Title: Associations between objectively-measured physical activity and later mental health outcomes in children: findings from the UK Millennium Cohort Study

Corresponding author: Jane V Ahn; University College London Institute of Education, Psychology and Human Development, 25 Woburn Square, London, UK WC1H 0AA; jane.ahn@ucl.ac.uk

Co-authors:
Francesco Sera; London School of Hygiene & Tropical Medicine, Department of Social & Environmental Health Research, 15-17 Tavistock Place, London, UK WC1H 9SH

Steven Cummins; London School of Hygiene & Tropical Medicine, Department of Social & Environmental Health Research, 15-17 Tavistock Place, London, UK WC1H 9SH

Eirini Flouri; University College London Institute of Education, Psychology and Human Development, 25 Woburn Square, London, UK WC1H 0AA

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# Abstract

## Background

The beneficial effect of physical activity (PA) on mental health in adults is well established, but less is known about this relationship in children. We examine associations between objectively measured sedentary time, PA and mental health in eleven-year olds from the UK Millennium Cohort Study (MCS).

## Methods

Longitudinal data from MCS sweeps 4 (age 7) and 5 (age 11) were used (N=6,153). Accelerometer data were collected at MCS4, and mental health was measured at MCS4 and MCS5 using subscales (peer, emotional, conduct, hyperactivity) of the Strengths and Difficulties Questionnaire (SDQ). Associations between mean daily PA minutes at different intensities (sedentary, light, moderate-to-vigorous) at MCS4 and SDQ outcomes at MCS5 (score range 0-10) were estimated using multiple linear regression models, adjusting for SDQ at MCS4 and individual and family characteristics, and stratified by gender.

## Results

In fully adjusted models, increased PA at MCS4 was associated with fewer peer problems in boys and girls at MCS5. For each additional 15 minutes in moderate-to-vigorous physical activity (MVPA), peer problems decreased -0.077 points (95% CI -0.133,-0.022) in boys. For girls, light PA was associated with decreased peer problems (-0.071 points/30 minutes, 95% CI -0.130,-0.013). Greater sedentary time was associated with more peer problems and fewer hyperactivity symptoms in boys and girls. Increased MVPA was associated with more conduct and hyperactivity problems in boys and more hyperactivity in girls.

## Conclusions

Increased sedentary time is associated with more peer problems in children, and physical activity, generally, is beneficial for peer relations in children aged 11.

## What is already known on this subject?

Existing research suggests that children who engage in higher levels of physical activity have better mental health than their less active counterparts. However, few studies have been carried out using objective physical activity measures, particularly in large, nationally representative samples. To our knowledge, no studies have used longitudinal data to estimate the effect of physical activity on change in child mental health.

## What this study adds:

Peer problems decreased with more time at light PA and MVPA in boys, but light PA only in girls. Increased sedentary time was associated with more peer problems in both boys and girls. There was no evidence of any effect of sedentary time or physical activity (PA) on emotional health in children. Higher scores for hyperactivity were positively associated with both light PA and moderate-to-vigorous physical activity (MVPA), and inversely associated with sedentary time. Higher MVPA levels were associated with more conduct problems in boys only. Caution should be exercised when interpreting effects of objective physical activity on hyperactivity because of how externalising symptoms are recorded. Decreasing sedentary time and increasing PA at both light and moderate-to-vigorous intensities may help to improve peer relations in children.

# Associations between objectively-measured physical activity and later mental health outcomes in children: findings from the UK Millennium Cohort Study

## Introduction

Approximately ten percent of children aged 5-16 years in the UK have a mental health disorder[1], with the consequences of ignoring mental health disorders in early years increasingly recognised[2, 3]. Mental health problems in young people are associated with poor physical health and negative psychosocial outcomes throughout the lifecourse, including lower educational qualifications, un- or underemployment, teenage parenthood, criminal convictions and psychiatric disorder[2, 3].

There is a growing body of evidence that suggests formal physical activity (PA) via aerobic, resistance, and circuit training, as well as recreational and leisure time PA, such as sports participation and unstructured play, are associated with improvements in child self-esteem and psychological health[4-7]. Conversely, low levels of PA are associated with poorer psychological well-being in children[4, 8, 9]. Other studies have also shown that increased sedentary time in children is associated with poor mental health, particularly emotional and peer problems[8, 10-12]. Sedentary and particularly screen time has been identified as a risk factor of psychological distress in children, and may interact with low levels of PA to increase risk[5]. Proposed psychosocial and physiological mechanisms suggest that PA can improve mental health via increased self-efficacy and confidence, reduced stress and anxiety, better social support and relationships, and increased secretion of endorphins and monoamine transmission[13, 14].

