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Tracking of MVPA across childhood and adolescence

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ABSTRACT

Objectives: Tracking of physical activity from childhood onwards is an important public health issue, but evidence on tracking is limited. This study quantified the tracking of Moderate-Vigorous Physical Activity (MVPA) across childhood and adolescence in a recent cohort from England.

Design: Longitudinal, with a socio-economically representative sample from North-East England, over an 8-year period.

Methods: Measures of time spent in MVPA, with an Actigraph GT1M accelerometer, were made at age 7–8y ($n = 622$, T1), age 9–10y ($n = 585$, T2), age 12–13y ($n = 525$, T3) and age 14–16y ($n = 361$, T4). Tracking of MVPA was assessed using rank order correlations between time spent in MVPA T1–T2, T1–T3, and T1–T4, and by using Cohen's kappa to examine tracking of meeting the MVPA guideline (mean of 60 min/d). We examined whether tracking varied by sex, socio-economic status (SES), initial MVPA, or initial body fatness.

Results: Rank order correlations were all statistically significant at $p < 0.01$ and moderate: 0.58 between T1 and T2; 0.42 between T1 and T3; 0.41 between T1 and T4. Cohen's kappas for meeting the global MVPA guideline were all significant, weakening from moderate to low over the 8 years. Tracking was stronger in higher SES compared to lower SES groups, and there was some evidence that it was stronger in girls than boys, but the other explanatory variables had little influence on tracking.

Conclusions: Tracking of MVPA from mid-childhood to mid-adolescence in this cohort was moderate. This study suggests there is a need to establish high MVPA by mid-childhood, and to mitigate the age-related reduction in MVPA which occurs from mid-childhood.

Practical implications

- Adequate MVPA in mid-childhood and adolescence probably requires higher levels of MVPA in early childhood.
- Research and public health interventions which aim to increase MVPA during adolescence and adulthood should prioritize promoting MVPA in early childhood.
- Research and public health interventions which aim to increase MVPA during adolescence and adulthood should prioritize mitigating the small annual age-related declines in MVPA which begin in early childhood.
- Moderate tracking of MVPA in all subgroups highlights the need for population-wide public health strategies, rather than targeting specific "high risk" subgroups.

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1. Introduction

Time spent in moderate-to-vigorous-intensity physical activity (MVPA) is important to current and future physical and mental health of children and adolescents, and has important non-health effects, notably for cognition and academic attainment.[1–3] The most recent evidence-based global WHO guideline states that time spent in MVPA should average at least 60 min per day in school-age children and adolescents.[1]

There is a widespread view that time spent in MVPA in childhood influences time spent in MVPA later in life. For example, in 2011 the American Academy of Pediatrics concluded that there was reasonable evidence that PA tracked moderately strong, and that level of physical activity in childhood was an important determinant of later level of physical activity.[4] If time spent in MVPA in childhood determines adolescent and/or adult MVPA then increased public health effort should be invested in ensuring high levels of MVPA in childhood. Globally, levels of MVPA are typically low with only a minority of school-age children and adolescents meeting the WHO guideline.[5]

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Previous systematic reviews of the tracking of physical activity during childhood and adolescence have all been highly cited, supporting the view that tracking is an important public health issue.[6–8] One narrative review of tracking studies has also been very highly cited, with > 1090 citations in Pubmed in only 13 years.[9] These reviews have identified many gaps and weaknesses in the evidence on tracking though. Craigie et al.[6] in 2011 found no (zero) eligible studies on the tracking of objectively measured MVPA. Jones et al.[7] in 2013 found only four eligible studies on tracking of MVPA, none of which extended from childhood into adolescence and all of which had follow-ups of either 1 or 2 years only.[6,7] The most recent systematic review of the topic, by Hayes et al.[8] in 2019 was confined to the issue of tracking across adolescence and adulthood only and did not consider tracking of MVPA during childhood, or from childhood to adolescence. No systematic reviews have considered tracking of meeting the MVPA Guideline from WHO in 2020.[5] The systematic reviews by Hayes et al.[8] and Jones et al.[7] both noted that tracking was typically assessed by measurement of changes in *relative* position over time, usually with rank order correlations ('tracking coefficients'): both reviews suggested that future assessments of tracking should also use analyses of agreement in the *absolute* amount of MVPA over time (e.g., with kappa analysis), and should consider correlates/determinants of tracking.

