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Abstract 200 words

Background: Previous studies have reported on the associations between obesity and sedentary behavior (SB) or physical activity (PA) for children. The present study examined longitudinal and bidirectional associations between adiposity and SB and PA in children. **Methods:** Participants were 356 children in England. PA was measured at age 7 and 9 years using accelerometry. Outcome and exposures were time in SB and PAs and concurrent body mass index (BMI) Z-score and fat index (FI). **Results:** Adiposity at baseline was positively associated with change in SB (β =0.975, for FI) and negatively associated with changes in moderate-to-vigorous PA (MVPA) (β =-0.285 for BMI Z-score, β =-0.607 for FI), vigorous PA (VPA) (β = -0.095 for FI) and total PA (β =-48.675 for FI), but not vice versa. The changes in SB, MVPA and total PA for children with overweight/obesity were significantly more adverse than those of healthy weight children. **Conclusions:** A high BMI Z-score or high body fatness at baseline was associated with lower MVPA and VPA after 2 years, but not vice versa, which suggests that in this cohort adiposity influenced PA and SB, but the associations between adiposity and SB or PA were not bidirectional.

Introduction

Childhood obesity is a widespread health and social problem which is still increasing in prevalence in many countries.[1] A previous review of prospective studies concluded that low levels of baseline physical activity (PA) were only weakly or not at all associated with body fat gain.[2] More recent reviews also suggest that the influence of changes in objectively measured sedentary behavior (SB) on change in adiposity in children and adolescents was unclear.[3-5]

Only a few previous longitudinal studies have reported on the associations between obesity as a predictor and SB or PA as an outcome by using an accelerometer as an objective measure of habitual physical activity and sedentary behavior for children and adolescents,[6-10] and these studies did not examine bidirectional associations. We have identified only four prospective studies that examined bidirectional associations between adiposity and objectively measured SB and/or PA in children and adolescents.[11-14] In two studies in children, increased adiposity or adiposity at baseline was negatively associated with change in moderate-vigorous PA (MVPA) but not vice versa.[12,14] On the other hand, one prospective study of preschool children demonstrated that adiposity did not influence change in total PA, MPA and VPA.[11] Moreover, one prospective study of adolescents showed that adiposity did not influence MVPA level or adiposity later in life.[13] One prospective study of adults also demonstrated that obesity as a predictor was negatively associated with subjective PA level later in life,[15] but that PA level did not influence fatness. Moreover, in regard to sedentary behavior, the other prospective adult cohort study showed that fatness led to objectively measured sedentary behavior but that sedentary behavior did not lead to fatness.[16] However, a number of recent childhood studies have found that reductions in objectively measured PA are associated with increased adiposity,[17,18] but did not examine bidirectional associations. It is possible that the associations between obesity and SB or PA may be bidirectional, and that increased adiposity may increase SB and/or decrease PA in children and adolescents.[19]

With an evidence base limited apparently to just four studies of bidirectionality in children and adolescents, one of which followed up for only 200 days,[14] and the others which simply considered baseline adiposity or PA and SB,[11-13] the reverse causation or 'bidirectionality hypothesis' needs to be tested by new evidence. Thus, the main aim of the present study was to examine the longitudinal bidirectional associations between adiposity and daily SB and PA, measured objectively, in childhood.

Materials and Methods

The Gateshead Millennium Study (GMS) is an observational cohort study which has been described in detail elsewhere.[20,21] The sample was socioeconomically representative of northeast England at the first SB and PA data collection in 2006/2007.[20] Baseline measures of PA and SB for the present study were collected between October 2006 and December 2007 when the children were aged 6–7 years, and follow-up data were collected 2 years later. Children aged 6–7 years (n=510 at baseline) were included in the study. The study was approved by the Gateshead and South Tyneside LREC (6-7y) and Newcastle University Ethics Committee (9y). Informed written consent was obtained from the parent/main caregiver of each child, and children provided assent to their participation.

Objective measurement of sedentary behavior and physical activity

Overall SB and PA were measured with the Actigraph GT1M accelerometer as described previously.[21] The Actigraph has high validity, high reliability, and low reactivity in children.[22] In UK children, there are small but significant seasonal variations in objectively measured PA,[23,24] and so baseline and follow-up measurements were made during the same season. Children in the present study were asked to wear an accelerometer during waking hours for 7 days. Accelerometers were attached to an elastic belt and worn on the hip. Accelerometer counts were collected in 15 second intervals (epochs). Data were reduced manually, by juxtaposing accelerometry output and log-sheets in order to delete occasional periods of nonwear time.[22,24] Children were only included if they recorded complete wear time diaries. Non-wear time and sleep data were removed manually based on the wear time diaries and visual inspection by a trained researcher. It was decided not to define non-wear time using consecutive zeros as previous research has shown this affects the outcomes significantly especially in longitudinal studies where changes in their behavioral patterns are very likely.[25] In this cohort, 3 days of accelerometry with a minimum of 6 hours recording per day provides acceptable reliability,[26] 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, but in practice the actual accelerometry monitoring periods were typically much longer than these minimum values and are reported below.

Five constructs were measured: SB (expressed as minutes/day and %); light PA (LPA) (expressed minutes/day and %); moderate PA (MPA) (expressed as minutes/day and %), MVPA (expressed as minutes/day and %); total volume of physical activity (TPA, expressed as counts per minute; cpm). Evidence-based "cutoff points" were used to measure SB and the intensity of PA : <25 counts per 15 seconds to quantify SB;[28,29] 25-799 counts per 15 seconds to quantify LPA;[27,28] 800-2049 counts per 15 seconds or more to quantify MPA;[28] 2050 counts per 15 seconds or more to quantify vigorous PA.[28] MVPA was calculated as a sum of MPA and vigorous PA.