Much of the existing evidence is cross-sectional[4, 5, 8, 9], thus, children with psychological disorders may experience decreased motivation or ability to engage in physical activity, rather than the psychological disorder being symptomatic of PA levels. Also, PA and sedentary time are frequently measured using indirect methods such as parent- or self-report, which can lead to poor estimation of physical activity when compared with objective measures[15, 16]. Randomised controlled trials and intervention studies have shown that depression, anxiety and self-esteem are all improved by PA[7], but these conclusions cannot be generalised to the broader population due to the small and non-representative samples used.

The present study addresses some of these research gaps by estimating the effects of objectively-measured physical activity on child mental health, using longitudinal data from a nationally-representative cohort of UK-born children. We estimate the effect of PA levels at age 7 on mental health at age 11, measured by the individual subscales of the Strengths and Difficulties Questionnaire (SDQ). By adjusting for baseline mental health status at age 7, we can attribute change in SDQ score to PA and sedentary time. Based on the literature, we hypothesised that higher activity levels in children would be predictive of fewer peer and emotional problems and more conduct problems and hyperactivity, and that increased sedentary time would mirror these relationships.

## Methods

### Participants

We used data from the Millennium Cohort Study (MCS), a nationally-representative longitudinal study of children born in the UK between September 2000 and January 2002. Children were over-sampled from disadvantaged wards across the UK, ethnic minority areas in England, and from Scotland, Wales, and Northern Ireland[17]. Data were collected on a range of topics that cover child and family health and the families' wider social circumstances. At the first contact (MCS1), when the children were 9 months of age, 18,552 families were interviewed. A further five surveys have since been carried out when the children were 3, 5, 7, 11 and 14 years of age. We examined PA data from the fourth sweep (MCS4) which took place at age 7. Of the 7,704 children who returned accelerometers with at least one hour of wear time, after applying cleaning procedures[18], excluding invalid PA data, and removing children who did not participate in the study at age 11 (MCS5) (n=522), the final sample size for the present analysis was 6,153 (see Figure 1).

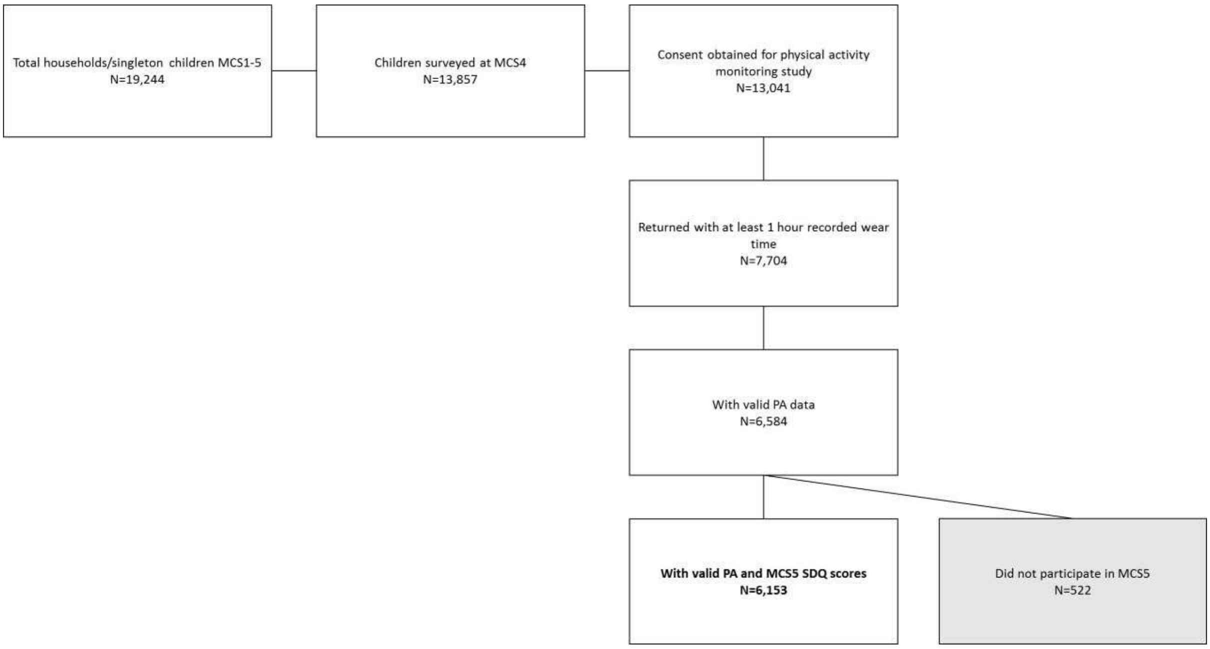


*Figure 1: Summary of MCS Physical Activity Study recruitment, accelerometer return, compliance, and exclusions*

Ethics approval for the MCS was obtained from a Multi-centre Research Ethics Committee in the UK (Ref: 11/YH/0203). Data for this analysis are publicly available and obtained from the UK Data

Archive, University of Essex. Informed written consent to participate in the physical activity monitoring portion of the study was given by parents or guardians at the age 7 interview.

