Associations between objectively measured physical activity and academic attainment in adolescents from a UK cohort

J N Booth,¹,² S D Leary,³ C Joinson,⁴ A R Ness,³ P D Tomporowski,⁵ J M Boyle,¹ J J Reilly¹

ABSTRACT

Background To test for cross-sectional (at age 11) and longitudinal associations between objectively measured free-living physical activity (PA) and academic attainment in adolescents.Method Data from 4755 participants (45% male) with valid measurement of PA (total volume and intensity) by accelerometry at age 11 from the Avon Longitudinal Study of Parents and Children (ALSPAC) was examined. Data linkage was performed with nationally administered school assessments in English, Maths and Science at ages 11, 13 and 16. Results In unadjusted models, total volume of PA predicted decreased academic attainment. After controlling for total volume of PA, percentage of time spent in moderate-vigorous-intensity PA (MVPA) predicted increased performance in English assessments in both sexes, taking into account confounding variables. In Maths at 16 years, percentage of time in MVPA predicted increased performance for males (standardised β=0.11, 95% CI 0.00 to 0.22) and females (β=0.08, 95% CI 0.00 to 0.16). For females the percentage of time spent in MVPA at 11 years predicted increased Science scores at 11 and 16 years (β=0.14 (95% CI 0.03 to 0.25) and 0.14 (0.07 to 0.21), respectively). The correction for regression dilution approximately doubled the standardised β coefficients. Conclusions Findings suggest a long-term positive impact of MVPA on academic attainment in adolescence.

INTRODUCTION

Few school-age children or adolescents meet recommendations for 1 h of moderate-vigorous intensity physical activity (MVPA) daily.¹–³ Low levels of physical activity (PA) may have substantial adverse public health impact.⁴–⁶ Recent UK studies have found that MVPA is low in decline by midchildhood² ⁷ and is associated with excessive gains in body fat.⁸ The 2011 Cochrane review on obesity prevention in children⁹ concluded that PA promotion will prevent obesity in children and adolescents and so the crucial public health issue is how to promote PA successfully.¹⁰ Consensus conferences hosted by the US Center for Disease Control and Prevention¹⁰ ¹¹ and the American College of Sports Medicine, concluded that schools will require a much stronger ‘stake’ in PA in order to make the kind of changes which will lead to sustained and substantial increases in PA. Evidence that increased PA improves academic attainment would provide schools, adolescents and parents with the necessary stake in making changes which will increase PA.

There is an emerging body of evidence that PA, particularly MVPA, in childhood and adolescence has cognitive effects that should be conducive to improved academic attainment.¹²⁻²⁰ In a review, Chaddock et al²¹ suggested that low PA can have a detrimental effect on brain structure and function and that these effects are related to cognitive performance and academic attainment. There is also evidence for a ‘dose–response’ effect of increasing PA on academic attainment in obese adolescents.¹³ ²² However, recent reviews²³ ²⁴ found that studies of associations between PA and academic attainment in children and adolescents are limited: small sample sizes; cross-sectional design; failure to take account of confounders; subjective measures of PA prone to imprecision and bias. The present study aimed to test for cross-sectional (at age 11) and longitudinal associations between objectively measured PA, in particular MVPA and academic attainment in adolescents participating in the Avon Longitudinal Study of Parents and Children (ALSPAC).

METHOD

Study cohort

The sample comprised participants from the ALSPAC (http://www.alspac.bris.ac.uk). ALSPAC is an ongoing population-based study investigating a wide range of influences on health and development of children. Pregnant women resident in the former Avon Health Authority in south-west England, having an estimated date of delivery between 1 April 1991 and 31 December 1992 were invited to take part, resulting in a cohort of 14 541 children. Pregnant women resident in the former Avon Health Authority in south-west England were invited to take part, resulting in a cohort of 14 541 pregnancies and 13 988 children (n=6762 girls) alive at 12 months of age. The phases of enrolment are described in detail elsewhere.²² Please note that the study website contains details of all the data that is available through a fully searchable data dictionary (http://www.bristol.ac.uk/alspac/researchers/data-access/data-dictionary/).

