OPEN ACCESS

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 Reilly[1]

▸ Additional material is published online only. To view please visit the journal online (http://dx.doi.org/10.1136/bjsports-2013-092334).

[1]School of Psychological Sciences and Health, University of Strathclyde, Glasgow, UK
[2]School of Psychology, University of Dundee, Dundee, UK
[3]School of Oral and Dental Sciences, University of Bristol, Bristol Dental School, Bristol, UK
[4]School of Social and Community Medicine, University of Bristol, Canynge Hall, Bristol, UK
[5]University of Georgia, Athens, Georgia, USA

Correspondence to
Dr J N Booth, School of Psychology, University of Dundee, Dundee, DD1 4HN, UK; j.booth@dundee.ac.uk

Accepted 11 September 2013
Published Online First 22 October 2013

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 midchildhood[2 7]and is associated with excessive gains in body fat.[8] The 2011 Cochrane review on obesity prevention in children[9] 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 Prevention[10 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 al*[21] 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 reviews[23 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[25]). 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 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,

Open Access
Scan to access more free content

To cite: Booth JN, Leary SD, Joinson C, *et al*. *Br J Sports Med* 2014;**48**:265–270.

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 accelerometry of at least 3 days and 10 h of wear time per day.[33 34] The previous examination of measurement variation with the accelerometry 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 PA[28] correlating well with total and physical activity energy expenditure derived from the doubly labelled water technique.[35–37] For school-aged children and adolescents PA recommendations[4 5 38] are in MVPA.[32] We applied the MVPA cut-point of 3600 cpm derived from the validation and calibration study conducted in a subsample of ALSPAC participants.[32] This sample-specific cut-point was calibrated against VO_2 and defines MVPA as equivalent to four MET's[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 evaluated at age of outcome[39–41]; 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 diagnosis[45]; participants with a Statement of Educational Needs as reported by school or parents; participants with behavioural difficulties defined as Total Difficulties scores of 16 and greater on the teacher-completed version of the Strengths and Difficulties Questionnaire[46] at age 11 were excluded from the study.

Statistical analyses

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 accelerometry 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)[i] 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.[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[31] and academic attainment[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.[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.[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.[30 31 40] Data from 4755 eligible participants (2128 males

[i]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 com; vigorous ≥6200 cpm.

and 2627 females) remained for analyses; table 1 provides the characteristics of these participants.[ii] As reported elsewhere[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.[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 β-coefficients for the fully adjusted models can be found in table 3 for males and table 4 for females.[iii] 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 β 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 β 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 β-coefficients for the fully adjusted models including cpm as a confounder are shown in tables 3 and 4.[iv] 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 β coefficient was attenuated in the final step of adjustment for confounders though.

Associations with academic attainment at 16

Table 3 reveals the associations between % MVPA at age 11 and academic attainment at age 16 in males.[v] 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 β 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 β's were attenuated and only comparison of the highest quintile remained substantial (unstandardised β=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 β values=0.49, 0.26 and 0.25, respectively). However, when the model was fully adjusted for all confounders; the β's were greatly attenuated and the CIs were wide, with the β for the highest quintile compared with the lowest quintile remaining the largest (unstandardised β=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.[33] When the standardised

[ii]Descriptive statistics for pubertal status at all three time points can be found in online supplementary table 1.

[iii]Coefficients for each stage of adjustment can be found in supplementary tables 2 and 3.

[iv]Coefficients for cpm and for each stage of adjustment can be found in supplementary tables 4 and 5.

[v]Tables 3 and 4 show coefficients for the minimally adjusted and the fully adjusted models only. Coefficients for each stage of adjustment are shown in online supplementary material.