Anthropometric measurements

Height was measured to 0.1 cm with a Leicester Portable height measure and weight measured to 0.1 kg in light indoor clothing. Body mass index (BMI=weight [kg]/height $[m]^2$) was calculated for each child and Z-scores expressed relative to UK 1990 population reference data.[31] Definitions of obesity as a BMI of more than the 95th centile (z score > 1.645) and overweight as a BMI greater than the 85th centile (z score >1.036) compared to 1990 BMI UK reference data were used. Body fat was estimated with a TANITA TBF 300MA. Fat mass was estimated from TANITA bioelectric impedance (TBF-300MA) by applying constants for the hydration of fat-free mass having first estimated total body water using validated sex and age-specific prediction equations.[32, 33] Then fatness was estimated from total body water using sex- and age-specific prediction equations from Haroun et al. [33] Fat index (FI) was calculated as a Z score relative to age and sex specific reference data from the UK ALSPAC (Avon Longitudinal Study of Parents and Children) cohort (born in 1991/92), as described in Wright et al..[34]

Statistical analysis

Descriptive characteristics of the study sample were presented as a mean and standard deviation (SD).

Change variables were calculated as follow-up values minus baseline values. An independent samples t-test was used to compare between boys and girls. There were no significant interactions between gender and variation of each variable. Partial correlations were analyzed between BMI Z-score and FI, changes in BMI Z-score and changes in FI, SB and each PA intensity at baseline and changes in SB and each PA intensity while adjusting for gender.

The associations between change of BMI Z-score or FI and SB or each PA variable at baseline variables were analyzed by analysis of covariance (ANCOVA) adjusted for gender and BMI Z-score or FI at baseline. Moreover, if the association was found to be significantly associated with SB or MVPA or MPA variable, extra analysis was conducted adjusting for the other variable (MVPA or SB). The associations between change of SB or each PA variable and BMI Z-score or FI at baseline variables were analyzed by ANCOVA adjusted for sex and SB or each PA variable at baseline. Moreover, the associations between change in BMI Z-score or FI and change in SB or each PA variable were analyzed using ANCOVA adjusted for gender and BMI Z-score or FI at baseline and SB or each PA variable at baseline. The associations between weight status at baseline (children with overweight/obesity versus healthy weight children) and change of SB or PA were analyzed by ANCOVA, adjusted for sex and the SB or each PA variable at baseline. Moreover, if weight status was found to be significantly associated with SB or each PA variable extra analysis was conducted adjusting for SB or MVPA. Analyses were performed with the entire sample and for boys and girls separately, because our previous study found a possible gender difference in the relationship between SB or MVPA on adiposity in childhood using the longitudinal GMS data.[17] Statistical analysis was performed with IBM SPSS statistics 20.0 for Windows (IBM Co., Tokyo, Japan). All statistical tests were regarded as significant when p-values were less than 0.05.

Results

Due to missing data (no consent to take part/unable to trace for follow-up measures [n=55], no accelerometer data at follow-up [n=59], no height/weight data at follow-up [n=4] and no body composition data at follow-up [n=36]), our longitudinal sample for the present study comprised data from 356 children.

Characteristics of study participants

The characteristics of study participants are presented in Table 1. Ninety (25%) of the sample was categorized as having overweight/obesity at baseline. The duration of accelerometry was much greater than the minimum criteria specified (at least 3 days and 6 hours), with an average of 6.4 days and 11.2 hours at baseline and 6.1 days and 11.4 hours at follow-up, respectively. Boys had lower SB and VPA and higher MVPA, MPA and TPA (only at follow-up) than girls at each time point. The partial correlations between baseline values of BMI Z-score and FI and change in BMI Z-score and FI were $r=0.705$ ($p<0.001$) and $r=0.603$ ($p<0.001$), respectively.

The partial correlations at baseline and the change between SB (%) and LPA (%) were strong ($r=-0.937$ and $r=-0.939$, respectively; $p<0.001$). However, the relationship between absolute SB (min/day) and LPA (min/day) was weak at baseline ($r=-0.217$, $p<0.001$) and the relationship between the change in SB and LPA was not significantly correlated ($r=-0.053$, $p=0.318$). The partial correlations between SB (% or min/day) and MVPA (%), MPA (%) or TPA (cpm) were moderate. The partial correlation between SB (%) and VPA (%) was weak. The details of partial correlations are shown in the Supplementary Table1.

Baseline adiposity as a predictor of change in sedentary behavior, physical activity, and vice versa

Changes in BMI Z-score or FI were not associated with SB or the different intensities of PA at baseline. On the other hand, changes in MVPA (min/day and %), MPA (min/day and %) were associated with both BMI Z-score and FI at baseline (Table 2a). The change in SB (%), VPA (min/day and %) and TPA (cpm) were also associated with FI at baseline. These associations remained after adjusting for change in MVPA (%) or SB (min/day, %) as covariates. The change in LPA was not associated with both BMI Z-score and FI at baseline.

