health*. 2008;5(6):777–94.
2. Booth JN, Leary SD, Joinson C, et al. Associations between objectively measured physical activity and academic attainment in adolescents from a UK cohort. *Br J Sports Med*. 2014;48(3):265–70.
3. Booth JN, Tomporowski PD, Boyle JM, et al. Associations between executive attention and objectively measured physical activity in adolescence: findings from ALSPAC, a UK cohort. *Ment Health and Phys Act*. 2013;6(3):212–9.
4. Chaddock L, Pontifex MB, Hillman CH, Kramer AF. A review of the relation of aerobic fitness and physical activity to brain structure and function in children. *J Int Neuropsychol Soc*. 2011;17:975–85.
5. Coe D, Pivarnik JM, Womack CJ, Reeves MJ, Malina RM. Effect of physical education and activity levels on academic achievement in children. *Med Sci Sports Exerc*. 2006;38(8):1515–9.



EPIDEMIOLOGY

6. Craig CL, Marshall AL, Sjöström M, et al. International physical activity questionnaire: 12-country reliability and validity. *Med Sci Sports Exerc*. 2003;35(8):1381–95.
7. da Silva IC, van Hees VT, Ramires VV, et al. Physical activity levels in three Brazilian birth cohorts as assessed with raw triaxial wrist accelerometry. *Int J Epidemiol*. 2014;43:1959–68.
8. Dumith SC, Gigante DP, Domingues MR, Kohl HW 3rd. Physical activity change during adolescence: a systematic review and a pooled analysis. *Int J Epidemiol*. 2011;40(3):685–8.
9. Esteban-Cornejo I, Tejero-González CM, Martinez-Gomez D, et al. Objectively measured physical activity has a negative but weak association with academic performance in children and adolescents. *Acta Paediatr*. 2014 doi: 10.1111/apa.12757.
10. Esteban-Cornejo I, Tejero-Gonzalez CM, Sallis JF, Veiga OL. Physical activity and cognition in adolescents: a systematic review. *J Sci Med Sport*. 2015;18(5):534–9.
11. Gale CR, Batty GD, Tynelius P, Deary IJ, Rasmussen F. Intelligence in early adulthood and subsequent hospitalization for mental disorders. *Epidemiology*. 2010;21(1):70–7.
12. GonÇalves H, AssunÇão MC, Wehrmeister FC, et al. Cohort profile update: the 1993 Pelotas (Brazil) birth cohort follow-up visits in adolescence. *Int J Epidemiol*. 2014;43(4):1082–8.
13. Gottfredson LS, Deary IJ. Intelligence predicts health and longevity, but why? *Curr Dir Psychol Sci*. 2004;13(1):1–4.
14. Hamer M, Chida Y. Physical activity and risk of neurodegenerative disease: a systematic review of prospective evidence. *Psychol Med*. 2009;39(1):3–11.
15. Hart CL, Taylor MD, Davey Smith G, et al. Childhood IQ, social class, deprivation, and their relationships with mortality and morbidity risk in later life: prospective observational study linking the Scottish Mental Survey 1932 and the Midspan studies. *Psychosom Med*. 2003;65(5):877–83.
16. Hildebrand M, Van Hees VT, Hansen BH, Ekelund U. Age-group comparability of raw accelerometer output from wrist- and hip-worn monitors. *Med Sci Sports Exerc*. 2014;46:1816–24.
17. Hillman CH, Erickson KI, Kramer AF. Be smart, exercise your heart: exercise effects on brain and cognition. *Nat Rev Neurosci*. 2008;9(1):58–65.
18. Jaycox LH, Stein BD, Paddock S, et al. Impact of teen depression on academic, social, and physical functioning. *Pediatrics*. 2009; 124(4):e596–605.
19. Jeykumar SLE, Warrier EM, Raval W, Ahmad AS. Balancing the need for reliability and time efficiency: short forms of the WAIS-III. *Educ Psychol Meas*. 2004;64(1):71–87.
20. Lager A, Bremberg S, Vågerö D. The association of early IQ and education with mortality: 65 year longitudinal study in Malmö, Sweden. *BMJ* . 2009;339(7735):b5282.
21. Lawlor DA, Batty GD, Clark H, McIntyre S, Leon DA. Association of childhood intelligence with risk of coronary heart disease and stroke: findings from the Aberdeen Children of the 1950s Cohort Study. *Eur J Epidemiol*. 2008;23(10):695–706.
22. Marsh H, Kleitman S. School athletic participation: mostly gain with little pain. *J Sport Exerc Psychol*. 2003;25(2):205–8.
23. Martínez-Gómez D, Ruiz J, Gómez-Martínez S, et al. Active commuting to school and cognitive performance in adolescents: the AVENA study. *Arch Pediatr Adolesc Med*. 2011;165(4):300–5.
24. Morales J, Gonzalez L, Guerra M, et al. Physical activity, perceptual-motor performance, and academic learning in 9- to 16-years-old school children. *Int J Sport Psychol*. 2011;42(4):401–15.
25. Nascimento E, Figueiredo VM. WISC-III and WAIS-III: alterations in the current American original versions of the adaptations for use in Brazil. *Psicol Reflex Crit*. 2002;15:603–2.
26. Rombaldi AJ, Clark VL, Reichert FF, et al. Incidence of school failure according to baseline leisure-time physical activity practice: prospective study. *J Adolesc Health*. 2012;51(6 Suppl):S22–6.
27. Romeo RD, McEwen BS. Stress and the adolescent brain. *Ann N Y Acad Sci*. 2006;1094:202–14.
28. Ruiz JR, Ortega FB, Castillo R, et al. Physical activity, fitness, weight status, and cognitive performance in adolescents. *J Pediatr*. 2010;157(6):917–22.
29. Travlos AK. High intensity physical education classes and cognitive performance in eighth-grade students: an applied study. *Int J Sports Exerc Psychol*. 2010;8(3):302–11.
30. Van Dijk ML, De Groot RH, Van Acker F, Savelberg HH, Kirschner PA. Active commuting to school, cognitive performance, and academic achievement: an observational study in Dutch adolescents using accelerometers. *BMC Public Health*. 2014;14:799.
31. van Hees VT, Gorzelniak L, Dean León EC, et al. Separating movement and gravity components in an acceleration signal and implications for the assessment of human daily physical activity. *PLoS One*. 2013;8:e61691.
32. Victora CG, Araújo CL, Menezes AM, et al. Methodological aspects of the 1993 Pelotas (Brazil) Birth Cohort Study. *Rev Saude Publica*. 2006;40(1):39–46.
33. Victora CG, Hallal PC, Araújo CL, Menezes AM, Wells JC, Barros FC. Cohort profile: the 1993 Pelotas (Brazil) birth cohort study. *Int J Epidemiol*. 2008;37(4):704–9.
34. Syväoja HJ, Kantomaa MT, Ahonen T, Hakonen H, Kankaanpää A, Tammelin TH. Physical activity, sedentary behavior, and academic performance in Finnish children. *Med Sci Sports Exerc*. 2013;45(11):2098–104.
35. Syväoja HJ, Tammelin TH, Ahonen T, Kankaanpää A, Kantomaa MT. The associations of objectively measured physical activity and sedentary time with cognitive functions in school-aged children. *PLoS One*. 2014;9(7):e103559.