In summary, while there appears to be a widespread acceptance of the notion that physical activity tracks strongly from childhood, systematic reviews have found little empirical evidence on tracking: the confidence which many have in tracking of MVPA at present may therefore be misplaced. Two recent studies, published after the systematic reviews of tracking, and which started around the same time as the present study, have added to the evidence base significantly. Downing et al.[10] reported on tracking of accelerometer measured moderate intensity time spent in moderate intensity and vigorous intensity physical activity separately (not MVPA) from 2008/9 in an early childhood sample from the Melbourne-based HAPPY Study (age 3–5 at baseline, n 758) followed up to the end of childhood/early adolescence 6 years later (n 478). Breau et al.[11] reported on a follow-up of the IDEFICS/ iFamily European study which started on average in mid-childhood (7.5 years) in 2007–2008 and followed up the sample to early adolescence 5 years later (analytic sample n 1886), reporting on the tracking of meeting the WHO 2020 MVPA guideline of an average of 60 min of MVPA per day. Only one previous study has therefore examined the accelerometer-measured tracking of meeting WHO MVPA guidance, and that was from mid-childhood to early adolescence.[11] The evidence base on the strength of tracking and the correlates/determinants of tracking remains very limited.

he Gateshead Millennium Cohort Study (GMS)[12] represents a valuable opportunity to assess the tracking of MVPA across childhood and adolescence. The GMS has longitudinal design, is based on a sample socio-economically representative of North-East England, is relatively contemporary (children born in 1999/2000 and physical activity measures started in 2006–2007), important because tracking of MVPA may change over time. In addition, the GMS cohort study uses accurate objective (accelerometer) measures of MVPA,[13–17] and extends over a relatively long (8-year) period from mid-childhood to mid-adolescence. The primary aim of the present study was therefore to determine tracking of MVPA in GMS participants across mid-childhood to mid-adolescence. We assessed tracking using both conventional assessments of *relative* position in the cohort over time (rank order correlations), but also tracking of meeting the WHO MVPA guideline[1] across the 8 year period. We also aimed to examine differences in tracking of MVPA over time in subgroups defined by socio-economic status (SES), gender, initial level of body fatness, and initial level of MVPA.

2. Methods

The GMS cohort study, including setting, sampling and recruitment, is described in detail elsewhere.[12,18,19] Physical activity and sedentary behavior measures in the cohort began in 2006–2007 when study participants were aged 6–7 years. Initial measures (T1 in the present study) were made between October 2006 and December 2007, when the children were aged 7–8 years, then again at 9–10 years old (T2), 12–13 years old (T3), and 14–16 years old (T4). Ethical approval (from local research ethics committees) and parental consent were obtained during each data collection period. Each child's date of birth, sex and parental SES, measured by Townsend score (an area-based measure derived from the UK census in 2001 based on car ownership, unemployment, overcrowded housing, and home ownership), were recorded at birth. The measures described below were made at T1, T2, T3, and T4.

While loss-to-follow-up occurred across the 8-year period, previous analyses showed that this was not differential: baseline SES, body composition, BMI-for-age, and time spent sedentary and in MVPA for those study participants lost to follow up did not differ significantly from those retained at T4.[14]

Height was measured to the nearest 0.1 cm using a Leicester Portable Height Measure (Chasmors, London, UK). Weight (kg) and body composition were measured while children wore light clothing using a Tanita TBF300MA. Body mass index (BMI) was calculated as weight (kg) divided by height (m) squared and expressed as a BMI-Z score relative to UK 1990 reference data. Fat mass (kg) was derived from Tanita impedance estimates of total body water, using age and sex-specific constants for hydration of fat-free mass.[20] Body fat percentage of > 25 % (boys) and > 30 % (girls) at T1 was considered high, as in many other studies, based on evidence of associations between childhood body fatness and cardio-metabolic risk factors.[20]