Study design and procedures

The present longitudinal study is based on associations between objectively measured PA at an ALSPAC research clinic attended at age 11 and academic attainment at ages11, 13 and 16.

Exposure, outcome measures and covariates

Habitual PA was measured objectively with the Actigraph AM 7164 2.2 accelerometer (Fort Walton Beach, Florida). Systematic reviews show that the Actigraph has high criterion validity,
acceptable reliability and low reactivity for measurement of PA in children and adolescents.\textsuperscript{27} Moreover, the ability to detect associations between PA and outcomes is much greater when PA is measured objectively.\textsuperscript{28} \textsuperscript{29}

The Actigraph was used in the present study as described previously.\textsuperscript{30} \textsuperscript{31} Participants were requested to wear the accelerometer during waking hours for 7 consecutive days. The Actigraph was worn on the right hip and strings of consecutive zero’s lasting 10 min or more were removed.\textsuperscript{30} \textsuperscript{32} Acceptable reliability required accelerometer of at least 3 days and 10 h of wear time per day.\textsuperscript{31} \textsuperscript{34} The previous examination of measurement variation with the accelerometer data from ALSPAC revealed small differences between weekdays and weekend days therefore including a weekend day is not required in this sample.\textsuperscript{30}

Accelerometry output per unit time is presented as counts per minute (cpm) and in the present study was based on 60 s epochs and adjusted for wear time. Accelerometer cpm is used widely as a proxy for the total volume of physical activity and provides a fairly valid measure of the total volume of PA\textsuperscript{28} correlating well with total and physical activity energy expenditure derived from the doubly labelled water technique.\textsuperscript{35} \textsuperscript{37} For school-aged children and adolescents PA recommendations\textsuperscript{4} \textsuperscript{5} \textsuperscript{28} are in MVPA.\textsuperscript{22} We applied the MVPA cut-point of 3600 cpm derived from the validation and calibration study conducted in a subsample of ALSPAC participants.\textsuperscript{12} This sample-specific cut-point was calibrated against VO₂ and deaccelerations from the validation and calibration study conducted in a sub-sample of ALSPAC participants.\textsuperscript{32} MVPA as equivalent to four MET’s\textsuperscript{32} and has been widely reported in previous studies.

The outcome measures were academic attainment assessed at 11, 13 and 16 years. Compulsory nationally administered tests are completed in England at age 6/7 (key stage 1), 10/11 (key stage 2), 13/14 (key stage 3) and 15/16 (key stage 4: General Certificate of Secondary Education, GCSE). Data linkage with the National Pupil Database in England (http://www.adls.ac.uk/department-for-education/dcsf-npd/?detail) was performed by a team. This linkage provided results of assessments in English, Maths and Science at key stages 2, 3 and 4 and was calibrated against VO₂ and deaccelerations from the doubly labelled water technique.\textsuperscript{35} \textsuperscript{37} For school-aged children and adolescents PA recommendations\textsuperscript{4} \textsuperscript{5} \textsuperscript{28} are in MVPA.\textsuperscript{22} We applied the MVPA cut-point of 3600 cpm derived from the validation and calibration study conducted in a subsample of ALSPAC participants.\textsuperscript{12} This sample-specific cut-point was calibrated against VO₂ and defines MVPA as equivalent to four MET’s\textsuperscript{32} and has been widely reported in previous studies.

The outcome measures were academic attainment assessed at 11, 13 and 16 years. Compulsory nationally administered tests are completed in England at age 6/7 (key stage 1), 10/11 (key stage 2), 13/14 (key stage 3) and 15/16 (key stage 4: General Certificate of Secondary Education, GCSE). Data linkage with the National Pupil Database in England (http://www.adls.ac.uk/department-for-education/dcsf-npd/?detail) was performed by a third party company and checked extensively by the ALSPAC team. This linkage provided results of assessments in English, Maths and Science at key stages 2–4 (see Department of Education for further details http://www.education.gov.uk/). At key stages 2 and 3, raw scores are converted to levels (levels 1–8, with 8 being highest) and at key stage 4, GCSE’s are graded from A* to G and U (ungraded) with A* being highest.