For boys, the changes in MVPA (min/day and %) and MPA (min/day and %) were associated with BMI Z-score and FI at baseline (Table 2b). The change in SB (%) and TPA (cpm) were also associated with FI at baseline. On the other hand, for girls, the associations were only significant between FI at baseline and changes in MVPA (min/day and %), MPA (min/day and %) and VPA (min/day and %) (Table 2c). All these significant associations remained significant after addition of MVPA (%) or SB (min/day and %) as the further covariates in both genders. On the other hand, changes in BMI Z-score or FI were not associated with SB or the different intensities of PA at baseline in both genders.

The results of associations between change in adiposity and change in SB or PA are shown in the Supplementary Table 2a, Table 2b and Table 2c. Change in FI was negatively associated with change in MVPA and MPA in both genders.

Influence of baseline overweight and obesity on changes in sedentary behavior and physical activity

Children with overweight/obesity at baseline had a significantly bigger increase in SB (%; p=0.022) and significantly bigger reductions in MVPA (min/day; p=0.001, %; p<0.001), MPA (min/day; p=0.002, %; p=0.001) and TPA (cpm; p=0.002) than those of healthy weight children, with all associations remaining significant after adjusting for change in MVPA (%) or SB (min/day, %) as covariates. The table is shown in the Supplementary Table 3a.

For boys, children with overweight/obesity at baseline had a significantly bigger increase in SB (%; p=0.043) and a significantly bigger reduction in MVPA (min/day; p=0.004, %; p=0.001), MPA (min/day; p=0.004, %; p=0.001) and TPA (cpm; p=0.009) than those of normal weight children. All of these associations remained significant after adjusting for change in MVPA (%) and SB (min/day or %). However, there were no significant differences in SB or PA between weight status categories for girls. The tables are shown in the Supplementary Table 3b and Table 3c.

Discussion

This study examined whether adiposity was associated with subsequent SB or PA level in childhood and vice versa. To our knowledge, no previous study has addressed both habitual SB and the different intensities of PA in the 'bidirectionality hypothesis' in children. Previously, we reported the unidirectional associations between of accelerometer-measured SB or MVPA on adiposity in childhood using longitudinal GMS data.[17,21] Using the same cohort study, we herein examined the bidirectional associations between baseline and subsequent changes of adiposity and habitual SB or the different intensities of PA during childhood. Adiposity at baseline was associated with subsequent changes in SB (%) or PA, independent of changes in MVPA or SB, but not vice versa. Moreover, higher baseline adiposity predicted greater increases in SB and declines in PA.

We identified only four prospective studies that examined bidirectional associations between adiposity and objectively measured SB and/or PA in children and adolescents.[12,14] Hjorth et al.[14] demonstrated that changes over time in MVPA were negatively associated with changes in adiposity. However, none of the movement behaviors (SB, MVPA and total PA) at baseline predicted changes in adiposity, but higher adiposity at baseline predicted a decrease in MVPA and total PA, and an increase in sedentary time.[14] Metcalf et al.[12] reported that there were no significant associations between baseline total PA and subsequent change in adiposity, yet for the reverse analysis, baseline adiposity versus changes in total PA from age 7 to 8 years and 9 to 10 years were found to be significantly associated. In addition, adiposity at baseline predicted change in MVPA from 7 to 10 years, but MVPA at 7 years did not predict change in adiposity from 7 to 10 years.[12] On the other hand, Burgi et al.[11] demonstrated that adiposity or total PA, MPA and VPA as a predictor did not influence change in total PA, MPA and VPA level in age 4-6 year children. Moreover, Hallal et al. [13] reported that adiposity at 11.3 years or MVPA at 13.3 years as a predictor did not influence MVPA level at 13.3 years or adiposity at 14.7 years. The present study findings are consistent with the two studies in primary school children on the relation between adiposity and MVPA at baseline or change in MVPA that respects the temporal sequence of possible cause and effect.[12,14]

Two previous studies in children or adolescents reported significant associations between adiposity at baseline and MVPA at follow-up, or the change on total PA.[7,8] However, six previous studies among children and adolescents reported no associations between adiposity at baseline and change in SB, MVPA, MPA and VPA, or MVPA and total PA at follow-up.[6, 7, 9, 10, 11, 13] Potential confounding factors may partially explain the inconsistency across studies. Some previous studies did not take into account LPA or SB, which were found to be significant confounding factors in the present study. Moreover, it may be inappropriate to directly compare results across studies, even where studies have used the same hardware and software, because of the use of different of accelerometer cut points and decisions about issues such as epoch length and non-wear time for the assessment of habitual SB or PA. However, in the current study and our previous studies in this cohort the use of two distinct SB accelerometer cut-points (>100 cpm/min vs >1100 cpm/min) and epoch length (15 sec vs 60 sec) and this did not influence the association between SB and adiposity.[17,21]

In the present study, the percentages of MVPA, MPA and total PA (only at follow-up) were significantly higher in boys than girls, and the percentages of time in SB and VPA were significantly lower in boys than girls. However, the differences between the sexes were small, and it is not clear if these small differences could explain the different associations between adiposity and SB or PA between boys and girls found in the present study. In addition, the numbers of boys and girls in the present study were similar and 2-year changes in SB and PA were actually more marked in girls than boys.[21,35] We compared coefficient of variation for SB and PA in boys versus girls. In general, CV values were comparable between boys and girls. A systematic review concluded that PA was associated more consistently with adiposity in boys than girls, and the present study was consistent with this finding.[36] It is not clear why adiposity might be more sensitive to variation in SB (%) and total PA 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. One additional possible reason might be the gender difference in the level of maturation.[37]