Table 1 Characteristics of participants

	Males		Females	
Characteristic	**n**	**Mean (SD)**	**n**	**Mean (SD)**
Age in years at physical activity monitoring	2128	11.7 (0.23)	2627	11.7 (0.23)
Birthweight (g)	1996	3457.1 (579.6)	2446	3375.2 (490.5)
Gestation (weeks)	2020	39.4 (2.0)	2484	39.5 (1.6)
Age of mother in years at delivery	2020	29.2 (4.6)	2484	28.9 (4.5)
BMI Z score at 11	2117	0.34 (1.17)	2609	0.27 (1.17)
BMI Z score at 13	1093	0.27 (1.18)	1392	0.18 (1.16)
BMI Z score at 16	1531	0.27 (1.07)	1918	0.36 (1.06)
Number of valid days of accelerometry	2128	5.9 (1.2)	2627	5.9 (1.2)
Accelerometer wear time (min)	2128	4639 (1040)	2627	4557 (1006)
Counts-per-minute (cpm)	2128	662 (186)	2627	553 (153)
Average daily minutes of MVPA	2128	29 (17)	2627	18 (12)
Percentage of time spent in MVPA	2128	8 (4)	2627	5 (3)
	n	Percentage	n	Percentage
Ethnicity				
White	1846	95.6	2281	96.4
Non-white	84	4.4	85	3.6
BMI at 11 years				
Normal	1512	71.4	1917	73.5
Overweight	288	13.6	339	13.0
Obese	317	15.0	353	13.5
BMI at 13 years				
Normal	810	74.1	1061	76.0
Overweight	143	13.1	192	13.8
Obese	140	12.8	139	10.0
BMI at 16 years				
Normal	1179	77.0	1444	75.5
Overweight	184	12.0	245	12.8
Obese	168	11.0	229	11.9
Mother's oily fish intake				
Never/rarely	714	37.2	900	38.3
Once in 2 weeks	674	35.2	806	34.3
1–3 times a week	508	26.5	615	26.1
4–7 times a week	20	1.0	30	1.3
More than once a day	1	0.1	1	0.0
Mother smoked during pregnancy				
Yes	308	15.5	411	16.8
No	1681	84.5	2029	83.2
Mothers education				
CSE	244	12.4	310	12.9
Vocational	171	8.7	186	7.8
O level	695	35.4	874	36.4
A level	536	27.3	632	26.3
Degree	317	16.1	397	16.5
Occupational social class				
I (Professional)	134	7.8	142	6.8
II	600	35.1	710	34.2
III (Non-manual)	734	42.9	894	43.0
III (Manual)	103	6.0	121	5.8
IV	122	7.1	180	8.7
V (Unskilled)	15	0.1	30	1.4
Armed forces	1	0.1	0	0

BMI body mass index; MVPA, moderate-vigorous intensity physical activity.

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 for English GCSE attainment. For Maths, they increased to 0.25 and 0.18 for males and females, respectively and for Science increased to 0.27 for males and 0.32 for females.

Table 2 Descriptive statistics for academic attainment

	Males		Females	
Academic attainment	**n**	**Mean (SD)/mode (range)**	**n**	**Mean (SD)/mode (range)**
11-years-old (key stage 2)				
English mark	1704	61.4 (13.7)	2114	65.7 (13.1)
English level	1700	4 (3)	2108	5 (2)
Maths mark	1708	73.5 (18.1)	2104	70.1 (17.7)
Maths level	1707	5 (4)	2099	4 (4)
Science mark	1710	63.4 (9.8)	2110	63.0 (10.0)
Science level	1712	5 (4)	2113	5 (3)
13-years-old (key stage 3)				
English mark	1484	48.6 (16.0)	1827	54.7 (14.9)
English level	1468	5 (4)	1823	6 (4)
Maths mark	1483	89.2 (20.9)	1831	86.0 (20.7)
Maths level	1483	7 (5)	1827	7 (5)
Science mark	1494	101.8 (21.6)	1836	101.4 (22.8)
Science level	1491	6 (4)	1832	6 (5)
16-years-old (key stage 4)				
GCSE English	1647	6.4 (1.3) (Grade C)	2038	6.8 (1.2) (Grade B)
GCSE Maths	1584	6 .6 (1.5) (Grade C)	2014	6.5 (1.5) (Grade C)
GCSE Science	966	6.5 (1.4) (Grade C)	1199	6.4 (1.4) (Grade C)

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.