A series of potential confounders were included: age; birth weight; gestation; age of mother at delivery; mother’s oily fish intake during pregnancy as assessed by questionnaire at 32 weeks gestation; maternal smoking in the first 3 months of pregnancy; weight status, expressed as a body mass index (BMI) Z score relative to UK 1990 reference data; pubertal status based on Tanner pubic hair stage for males (stage I (least advanced)–V (most advanced)) and menarche status for females at ages 11 and 13, raw scores for academic attainment were used in analyses and at age 16, GCSE grades were converted from alphabetic grades (U–A*) to numerical values ranging from 1 to 9, with 9 being highest. Previous ALSPAC reports of accelerometer assessed PA have employed both cpm and average daily number of minutes of MVPA adjusted for wear time as explanatory variables. Furthermore, the percentage of time spent in MVPA (percentage of MVPA)\textsuperscript{1} has also been reported which allows conclusions regarding the impact of MVPA (ie, the intensity of PA) to be made independently of the total volume of PA and sedentary time.\textsuperscript{39} The correlation between cpm and % MVPA for males was 0.73 and 0.68 for females. The present study therefore explored the associations between PA and academic attainment using linear regression analyses with cpm and % MVPA as predictor variables; however as the PA guidelines and previous research highlight the importance of MVPA, associations with cpm as a predictor are presented in online supplementary material. As males and females have been found to differ in relation to PA levels\textsuperscript{33} and academic attainment\textsuperscript{47} the interaction between gender and PA was formally tested. As evidence suggested interaction effects (p values <0.05), analyses were conducted separately for males and females.

A series of models were used to explore the impact of confounders with % MVPA as the predictor variable and cpm included as a confounder so as to assess the independent effect of time spent in MVPA. Model 1 (minimally adjusted model) was adjusted for cpm and age of participants. Model 2 was adjusted for the potential confounders in model 1, plus birth weight and gestation. In model 3, the variables included in model 2 were adjusted, together with age of mother at delivery, mother’s oily fish intake and whether the mother of participants smoked in the first 3 months of pregnancy. Model 4 adjusted for potential confounding variables in model 3 plus the inclusion of BMI Z score relative to UK 1990 reference data and pubertal stage of participant (recorded at the time of outcome). The final fully adjusted model (model 5) adjusted for all confounders in model 4 plus ethnicity, maternal educational attainment and occupational social class.

In order to assess whether changes in effect sizes identified in models 2–5 were due to bias relating to missing data or not, model 1 was repeated for only those participants with complete data in model 5. The intraclass correlation coefficient (ICC) was used to make adjustment for regression dilution.\textsuperscript{33} A subset of the ALSPAC sample (n=315) was asked to wear the Actigraph on four separate occasions over a year in order to examine seasonal and intraindividual variation.\textsuperscript{33} The ICC derived from this subset was 0.53 for total volume of PA and for MVPA was 0.45. SPSS V.19 was used for all analyses.

**RESULTS**

**Characteristics of study participants**

Of the 11 952 invited to attend the 11-year clinic, 60% attended, 93% of those who attended agreed to wear an Actigraph and 85% of those, provided valid activity data.\textsuperscript{30} \textsuperscript{31} Data from 4755 eligible participants (2128 males

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1. Percentage of time in MVPA = (min of MVPA/min of light + min of moderate + min of vigorous activity)×100. Light intensity = 200–3599 cpm; moderate = 3600–6199 cpm; vigorous ≥6200 cpm.
Associations with academic attainment at 11

Associations between PA and academic attainment assessed at 11 years and the standardised $\beta$-coefficients for the fully adjusted models can be found in table 3 for males and table 4 for females.\(^a\) For English attainment for males, when % MVPA was entered as a predictor with cpm included as a confounder, % MVPA predicted increased attainment (increase of 0.20 SD for every 1 SD increase in % MVPA). Inclusion of additional confounding variables decreased the $\beta$ but the fully adjusted model continued to predict increased attainment (increase of 0.10 SD). Similar results were found for Maths attainment with % MVPA predicting 0.09 SD increase in attainment in the fully adjusted model when total volume of PA was controlled for. For Science attainment, the same pattern of results was found (increase of 0.06 SD) although the CIs were somewhat wider in the final step of adjustment.