Time spent in MVPA was measured using Actigraph GT1M accelerometers (ActiGraph Corporation; Pensacola USA), with a request that these were worn for 7 consecutive days at T1–T4. The accelerometry protocol used in the GMS study has been described in detail elsewhere.[13,14] In summary, participants/their parents recorded when the device was worn and removed using a log sheet and non-wear time was removed before data analyses based on the accelerometry log and visual inspection by an experienced researcher. This method has been used in several previous studies[13–17]: the consecutive zeros method to remove non-wear time was not used as it has been shown to affect the outcome significantly, especially in longitudinal studies in childhood and adolescence.[17] Data were collected in 15-second epochs and included in the analyses if participants had at least three days with ≥6 h per day of accelerometer data-accelerometer decision rules vary between studies but those used in the present study have been used widely elsewhere and are considered acceptable for studies of children and adolescents.[13–17] Accelerometry output was converted into time spent in MVPA using published cutoffs based on two high quality calibration studies: Evenson et al.[21] calibrated an MVPA cut point for 5–8 years olds during treadmill exercise; Puyau et al.[22] calibrated an MVPA cut point for 6–16 year olds within a whole-room calorimeter; the cut points were equivalent to 2296 and 3200 counts per 60 s respectively. The differing accelerometry cut points produce different estimates of time spent in MVPA, but the extent to which they might influence measurement of tracking of MVPA, or correlates/determinants of tracking, was unclear.

In children and adolescents in the UK there are small but statistically significant differences in MVPA between summer and winter and so accelerometry measurements at ages 7, 9 and 12 years were made at the same time of the year as described previously[14]; at age 15–16 years close matching for season was not possible in all cases, hence accelerometry data were adjusted for season (summer or winter) during analysis.[14]

Study power was uncertain at the outset and was effectively fixed by the size of the cohort at T1 and the extent of loss to follow up to T4, so we did not carry out a formal power calculation. We note that the sample was as large or larger than in many of the studies included in the key systematic reviews of tracking of physical activity.[6–8]

Most previous studies quantified tracking using a measure of change in relative position over time, the rank order correlation, so we used that in the present study, between T1–T2, T1–T3, and T1–T4. Rank order correlations were considered as weak (<0.30), moderate (0.30–0.60), or strong (>0.60) using the scheme adopted by many previous studies and suggested by Hayes et al.[8]

Since Hayes et al.[8] and Jones et al.[7] highlighted the value of measuring tracking by *agreement* of the *absolute* amount of physical activity over time e.g., using kappa analysis, we determined whether study participants met the WHO 2020 guideline of at least 60 min of MVPA at T1–T4, and then used kappa analysis to assess agreement between meeting the guideline between T1 and T4. To interpret the kappa analysis data, we used the conventional Landis and Koch[23] definitions of 0.00–0.20 slight agreement, 0.21–0.40 fair agreement, 0.41–0.60 moderate agreement, 0.61–0.80 substantial agreement, 0.81–1.00 almost perfect agreement.[23] Kappa values were calculated with 95 % confidence intervals in order to interpret differences in tracking between time periods, between the different accelerometer cut points used, and between sub-groups in the analyses of correlates/determinants of tracking described below.

It is possible that tracking of MVPA may vary between groups (e.g. between boys and girls), though previous systematic reviews of MVPA tracking have not identified any between-group differences definitively.[6–8] We therefore assessed whether the tracking of MVPA between T1 and T4 varied by subgroup. Kappa analyses were conducted with the sample subdivided at T1 by: sex (boys and girls); initial level of MVPA (defined as averaging at least 60 min or not at T1); high or low SES (two categories based on Townsend index, most socio-economically deprived being in the bottom 2 quintiles vs least socio-economically deprived being in the top three quintiles) at T1; healthy vs unhealthy levels of body fatness (where unhealthy fatness was defined as ≥25 % in boys, ≥30 in girls) (18) at T1.