## Outcome variables: Strengths and Difficulties Questionnaire (SDQ)

At ages 7 and 11, the child's main caregiver completed the Strengths and Difficulties Questionnaire (SDQ), which is a tool used to assess mental health and behavioural problems in children and adolescents (4-17 years). The SDQ consists of four subscales which rate areas of difficulties (emotional symptoms, conduct problems, hyperactivity, and peer problems) with each consisting of five items on a three-point scale. Individual item scores are then summed to produce a component score for each scale. The sum of these components then produces a Total Difficulties score. The SDQ has been widely used by researchers and clinicians and has been normalised for the UK population[19]. All SDQ difficulties subscales were separately considered as continuous outcome variables in addition to the Total Difficulties score in the analyses reported here.

## Exposure variable: Objectively-measured physical activity

Physical activity and sedentary time were measured using the Actigraph GT1M uni-axial accelerometer (Actigraph, Pensacola, Florida). The Actigraph accelerometer has been validated in children and used in large-scale epidemiological studies[20-22]. As part of the age 7 survey, children were invited to participate in the physical activity monitoring study. Children wore accelerometers between May 2008 and August 2009. These were programmed with 15 second epochs and also recorded step counts. Children were instructed to wear the accelerometers for seven consecutive days during waking hours, except during swimming and bathing.

Cleaning and processing of the raw accelerometer data were undertaken by the research team at the Institute of Child Health (ICH)[18]. Cut-offs based on a calibration study conducted by the ICH team were established for counts on the accelerometer at <100 counts per minute (cpm) for sedentary behaviour, 100-2,240 cpm for light activity and 2,241-11,714 cpm for moderate-to-vigorous physical activity (MVPA)[23]. A reliability study found that values in excess of 11,714 cpm were likely to be spurious, so these were removed (0.7% of all non-zero accelerometer counts obtained)[24]. Non-wear time was defined as any period of consecutive zero-counts of at least 20 minutes[18]. A reliability study determined that participants were required to have recorded a minimum of 10 hours of wear-time on at least two days in order to be included in the final dataset[25]. Summary measures for mean daily minutes spent in sedentary time, light activity and MVPA were calculated and standardised for wear time. To make the units more meaningful in the context of activity duration in analyses and to approximate the standard deviation, sedentary time, light PA, and MVPA minutes were divided by 60 minutes, 30 minutes, and 15 minutes, respectively.

## Confounding factors

Based on existing evidence, potential confounding factors were selected a priori[26-28]. Child characteristics included season of accelerometer wear, ethnicity (white; mixed; Indian; Pakistani or Bangladeshi; black or black British; other), exact age, whether longstanding limiting illness (LSLI) affects activity (no LSLI, not at all, a little, a lot), whether the child has special educational needs (SEN), child's cognitive ability (age-standardised reading ability and pattern construction from the British Ability Scales; BAS), self-esteem (revised, five-item version of the Rosenberg self-esteem scale, alpha=0.679), and weight status (not overweight or overweight/obese). Maternal characteristics included employment (in work or not), depression (measured using the Kessler (K6) scale and dichotomised to no increased risk of mental illness or increased risk of mental illness), and educational attainment (degree educated or not). Household factors included family structure (both natural parents resident full time or not), number of siblings, and income poverty (household income below 60% of the UK median household income). Time-varying characteristics (LSLI, SEN, self-esteem, weight status, maternal employment, maternal depression, family structure, number of siblings, income poverty) for children and families were measured when the children were aged 11 years, except for children's cognitive ability, which was measured at age 7.

## Statistical analyses

In all inferential procedures the stratified cluster sampling design of MCS study, as well as attrition between contacts at successive MCS sweeps and missing accelerometer data, were taken into account using the Stata command svyset[18]. Given established differences in both SDQ scores and PA levels between boys and girls, all models were stratified by sex[29, 30]. Descriptive characteristics of the sample were survey-weighted relative frequencies for categorical variables and means for continuous variables. Chi-squared tests and independent t-tests were performed to measure differences between boys and girls.

