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 midchildhood 7 and is associated with excessive gains in body fat.8 The 2011 Cochrane review on obesity prevention in children concluded that PA promotion will prevent obesity in children and adolescents and so the crucial public health issue is how to promote PA successfully.9 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.uk25). 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 pregnancies and 13 988 children (n=6762 girls) alive at 12 months of age. The phases of enrolment are described in detail elsewhere.26 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 ages 11, 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.27 Moreover, the ability to detect associations between PA and outcomes is much greater when PA is measured objectively.28 29

The Actigraph was used in the present study as described previously.30 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.30 32 Acceptable reliability required accelerometer of at least 3 days and 10 h of wear time per day.33 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.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 PA35 correlating well with total and physical activity energy expenditure derived from the doubly labelled water technique.35 36 37 For school-aged children and adolescents PA recommendations4 5 38 are in MVPA.39 We applied the MVPA cut-point of 3600 cpm derived from the validation and calibration study conducted in a subsample of ALSPAC participants.12 This sample-specific cut-point was calibrated against VO2 and defines MVPA as equivalent to four MET’s40 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.education.gov.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 evaluated at age of outcome39–41; ethnicity; socioeconomic status based on maternal educational attainment (none/CSE to University degree); and occupational social class as classified by the Office of Population Census and Survey in 1991 (classes I (professional/managerial) to V (unskilled manual workers)).42

Exclusions
Participants with a psychiatric diagnosis based on evaluation of the Development and Well-being Assessment (DAWBA)43 which provides information to make a Diagnostic and Statistical Manual of Mental Disorder, fourth edition (DSM-IV)44 clinical diagnosis45; participants with a Statement of Educational Needs in children and adolescents; and occupational social class.

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.30 31 40 Data from 4755 eligible participants (2128 males

1Percentage 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.
and 2627 females) remained for analyses; table 1 provides the characteristics of these participants.\textsuperscript{30 31 40} As reported elsewhere\textsuperscript{30 31 40} when comparisons of characteristics were made between those who attended the clinic and those who did not, small differences were found in birth weight, social class, maternal education, maternal height and age. When those who provided valid accelerometer data were compared to those who did not, small differences were found in gender, age, weight, BMI and pubertal status.\textsuperscript{30 31 40}

Daily number of minutes of MVPA for males was 29 (SD=17) and for females was 18 (SD=12) and the % MVPA was 8\% (SD=4) for males and 5\% (SD=3) for females. Descriptive statistics for academic attainment are shown in table 2.

**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.\textsuperscript{30}

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 ensued 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.\textsuperscript{30} 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.

\textsuperscript{3}Descriptive statistics for pubertal status at all three time points can be found in online supplementary table 1.

\textsuperscript{4}Coefficients for each stage of adjustment can be found in supplementary tables 2 and 3.

\textsuperscript{5}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.\textsuperscript{7} 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 when 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.\textsuperscript{33} When the standardised
from 0.16 to 0.35 for males, and from 0.11 to 0.25 for females at 16 in the fully adjusted models were corrected, they increased to 0.27 for males and 0.32 for females. This is an important finding, especially in light of the widening of CIS (β for males=0.09, for females=0.06). This finding, especially in light of the increasing evidence from intervention studies in children and adolescents, supports our interpretation that higher levels of MVPA predict improved academic attainment independent of previous levels of attainment and of the volume of PA. 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, for Science for females. This is an important finding, especially in light of the 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.

### Table 1: Characteristics of participants

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Males n Mean (SD)</th>
<th>Females n Mean (SD)</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>2020 29.2 (4.6)</td>
<td>2484 28.9 (4.5)</td>
</tr>
<tr>
<td>BMI at 11</td>
<td>2117 0.34 (1.17)</td>
<td>2609 0.27 (1.17)</td>
</tr>
<tr>
<td>BMI at 13</td>
<td>1093 0.27 (1.18)</td>
<td>1392 0.18 (1.16)</td>
</tr>
<tr>
<td>BMI 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 28 (4)</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 n Mean (SD)/mode (range)</th>
<th>Females n Mean (SD)/mode (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11-years-old (key stage 2)</td>
<td></td>
<td></td>
</tr>
<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>13-years-old (key stage 3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>English mark</td>
<td>1484 48.6 (16.0)</td>
<td>1827 54.7 (14.9)</td>
</tr>
<tr>
<td>English level</td>
<td>1468 5 (4)</td>
<td>1823 6 (4)</td>
</tr>
<tr>
<td>Maths mark</td>
<td>1483 89.2 (20.9)</td>
<td>1831 86.0 (20.7)</td>
</tr>
<tr>
<td>Maths level</td>
<td>1483 7 (5)</td>
<td>1827 7 (5)</td>
</tr>
<tr>
<td>Science mark</td>
<td>1494 101.8 (21.6)</td>
<td>1836 101.4 (22.8)</td>
</tr>
<tr>
<td>Science level</td>
<td>1491 6 (4)</td>
<td>1832 6 (5)</td>
</tr>
<tr>
<td>16-years-old (key stage 4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GCSE English</td>
<td>1647 6.4 (1.3) (Grade C)</td>
<td>2038 6.8 (1.2) (Grade B)</td>
</tr>
<tr>
<td>GCSE Maths</td>
<td>1584 6.6 (1.5) (Grade C)</td>
<td>2014 6.5 (1.5) (Grade C)</td>
</tr>
<tr>
<td>GCSE Science</td>
<td>966 6.5 (1.4) (Grade C)</td>
<td>1199 6.4 (1.4) (Grade C)</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.