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

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

	English			Maths			Science		
	β	95% CI	p Value	β	95% CI	p Value	β	95% CI	p Value
Academic attainment at 11									
Minimally adjusted model	0.197	0.13 to 0.26	<0.001	0.182	0.11 to 0.25	<0.001	0.144	0.08 to 0.21	<0.001
Fully adjusted model	0.096	0.01 to 0.18	0.03	0.085	0.00 to 0.17	0.06	0.060	−0.03 to 0.15	0.18
Academic attainment at 13									
Minimally adjusted model	0.233	0.16 to 0.31	<0.001	0.142	0.06 to 0.22	<0.001	0.042	−0.04 to 0.12	0.30
Fully adjusted model	0.131	0.01 to 0.25	0.03	0.043	−0.08 to 0.17	0.50	0.070	−0.06 to 0.20	0.28
Academic attainment at 16									
Minimally adjusted model	0.242	0.16 to 0.32	<0.001	0.236	0.16 to 0.32	<0.001	0.253	0.15 to 0.36	<0.001
Fully adjusted model	0.158	0.05 to 0.26	<0.001	0.111	0.00 to 0.22	0.05	0.122	−0.02 to 0.26	0.10

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 world[1] 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.[33] Measurement error correction[33] 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

	English			Maths			Science		
	β	95% CI	p Value	β	95% CI	p Value	β	95% CI	p Value
Academic attainment at 11									
Minimally adjusted model	0.240	0.18 to 0.30	<0.001	0.145	0.09 to 0.20	<0.001	0.197	0.14 to 0.25	<0.001
Fully adjusted model	0.151	0.08 to 0.22	<0.001	0.048	−0.02 to 0.12	0.19	0.136	0.07 to 0.21	<0.001
Academic attainment at 13									
Minimally adjusted model	0.236	0.17 to 0.30	<0.001	0.158	0.09 to 0.22	<0.001	0.070	0.00 to 0.14	0.04
Fully adjusted model	0.171	0.08 to 0.27	<0.001	0.028	−0.07 to 0.12	0.57	−0.035	−0.13 to 0.06	0.49
Academic attainment at 16									
Minimally adjusted model	0.213	0.15 to 0.28	<0.001	0.208	0.14 to 0.27	<0.001	0.199	0.11 to 0.28	<0.001
Fully adjusted model	0.111	0.03 to 0.19	0.010	0.081	0.00 to 0.16	0.05	0.143	0.03 to 0.25	0.01

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 age 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[53] it may be that fitness is mediating the relationships observed or indeed these effects may be independent.[54] 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.[55] 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.[24] 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.[1] 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.[56]

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 previous validation and calibration study with a subsample of ALSPAC participants at age 11.[32] 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)[1] 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.[16 19 54 57] 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.[50 58]

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.

Acknowledgements The authors are extremely grateful to all the families who took part in this study, the midwives for their help in recruiting them and the whole ALSPAC team, which includes interviewers, computer and laboratory technicians, clerical workers, research scientists, volunteers, managers, receptionists and nurses.

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.

Funding The UK Medical Research Council (Grant ref: 74882) the Wellcome Trust (Grant ref: 076467) and the University of Bristol provide core support for ALSPAC. This work was specifically supported by the BUPA Foundation (Grant ref: TBF-08-031).

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.

REFERENCES

1 Ekelund U, Luan J, Sherar LB, *et al*. Moderate to vigorous physical activity and sedentary time and cardiometabolic risk factors in children and adolescents. *JAMA* 2012;307:704–12.
2 Basterfield L, Adamson AJ, Frary JK, *et al*. Longitudinal study of physical activity and sedentary behavior in children. *Pediatrics* 2011;127:e24–30.

