Physical Activity, Sedentary Behavior, and Adiposity in English Children

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Background: The importance of variation in total volume of physical activity or moderate- to vigorous-intensity physical activity (MVPA) to development of body fatness in childhood is unclear, and it is unclear if physical activity has a greater influence on adiposity in boys than girls.

Purpose: To assess relationships between 2-year changes in objectively measured physical activity, sedentary behavior, and adiposity in English children.

Methods: Prospective cohort study, set in Northeast England, of a socioeconomically representative sample of 403 children. Measures were change in accelerometer-determined physical activity and sedentary behavior from age 7 to 9 years (data collected 2006/2007 and 2008/2009; analyzed in 2010) and concurrent change in adiposity (fat mass index derived from bioelectric impedance) and change in BMI *Z*-score.

Results: Decline in MVPA was associated with a greater increase in fat mass index in boys but not girls. Declining MVPA was associated with increased BMI *Z*-score in boys but not girls. Increased sedentary behavior was not associated with increased BMI *Z*-score in either gender.

Conclusions: Avoiding mid–late childhood reductions in MVPA may reduce excessive fat gain, although such strategies may have greater impact on boys than girls.
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Introduction

Levels of physical activity and sedentary behavior may be important influences on adiposity of children and adolescents.[1–3] Recent systematic reviews found that high levels of regular physical activity probably prevent obesity in children and adolescents,[4] and high levels of sedentary behavior probably promote obesity.[5] However, these reviews highlighted numerous weaknesses in the evidence base.[4,5]

Recent studies[6–13] that have used accelerometry have begun to identify "dose–response" relationship(s) between physical activity and adiposity, and they are beginning to provide evidence on the relative importance of various physical activity constructs, total volume of physical activity, and moderate- to vigorous-intensity physical activity (MVPA). However, a recent systematic review[4] found that most of these studies were cross-sectional, were unable to test whether associations with physical activity were independent of sedentary behavior, and did not consider possible between-gender differences in the strength of the relationships observed. A recent systematic review found a suggestion of stronger associations between physical activity and adiposity in boys than girls and a suggestion that associations might be more detectable when measures of body composition are used as the outcome than when proxies for adiposity are used as the outcome.[4]

By age 7 years, physical activity is in decline in English children, and sedentary behavior is increasing.[14,15] Age 7–11 years also appears to be the period of childhood and adolescence in which most excess weight gain occurs in English children,[16] and when obesity incidence (emergence of new cases) is at its highest.[17] It is important for the development of evidence-informed obesity prevention strategies to establish which lifestyle changes influence subsequent increases in adiposity, but as noted

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above, the evidence on the relationships of physical activity and sedentary behavior with adiposity in childhood is inconclusive.

The primary aim of the present study was therefore to test the hypothesis that changes in objectively measured physical activity and sedentary behavior were associated with changes in adiposity. Secondary aims were to test the hypotheses that MVPA has greater influence on adiposity than total volume of physical activity; associations of sedentary behavior and physical activity with adiposity are independent of each other; relationships among physical activity, sedentary behavior, and adiposity are stronger in boys than girls; and that associations observed with body fatness as the outcome measure would not be detected with BMI *Z*-score as the outcome measure.

Methods

Participants, Recruitment, and Consent

The Gateshead Millennium Study (GMS) has been described elsewhere.[14,18] The sample was socioeconomically representative of North-East England at baseline data collection for the present study in 2006/2007.[18] Baseline measures were collected between October 2006 and December 2007 when the children were aged 6–7 years, and follow-up data were collected 24 months later. The study was approved by the Newcastle University Ethics Committee. Informed written consent was obtained from the parent/main caregiver of each child, and children provided assent to their participation.

Exposure Measures: Objective Measurement of Physical Activity and Sedentary Behavior

Physical activity and sedentary behavior were measured with the Actigraph GT1M accelerometer as described previously.[14] The Actigraph has high validity, high reliability, and low reactivity in children.[19,20] Children in the present study were asked to wear the accelerometer during waking hours for 7 days. Data were reduced manually, by juxtaposing accelerometry output and log-sheets in order to delete occasional periods of nonwear time. These were identified as recorded and explained (e.g., showering) or unexplained strings of zero output.[20,21]