In the present study higher baseline adiposity, and overweight/obesity at baseline, predicted a greater increase in SB (%) and decline in PA (most marked for MVPA). This indicates that children who are overweight and obese at age 7 may be a high risk group for becoming inactive and may benefit from PA interventions more than those who are of normal weight. The present study supports Kwon's study showing that the odds of being in the lowest quartile relative to the highest quartile of intensity-weighted MVPA at age 11 for boys and girls with high BF% at age 8 were approximately four times higher than the odds for those with low BF% at age 8.[8] Weight status-specific intervention strategies for PA promotion or SB reduction may be important in boys. Furthermore, our recent review showed that school-aged boys spent more time in sedentary behavior compared to adolescent boys.[5] However, time spent in SB was similar for school-aged and adolescent girls.[5] Therefore, if further studies support the findings of the present study, future intervention studies aiming to decrease SB should possibly focus on primary (elementary) school-aged boys with overweight/obesity.

There were several limitations to the present study. Sleep is an important predictor of overweight and obesity.[38] However, the present study focused on habitual SB or PA in waking time only, and so any influence of adiposity on sleep cannot be considered by the present study. Moreover, although adiposity may impact PA levels by influencing cognition such as the intention to be active and perceived behavioral control over factors which influence PA,[39,40] those potentially mediating variables, and indeed other mediators, were not assessed in the present study. Moreover, total sedentary time is not the same as breaks in sedentary time (e.g. number of breaks in sedentary time)[41], and this is another limitation of the present study. Nonetheless, to our knowledge, this study is the first prospective cohort study in a fairly large childhood sample to explicitly examine the bidirectionality hypothesis. The use of objective and accurate measures for both SB and PA and adiposity helped reduce measurement error. Future studies should prospectively examine the bidirectional association between adiposity and patterns of SB to obtain more evidence on this important issue.

In conclusion, the present study suggested that the children with lowest adiposity at baseline showed smallest declines in PA at two-year follow-up than those with highest adiposity at baseline, but not vice versa. The present study also suggests that adiposity might be particularly influential on MVPA, and that it also influences time spent sedentary, a behavioral risk factor which increases across childhood and adolescence.[5] Regarding future research, more evidence should be accumulated to test the reverse causation hypothesis in childhood and adolescence, and in different populations.

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References

1) World Health Organization. Obesity and overweight. 2013. Available at http://www.who.int/mediacentre/factsheets/fs311/en/
2) Wilks DC, Besson H, Lindroos AK, Ekelund U. Objectively measured physical activity and obesity prevention in children, adolescents and adults: a systematic review of prospective studies. *Obes Rev* 2011;12:e119-e29.
3) Mitchell JA, Byun W. Sedentary Behavior and Health Outcomes in Children and Adolescents. *Am J Lifestyle Med* 2013;13:1-27.
4) Ekelund U, Hildebrand M, Collings PJ. Physical activity, sedentary time and adiposity during the first two decades of life. *Proc Nutr Soc* 2014;73:319-329.
5) Tanaka C, Reilly JJ, Huang WY. Longitudinal changes in objectively measured sedentary behavior and their relationship with adiposity in children and adolescents: systematic review and evidence appraisal. Obesity Reviews *Obes Rev* 2014; 15:791-803.
6) Sallis JF, Alcaraz JE, McKenzie TL, Hovell MF. Predictors of change in children's physical activity over 20 months. Variations by gender and level of adiposity. *Am J Prev Med* 1999; 16:222–229.
7) Corder K, van Sluijs EM, Ekelund U, Jones AP, Griffin SJ. Changes in children's physical activity over 12 months: longitudinal results from the SPEEDY study. *Pediatrics* 2010;126:e926-e935.
8) Kwon S, Janz KF, Burns TL, Levy SM. Effects of adiposity on physical activity in childhood: Iowa Bone Development Study. *Med Sci Sports Exerc* 2011;43:443-448.
9) Hallal PC, Dumith SC, Ekelund U, et al. Infancy and childhood growth and physical activity in adolescence: prospective birth cohort study from Brazil. *Int J Behav Nutr Phys Act* 2012;9:82.
10) Cumming SP, Sherar LB, Esliger DW, Riddoch CJ, Malina RM. Concurrent and prospective associations among biological maturation, and physical activity at 11 and 13 years of age. *Scand J Med Sci Sports* 2014;24:e20-e28.

11) Bürgi F, Meyer U, Granacher U, et al. Relationship of physical activity with motor skills, aerobic fitness and body fat in preschool children: a cross-sectional and longitudinal study (Ballabeina). *Int J Obes (Lond)* 2011;35, 937–944.

12) Metcalf BS, Hosking J, Jeffery AN, Voss LD, Henley W, Wilkin TJ. Fatness leads to inactivity, but inactivity does not lead to fatness: a longitudinal study in children (EarlyBird 45). *Arch Dis Child* 2011;96:942-947.

13) Hallal PC, Reichert FF, Ekelund U, et al. Bidirectional cross-sectional and prospective associations between physical activity and body composition in adolescence: birth cohort study. *J Sports Sci* 2012;30:183-190.

14) Hjorth MF, Chaput JP, Ritz C, Dalskov SM, et al. Fatness predicts decreased physical activity and increased sedentary time, but not vice versa: support from a longitudinal study in 8- to 11-year-old children. *Int J Obes (Lond)* 2014;38:959-965.