3. Results

Descriptive data are provided in Table 1. Full data for inclusion in analyses were available for 515, 414, 340 and 259 participants at age 7–8y (T1), 8–9y (T2), 12–13y (T3) and 14–16y (T4). The number of participants for analysis of tracking between time points was 414 (T1–T2), 340 (T1–T3), and 259 (T1–T4).

Table 2 summarizes the results of the tracking analyses defined by Spearman's Rank correlation, for the whole sample, by the different cut points to define MVPA, and the exploratory analysis of tracking by the four different subgroups (categorized by sex, initial MVPA, initial fatness, and SES).

Tracking analyzed by Spearman's Rank Correlations was statistically significant and moderate across the 8 year period by both cut points, though weakened slightly over the 8 years. Tracking as defined by Spearman's Rank Correlations was similar with both accelerometry cut points, varied little between the sexes, and varied little between groups defined based on initial body fatness and initial MVPA, but did differ by SES (stronger tracking in the higher SES group).

Kappa analyses between T1 and T4 are summarized in Table 3. Overall, tracking of MVPA was moderate-fair, weakening over the 8 year period, and broadly similar regardless of whether Evenson et al. or Puyau et al. cut points were used to define MVPA. There was no conclusive evidence of differences in the kappa analysis results between

Table 2
Results of rank order correlations (Spearman).

		Evenson cut point			Puyau cut point		
		T1–T2	T1–T3	T1–T4	T1–T2	T1–T3	T1–T4
Entire sample (n = 515)		0.57*	0.41*	0.42*	0.58*	0.41*	0.44*
MVPA	Active (n = 315/59)	0.47*	0.37*	0.33*	0.11	0.029	0.027
	Inactive (n = 200/456)	0.29*	0.19*	0.13	0.49*	0.33*	0.36*
Sex	Male (n = 258)	0.48*	0.39*	0.39*	0.51*	0.40*	0.44*
	Female (n = 257)	0.60*	0.37*	0.39*	0.61*	0.35*	0.39*
SES	High (n = 326)	0.59*	0.43*	0.50*	0.60*	0.43*	0.49*
	Low (n = 183)	0.53*	0.37*	0.24*	0.51	0.39*	0.34*
Body fat	Unhealthy (n = 163)	0.57*	0.40*	0.30*	0.56*	0.41*	0.43*
	Healthy (n = 429)	0.55*	0.38*	0.46*	0.54*	0.38*	0.44*

MVPA, moderate-vigorous physical activity; SES, socioeconomic status social; SES, two categories based on Townsend index, most socio-economically deprived being in the bottom 2 quintiles vs least socio-economically deprived being in the top three quintiles; MVPA, defined in two categories, active which includes boys and girls who meet the 60 min recommendations and inactive which includes boys and girls who do not meet the recommendations. The sample size varies depending on the cutoff point criteria for Evenson and Puyau. For Puyau, the cutoff points are as follows: sedentary (0–799), light (800–3199), moderate (3200–8199), and vigorous (8120 and above). For Evenson, the cutoff points are: sedentary (0–100), light (101–2295), moderate (2296–4012), and vigorous (4013 and above); body fat, defined in two categories in which unhealthy includes boys and girls with a high fat percentage and healthy includes boys and girls with a low fat percentage (>25 % boys and >30 % girls).
* $p < 0.05$.

Table 1
Characteristics of study participants.