Linear regression models were fitted to assess the association between sedentary time and physical activity at age 7, and SDQ scores at age 11. Minimally-adjusted models were run (adjusting for age, season, and SDQ total difficulties score at age 7), and fully-adjusted models included the remaining potential confounders described above.

All regression models were initially fitted in the complete case sample. For the prospective analyses, the exposure variables were fully observed, however, around 147 (2.4%) children had missing data for SDQ outcomes and up to 414 (6.7%) for covariates. Full details of missingness is shown in Table 1. Multiple imputation analysis was performed to mitigate possible bias due to item non-response. Twenty imputed datasets were built using the weighted iterative chain algorithm, and estimates were combined using Rubin's rule. Regression model results presented below were estimated using imputed data.

Analyses were conducted using Stata 14 (Stata Corporation, TX).

# Results

## Sample characteristics

Mean SDQ scores for peer problems, conduct problems, hyperactivity, and total difficulties were higher for boys than for girls ($p<0.01$). There were no significant differences between boys and girls in emotional problems.

Half of the children (50.7%) met the cut-offs of at least 60 minutes MVPA per day, but only 38% of girls met the guidelines compared with 63% of boys (data not shown). Mean daily number of sedentary minutes was higher for girls than boys (399.09 compared with 382.05), and boys spent more time at both light PA and MVPA intensities than girls – these differences were statistically significant ($p<0.05$).

The majority of children were White (85.1%). 18.8% of children were living in poverty. 9.7% of children had special educational needs (SEN) and 12.6% had a long-standing limiting illness. By MCS5 (age 11), 18.9% of mothers were educated to degree levels, 68.7% were in work, and 5.6% were at risk of serious mental illness. 64.0% of children were living with both natural parents, and 88.2% had at least one sibling.

Full results of the descriptive analyses are presented in Table 1.

*Table 1: Descriptive characteristics of the sample by sex (N=6,153).*

| | Males | | | Females | | |
|---|---|---|---|---|---|---|
| | % (N) | Mean | SD | % (N) | Mean | SD |
| Strengths and Difficulties Questionnaire (age 11) | | | | | | |
| Emotional symptoms | | 1.79 | 1.92 | | 1.89 | 2.09 |
| Peer problems * | | 1.47 | 1.72 | | 1.28 | 1.65 |
| Conduct problems * | | 1.54 | 1.59 | | 1.26 | 1.51 |
| Hyperactivity * | | 3.56 | 2.46 | | 2.66 | 2.33 |
| Total difficulties * | | 8.36 | 5.80 | | 7.08 | 5.69 |
| Physical activity variables (weighted average minutes per day) | | | | | | |
| Sedentary time * | | 382.05 | 48.99 | | 399.09 | 50.54 |
| Light PA * | | 282.83 | 37.67 | | 279.46 | 39.69 |
| MVPA * | | 70.06 | 22.76 | | 56.25 | 19.86 |
| Season physical activity monitor was worn | | | | | | |
| Summer | 47.2 (1330) | | | 44.2 (1366) | | |
| Autumn | 31.6 (929) | | | 35.4 (1047) | | |
| Winter | 9.6 (401) | | | 9.4 (405) | | |
| Spring | 11.7 (334) | | | 11 (341) | | |
| Age (to the nearest 10th of year) | | 11.15 | 0.32 | | 11.15 | 0.33 |
| Ethnicity | | | | | | |
| White | 85.1 (2650) | | | 85.0 (2773) | | |
| Mixed | 3.3 (77) | | | 2.8 (76) | | |
| Indian | 1.9 (55) | | | 2.4 (76) | | |
| Pakistani or Bangladeshi | 5.3 (112) | | | 4.9 (123) | | |
| Black or Black British | 3.1 (65) | | | 3.1 (69) | | |
| Other Ethnic group | 1.3 (35) | | | 1.9 (42) | | |
| Child has special educational needs * | | | | | | |
| no | 87.3 (2655) | | | 93.4 (2978) | | |
| yes | 12.7 (339) | | | 6.6 (181) | | |
| Does LSLI limit your child's activity? * | | | | | | |
| No limiting illness | 85.4 (2576) | | | 89.5 (2833) | | |
| No | 7.2 (221) | | | 6.2 (190) | | |
| Yes | 7.4 (197) | | | 4.3 (136) | | |
| Household income below 60% of the UK median household income | | | | | | |
| No | 81.8 (2651) | | | 80.5 (2771) | | |
| yes | 18.2 (343) | | | 19.5 (388) | | |
| Number of siblings in the household | | | | | | |
| 0 | 11.5 (329) | | | 12.1 (361) | | |
| 1 | 44.8 (1434) | | | 45.1 (1492) | | |
| 2 | 26.5 (788) | | | 26.9 (874) | | |
| 3 | 12.7 (314) | | | 10.3 (306) | | |
| 4+ | 4.6 (129) | | | 5.6 (126) | | |
| Both natural parents resident in household full-time | | | | | | |
| No | 36.2 (801) | | | 35.9 (821) | | |
| yes | 63.8 (2193) | | | 64.1 (2338) | | |
| Highest academic qualification mother attained up to MCS5 | | | | | | |
| no degree | 81.3 (2167) | | | 81.0 (2292) | | |
| degree or higher | 18.7 (827) | | | 19.0 (867) | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Mother in work | | | | | | | |
| | No | 31.0 (702) | | | 31.6 (772) | | |
| | yes | 69.0 (2202) | | | 68.4 (2286) | | |
| Kessler K6 score | | | | | | | |
| | normal (0-12) | 94.6 (2708) | | | 94.2 (2861) | | |
| | higher likelihood of serious mental illness (13+) | 5.4 (119) | | | 5.8 (122) | | |
| BAS Pattern construction score | | | 53.78 | 10.73 | | 54.27 | 10.32 |
| BAS Word reading score * | | | 111.95 | 18.40 | | 113.80 | 16.49 |
| Self-esteem * | | | 13.49 | 1.71 | | 13.34 | 1.83 |
| Weight status * | | | | | | | |
| | Not overweight | 75.7 (2291) | | | 70.2 (2289) | | |
| | Overweight/obese | 24.3 (650) | | | 29.8 (804) | | |