15) Petersen L, Schnohr P, Sørensen TI. Longitudinal study of the long-term relation between physical activity and obesity in adults. *Int J Obes Relat Metab Disord* 2004;28:105-112.

16) Ekelund U, Brage S, Besson H, Sharp S, Wareham NJ. Time spent being sedentary and weight gain in healthy adults: reverse or bidirectional causality? *Am J Clin Nutr* 2008;88:612-617.

17) Basterfield L, Pearce MS, Adamson AJ, et al. Physical activity, sedentary behavior, and adiposity in English children. *Am J Prev Med* 2012;42:445-451.

18) Mitchell JA, Pate RR, España-Romero V, O'Neill JR, Dowda M, Nader PR. Moderate-to-vigorous physical activity is associated with decreases in body mass index from ages 9 to 15 years. *Obesity (Silver Spring)* 2013;21:E280-E293.

19) Bauman AE, Reis RS, Sallis JF, et al. Correlates of physical activity: why are some people physically active and others not? *Lancet* 2012; 380:258-271.

20) Parkinson KN, Pearce MS, Dale A, et al. Cohort profile: the Gateshead Millennium Study. *Int J Epidemiol* 2010;40:308 -317.

21) Basterfield L, Adamson AJ, Frary JK, et al. Longitudinal study of physical activity and sedentary behavior in children. *Pediatrics* 2011;127:e24-e30.

22) Reilly JJ, Penpraze V, Hislop J, Davies G, Grant S, Paton JY. Objective measurement of physical activity and sedentary behaviour: review with new data. *Arch Dis Child* 2008;93:614 -619.

23) Fisher A, Reilly JJ, Montgomery C, et al. Seasonality in physical activity and sedentary behavior in young children. Pediatr Exerc Sci 2005;17:31-40.

24) Mattocks C, Leary S, Ness A, et al. Intraindividual variation of objectively measured physical activity in children. *Med Sci Sports Exerc* 2007;39:622-629.

25) Janssen X, Basterfield L, Parkinson KN, et al. Objective measurement of sedentary behavior: impact of non-wear time rules on changes in sedentary time. *BMC public health* 2015;15:504.

26) Basterfield L, Adamson AJ, Pearce MS, Reilly JJ. Stability of habitual physical activity and sedentary behavior monitoring by accelerometry in 6-8 year olds. *J Phys Act Health* 2011;**8**:543-547.

27) Evenson KR, Catellier DJ, Gill K, Ondrak KS, McMurray RG. Calibration of two objective measures of physical activity for children. *J Sports Sci* 2008;26:1557-1565.

28) Trost SG, Loprinzi PD, Moore R, Pfeiffer KA. Comparison of accelerometer cut points for predicting activity intensity in youth. *Med Sci Sports Exerc* 2011;43:1360-1368.

29) Matthews CE, Chen KY, Freedson PS, et al. Amount of time spent in sedentary behaviors in the United States, 2003-2004. *Am J Epidemiol* 2008;167:875-881.

30) Puyau MR, Adolph AL, Vohra FA, Butte NF. Validation and calibration of physical activity monitors in children. *Obes Res* 2002;10:150 -157.

31) Cole TJ, Freeman JV, Preece MA. Body mass index reference curves for the UK, 1990. Arch Dis Child. 1995;73:25-29.

32) Lohman T. Assessment of body composition in children. *Pediatr Exerc Sci* 1989;1:19 -30.

33) Haroun D, Taylor SJ, Viner RM, et al. Validation of bioelectrical impedance analysis in adolescents across different ethnic groups. *Obesity (Silver Spring)* 2010;18:1252-1259.

34) Wright CM, Sherriff A, Ward SC, McColl JH, Reilly JJ, Ness AR. Development of bioelectrical

impedance-derived indices of fat and fat-free mass for assessment of nutritional status in childhood. *Eur J Clin Nutr* 2008;62:210-217.

35) Pearce MS, Basterfield L, Mann KD, et al. Gateshead Millennium Study Core Team. Early predictors of objectively measured physical activity and sedentary behaviour in 8-10 year old children: the Gateshead Millennium Study. *PLoS One* 2012;7:e37975.

36) Jiménez-Pavón D, Kelly J, Reilly JJ. Associations between objectively measured habitual physical activity and adiposity in children and adolescents: Systematic review. *Int J Pediatr Obes* 2010;5:3-18.

37) Malina RM, Bouchard C, Bar-Or O. (eds.) Growth, maturation, and physical activity. 2nd edn. Human Kinetics, Champaign, IL, 2004.

38) Carter PJ, Taylor BJ, Williams SM, Taylor RW. Longitudinal analysis of sleep in relation to BMI and body fat in children: the FLAME study. *BMJ* 2011;342:d2712.

39) Godin G, Bélanger-Gravel A, Nolin B. Mechanism by which BMI influences leisure-time physical activity behavior. *Obesity (Silver Spring)* 2008;16:1314-1317.

40) Uijtdewilligen L, Nauta J, Singh AS, et al. Determinants of physical activity and sedentary behaviour in young people: a review and quality synthesis of prospective studies. *Br J Sports Med* 2011:45:896-905.

41) Dunstan DW, Healy GN, Sugiyama T, Owen N. Too Much Sitting and Metabolic Risk—Has Modern Technology Caught Up with Us? *European Endocrinology* 2010;6:19-23.