For females, % MVPA predicted increased English attainment and this continued to be the case after adjustment for all confounders (0.15 SD increase). As with males, the same pattern of results ensured for Maths (0.05 SD increase) and Science (increase of 0.14 SD), however the magnitude of the $\beta$ for Science was more than double that found for males, indicating % MVPA predicted a more meaningful increase in Science for females than it did for males.

Associations with academic attainment at 13 years

Associations between % MVPA at 11 years and academic attainment at 13 and the standardised $\beta$-coefficients for the fully adjusted models including cpm as a confounder are shown in tables 3 and 4.\(^a\) For males, when the total volume of PA was controlled for, the % MVPA predicted increased attainment when fully adjusted for all confounders (increase of 0.13 SD, 0.04 SD and 0.07 SD for English, Maths and Science, respectively). For females, % MVPA predicted an increase in attainment which continued after adjustment for all confounders and with total volume of PA taken into account (increase of 0.17 SD). For Maths attainment, the same pattern of results emerged with % MVPA predicting increased attainment when adjusted for total volume of physical activity (0.16 SD increase). The magnitude of the $\beta$ coefficient was attenuated in the final step of adjustment for confounders though.

\(^a\)Descriptive statistics for pubertal status at all three time points can be found in online supplementary table 1.
\(^a\)Coefficients for each stage of adjustment can be found in supplementary tables 2 and 3.
\(^a\)Coefficients for cpm and for each stage of adjustment can be found in supplementary tables 4 and 5.

Associations with academic attainment at 16

Table 3 reveals the associations between % MVPA at age 11 and academic attainment at age 16 in males.\(^a\) As at 11 and 13 years, when the total volume of PA was controlled for, % MVPA predicted increased attainment after adjustment for all confounders. The resulting $\beta$ suggests that for every 1 SD increase in time spent in MVPA (ie, 17 min or 4% of time), GCSE results increased by 0.16 SD.

Similar results were found for both GCSE Maths and Science. For Maths, a 4% increase in MVPA predicted a 0.11 SD increase in Maths attainment after adjustment for all confounding variables and when the total volume of PA was controlled for whereas in Science it predicted a 0.12 SD increase.

Results of a similar nature were found for females (cf. table 4). For GCSE English, a 3% increase in time spent in MVPA (ie, approximately 12 min/day) predicted a 0.11 SD increase in GCSE English attainment after adjustment for all confounding variables. For Maths, % MVPA predicted an increase of 0.08 SD after adjustment for total volume of PA and all confounders. In Science, however, % MVPA predicted a 0.14 SD increase in the fully adjusted model when the total volume of PA was also controlled for.

Dose–response analysis

In order to evaluate whether there was evidence for a dose–response effect, participants were grouped into quintiles of MVPA min/day. Dummy variables representing each quintile were entered as predictors into a regression model predicting English attainment at 16, adjusted for cpm. The lowest quintile was the reference group. For males, those in the highest (MVPA=55.5 SD=12.2), second highest (MVPA=35.4, SD=3.6) and middle quintile of MVPA (MVPA=25.6, SD=2.3) had a higher predicted English attainment than those in the lowest quintile (MVPA=9.1, SD=3.4); however when the model was adjusted for all confounders the $\beta$’s were attenuated and only comparison of the highest quintile remained substantial (unstandardised $\beta=0.51$, 95% CI=0.05 to 0.98, p<0.05) suggesting evidence for a dose–response effect. No other quintiles differed substantially from those in the lowest quintile when fully adjusted though.

For females, those in the highest (MVPA=37.3 SD=8.8), second highest (MVPA=22.8 SD=2.5) and middle quintile of MVPA (MVPA=16.0 SD=1.5), had a higher predicted English attainment than those in the lowest quintile (MVPA=5.4 SD=2.0), when no confounders were entered in the model (unstandardised $\beta$ values=0.49, 0.26 and 0.25, respectively). However, when the model was fully adjusted for all confounders; the $\beta$’s were greatly attenuated and the CIs were wide, with the $\beta$ for the highest quintile compared with the lowest quintile remaining the largest (unstandardised $\beta=0.10$, 95% CI=−0.23 to 0.44, p>0.05).