Missing observations (all children): Emotional problems (138); peer problems (137); conduct problems (139); hyperactivity (147); total difficulties (151); SEN (42); maternal employment (191); Kessler K6 (343); BAS pattern construction (34); BAS word reading (106); self-esteem (414); weight status (119).

* indicates sex differences using design-based F statistic, p<0.05

Note: Ns are unweighted, percentages and means are weighted.

## Multivariate linear regression results

Table 2 presents the results from the multivariate linear regression analyses for boys and girls, separately. The b coefficients are the point change in SDQ score per unit increase of time: 60 minutes sedentary time, 30 minutes light activity, and 15 minutes MVPA. The final models showed that, for boys, a one-hour increase in sedentary time at age seven was associated with increased peer problems at age 11 (B=0.169, 95% CI: 0.064,0.273). Conversely, a one-hour increase in sedentary time was associated with decreased hyperactivity scores (B=-0.325, 95% CI: -0.447,-0.203). For girls, increased sedentary time was also associated with increased peer problems (B=0.084, 95%CI: 0.000,0.168) as well as decreased hyperactivity (B=-0.269, 95% CI: -0.378,-0.159) for each additional hour of sedentary time. Boys who were more lightly active had lower peer problems (B=-0.086, 95% CI: -0.150,-0.021) and higher hyperactivity scores (B=0.157, 95% CI: 0.077,0.237). Increases in light activity in girls showed decreases in peer problems of -0.071 (95% CI: -0.130,-0.013) per 30 minutes. The effect of light activity on hyperactivity scores in girls was 0.164 (95% CI: 0.091,0.238) points per 30 minutes.

With respect to MVPA, for boys, increased MVPA time was associated with fewer peer problems (-0.077 per 15 minutes, 95% CI: -0.133,-0.022), more conduct problems (0.084 per 15 minutes, 95% CI: 0.030,0.139) and higher hyperactivity scores (0.153 per 15 minutes, 95% CI: 0.082,0.224) in the fully adjusted models. For girls, the only relationship with MVPA in the fully adjusted models was with hyperactivity, where a 15 minute increase was associated with 0.092 higher scores (95% CI: 0.028,0.155). No other relationships were observed in the other subscales. Standardised coefficients are available in Supplementary Table A.