Table 1 Physical characteristics and sedentary behavior and physical activity for participants at baseline and follow-up

	All (n=356)		Boys (n=174)		Girls (n=182)	
	Baseline	Follow-up	Baseline	Follow-up	Baseline	Follow-up
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Age (years)	7.5 (0.4)	9.3 (0.4)	7.4 (0.4)	9.3 (0.4)	7.5 (0.4)	9.3 (0.4)
Height (cm)	124.9 (5.7)	135.7 (6.2)	125.2 (6.0)	135.9 (6.5)	124.6 (5.4)	135.4 (6.0)
Body weight (kg)	26.3 (5.2)	33.5 (7.2)	26.4 (5.3)	33.2 (7.2)	26.3 (5.1)	33.6 (7.2)
BMI (kg/m^2)	16.7 (2.2)	18.0 (2.8)	16.7 (2.3)	17.9 (2.8)	16.8 (2.2)	18.2 (2.7)
BMI_Z score	0.40 (1.07)	0.58 (1.07)	0.44 (1.13)	0.61 (1.13)	0.36 (1.01)	0.53 (1.03)
Fat index	0.46 (0.71)	0.55 (0.81)	0.52 (0.73)	0.54 (0.83)	0.40 (0.69)	0.56 (0.80)
Obese (n)	46	59	19	26	19	26
Overweight (n)	44	60	27	34	27	34
Normal weight (n)	266	237	136	122	136	122
Wearing time (min/day)	669 (68)	681(69)	675 (68)	683 (70)	664 (66)	680 (69)
Valid days (days)	6.4 (1.0)	6.1 (1.1)	6.4 (0.9)	6.1 (1.1)	6.3 (1.0)	6.1 (1.1)
CPM	758.0 (225.4)	676.8 (207.6)	774.3 (225.2)	712.6 (189.9)	742.4 (225.1)	642.6 (218.2)
Sedentary behavior (min/day)	337.8 (56.3)	377.4 (60.5)	334.4 (57.8)	369.3 (59.0)	341.1 (54.7)	385.1 (61.1)
Light physical activity (min/day)	290.3 (49.2)	266.0 (47.5)	295.5 (50.4)	270.2 (50.8)	285.4 (47.6)	262.0 (44.0)
MVPA (min/day)	41.0 (17.0)	37.9 (17.4)	45.1 (18.6)	43.5 (18.3)	37.0 (14.3)	32.4 (14.5)
Moderate physical activity (min/day)	38.0 (15.4)	35.2 (16.2)	42.9 (16.9)	41.4 (17.4)	33.3 (12.2)	29.2 (12.3)
Vigorous physical activity (min/day)	3.0 (4.3)	2.7 (3.9)	2.2 (3.8)	2.1 (3.0)	3.7 (4.7)	3.2 (4.5)
Sedentary behavior (%)	50.5 (6.9)	55.4 (6.9)	49.6 (7.2)	54.1 (7.0)	51.4 (6.4)	56.6 (6.6)
Light physical activity (%)	43.4 (5.8)	39.0 (5.8)	43.7 (6.0)	39.5 (6.0)	43.0 (5.5)	38.6 (5.7)
MVPA (%)	6.1 (2.5)	5.5 (2.4)	6.7 (2.8)	6.0 (2.4)	5.6 (2.2)	4.8 (2.0)
Moderate physical activity (%)	5.7 (2.3)	5.1 (2.3)	6.4 (2.5)	6.0 (2.4)	5.0 (1.8)	4.3 (1.7)
Vigorous physical activity (%)	0.4 (0.7)	0.4 (0.6)	0.3 (0.6)	0.3 (0.4)	0.6 (0.7)	0.5 (0.6)

BMI: body mass index, MVPA: moderate-to-vigorous physical activity.

Table 2a Baseline sedentary behavior and physical activity as predictors of change in adiposity and vice versa