3 Riddoch CJ, Mattocks C, Deere K, *et al*. Objective measurement of levels and patterns of physical activity. *Arch Dis Child* 2007;92:963–9.
4 Janssen I, LeBlanc AG. Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. *Int J Behav Nutr Phys Act* 2010;7:40.
5 Strong WB, Malina RM, Blimkie CJR, *et al*. Evidence based physical activity for school-age youth. *J Pediatr* 2005;146:732–7.
6 Lee IM, Shiroma EJ, Lobelo F, *et al*. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *Lancet* 2012;380:219–29.
7 Corder K, Van Sluijs EMF, Ekelund U, *et al*. Changes in children's physical activity over 12 months: longitudinal results from the SPEEDY Study. *Pediatrics* 2010;126: e926–35.
8 Basterfield L, Pearce MS, Adamson AJ, *et al*. Physical activity, sedentary behavior, and adiposity in English children. *Am J Prev Med* 2012;42:445–51.
9 Waters E, DeSilva-Sanigorski A, Hall BJ, *et al*. Interventions for preventing obesity in children. *Cochrane Database Syst Rev* 2011;(12):CD001871.
10 Roberts CK, Freed B, McCarthy WJ. Low aerobic fitness and obesity are associated with lower standardized test scores in children. *J Pediatr* 2010;156:711–18.e1.
11 Centers for Disease Control and Prevention. *The association between school based physical activity, including physical education, and academic performance*. In: Services USDoHaH, ed. Atlanta: U.S. Department of Health and Human Services, 2010.
12 Hillman CH, Erickson KI, Kramer AF. Be smart, exercise your heart: exercise effects on brain and cognition. *Nat Rev Neurosci* 2008;9:58–65.
13 Davis CL, Tomporowski PD, McDowell JE, *et al*. Exercise improves executive function and achievement and alters brain activation in overweight children: a randomized controlled trial. *Health Psychol* 2011;30:91–8.
14 Tomporowski PD, Lambourne K, Okumura M. Physical activity interventions and children's mental function: an introduction and overview. *Prev Med* 2011;52: S3–9.
15 Sibley BA, Etnier JL. The relationship between physical activity and cognition in children: a meta-analysis. *Pediatr Exerc Sci* 2003;15:243–56.
16 Coe DP, Pivarnik JM, Womack CJ, *et al*. Effect of physical education and activity levels on academic achievement in children. *Med Sci Sports Exerc* 2006;38:1515–19.
17 Pirrie AM, Lodewyk KR. Investigating links between moderate-to-vigorous physical activity and cognitive performance in elementary school students. *Mental Health Phys Act* 2012;5:93–8.
18 Best JR. Effects of physical activity on children's executive function: contributions of experimental research on aerobic exercise. *Dev Rev* 2010;30:331–51.
19 Telford RD, Cunningham RB, Fitzgerald R, *et al*. Physical education, obesity, and academic achievement: a 2-year longitudinal investigation of Australian elementary school children. *Am J Public Health* 2011;102:368–74.
20 Donnelly JE, Greene JL, Gibson CA, *et al*. Physical activity across the curriculum (PAAC): a randomized controlled trial to promote physical activity and diminish overweight and obesity in elementary school children. *Prev Med* 2009;49:336–41.
21 Chaddock L, Pontifex MB, Hillman CH, *et al*. 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.
22 Davis CL, Tomporowski PD, Boyle CA, *et al*. Effects of aerobic exercise on overweight children's cognitive functioning: a randomized controlled trial. *Res Q Exerc Sport* 2007;78:510–19.
23 Singh A, Uijtdewilligen L, Twisk JR, *et al*. Physical activity and performance at school: a systematic review of the literature including a methodological quality assessment. *Arch Pediatr Adolesc Med* 2012;166:49–55.
24 Biddle SJH, Asare M. Physical activity and mental health in children and adolescents: a review of reviews. *Br J Sports Med* 2011;45:886–95.
25 Golding J, Pembrey M, Jones R, ALSPAC. ALSPAC—The Avon Longitudinal Study of Parents and Children I. Study methdology. *Paediatr Perinat Epidemiol* 2001;15:74–87.
26 Boyd A, Golding J, Macleod J, *et al*. Cohort profile: The 'Children of the 90s'—the index offspring of the Avon Longitudinal Study of Parents and Children. *Int J Epidemiol* 2012;42:111–27.
27 DeVries S, VanHirtum HWJEM, Bakker I, *et al*. Validity and reproducibility of motion sensors in youth: a systematic update. *Med Sci Sports Exerc* 2009;41:818–27.
28 Reilly JJ, Penpraze V, Hislop J, *et al*. Objective measurement of physical activity and sedentary behaviour: review with new data. *Arch Dis Child* 2008;93:614–19.
29 Janz KF. Physical activity in epidemiology: moving from questionnaire to objective measurement. *Br J Sports Med* 2006;40:191–2.