*Table 2: Multiple linear regression analyses – regression coefficients and 95% confidence intervals representing the change in SDQ scores at age 11 per unit time increase of sedentary behaviour (60 minutes), light activity (30 minutes) and MVPA (15 minutes); minimally-adjusted and fully-adjusted models*

| | | Males | | | | Females | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Model 1 | | Model 2 | | Model 1 | | Model 2 | |
| | | b | 95% CI | b | 95% CI | b | 95% CI | b | 95% CI |
| Emotional | sedentary | 0.105 | -0.017,0.227 | 0.089 | -0.024,0.201 | 0.040 | -0.072,0.151 | 0.064 | -0.039,0.168 |
| | light PA | -0.039 | -0.110,0.032 | -0.039 | -0.106,0.028 | -0.013 | -0.083,0.057 | -0.026 | -0.094,0.041 |
| | MVPA | -0.065 | -0.136,0.006 | -0.048 | -0.111,0.015 | -0.035 | -0.110,0.041 | -0.049 | -0.115,0.016 |
| Peer | sedentary | 0.192 *** | 0.080,0.303 | 0.169 ** | 0.064,0.273 | 0.062 | -0.025,0.149 | 0.084 * | 0.000,0.168 |
| | light PA | -0.087 * | -0.158,-0.016 | -0.086 ** | -0.150,-0.021 | -0.059 * | -0.116,-0.002 | -0.071 * | -0.130,-0.013 |
| | MVPA | -0.096 ** | -0.160,-0.032 | -0.077 ** | -0.133,-0.022 | 0.015 | -0.056,0.087 | 0.007 | -0.057,0.071 |
| Conduct | sedentary | -0.070 | -0.184,0.044 | -0.089 | -0.199,0.020 | -0.074 | -0.154,0.006 | -0.024 | -0.102,0.053 |
| | light PA | -0.008 | -0.071,0.055 | 0.012 | -0.052,0.075 | 0.035 | -0.019,0.088 | 0.01 | -0.042,0.062 |
| | MVPA | 0.086 ** | 0.028,0.144 | 0.084 ** | 0.030,0.139 | 0.049 * | 0.005,0.094 | 0.019 | -0.026,0.065 |
| Hyperactivity | sedentary | -0.331 *** | -0.451,-0.210 | -0.325 *** | -0.447,-0.203 | -0.296 *** | -0.409,-0.182 | -0.269 *** | -0.378,-0.159 |
| | light PA | 0.145 *** | 0.062,0.229 | 0.157 *** | 0.077,0.237 | 0.178 *** | 0.100,0.255 | 0.164 *** | 0.091,0.238 |
| | MVPA | 0.167 *** | 0.091,0.243 | 0.153 *** | 0.082,0.224 | 0.116 *** | 0.052,0.180 | 0.092 ** | 0.028,0.155 |
| Total difficulties | sedentary | -0.104 | -0.416,0.208 | -0.157 | -0.449,0.136 | -0.268 | -0.547,0.011 | -0.145 | -0.400,0.111 |
| | light PA | 0.011 | -0.177,0.200 | 0.044 | -0.135,0.222 | 0.141 | -0.048,0.329 | 0.077 | -0.100,0.254 |
| | MVPA | 0.092 | -0.099,0.283 | 0.112 | -0.060,0.283 | 0.146 | -0.023,0.315 | 0.069 | -0.084,0.221 |

Model 1) Adjusted for age, season, total difficulties at age 7
Model 2) Adjusted for the covariates of Model 1 as well as limiting illness, SEN, weight status, self-esteem, ethnicity, income, siblings, family structure, maternal education, maternal depression, maternal employment, BAS pattern construction, BAS word reading

* p<0.05, ** p<0.01, *** p<0.001

## Discussion

In this paper we observed that objectively-measured sedentary time and PA levels at age 7 were associated with specific domains of mental health functioning at age 11. Evidence of beneficial effects of any PA intensity on peer problems for boys, and of light activity for girls was observed. Sedentary time was associated with more peer problems in both boys and girls.

Increased sedentary time was associated with lower hyperactivity, while PA at any intensity was associated with higher hyperactivity scores and, in boys, more MVPA was associated with more conduct problems. Cross-sectional analyses in the MCS examining the relationship between SDQ and PA found that higher externalising scores in both boys and girls were associated with less sedentary time at age 7[31]. Conversely, other cross-sectional studies found higher hyperactivity scores in sedentary children[8, 32]; however, the measure of sedentary activity was reported screen time, which may explain the differences in findings from the present study. Sedentary time spent doing homework or reading may have different mental health effects than screen time. Similar findings were reported in a longitudinal study using questionnaire-reported PA, which found that children who were more active at baseline had more hyperactive symptoms[33]. With hyperactivity, the challenge in ascribing causality with both the possibility of residual confounding and the absence of PA measures at an earlier time point is discussed in the literature, as well as the possibility that hyperactive symptoms are simply being misclassified as physical activity[8, 31, 33].