In order to assess whether changes in effect sizes identified in models 2–5 were due to bias because of missing data or not, for each association model 1 was repeated for participants who had complete data at model 5. The resulting coefficients were slightly larger than when all available data were included and results summarised in online supplementary material.

Regression coefficients for the fully adjusted models were corrected for the effects of regression dilution using ICC derived from a previous calibration study.\(^a\) When the standardised
regression coefficients for associations with academic attainment at 16 in the fully adjusted models were corrected, they increased from 0.16 to 0.35 for males, and from 0.11 to 0.25 for females. This is an important finding, especially in light of the evidence from intervention studies in children and adolescents.13 22

**DISCUSSION**

**Main findings and study implications**

The present study found that higher MVPA at 11 was associated with higher subsequent attainment, after controlling for total volume of PA and independent of a range of confounders. This was true across all academic subjects, and all time points with some evidence for a dose response effect. In this sample the vast majority of the PA was of light intensity and when this light intensity movement was taken into account by controlling for cpm, higher intensity PA contributed to increased academic attainment. A beneficial influence of MVPA on academic attainment is consistent with the limited but emerging body of evidence from intervention studies in children and adolescents.13 22

An alternative explanation is that increasing MVPA in the context of controlling for total volume of PA has implications for sedentary behaviour. Further analyses (data not shown) that included time spent in sedentary behaviour in the regression models showed that while the β-coefficients were attenuated, the same pattern of result ensued, with increased MVPA predicting increased academic attainment. Furthermore, when English attainment at 11 years was included as a confounder in the model predicting English attainment at 13 years, the pattern of results remained, although there was some attenuation and widening of CIS (β for males=0.09, for females=0.06). This supports our interpretation that higher levels of MVPA predict improved academic attainment independent of previous levels of attainment and of the volume of PA.

Robust longitudinal associations were observed for attainment in English for males and females and in addition, in Science for females. This is an important finding, especially in light of the

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**Table 1** Characteristics of participants

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age in years at physical activity monitoring</td>
<td>2128 11.7 (0.23)</td>
<td>2627 11.7 (0.23)</td>
</tr>
<tr>
<td>Birthweight (g)</td>
<td>1996 3457.1 (579.6)</td>
<td>2446 3375.2 (490.5)</td>
</tr>
<tr>
<td>Gestation (weeks)</td>
<td>2020 39.4 (2.0)</td>
<td>2484 39.5 (1.6)</td>
</tr>
<tr>
<td>Age of mother in years at delivery</td>
<td>2050 29.1 (4.6)</td>
<td>2484 28.9 (4.5)</td>
</tr>
<tr>
<td>BMI score at 11</td>
<td>2117 0.34 (1.17)</td>
<td>2609 0.27 (1.17)</td>
</tr>
<tr>
<td>BMI score at 13</td>
<td>1093 0.27 (1.18)</td>
<td>1392 0.18 (1.16)</td>
</tr>
<tr>
<td>BMI score at 16</td>
<td>1531 0.27 (1.07)</td>
<td>1918 0.36 (1.06)</td>
</tr>
<tr>
<td>Number of valid days of accelerometry</td>
<td>2128 5.9 (1.2)</td>
<td>2627 5.9 (1.2)</td>
</tr>
<tr>
<td>Accelerometer wear time (min)</td>
<td>2128 4639 (1040)</td>
<td>2627 4557 (1006)</td>
</tr>
<tr>
<td>Counts-per-minute (cpm)</td>
<td>2128 662 (186)</td>
<td>2627 553 (153)</td>
</tr>
<tr>
<td>Average daily minutes of MVPA</td>
<td>2128 29 (17)</td>
<td>2627 18 (12)</td>
</tr>
<tr>
<td>Percentage of time spent in MVPA</td>
<td>2128 8 (4)</td>
<td>2627 5 (3)</td>
</tr>
</tbody>
</table>