	All				Boys				Girls			
	T1 (n = 515)	T2 (n = 455)	T3 (n = 390)	T4 (n = 284)	T1 (n = 257)	T2 (n = 227)	T3 (n = 193)	T4 (n = 137)	T1 (n = 258)	T2 (n = 228)	T3 (n = 197)	T4 (n = 147)
Age, years (SD)	7.5 (0.5)	9.3 (0.4)	12.5 (0.3)	15.2 (0.4)	7.5 (0.5)	9.3 (0.4)	12.5 (0.3)	15.2 (0.4)	7.5 (0.5)	9.4 (0.4)	12.5 (0.3)	15.3 (0.4)
Height (cm)	124.9 (5.6)	135.5 (6.1)	154.8 (7.8)	167.3 (8.2)	125.4 (5.7)	135.8 (6.2)	154.4 (8.5)	171.8 (7.9)	124.3 (5.5)	135.3 (6.0)	155.2 (7.1)	163.2 (6.1)
Weight (kg)	26.3 (5.2)	33.2 (7.0)	49.3 (11.2)	62.6 (13.7)	26.5 (5.4)	33 (7.1)	48.5 (11.7)	64.4 (15.0)	26.1 (5.1)	33.3 (6.9)	50.0 (10.6)	61.0 (12.1)
BMI, mean (SD) (kg/m^2)	16.8 (2.3)	17.9 (2.7)	20.4 (3.5)	22.3 (4.1)	16.7 (2.4)	17.8 (2.8)	20.2 (3.7)	21.7 (4.2)	16.8 (2.2)	18.1 (2.6)	20.7 (3.4)	22.8 (3.9)
BMIz, mean (SD)	0.40 (1.10)	0.53 (1.09)	0.66 (1.15)	0.63 (1.22)	0.45 (1.17)	0.57 (1.17)	0.71 (1.26)	0.52 (1.37)	0.35 (1.01)	0.50 (1.01)	0.60 (1.04)	0.73 (1.07)
MVPA (Evenson), mean (SD) (min/day)	69.4 (24.0)	63.8 (23.3)	60.7 (24.8)	51.6 (22.5)	75.5 (25.5)	70.8 (24.2)	60.4 (24.4)	51.5 (22.4)	63 (20.9)	53.4 (19.8)	47.4 (20.9)	41.1 (16.8)
MVPA (Puyau), mean (SD) (min/day)	40.3 (17.2)	37.4 (16.9)	32.0 (17.5)	30.5 (17.2)	43.9 (18.5)	42.4 (17.7)	37.6 (18.3)	36.2 (18.6)	36.7 (14.9)	32.6 (14.6)	26.7 (14.9)	25.7 (14.2)
Sex, %	Male (n = 258) 50.9		Female (n = 257) 49.1		(n = 258) 50.9				(n = 257) 49.1			
SES category %	High (n = 326) 62.2		Low (n = 183) 37.8		High (n = 154) 60.7		Low (n = 102) 39.3		High (n = 172) 63.7		Low (n = 81) 36.3	

BMI, body mass index; MVPA, Moderate-Vigorous Physical Activity; Evenson, database calculated with Evenson cutoff points[21]; Puyau, database calculated with Puyau cutoff points.[22]
SES category% = During the process of evaluating the children, some data were lost or became missing. Therefore, the sample size has decreased.

Table 3
Results of kappa analysis for tracking of compliance with 60 min of physical activity (value, CI).