Three constructs were measured: total volume of physical activity, expressed as counts per minute (cpm); MVPA (expressed as percentage of daily time spent in MVPA); sedentary behavior, equivalent to sitting, lying, or standing with no translocation of the trunk (expressed as percentage of daily time spent in sedentary behavior). Evidence-based "cutoff points" were used[20]: 3200 cpm to quantify MVPA[22]; 1100 cpm (which measures sitting and standing with no movement) to quantify sedentary behavior.[20,23] Because the Actigraph cut-points that were used in the present study were derived from studies of a previous model of the Actigraph (model 7164), a +9% correction was applied to the raw accelerometry data before applying the accelerometry cut-points in the present study.[24]

In this cohort, 3 days of accelerometry with a minimum of 6 hours recording per day provides acceptable reliability,[25] so measures were included in the present study if at least 3 days of accelerometry of at least 6 hours were obtained at both baseline and follow-up measures. In practice, duration of accelerometry was much greater than this: 6.4 days (11.1 hours/day) at baseline and 6.1 days (11.3 hours/day) at follow-up. In UK children, there are small but significant seasonal variations in objectively measured physical activity,[26,27] and so follow-up measurements were made as close to the baseline time of year as practicable.

Descriptive Characteristics of Study Participants

Height was measured to 0.1 cm with a Leicester Portable height measure and weight measured to 0.1 kg in light indoor clothing and body fat estimated with a TANITA TBF 300MA as described below. BMI was calculated for each child and Z-scores expressed relative to UK 1990 population reference data. SES was described using the Townsend score, an area-based measure derived from the UK census in 2001 derived from the percentage of unemployed people aged 16–65 years; household overcrowding; not owning a home; and not owning a car.

Outcome Measures

The primary outcome measure was change in fat mass index (fat mass [kg]/height [m]^2). Fat mass was estimated from TANITA bioelectric impedance by applying constants for the hydration of fat-free mass,[28] having first estimated total body water using gender- and age-specific prediction equations from Haroun et al.[29] The secondary outcome measure was change in BMI *Z*-score. The rank correlations between BMI *Z*-score and FMI at age 7 years were 0.60 and 0.74, and at age 9 years were 0.71 and 0.84 in boys and girls, respectively.

Statistical Analysis

Data were checked for normality, and medians and interquartile ranges are presented where appropriate. Differences between the genders were assessed using Mann–Whitney *U* tests. Linear regression analysis was used to test for associations between changes in physical activity, changes in sedentary behavior, changes in adiposity, and changes in BMI *Z*-score. The exposure variables were change in total physical activity (mean cpm); change in percentage time in MVPA; and change in percentage time in sedentary behavior.

The analyses were initially carried out without any adjustments; then multivariable analysis was carried out, adjusted for baseline variables (fat mass index, gender, SES) and with factors significant at $p<0.10$ in the univariable analysis added. In the final stage of the analysis, physical activity and sedentary behavior variables that remained significant were considered in the same model. Analyses were performed with the entire sample, and then for boys and girls separately, as a recent systematic review found that physical activity is associated more consistently with adiposity in boys than girls.[4] SPSS, release 17, and Stata, version 10, were used for analyses. For final multivariable models, significance was set at $p<0.05$.

Results

Characteristics of Study Sample and Sample Attrition

Characteristics of study participants are described in Table 1. A total of 510 children had successful baseline measures, but 107 children studied at baseline were lost to follow-up be-

Table 1. Characteristics of study participants, median and IQR unless otherwise noted

	All children (N=403)		Boys (*n*=198)		Girls (*n*=205)	
Variable	Aged 7 years	Aged 9 years	Aged 7 years	Aged 9 years	Aged 7 years	Aged 9 years
Age (years) (range)	7.4 (6.4, 8.4)	9.3 (8.4, 10.2)	7.4 (6.4, 8.4)	9.3 (8.4, 10.2)	7.4 (6.5, 8.4)	9.4 (8.4, 10.2)
Total physical activity (mean cpm)	721 (600, 866)	643[a] (524, 786)	731 (623, 876)	688 (569, 831)	708 (586, 849)	606[b] (495, 727)
MVPA, minutes/day	26 (18, 37)	24[a] (15, 37)	28 (19, 42)	28 (20, 43)	24 (16, 34)	21[b] (13, 29)
MVPA, % time	3.8 (2.6, 5.6)	3.6[a] (2.3, 5.2)	4.2 (2.8, 6.3)	4.3 (2.9, 6.2	3.7 (2.5, 5.2)	3.0[b] (2.0, 4.5)
Sedentary behavior, % time	78.0 (74.0, 81.9)	81.2[a] (76.9, 84.4)	77.2 (72.6, 80.9)	79.5 (75.5, 83.2)	78.7 (74.6, 82.9)	82.4 (78.5, 85.4)
BMI *Z*-score	0.32 (−0.35, 1.03)	0.54[a] (−0.18, 1.22)	0.26 (−0.35, 1.01)	0.53 (−0.19, 1.23)	0.35 (−0.36, 1.05)	0.55 (−0.15, 1.23)
Fat mass index	3.6 (2.7, 4.8)	4.1[a] (3.0, 5.9)	3.7 (2.9, 5.0)	4.1 (3.0, 5.9)	3.5 (2.6, 4.6)	4.7[b] (3.3, 6.0)
Weight (kg)	25.3 (22.6, 28.6)	32.1[a] (27.9, 37.3)	25.1 (22.6, 28.6)	31.6 (27.9, 36.1)	25.5 (22.7, 28.6)	32.6 (27.9, 38.0)