**Table 2** Descriptive statistics for academic attainment

<table>
<thead>
<tr>
<th>Academic attainment</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>English mark</td>
<td>1704 61.4 (13.7)</td>
<td>2114 65.7 (13.1)</td>
</tr>
<tr>
<td>English level</td>
<td>1700 4 (3)</td>
<td>2108 5 (2)</td>
</tr>
<tr>
<td>Maths mark</td>
<td>1708 73.5 (18.1)</td>
<td>2104 70.1 (17.7)</td>
</tr>
<tr>
<td>Maths level</td>
<td>1707 5 (4)</td>
<td>2099 4 (4)</td>
</tr>
<tr>
<td>Science mark</td>
<td>1710 63.4 (9.8)</td>
<td>2110 63.0 (10.0)</td>
</tr>
<tr>
<td>Science level</td>
<td>1712 5 (4)</td>
<td>2113 5 (3)</td>
</tr>
<tr>
<td>GCSE English</td>
<td>1484 48.6 (16.0)</td>
<td>1827 54.7 (14.9)</td>
</tr>
<tr>
<td>GCSE Maths</td>
<td>1486 5 (4)</td>
<td>1823 6 (4)</td>
</tr>
<tr>
<td>GCSE Science</td>
<td>1483 89.2 (20.9)</td>
<td>1831 86.0 (20.7)</td>
</tr>
<tr>
<td>GCSE Science level</td>
<td>1483 7 (5)</td>
<td>1827 7 (5)</td>
</tr>
<tr>
<td>GCSE Science mark</td>
<td>1494 101.8 (21.6)</td>
<td>1836 101.4 (22.8)</td>
</tr>
<tr>
<td>GCSE Science level</td>
<td>1491 6 (4)</td>
<td>1832 6 (5)</td>
</tr>
</tbody>
</table>

At key stages 2 and 3, raw scores are converted to levels (levels 1–8, with 8 being highest). By the end of key stage 2, most pupils will have reached level 4 and at the end of key stage 3, most pupils will have reached levels 5–6.

BMI body mass index; MVPA, moderate-vigorous intensity physical activity.
Table 3  Associations between percentage of moderate-vigorous intensity physical activity at 11-years and academic attainment at 11 and 13 and 16-years in boys

<table>
<thead>
<tr>
<th></th>
<th>English 95% CI</th>
<th>p Value</th>
<th>Maths 95% CI</th>
<th>p Value</th>
<th>Science 95% CI</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Academic attainment at 11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimally adjusted model</td>
<td>0.197</td>
<td>0.13 to 0.26</td>
<td>&lt;0.001</td>
<td>0.182</td>
<td>0.11 to 0.25</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Fully adjusted model</td>
<td>0.096</td>
<td>0.01 to 0.18</td>
<td>0.03</td>
<td>0.085</td>
<td>0.00 to 0.17</td>
<td>0.06</td>
</tr>
<tr>
<td>Academic attainment at 13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimally adjusted model</td>
<td>0.233</td>
<td>0.16 to 0.31</td>
<td>&lt;0.001</td>
<td>0.142</td>
<td>0.06 to 0.22</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Fully adjusted model</td>
<td>0.131</td>
<td>0.01 to 0.25</td>
<td>0.03</td>
<td>0.043</td>
<td>−0.08 to 0.17</td>
<td>0.50</td>
</tr>
<tr>
<td>Academic attainment at 16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimally adjusted model</td>
<td>0.242</td>
<td>0.16 to 0.32</td>
<td>&lt;0.001</td>
<td>0.236</td>
<td>0.16 to 0.32</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Fully adjusted model</td>
<td>0.158</td>
<td>0.05 to 0.26</td>
<td>&lt;0.001</td>
<td>0.111</td>
<td>0.00 to 0.22</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Tables include standardised β coefficients and 95% CIs for physical activity variables predicting academic attainment. Minimally adjusted model (model 1) adjusts for cpm and age of participants; fully adjusted model (model 5) adjusted for cpm and age plus birthweight, gestation, age of mother at delivery, mother’s oily fish intake, whether the mother of participants smoked in the first 3 months of pregnancy, BMI Z score relative to UK 1990 reference data, pubertal stage of participant (recorded at time of outcome) ethnicity, maternal educational attainment and occupational social class. Coefficients for each stage of adjustment and for cpm as a predictor are shown in online supplementary material. At 16, correction for the effects of regression dilution using ICC increased coefficients from 0.16 to 0.35 for males for English GCSE attainment. For Maths, the coefficient increased to 0.25 and for Science increased to 0.27.

current UK and European Commission policy aimed to increase the number of females in Science subjects.48 49 While it is possible that this may reflect a chance finding, results may also suggest that there are gender differences in the way in which PA impacts the brain. Further work is required to confirm and understand this finding though.