		Evenson cut point			Puyau cut point		
		T1–T2	T1–T3	T1–T4	T1–T2	T1–T3	T1–T4
Entire sample (n = 515)		0.36 (0.27–0.44)	0.20 (0.11–0.29)	0.18 (0.10–0.26)	0.39 (0.26–0.53)	0.21 (0.06–0.36)	0.19 (0.01–0.36)
MVPA	Active (n = 315/59)	0.39 (0.33–0.46)	0.62 (0.55–0.69)	0.75 (0.68–0.81)	0.56 (0,40–0.71)	0.82 (0.70–0.94)	0.83 (0.71–0.96)
	Inactive (n = 200/456)	−0.23 (−0.29 to −0.16)	−0.16 (−0.22 to −0.1)	−0.07 (−0.11 to −0.03)	−0.07 (−0.09–0.04)	−0.05 (−0.07 to −0.03)	−0.04 (−0.06 to −0.03)
Sex	Male (n = 258)	0.30 (0.18–0.42)	0.16 (0.04–0.28)	0.14 (0.03–0.25)	0.22 (−0.22–0.46)	0.07 (−0.14.0.27)	−0.03 (−0.06 to −0.01)
	Female (n = 257)	0.36 (0.23–0.49)	0.21 (0.08–0.34)	0.18 (0.06–0.30)	0.43 (0.26–0.59)	0.24 (0.05–0.42)	0.22 (0.004–0.44)
SES	High (n = 326)	0.40 (0.29–0.50)	0.21 (0.10–0.32)	0.24 (0.15–0.33)	0.41 (0.25–0.58)	0.21 (0.04–0.39)	0.15 (−0.04–0.35)
	Low (n = 183)	0.28 (0.12–0.43)	0.20 (0.06–0.33)	0.05 (−0.11–0.22)	0.35 (0.11–0.59)	0.21 (−0.06–0.48)	0.28 (−0.08–0.64)
Body fat	High (n = 163)	0.37 (0.20–0.54)	0.17 (−0.02–0.35)	0.09 (−0.09–0.26)	0,31 (−0.18–0.81)	−0.03 (−0.06–(−0.0004))	−0.04 (−0.08–(−0.0004))
	Low (n = 429)	0.31 (0.21–0.42)	0.19 (0.10–0.29)	0.19 (0.10–0.28)	0.38 (0.24–0.52)	0.22 (0.06–0.38)	0.21 (0.02–0.40)

SES, socioeconomic status social; SES, two categories based on Townsend index, most socio-economically deprived being in the bottom 2 quintiles vs least socio-economically deprived being in the top three quintiles; MVPA, defined in two categories, active which includes boys and girls who meet the 60 min recommendations and inactive which includes boys and girls who do not meet the recommendations. The sample size varies depending on the cutoff point criteria for Evenson and Puyau; body fat, defined in two categories in which unhealthy includes boys and girls with a high fat percentage and healthy includes boys and girls with a low fat percentage (>25 % boys and >30 % girls); all reported sample sizes in this table are derived from the baseline data presented in Table 1.

subgroups, though tracking was stronger in the high SES group compared to the low SES group, and in the girls compared to the boys.

4. Discussion

4.1. Main findings

The present study found that tracking of MVPA was moderate across the 8 year period of mid-childhood to mid-adolescence, weakening slightly over time. Tracking of MVPA was similar for both the relative position in the sample distribution over time (Spearman's Rank Correlations) and meeting/not meeting the MVPA guideline (kappa analysis). The present study therefore suggests that level of MVPA in mid-childhood was a strong influence on level of MVPA across childhood and into mid-adolescence. This finding in turn suggests that achieving an adequate level of MVPA by mid-childhood may be important to achieving an adequate late childhood and adolescent MVPA. While the present study findings on the importance of childhood physical activity for later physical activity are not radically different from the widespread belief in moderately strong tracking,[4] the evidence base for this belief was actually very limited as shown by previous systematic reviews.[6–8] The present study findings therefore add significantly to the evidence base by providing evidence on tracking of MVPA, tracking of meeting WHO Guidelines for MVPA, and tracking over a much longer period (and into mid-late adolescence) than has been described to date.

4.2. Implications for future research and public health

Taken together with other recent studies[10,11] there is increasing evidence that moderate and/or vigorous intensity physical activity track moderately strong across childhood, and into adolescence. Systematic reviews and meta-analyses of interventions which aimed to increase MVPA during childhood and adolescence have generally been disappointing, with clear evidence of small effects on MVPA, even smaller effects for some groups than others, and effects which are typically not sustained once the intervention stops.[24–26] These reviews therefore suggest that secondary prevention, i.e., increasing MVPA once low MVPA has become established, has not been very successful to date. Tracking of MVPA is important to the issue of primary prevention of low MVPA by adolescence and early adulthood: strong tracking suggests that primary prevention interventions (in research or public health) should have a much greater emphasis on early childhood or infancy/toddlerhood in order to have effects across later childhood and adolescence.