### 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.
current UK and European Commission policy aimed to increase the number of females in Science subjects. 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 \( \beta \) 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 world low and well below the levels observed in the present study are modest, but are conservative. This finding though, 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.

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<table>
<thead>
<tr>
<th>Academic attainment at 11</th>
<th>Minimally adjusted model</th>
<th>0.197</th>
<th>(0.13 to 0.26)</th>
<th>&lt;0.001</th>
<th>0.182</th>
<th>(0.11 to 0.25)</th>
<th>&lt;0.001</th>
<th>0.144</th>
<th>(0.08 to 0.21)</th>
<th>&lt;0.001</th>
</tr>
</thead>
<tbody>
<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>
<td>0.060</td>
<td>(−0.03 to 0.15)</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>Academic attainment at 13</td>
<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>
<td>0.042</td>
<td>(−0.04 to 0.12)</td>
<td>0.30</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>
<td>0.070</td>
<td>(−0.06 to 0.20)</td>
<td>0.28</td>
<td></td>
</tr>
<tr>
<td>Academic attainment at 16</td>
<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>
<td>0.253</td>
<td>(0.15 to 0.36)</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>
<td>0.122</td>
<td>(−0.02 to 0.26)</td>
<td>0.10</td>
<td></td>
</tr>
</tbody>
</table>

Tables include standardised \( \beta \) 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.

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>Academic attainment at 11</th>
<th>Minimally adjusted model</th>
<th>0.240</th>
<th>(0.18 to 0.30)</th>
<th>&lt;0.001</th>
<th>0.197</th>
<th>(0.14 to 0.26)</th>
<th>&lt;0.001</th>
<th>0.197</th>
<th>(0.14 to 0.25)</th>
<th>&lt;0.001</th>
</tr>
</thead>
<tbody>
<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>
<td>0.136</td>
<td>(0.07 to 0.21)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Academic attainment at 13</td>
<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>
<td>0.070</td>
<td>(0.00 to 0.14)</td>
<td>0.04</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>
<td>−0.035</td>
<td>(−0.13 to 0.06)</td>
<td>0.49</td>
<td></td>
</tr>
<tr>
<td>Academic attainment at 16</td>
<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>
<td>0.199</td>
<td>(0.11 to 0.28)</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>
<td>0.143</td>
<td>(0.03 to 0.25)</td>
<td>0.01</td>
<td></td>
</tr>
</tbody>
</table>

Tables include standardised \( \beta \) 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.

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, as well as studies suggesting that PA might increase time ‘on task’ in class and reduce classroom ‘problem behaviour’. Furthermore, research suggests that physical fitness is also associated with academic attainment. 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>Academic attainment at 11</th>
<th>Minimally adjusted model</th>
<th>0.240</th>
<th>(0.18 to 0.30)</th>
<th>&lt;0.001</th>
<th>0.145</th>
<th>(0.09 to 0.20)</th>
<th>&lt;0.001</th>
<th>0.197</th>
<th>(0.14 to 0.25)</th>
<th>&lt;0.001</th>
</tr>
</thead>
<tbody>
<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>
<td>0.136</td>
<td>(0.07 to 0.21)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Academic attainment at 13</td>
<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>
<td>0.070</td>
<td>(0.00 to 0.14)</td>
<td>0.04</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>
<td>−0.035</td>
<td>(−0.13 to 0.06)</td>
<td>0.49</td>
<td></td>
</tr>
<tr>
<td>Academic attainment at 16</td>
<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>
<td>0.199</td>
<td>(0.11 to 0.28)</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>
<td>0.143</td>
<td>(0.03 to 0.25)</td>
<td>0.01</td>
<td></td>
</tr>
</tbody>
</table>

Tables include standardised \( \beta \) 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.
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 (eg, 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 cut point employed to signify moderate-vigorous intensity activity. A cut point of 3600 cpm was employed as derived from a study reported positive associations between physical activity 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.

What are the new findings
- Evidence from this large-scale population study confirms the long-term positive impact of moderate-to-vigorous physical activity on academic attainment in adolescence.
- Findings should provide greater impetus for school-based physical activity promotion.

How might it impact on clinical practice in the near future
The findings have 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 accessible 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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Associations between objectively measured physical activity and academic attainment in adolescents from a UK cohort

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