[a]Follow-up data significantly different from baseline
[b]Significant difference between boys and girls in change from baseline to follow-up
IQR, interquartile range; MVPA, moderate- to vigorous-intensity physical activity

cause of missing accelerometry log-sheets (*n*=9); not wearing the accelerometer (*n*=6); not reaching the minimum wear criteria (*n*=8); lost accelerometers (*n*=14); accelerometer malfunctions (*n*=13); no consent to take part/unable to trace for follow-up measures (*n*=55); and no height/weight measure (*n*=2), leaving a total of 403 for the analyses in the present study. Participants followed up over the 2-year period were not statistically different compared with those lost to follow-up for initial levels of physical activity and sedentary behavior, or for SES. Physical activity declined; sedentary behavior, fat mass index, and BMI *Z*-score all increased over the 2-year period (Table 1). At baseline, 99 (24.6%) of 403 of the children were overweight or obese (BMI at or above the 85th percentile relative to UK 1990 reference data) and this increased to 131 (32.5%) of 403 at follow-up.

Associations of Changes in Physical Activity with Changes in Adiposity

In univariable analyses (simple linear regression with no adjustments), changes in both total volume of physical activity and MVPA were associated with change in fat mass index in boys and in the entire sample at $p=0.10$ (Table 2). Associations between changes in total volume of physical activity and FMI in univariable analyses were not significant in subsequent models. Addition of MVPA removed the association between total volume of physical activity and FMI.

In multivariable analyses (Table 3), with adjustments for baseline variables, SES, and other factors significant at $p<0.10$ in the univariable analyses, changes in MVPA were not associated with changes in fat mass index in the entire sample. When the genders were considered separately, changes in MVPA were associated with changes in fat mass index in boys but not girls; smaller reductions in MVPA over the 2 years were associated with smaller increases in fat mass index, with a 50% increase in MVPA in boys (of ~14 minutes per day), predictive of a reduction in FMI of −0.24. There was no association between total volume of physical activity and change in BMI *Z*-score in either gender. In boys, but not girls, associations were observed between change in BMI *Z*-score and change in MVPA in univariable analysis (Table 2), and the association remained significant in more-complex models (Table 3).

Associations of Changes in Sedentary Behavior with Changes in Adiposity

In univariable analyses, changes in sedentary behavior were associated with changes in fat mass index (Table 2). In multivariable analyses with inclusion of baseline variables and SES, changes in sedentary behavior were associated with changes in fat mass index in the entire sample and in boys, and were of borderline significance in girls. However, in a final model that included both MVPA and time spent sedentary, the latter was not associated with changes in FMI in the entire sample or in boys, and the association was of borderline significance in girls (Table 4). Changes in BMI *Z*-score were not associated with changes in time spent sedentary in univariable analyses with both genders combined or considered separately (Table 2) and so did not enter subsequent models.