Accelerometer-measured MVPA has been associated with improved emotional health in a cohort of 8-year old Finnish children, and inversely correlated with internalising difficulties in 10-11-year old children in the Avon Longitudinal Study of Parents and Children[4, 10]. Findings from the present analysis show no evidence of an association between MVPA and emotional problems in the fully adjusted models. In girls, this was surprising as studies have shown that the relationships between PA and emotional health were more pronounced in girls than boys[8].

Evidence of relationships between PA and peer problems were present in both boys and girls, although these differed by PA intensity, where only light activity was significant in girls. The literature supports these findings: sport-specific activity usually at the moderate-to-vigorous intensity was found to be protective in boys but not in girls[34]. Sedentary time was positively associated with boys' and girls' peer problems in this study, but Hinkley et al found only girls' peer problems were affected by sedentary time[11].

The mechanisms behind these sex differences are complex and likely influenced by social and cultural norms, but it has been suggested that physical activity expectations may be different for boys and girls, and, as a result, can operate on mental health through different pathways[30]. For example, boys may be faced with more pressure or be expected to participate and perform well in organised sports or active games both in and outside of school[35]. In turn, this could lead to the consistently significant relationship of physical activity with peer relations in boys observed in this study.

The relationship observed in girls is also important as it highlights the potential benefits of PA for peer relations in girls, who are less likely to be active. Qualitative work has shown that girls feel less supported in physical activity pursuits[36], and the absence of expectation to participate might result in fewer benefits for their mental health – this might be some indication as to why there were no significant relationships observed for girls and MVPA, barring that observed with hyperactivity. Given that girls were less likely to engage in MVPA, there may not have been sufficient data to allow any significant relationship to show in this domain.

A number of studies have reported no associations between PA and SDQ total difficulties[10, 33, 37]. Given that, as we showed, the associations for the internalising and externalising subscales tended to be in opposite directions, it is conceivable that, as in this study, any effects were likely neutralised.

## Strengths and limitations

To our knowledge, this is the first study to explore the effects of objective PA on mental health using longitudinal measures in a nationally-representative, UK-based sample of children. By incorporating SDQ measures at age 11 and adjusting for previous mental health status, this study uses longitudinal data from the MCS to understand how PA might affect mental health through time. While other studies have reported relationships between PA and SDQ total difficulties only, with potentially important relationships going unobserved, this study reported estimates for all SDQ subscales. In doing so, this study showed that PA is potentially related to different aspects of mental health functioning in children. Griffiths and colleagues used MCS data to explore the association between PA and child mental health as measured by the SDQ internalising, externalising and total difficulties scores, but in the opposite direction: how longitudinal SDQ scores influence MVPA and sedentary levels at age 7[31].

In this study, PA and sedentary time were not included in the same models for both statistical and theoretical reasons. The objective PA and sedentary variables are examples of compositional data (where each comprises a proportion of a day), which have a negatively biased covariance structure and standard statistical methods should not be used[38]. Collinearity is also problematic in simultaneously adjusting for compositional data[39]. On the theoretical considerations, Page et al[39] point out that if PA is not a common cause of sedentary behaviour and the outcome, and is not an effect of sedentary behaviour on the causal pathway to the outcome, there is no need to adjust for it[39].

The objective PA measures were only available at age 7, thus, the effect of patterns of objective PA over time cannot be estimated. PA measures at multiple sweeps would allow for further longitudinal analyses and could highlight possible causal pathways.

A limitation of this study is the level of non-response (did not participate or did not return the monitor) and non-compliance (did not follows the indication to wear the monitor for seven consecutive days during waking hours) in the physical activity monitoring. We used an inverse probability weighting approach to partially remove the selection bias due to non-response and non-compliance [40] ; in particular we used the specific inverse probability weights calculated for the MCS physical activity study [18] on which the probability of having accelerometer data is predicted from a set of auxiliary variables.

An important strength of this study is its use of objective PA measures, which helps limit some of the biases inherent in reported measures of PA. However, with accelerometer measures, the characteristics and context of the PA measures are unknown and these could be important to understanding the PA-mental health relationship.

In a study examining the relationship between PA and cognition in children, Aggio et al found that objectively-measured PA was inversely associated with cognition, while frequency of sports club participation increased cognitive scores[41]. Sports clubs, as opposed to playing sports with friends or family, tend to be more structured, interactive, strategic and goal-oriented which help develop cognitive function[42]. These contextual differences in sport might affect mental health similarly to cognition. Girls are less likely to engage in organised sports and so an hour of MVPA might not impart the same benefits.