	Outcome: ΔBMI Z-score				Outcome: Δfat index					Exposure: BMI Z-score at baseline				Exposure: fat index at baseline			
	β-Coefficient	95% CI		p value	β-Coefficient	95% CI		p value		β-Coefficient	95% CI		p value	β-Coefficient	95% CI		p value
Sedentary behaviour at baseline (min/day)	0.000	-0.001	0.001	0.643	0.000	-0.001	0.000	0.299	Δsedentary behaviour (min/day)	1.243	-3.936	6.422	0.637	4.602	-3.189	12.392	0.246
Light physical activity at baseline (min/day)	0.000	-0.001	0.001	0.850	0.000	-0.001	0.001	0.362	Δlight physical activity (min/day)	0.548	-3.334	4.429	0.782	-3.109	-8.949	2.730	0.296
MVPA at baseline (min/day)	-0.001	-0.004	0.002	0.368	0.000	-0.003	0.003	0.989	ΔMVPA (min/day)	-1.913	-3.214	-0.611	0.004	-4.004	-5.993	-2.014	<0.001
									ΔMVPA (min/day)*	-1.928	-3.228	-0.627	0.004	-4.051	-6.040	-2.063	<0.001
Moderate physical activity at baseline (min/day)	-0.001	-0.005	0.002	0.359	0.001	-0.003	0.004	0.766	Δmoderate physical activity (min/day)	-1.692	-2.878	-0.506	0.005	-3.334	-5.157	-1.510	<0.001
									Δmoderate physical activity (min/day)*	-1.713	-2.896	-0.530	0.005	-3.390	-5.210	-1.569	<0.001
Vigorous physical activity at baseline (min/day)	-0.002	-0.013	0.009	0.738	-0.005	-0.016	0.006	0.348	Δvigorous physical activity (min/day)	-0.179	-0.548	0.190	0.341	-0.710	-1.262	-0.158	0.012
									Δvigorous physical activity (min/day)*					-0.703	-1.256	-0.150	0.013
Total physical activity at baseline (cpm)	0.000	0.000	0.000	0.862	0.000	0.000	0.000	0.943	Δtotal physical activity (cpm)	-16.271	-33.782	1.239	0.068	-48.675	-74.950	-22.401	<0.001
Sedentary behaviour at baseline at baseline (%)	0.000	-0.006	0.007	0.936	-0.004	-0.011	0.003	0.296	Δsedentary behaviour (%)	0.201	-0.341	0.743	0.466	0.911	0.096	1.725	0.029
									Δsedentary behaviour (%)*					0.975	0.144	1.806	0.022
Light physical activity at baseline (%)	0.001	-0.007	0.009	0.866	0.005	-0.003	0.013	0.213	Δlight physical activity (%)	0.069	-0.398	0.535	0.772	-0.360	-1.061	0.340	0.312
MVPA at baseline (%)	-0.006	-0.025	0.013	0.537	0.000	-0.020	0.019	0.976	ΔMVPA (%)	-0.280	-0.463	-0.097	0.003	-0.603	-0.881	-0.326	<0.001
									ΔMVPA (%)*	-0.285	-0.469	-0.102	0.002	-0.607	-0.885	-0.330	<0.001
Moderate physical activity at baseline (%)	-0.008	-0.029	0.014	0.491	0.003	-0.020	0.026	0.795	Δmoderate physical activity (%)	-0.244	-0.410	-0.079	0.004	-0.497	-0.750	-0.244	<0.001
									Δmoderate physical activity (%)*	-0.250	-0.416	-0.083	0.003	-0.095	-0.175	-0.016	0.019
Vigorous physical activity at baseline (%)	-0.002	-0.013	0.009	0.738	-0.033	-0.104	0.037	0.354	Δvigorous physical activity (%)	-0.026	-0.079	0.027	0.329	-0.100	-0.179	-0.021	0.013
									Δvigorous physical activity (%)*					-0.095	-0.175	-0.016	0.019

BMI: body mass index, MVPA: moderate-to-vigorous physical activity, Δ : change, Δ variables were calculated as follow-up values minus baseline values, adjusted for gender, sedentary behaviour or physical activity and BMI Z-score or fat index at baseline,
*: adjusted for gender, sedentary behaviour and MVPA or moderate physical activity and BMI Z-score or fat index at baseline.

Table 2b Baseline sedentary behavior and physical activity as predictors of change in adiposity and vice versa for boys

	Outcome: ΔBMI Z-score				Outcome: Δfat index					Exposure: BMI Z-score at baseline				Exposure: fat index at baseline			
	β-Coefficient	95% CI		p value	β-Coefficient	95% CI		p value		β-Coefficient	95% CI		p value	β-Coefficient	95% CI		p value
Sedentary behaviour at baseline (min/day)	0.000	-0.001	0.002	0.519	0.000	-0.001	0.001	0.782	Δsedentary behaviour (min/day)	2.179	-4.919	9.277	0.545	8.673	-2.230	19.575	0.118
Light physical activity at baseline (min/day)	0.000	-0.002	0.001	0.473	0.000	-0.001	0.002	0.481	Δlight physical activity (min/day)	-1.956	-7.436	3.524	0.482	-5.139	-13.563	3.284	0.230
MVPA at baseline (min/day)	-0.001	-0.004	0.003	0.721	0.002	-0.002	0.005	0.394	ΔMVPA (min/day)	-2.216	-4.095	-0.338	0.021	-3.566	-6.595	-0.538	0.021
									ΔMVPA (min/day)*	-2.184	-4.051	-0.318	0.022	-3.673	-6.681	-0.666	0.017
Moderate physical activity at baseline (min/day)	-0.001	-0.005	0.003	0.652	0.002	-0.002	0.006	0.391	Δmoderate physical activity (min/day)	-2.000	-3.778	-0.223	0.028	-3.118	-5.997	-0.239	0.034
									Δmoderate physical activity (min/day)*	-1.972	-3.735	-0.209	0.029	-3.220	-6.073	-0.367	0.027
Vigorous physical activity at baseline (min/day)	0.002	-0.015	0.020	0.800	0.003	-0.013	0.019	0.720	Δvigorous physical activity (min/day)	-0.129	-0.525	0.267	0.521	-0.400	-1.011	0.210	0.197
Total physical activity at baseline (cpm)	0.000	0.000	0.000	0.760	0.000	0.000	0.000	0.593	Δtotal physical activity (cpm)	-19.405	-40.442	1.633	0.070	-44.602	-77.390	-11.814	0.008
Sedentary behaviour at baseline at baseline (%)	0.004	-0.005	0.014	0.366	-0.001	-0.010	0.008	0.819	Δsedentary behaviour (%)	0.414	-0.323	1.150	0.269	1.257	0.123	2.391	0.030
									Δsedentary behaviour (%)*					1.491	0.592	2.518	0.013
Light physical activity at baseline (%)	-0.006	-0.017	0.006	0.333	0.000	-0.010	0.010	0.967	Δlight physical activity (%)	-0.118	-0.755	0.518	0.714	-0.734	-1.709	0.241	0.139
MVPA at baseline (%)	-0.003	-0.028	0.022	0.793	0.006	-0.017	0.030	0.598	ΔMVPA (%)	-0.306	-0.572	-0.041	0.024	-0.306	-0.572	-0.041	0.024
									ΔMVPA (%)*	-0.318	-0.585	-0.052	0.020	-0.570	0.214	-2.668	0.008
Moderate physical activity at baseline (%)	-0.005	-0.033	0.022	0.706	0.007	-0.019	0.033	0.605	Δmoderate physical activity (%)	-0.269	-0.519	-0.019	0.035	-0.485	-0.883	-0.087	0.017
									Δmoderate physical activity (%)*	-0.278	-0.530	-0.027	0.030	-0.493	-0.893	-0.093	0.016
Vigorous physical activity at baseline (%)	0.021	-0.096	0.138	0.722	0.016	-0.091	0.122	0.770	Δvigorous physical activity (%)	-0.021	-0.078	0.035	0.462	-0.056	-0.143	0.031	0.209