Discussion

Main Findings

The current study supports the hypothesis that childhood declines in physical activity are associated with increased adiposity, and suggests that this is due to declines in MVPA rather than total volume of physical activity. The

Table 2. Univariable associations between exposure and outcome variables (β coefficient $\times 10^3$)

Exposure/outcome measure	Sample (*n*)	β coefficient (95% CI)	Adjusted R^2	*p*
Exposure: change in total volume of physical activity, mean cpm				
Change in fat mass index	Entire (377)	−0.51 (−1.05, 0.03)	0.007	0.062
	Boys (186)	−1.04 (−1.85, −0.24)	0.029	0.012
	Girls (191)	−0.04 (−0.75, 0.68)	−0.005	0.923
Change in BMI *Z*-score	Entire (403)	−0.12 (−0.32, 0.08)	0.001	0.225
	Boys (198)	−0.24 (−0.56, 0.08)	0.006	0.143
	Girls (205)	−0.05 (−0.31, 0.21)	−0.004	0.690
Exposure: change in MVPA, % time				
Change in fat mass index	Entire (377)	−91.85 (−141.75, −41.94)	0.031	<0.001
	Boys (186)	−123.76 (−192.04, −55.48)	0.060	<0.001
	Girls (191)	−47.00 (−119.46, 24.47)	0.009	0.202
Change in BMI *Z*-score	Entire (403)	−14.10 (−32.92, 4.73)	0.003	0.142
	Boys (198)	−31.88 (−59.50, −4.26)	0.021	0.024
	Girls (205)	1.34 (−24.65, 27.32)	−0.005	0.919
Exposure: change in sedentary behavior, % time				
Change in fat mass index	Entire (377)	37.41 (15.64, 59.17)	0.027	0.001
	Boys (186)	40.40 (10.87, 69.93)	0.033	0.008
	Girls (191)	31.41 (−0.28, 63.09)	0.015	0.052
Change in BMI *Z*-score	Entire (403)	1.92 (−6.16, 9.99)	−0.002	0.640
	Boys (198)	0.80 (−10.70, 0.21)	−0.005	0.891
	Girls (205)	3.29 (−8.17, 14.75)	−0.003	0.572

MVPA, moderate- to vigorous-intensity physical activity

findings support the hypothesis that physical activity has a greater influence on adiposity in boys than girls. The findings also support the hypothesis that measurement of body composition as an outcome, rather than anthropometric proxies for body composition, may provide increased sensitivity to detect associations in etiologic studies.[4]

Comparisons with Other Studies

Systematic reviews concluded that higher levels of objectively measured physical activity were associated with lower levels of body fatness in children and adolescents,[4] and that higher levels of sedentary behavior were associated with higher levels of body fatness,[5] but most studies included in the reviews were cross-sectional. More-recent evidence from studies using objective measures of physical activity is supportive of the conclusion that higher levels of physical activity are associated with lower adiposity,[7,8,12,13] but the evidence is not entirely consistent.[10]

Knowing whether sedentary behavior and physical activity associations with fatness are independent of each other is an important issue that could inform obesity prevention strategies, yet as far as we are aware, only two studies have addressed this issue. Both Steele et al.,[13] in a cross-sectional study of English children aged 10 years, and Mitchell et al., in a longitudinal study of English children aged 11–13 years,[30] found that associations of objectively measured sedentary behavior with adiposity were not significant after adjustment for MVPA. The findings of the present study are consistent with this result, suggesting a degree of commonality in the etiology of obesity at different ages,[31] or at different periods (the ALSPAC cohort study began 8–10 years before the present GMS cohort study).

Knowing whether total volume of physical activity or MVPA is most important to adiposity development is another issue that could inform obesity prevention strategies. The present study was consistent with recent studies of English adolescents in the ALSPAC cohort[7,32] in

Table 3. Multivariable analysis with physical activity as the exposure*: changes in MVPA, FMI, and BMI *Z*-score (β coefficient $\times 10^3$)

Outcome measure	Sample (*n*)	β coefficient (95% CI)	Adjusted R^2	*p*
Change in FMI	Entire (377)	−81.26 (−130.45, −32.06)	0.071	0.001
	Boys (186)	−121.07 (−186.57, −55.57)	0.135	<0.001
	Girls (191)	−45.50 (−118.18, 27.18)	0.007	0.218
With addition of sedentary behavior[a]	Entire (377)	−52.11 (−114.85, 10.64)	0.074	0.103
	Boys (186)	−112.90 (−201.07, −24.74)	0.131	0.012
Change in BMI *Z*-score	Entire (403)	−17.52 (−36.14, 1.08)	0.040	0.065
	Boys (198)	−34.80 (−61.84, −7.75)	0.065	0.012
	Girls (205)	−1.39 (−27.11, 24.32)	0.023	0.915

[a]Data for girls were not significant in the simpler model and so were not entered into the final model.
*With adjustment for baseline variables, SES, gender, and inclusion of explanatory variables significant in univariable analysis at $p<0.10$
FMI, fat mass index; MVPA, moderate- to vigorous-intensity physical activity

suggesting that MVPA has a greater influence on adiposity than total volume of physical activity.