As with PA, the context of sedentary time is important and this analysis cannot capture the quality of the sedentary activity undertaken. Page et al describe a low correlation between sedentary time and screen entertainment, with the view that sedentary time and sedentary behaviours are different constructs[10]. Summary measures of sedentary time may in fact be conflating behaviours that affect mental health in opposing directions.

In conclusion, these findings suggest that higher levels of PA at age 7 lower peer problems at age 11, while more sedentary time is associated with more peer problems for both boys and girls. Caution must be taken when interpreting the association between objectively-measured PA and hyperactivity and conduct problems because of how externalising symptoms are recorded. Policies aimed at increasing PA levels in children should consider the importance of activities that foster peer interaction and social inclusion. Further work should be carried out to investigate how the context of PA affects child mental health.

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JVA analysed the data, drafted and revised the paper. FS provided statistical support. FS, SC, and EF revised the paper.

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## Appendix

*Supplementary Table A: Multiple linear regression analyses – standardised regression coefficients and 95% confidence intervals representing the change in standard deviation of SDQ scores at age 11 per unit time increase of sedentary behaviour (60 minutes), light activity (30 minutes) and MVPA (15 minutes); minimally-adjusted and fully-adjusted models*

| | | Boys | | | | Girls | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Model 1 | | Model 2 | | Model 1 | | Model 2 | |
| | | β† | 95% CI | β† | 95% CI | β† | 95% CI | β† | 95% CI |
| Emotional | sedentary | 0.050 | -0.014,0.113 | 0.039 | -0.021,0.098 | 0.022 | -0.035,0.080 | 0.032 | -0.022,0.086 |
| | light | -0.016 | -0.053,0.020 | -0.016 | -0.051,0.020 | -0.008 | -0.044,0.029 | -0.013 | -0.048,0.023 |
| | MVPA | -0.033 | -0.071,0.004 | -0.023 | -0.056,0.011 | -0.019 | -0.058,0.020 | -0.026 | -0.060,0.008 |
| Peer | sedentary | 0.119 *** | 0.049,0.189 | 0.102 ** | 0.036,0.168 | 0.045 | -0.009,0.098 | 0.056 * | 0.005,0.107 |
| | light | -0.053 * | -0.097,-0.009 | -0.050 * | -0.091,-0.010 | -0.040 * | -0.075,-0.005 | -0.047 * | -0.083,-0.010 |
| | MVPA | -0.061 ** | -0.101,-0.021 | -0.048 ** | -0.083,-0.014 | 0.007 | -0.038,0.052 | 0.003 | -0.037,0.043 |
| Conduct | sedentary | -0.049 | -0.129,0.031 | -0.064 | -0.140,0.012 | -0.052 | -0.107,0.003 | -0.019 | -0.073,0.035 |
| | light | -0.005 | -0.050,0.039 | 0.01 | -0.035,0.054 | 0.026 | -0.011,0.063 | 0.01 | -0.026,0.046 |
| | MVPA | 0.060 ** | 0.020,0.101 | 0.059 ** | 0.021,0.097 | 0.033 * | 0.002,0.064 | 0.013 | -0.019,0.045 |
| Hyperactivity | sedentary | -0.141 *** | -0.192,-0.090 | -0.142 *** | -0.194,-0.089 | -0.131 *** | -0.180,-0.083 | -0.122 *** | -0.169,-0.075 |
| | light | 0.063 *** | 0.028,0.097 | 0.069 *** | 0.035,0.103 | 0.079 *** | 0.046,0.112 | 0.075 *** | 0.043,0.106 |
| | MVPA | 0.072 *** | 0.040,0.104 | 0.067 *** | 0.037,0.097 | 0.051 *** | 0.024,0.078 | 0.042 ** | 0.015,0.069 |
| Total difficulties | sedentary | -0.022 | -0.080,0.035 | -0.035 | -0.090,0.020 | -0.050 | -0.102,0.001 | -0.031 | -0.078,0.016 |
| | light | 0.005 | -0.030,0.039 | 0.012 | -0.021,0.046 | 0.027 | -0.008,0.062 | 0.017 | -0.016,0.050 |
| | MVPA | 0.018 | -0.017,0.053 | 0.023 | -0.009,0.054 | 0.026 | -0.005,0.057 | 0.013 | -0.015,0.041 |

Model 1) Adjusted for age, season, Total Difficulties at age 7

Model 2) Adjusted for limiting illness, SEN, weight status, self-esteem, ethnicity, income, siblings, family structure, maternal education, maternal depression, maternal employment, BAS pattern construction, BAS reading

* p<0.05, ** p<0.01, *** p<0.001

† Standardised coefficient; number of standard deviations per unit of PA or sedentary time