BMI: body mass index, MVPA: moderate-to-vigorous physical activity, Δ: change, Δ variables were calculated as follow-up values minus baseline values, CI: 95% confidence interval, adjusted for sedentary behavior or physical activity and BMI Z-score or fat index at baseline, *: adjusted for sedentary behavior and MVPA or moderate physical activity and BMI Z-score or fat index at baseline.

Table 2c Baseline sedentary behavior and physical activity as predictors of change in adiposity and vice versa for girls

	Outcome: ΔBMI Z-score				Outcome: Δfat index					Exposure: BMI Z-score at baseline				Exposure: fat index at baseline			
	β-Coefficient	95% CI		p value	β-Coefficient	95% CI		p value		β-Coefficient	95% CI		p value	β-Coefficient	95% CI		p value
Sedentary behaviour at baseline (min/day)	-0.001	-0.002	0.000	0.171	-0.001	-0.002	0.000	0.098	Δsedentary behaviour (min/day)	0.455	-7.209	8.119	0.907	0.529	-10.677	11.736	0.926
Light physical activity at baseline (min/day)	0.000	-0.001	0.002	0.614	0.000	-0.001	0.002	0.534	Δlight physical activity (min/day)	3.096	-2.435	8.627	0.271	-0.830	-8.957	7.298	0.841
MVPA at baseline (min/day)	-0.002	-0.007	0.002	0.310	-0.002	-0.007	0.003	0.496	ΔMVPA (min/day)	-1.515	-3.330	0.300	0.101	-4.307	-6.935	-1.679	0.001
									ΔMVPA (min/day)*					-4.300	-6.936	-1.663	0.002
Moderate physical activity at baseline (min/day)	-0.002	-0.008	0.003	0.346	-0.001	-0.007	0.005	0.777	Δmoderate physical activity (min/day)	-1.281	-2.846	0.283	0.108	-3.396	-5.675	-1.118	0.004
									Δmoderate physical activity (min/day)*					-3.404	-5.690	-1.118	0.004
Vigorous physical activity at baseline (min/day)	-0.004	-0.018	0.009	0.518	-0.010	-0.026	0.005	0.183	Δvigorous physical activity (min/day)	-0.236	-0.877	0.406	0.470	-1.047	-1.975	-0.120	0.027
									Δvigorous physical activity (min/day)*					-1.046	-1.976	-0.116	0.028
Total physical activity at baseline (cpm)	0.000	0.000	0.000	0.952	0.000	0.000	0.000	0.661	Δtotal physical activity (cpm)	-12.267	-40.957	16.423	0.400	-52.099	-93.619	-10.579	0.014
Sedentary behaviour at baseline at baseline (%)	-0.005	-0.014	0.005	0.362	-0.007	-0.018	0.004	0.205	Δsedentary behaviour (%)	-0.052	-0.860	0.755	0.898	0.540	-0.642	1.722	0.369
Light physical activity at baseline (%)	0.008	-0.004	0.019	0.184	0.011	-0.002	0.024	0.101	Δlight physical activity (%)	0.285	-0.408	0.978	0.418	0.034	-0.981	1.050	0.947
MVPA at baseline (%)	-0.010	-0.039	0.019	0.503	-0.007	-0.040	0.026	0.674	ΔMVPA (%)	-0.237	-0.491	0.016	0.067	-0.628	-0.995	-0.261	0.001
									ΔMVPA (%)*					-0.628	-0.996	-0.260	0.001
Moderate physical activity at baseline (%)	-0.012	-0.047	0.023	0.512	0.000	-0.040	0.040	0.995	Δmoderate physical activity (%)	-0.202	-0.419	0.015	0.068	-0.489	-0.806	-0.173	0.003
									Δmoderate physical activity (%)*					-0.492	-0.809	-0.175	0.003
Vigorous physical activity at baseline (%)	-0.016	-0.102	0.070	0.708	-0.061	-0.158	0.035	0.214	Δvigorous physical activity (%)	-0.032	-0.124	0.060	0.488	-0.149	-0.282	-0.016	0.029
									Δvigorous physical activity (%)*					-0.146	-0.280	-0.012	0.032

BMI: body mass index, MVPA: moderate-to-vigorous physical activity, Δ: change, Δ variables were calculated as follow-up values minus baseline values, CI: 95% confidence interval, adjusted for sedentary behavior or physical activity and BMI Z-score or fat index at baseline, *: adjusted for sedentary behavior and MVPA or moderate physical activity and BMI Z-score or fat index at baseline.