Since MVPA typically declines steadily with age across childhood and adolescence, with the decline starting in early-mid childhood,[27] the other implication of the recent accelerometer based studies of tracking is that future research and public health interventions could usefully focus on the aim of stopping or reducing the age related decline in MVPA which begins in early childhood. Annual MVPA declines on average are typically quite small[27] and so might be stopped or mitigated by public health interventions with small effect sizes so long as those interventions are sustained, year-on-year, across childhood and adolescence.

4.3. Comparisons with previous studies

One important but unresolved issue prior to the present study was the extent to which tracking of objectively measured MVPA might weaken over time. Systematic reviews to date have reported zero tracking studies of objectively measured MVPA across both childhood and adolescence as noted above[6–8] and the key recent studies of objectively measured tracking by Breau et al. and Downing et al. had only two measures of MVPA and so could not test whether tracking weakened over time. However, the systematic review by Jones et al.[7] found some evidence that tracking during childhood over 1 year was typically stronger than tracking over 2 years. The systematic review by Hayes et al.[8] (on tracking between adolescence and early adulthood) also found very little evidence from objectively measured studies, but the available evidence also suggested that tracking might weaken over time. It is reasonable to expect tracking to weaken over time given the dramatic biological and wider environmental changes which occur across childhood and adolescence summarized below. The present study, with four measures of MVPA across an 8-year period of childhood and adolescence, made it possible to test whether tracking declined over that period: there was evidence of slight weakening of tracking measures (rank correlations and kappa coefficients) over the 8 years.

The slight weakening of MVPA tracking over time observed in the present study might reflect profound changes in a range of biological (e.g. growth, pubertal development, changes in body composition, motor competence, chronic disease status including increasing prevalence of overweight and obesity) and environmental influences (e.g. social and cultural factors, changes in the educational environment, growing independence from parents) on MVPA over the 8-year period. Given the profound nature of the changes which occur at adolescence it is perhaps surprising that tracking did not weaken even further across adolescence in the present study.

Previous systematic reviews of the tracking of MVPA have generally found little evidence on whether tracking might vary between population subgroups, other than investigating the possible influence of sex/gender in a few studies.[6–8] The present study had the novel finding that both measures of tracking were slightly stronger in high SES vs low SES subgroups. Since tracking analyses by subgroup in the present study were probably exploratory rather than definitive, one implication of the present study is that future research should test the extent to which SES influences tracking of MVPA. If the suggestion from the present study is confirmed, then further research might focus on why tracking is influenced by SES, and how SES influences on tracking can be modified to promote MVPA across the population. Only one of the two measures of tracking in the present study suggested differences in the strength of tracking between boys and girls, and since the analysis might be considered exploratory future research on tracking might best focus on testing the hypothesis that the strength of MVPA tracking may differ between boys and girls. If sex/gender differences in tracking are confirmed then future research might be directed to understanding why such differences in tracking exist, and how they might be used to reduce sex/gender differences in MVPA found in most studies.

The individual *trajectories* of time spent in MVPA across childhood and adolescence is related to the issue of tracking of MVPA but is distinct from it. Identifying trajectories is challenging (requiring multiple measures over time) and there is even less evidence on MVPA trajectories and their correlates/determinants[16] than on the tracking of MVPA across childhood and adolescence (tracking is often just measured at two time points).[6–8] In a previous study from the same GMS cohort[16] we found that some factors were associated with a favorable MVPA trajectory across the 8 year period, but only 15 % of children, mostly boys, had a favorable trajectory and so the determinants of MVPA trajectory are very poorly understood.