A recent systematic review concluded that physical activity was associated more consistently with adiposity in boys than girls,[4] and the present study was consistent with this finding. It is not clear why adiposity development might be more sensitive to variation in physical activity in boys than in girls, but it is possible that influences on the energy-intake side of the energy-balance equation may be more important in girls than boys. In the present study, as in previous studies,[4] level of MVPA was significantly higher in boys than girls, but the between-gender difference was small, and it is not clear that it would explain the findings of the present study: mean time spent in MVPA was higher in boys than girls by only approximately 4 minutes/day at age 7 years and 7 minutes/day at age 9 years. In addition, the numbers of boys and girls in the present study were similar and 2-year changes in sedentary behavior and physical activity were actually more marked in girls than boys.[14]

Study Strengths and Weaknesses

The principal strengths of the present study were the longitudinal design, the inclusion of change measurements in both the exposure and outcome measures, the fact that the study sample was socioeconomically representative of England,[18] the use of objective measurement of all key constructs of physical activity and sedentary behavior simultaneously, and the availability of a body composition outcome variable in addition to a simple proxy for body composition. The body composition measure used has been validated in adolescents, but its validity has not been confirmed in children aged 7–9 years.[29] No data on maturational status were available in the present study: the importance of having such data for those aged 7–9 years is unclear.

The weight of evidence as summarized by systematic reviews[4,5] suggests that physical activity and sedentary behavior influence adiposity. Thus, the present study considered physical activity and sedentary behavior as the exposures and adiposity as the outcome. It is possible that increasing adiposity may reduce physical activity and increase sedentary behavior, although this is perhaps more likely when adiposity is extremely high or has increased markedly.[6,13,33]

The present study was able to ensure that follow-up measures occurred 24 months after initial measures, but there was no control over weather variables and no

Table 4. Multivariable analyses with sedentary behavior as the exposure*: changes in sedentary behavior and changes in FMI (β coefficient $\times 10^3$)

Outcome measure	Sample	β coefficient (95% CI)	Adjusted R^2	*p*
Change in FMI[a]	Entire (377)	34.34 (13.02, 55.67)	0.070	0.002
	Boys (186)	37.39 (8.95, 65.83)	0.105	0.009
With addition of MVPA	Entire (377)	20.30 (−6.89, 47.48)	0.074	0.143
	Boys (186)	5.23 (−32.41, 42.86)	0.131	0.784
	Girls (191)	30.96 (−0.79, 62.71)	0.012	0.056

[a]Data for girls were not significant in the simpler model and so were not entered into the final model.
*With adjustment for baseline variables, SES, gender, and inclusion of variables significant in univariable analysis at $p<0.10$
FMI, fat mass index; MVPA, moderate- to vigorous-intensity physical activity

weather data were available. Some other studies have required longer periods of accelerometry and/or the inclusion of a weekend day, but with data on those aged 7 years from the cohort, any 3 days of accelerometry with at least 6 hours per day provided adequate reliability of all constructs of physical activity and sedentary time,[25] and actual accelerometry wear time was much higher than the minimum wear time specified. In an ongoing study of those aged 12 years in the region, no differences were found in objectively measured physical activity or sedentary behavior associated with wear time.

In the present study, sedentary behavior was measured using Actigraph accelerometry with a cut-point of 1100 cpm, which has been calibrated and validated as a measure of time spent sitting, lying down, and standing with the trunk not moving.[23] Lower Actigraph cut-points probably provide a more specific measure of sitting.[34] Other aspects of sedentary behavior that were not measured also may be important to the etiology of childhood obesity, notably TV viewing/screen time.[35,36] In the present study, the overall measure of sedentary behavior would have included screen time, but screen time cannot be quantified separately using accelerometry.

Conclusion

The present study suggests that MVPA is the construct of physical activity most likely to be valuable as a behavioral target of obesity prevention interventions. It is possible that the influence of physical activity on energy balance in mid–late childhood is greater in boys than girls. Translating these findings into future public health strategies aimed at childhood obesity prevention may involve a greater emphasis on MVPA as a specific behavioral target (rather than just total volume of physical activity), and possibly a greater "tailoring" of childhood obesity prevention strategies by gender.

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