The effect sizes and β coefficients for the associations observed in the present study are modest, but are conservative and must be interpreted in context. Levels of objectively measured habitual MVPA were, as in other studies of children and adolescents in the western world1 low and well below the amounts recommended in evidence-based guidelines of 60 min/ day. In order to reach the recommended 60 min/day, a 2 SD increase in MVPA would have been required for boys and a 3 SD increase would have been required for girls. Second, PA is variable and measurement over a minimum of 3 days does not fully capture habitual physical activity.13 Measurement error correction13 approximately doubled standardised β coefficients and a 2 SD increase in MVPA at 11 years (to reach an average of 60 min/day in the boys) would translate to predicted increases in academic attainment of almost 1 GCSE grade/15 min increase in MVPA (eg, an increase from a grade C in English to a grade B).

However, without participants achieving the recommended levels of MVPA, this is speculative. Evidence for a dose response effect was found in males with those doing the most MVPA having a higher predicted attainment at age 16 than those doing the least MVPA. A similar pattern was found with females; however, the highest quintile were only averaging 37 min of MVPA, which might explain the disparity between the sexes in the fully adjusted results. Previous research has suggested that increasing time spent in MVPA in intervention studies (eg, after school classes for overweight and obese youth) has a positive impact on attainment.13 19 22

Mediators linking physical activity to academic attainment
Increased MVPA might improve academic attainment in a number of ways. Studies have revealed relationships between PA and relevant cognitive outcomes such as measures of executive function,12–15 as well as studies suggesting that PA might increase time ‘on task’ in class and reduce classroom ‘problem behaviour’.50 51 Furthermore, research suggests that physical fitness is also associated with academic attainment.21 52 As fitness

Table 4  Associations between % MVPA at 11-years and academic attainment at 11 and 13 and 16-years in females

<table>
<thead>
<tr>
<th></th>
<th>English 95% CI</th>
<th>p Value</th>
<th>Maths 95% CI</th>
<th>p Value</th>
<th>Science 95% CI</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Academic attainment at 11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimally adjusted model</td>
<td>0.240</td>
<td>0.18 to 0.30</td>
<td>&lt;0.001</td>
<td>0.145</td>
<td>0.09 to 0.20</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Fully adjusted model</td>
<td>0.151</td>
<td>0.08 to 0.22</td>
<td>&lt;0.001</td>
<td>0.048</td>
<td>−0.02 to 0.12</td>
<td>0.19</td>
</tr>
<tr>
<td>Academic attainment at 13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimally adjusted model</td>
<td>0.236</td>
<td>0.17 to 0.30</td>
<td>&lt;0.001</td>
<td>0.158</td>
<td>0.09 to 0.22</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Fully adjusted model</td>
<td>0.171</td>
<td>0.08 to 0.27</td>
<td>&lt;0.001</td>
<td>0.028</td>
<td>−0.07 to 0.12</td>
<td>0.57</td>
</tr>
<tr>
<td>Academic attainment at 16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimally adjusted model</td>
<td>0.213</td>
<td>0.15 to 0.28</td>
<td>&lt;0.001</td>
<td>0.208</td>
<td>0.14 to 0.27</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Fully adjusted model</td>
<td>0.111</td>
<td>0.03 to 0.19</td>
<td>0.010</td>
<td>0.081</td>
<td>0.00 to 0.16</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Tables include standardised β coefficients and 95% CIs for physical activity variables predicting academic attainment. Minimally adjusted model (model 1) adjusts for cpm and age of participants; fully adjusted model (model 5) adjusted for cpm and age plus birthweight, gestation, age of mother at delivery, mother’s oily fish intake, whether the mother of participants smoked in the first 3 months of pregnancy, BMI Z score relative to UK 1990 reference data, pubertal stage of participant (recorded at time of outcome) ethnicity, maternal educational attainment and occupational social class. Coefficients for each stage of adjustment and for cpm as a predictor are shown in online supplementary material. At 16, correction for the effects of regression dilution using ICC increased coefficients from 0.11 to 0.25 for females for English GCSE attainment. For Maths, the coefficient increased to 0.18 and for Science increased to 0.32.
and levels of MVPA are related in children it may be that fitness is mediating the relationships observed or indeed these effects may be independent. However, a recent longitudinal study reported positive associations between physical activity at age 8 and grade point average at age 16; however, similar results were not found for cardiorespiratory fitness. Therefore, further work is required to extrapolate the effects of fitness and MVPA.