30 Mattocks C, Ness A, Leary S, *et al*. Use of accelerometers in a large field-based study of children: protocols, design issues, and effects on precision. *J Phys Act Health* 2008;5(Suppl 1):S98–111.
31 Ness AR, Leary SD, Mattocks C, *et al*. Objectively measured physical activity and fat mass in a large cohort of children. *PLoS Med* 2007;4:e97.
32 Mattocks C, Leary S, Ness A, *et al*. Calibration of an accelerometer during free-living activities in children. *Int J Pediatr Obes* 2007;2:218–26.
33 Mattocks C, Leary S, Ness A, *et al*. Intraindividual variation of objectively measured physical activity in children. *Med Sci Sports Exerc* 2007;39:622–9.
34 Penpraze V, Reilly JJ, MacLean C, *et al*. Monitoring of physical activity in young children: how much is enough? *Pediatr Exerc Sci* 2006;18:483–91.
35 Ekelund U, Sjöström M, Yngve A, *et al*. Physical activity assessed by activity monitor and doubly labeled water in children. *Med Sci Sports Exerc* 2001;33:275–81.
36 Montgomery C, Reilly JJ, Jackson DM, *et al*. Relation between physical activity and energy expenditure in a representative sample of young children. *Am J Clin Nutr* 2004;80:591–6.
37 Plasqui G, Westerterp KR. Physical activity assessment with accelerometers: an evaluation against doubly labeled water. *Obesity* 2007;15:2371–9.
38 Department of Health Physical Activity, Health Improvement and Protection. *Start active, stay active: a report on physical activity from the four home countries' Chief Medical Officers*. Department of Health London, 2011.
39 Wiles N, Haase A, Lawlor D, *et al*. Physical activity and depression in adolescents: cross-sectional findings from the ALSPAC cohort. *Soc Psychiatry Psychiatr Epidemiol* 2011;47:1–11.
40 Leary SD, Ness AR, Smith GD, *et al*. Physical activity and blood pressure in Childhood. *Hypertension* 2008;51:92–8.
41 Tanner JM. 1 Normal growth and techniques of growth assessment. *Clin Endocrinol Metab* 1986;15:411–51.
42 Office of Population Census and Survey. *Standard Occupational Classification*. London: Her Majesty's Stationary Office, 1991.
43 Goodman R, Ford T, Richards H, *et al*. The Development and Well-Being Assessment: description and initial validation of an integrated assessment of child and adolescent psychopathology. *J Child Psychol Psychiatry* 2000;41:645–55.
44 APA. *Diagnostic and Statistical Manual of Mental Disorders*. 4th edn. Washington, DC: American Psychiatric Association, 2000.
45 Ford T, Goodman R, Meltzer H. The British Child and Adolescent Mental Health Survey 1999: The prevalence of DSM-IV disorders. *J Am Acad Child Adolesc Psychiatry* 2003;42:1203–11.
46 Goodman R. The strengths and difficulties questionnaire: a research note. *J Child Psychol Psychiatry* 1997;38:581–6.
47 Strand S, Deary IJ, Smith P. Sex differences in Cognitive Abilities Test scores: a UK national picture. *Br J Educ Psychol* 2006;76:463–80.
48 European-Commission. Commission launches "Science: it's a girl thing!" campaign, 2012.
49 Office of Science and Technology. *A strategy for women in science, engineering and technology*, Department of Trade and Industry, London: HMSO, 2003.
50 Fisher A, Boyle JME, Paton JY, *et al*. Effects of a physical education intervention on cognitive function in young children: randomized controlled pilot study. *BMC Pediatr* 2011;11:97.
51 Mahar MT, Murphy SK, Rowe DA, *et al*. Effects of a classroom-based physical activity program on physical activity and on on-task behavior in elementary school children. *Med Sci Sports Exerc* 2006;38:S80.
52 Castelli D, Hillman C, Buck SM, *et al*. Physical fitness and academic achievement in third- and fifth-grade students. *J Sport Exerc Psychol* 2007;29:239–52.
53 Parikh T, Stratton G. Influence of intensity of physical activity on adiposity and cardiorespiratory fitness in 5–18 year olds. *Sports Med* 2011;41:477–88.
54 Donnelly JE, Lambourne K. Classroom-based physical activity, cognition, and academic achievement. *Prev Med* 2011;52(Suppl 0):S36–42.
55 Kantomaa MT, Stamatakis E, Kankaanpää A, *et al*. Physical activity and obesity mediate the association between childhood motor function and adolescents' academic achievement. *Proc Natl Acad Sci* 2012;110:1917–22.
56 Field A. *Discovering statistics using SPSS*. 3rd edn. London: Sage, 2009.
57 Dwyer T, Sallis JF, Blizzard L, *et al*. Relation of academic performance to physical activity and fitness in children. *Pediatr Exerc Sci* 2001;13:225–37.
58 McMurray RG, Harrell JS, Bangdiwala SI, *et al*. A school-based intervention can reduce body fat and blood pressure in young adolescents. *J Adolesc Health* 2002;31:125–32.