4.4. Study strengths and weaknesses

The present study had several key strengths. First, the measurement of MVPA by accelerometry, and across a relatively long period of time (8 years) compared to previous studies; most previous studies of tracking have been of much shorter duration, typically only 1–2 years.[6–8] Second, the sample in the present study was fairly contemporary (born in 1999–2000) and broadly socio-economically representative of England, both factors that are likely to increase the generalizability of study findings. Third, we examined tracking of both relative position in the MVPA distribution over time, and tracking of meeting/not meeting the MVPA guideline - this adds value to the understanding of tracking, but has been quite rare in previous studies as noted in the systematic reviews of Hayes et al. and Jones et al.[7,8] Finally, we were able to examine the extent to which tracking varied by certain initial (baseline or T1) characteristics, not something which has been common in previous tracking studies, and previous studies have generally not considered this issue or considered sex/gender differences in tracking only.[6–8]

The present study also had a number of weaknesses. The sample size was limited for the later comparison (e.g. T1–T3) relative to the earlier comparison (T1–T2) as a result of loss-to-follow-up. Our previous studies with the Gateshead Millennium Study, using the same analytical sample as the present study, found that loss to follow up was not differential by baseline characteristics, but the sample size remains a limitation. Analyses of only those individuals with complete data at T1, T2, T3, and T4 (Supplemental material) were not that different from analysis summarized from all participants.

While the analyses of possible tracking differences between subgroups were a strength as noted above, the subgroup analyses were based on small sample sizes. Since the present study began at age 7 years we could not examine tracking from earlier in childhood, though other studies have suggested moderate tracking from the pre-school period to mid-childhood,[10,28] so the conclusion that MVPA tracks fairly strong from early-mid childhood into mid-adolescence is probably justifiable. Tracking studies with large samples over long periods of time is difficult to do, as evidenced by the dearth of such studies in the literature,[6–8] but further tracking studies with large and representative samples would be desirable. Tracking of MVPA may be influenced by secular trends in MVPA, so future studies will be valuable, though we note that the major recent studies on tracking began at around the same time as the present study,[10,11] and examining long-term tracking inevitably requires starting data collection with children born some time ago. Furthermore, it is likely that recent secular trends in child and adolescent MVPA – in the decade or so prior to the COVID-19 pandemic – were very small.[29] Finally, while the present study had a focus on the tracking of MVPA across childhood and adolescence, the trend for the time spent in MVPA across childhood and adolescence was downward, and regardless of the strength of tracking the overall downward trend in time spent in MVPA from mid-childhood (T1 in the present study) is a concern.

5. Conclusions

In conclusion, the present study provides robust evidence of moderate tracking of MVPA over an 8-year period, spanning mid-childhood to mid-adolescence. MVPA levels established by mid-childhood exerted long-term influence on MVPA. This finding highlights the importance of achieving high, or at least adequate, levels of MVPA by mid-childhood and/or mitigating the age-related decline in MVPA which begins from early childhood.

CRediT authorship contribution statement

Conception/Design: Reilly, Basterfield, Adamson, Janssen, Pearce, Ramos-Munell.

Acquisition of Data: Basterfield, Janssen.

Analysis of Data: Ramos-Munell, Reilly, Janssen, Basterfield.

Data Interpretation: All authors.

Drafting: Reilly, Ramos-Munell.

Reviewing for Important Intellectual Content: Basterfield, Janssen, Adamson, Pearce.

Final Approval: All authors.

Agreement to be accountable for all aspects of the work and the roles of authors: All authors.

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Confirmation of ethical compliance

Depending on the age of the subjects, the following have been employed: Early origins of obesity: developing strategies for intervention (age 6–7), Gateshead and South Tyneside LREC (06/Q0901/49); Role of physical activity and sedentary behavior in the development of obesity in an urban cohort of children: a longitudinal study (age 9–10), Newcastle University Faculty of Medical Sciences Ethics Committee (000104/2008); The Gateshead Millennium Study (age 12), Newcastle

University Faculty of Medical Sciences Ethics Committee (00510/2011) and Gateshead Millennium Study at age 15–16, Newcastle University Faculty of Medical Sciences Ethics Committee (00728/2014 and 00728_1/2014, amendment).

Declaration of interest statement

The authors declare no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jsams.2024.03.006.

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