**Study strengths and limitations**

The main strengths of the present study were large sample size, socioeconomically representative nature of the sample, objective measurement of PA and longitudinal design. This combination of strengths is almost unique in the field of physical activity–academic outcome relationships. However, the present study had a number of limitations. The restricted range of habitual PA within the cohort may limit conclusions about the impact of effects of higher levels of PA, although the low levels of PA observed are typical of adolescents in the western world. While the sample size in the present study is large, it represents less than half of those invited to attend the research clinic at 11 years. Only small differences were found in the characteristics of those who attended the clinic compared with those who did not attend though. Further, while the loss of data in the fully adjusted models compared with the unadjusted models could be considered a limitation, it is worth noting that when models were re-analysed including only participants with complete confounding information, no substantial differences were detected. In addition, as similar patterns of results were found in associations across three time points and for all subjects, the loss of data should not be considered a major limitation and still well above recommendations for minimum sample required for such analyses.

While the use of accelerometer assessed PA provides a measure of sedentary time, this was not the focus of the present analyses. The impact of sedentary behaviour is a burgeoning field and an understanding of the relationship between sedentary behaviour and academic attainment would add greatly to our understanding. However, lack of knowledge of what participants were doing during sedentary time in the present study (e.g. screen time) precludes conclusions from being drawn. Therefore, future work should aim to understand this complex relationship.

One further point for consideration concerns the use of the cut point employed to signify moderate-vigorous intensity activity. A cut point of 3600 cpm was employed as derived from a previous validation and calibration study with a subsample of ALSPAC participants at age 11. A range of alternative cut points have been employed in the literature and it is possible that the ‘dose–response’ associations between objectively measured physical activity and academic attainment may have altered if an alternative cut point had been employed. For example, by employing a high cut point, it is possible that the present study underestimates the levels of MVPA and potentially reports associations with academic attainment which are smaller in magnitude than might have been found with a lower cut point for MVPA. Therefore, the present associations may be interpreted as conservative estimates of these relationships. A recent study from the International Children’s Accelerometry Database (ICAD) examined a range of cut points for associations with other factors and found that there was no substantial alteration to associations as a function of choice of accelerometer cut point. Further research examining the impact of cut point selection on estimations of associations with academic attainment would therefore be fruitful.

**Conclusions and implications for public health**

The preponderance of evidence suggests that devoting more time to physical education benefits not only health and well-being but is not detrimental to academic attainment. If MVPA does influence academic attainment this has implications for public health and education policy by providing schools and parents with a potentially important ‘stake’ in meaningful and sustained increases in physical activity.

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**Contributors**

All authors were responsible for study conceptualisation. JNB conducted data analyses with all authors contributing to interpretation. JNB and JJR wrote the first draft of the manuscript. All authors commented on subsequent drafts and the final version of the manuscript. All authors had full access to all of the data in the study and take responsibility for the integrity and accuracy of the data analysis. JNB and JJR are the guarantors.

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**Competing interests**

None.

**Ethics approval**

Ethical approval for the study was obtained from the Avon Longitudinal Study of Parents and Children (ALSPAC) Law and Ethics Committee and the Local Research Ethics Committees.

**Provenance and peer review**

Not commissioned; externally peer reviewed.

**Data sharing statement**

ALSPAC data are an available resource. Data are anonymised at entry and identification information is concealed from researchers. Access to data items is provided on application to the ALSPAC Executive Committee.

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