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Short title: Inactive adolescence: environment or biology?

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ABSTRACT

Introduction: Contemporary adolescents are deemed inactive, especially girls, but whether for biological reasons associated with their maturation, changes in their behaviour or because of environmental constraints, is uncertain. We examined the trends in physical activity (PA) in relation to both biological and environmental factors in an attempt to establish what drives activity patterns from childhood through to adolescence. **Methods:** PA (7d Actigraph accelerometry) was measured annually from 5y-15y in a single cohort of some 300 UK children. Total PA (TPA – in-school and out-of-school separately and combined as whole day) and intensity-specific PA (sedentary, light and moderate-and-vigorous [MVPA]) were analysed. Biological age (years before/after measured peak height velocity) and pubertal stage (self-reported pubic hair development - Tanner staging) were also measured, as was socio-economic status (post-code derived index of multiple deprivation [IMD]). **Results:** TPA was stable from 5y-8y (trend $p=0.10$) but fell progressively from 9y-15y (by ~30% in girls and ~20% in boys, both $p<0.001$; sex interaction $p<0.01$). Half of this fall was attributable to light intensity PA, only a quarter to MVPA. The decline in PA was related similarly to chronological and biological age, while pubertal stage explained the more rapid PA decline in girls (puberty adjusted sex interaction, $p=0.51$). TPA fell to the same extent for in-school and out-of-school settings (both $p<0.001$), and for lower and higher IMD areas (both $p<0.001$). TPA tracked moderately-to-strongly from childhood into adolescence ($r=0.58$, $p<0.001$). **Conclusions:** The adolescent decline in physical activity is consistent across different environmental settings, attributable to falls in light-intensity/habitual activity and influenced by puberty, suggesting that the inactivity of adolescence may, in part, be under biological control. **Keywords:** activity, children, longitudinal, puberty, maturation, tracking.

INTRODUCTION

Physical activity (PA) during childhood is considered important because of its health benefits (12,14) and it is recommended by many governments that all children spend at least 60 minutes per day in moderate-or-vigorous intensity activity (6,33). However, teenagers tend to get labelled 'inactive' because few of them, girls in particular, achieve this target (4,28). Data from the Health Survey for England 2008, based on objectively-measured PA, reported that no girls aged 11-15y, and only 7% of boys, were meeting the objective of '60 minutes per day' (28).

The widely held perception of the modern teenager as a 'couch-potato' needs to be questioned, given two out of three reviews conclude that teenagers are no less active now than they were a generation ago (7,9,17). Findings from a number of studies have raised a fundamental question: is the inactivity of adolescence driven in part by biological changes, and not just changes in their behaviour or environment? One recent review showed that PA interventions made little sustained difference to the amount of activity that children undertook (18) and other reviews have shown that periods of more activity at one time of day/week were off-set by less activity at another – the so-called activitystat principle (11,36).

The EarlyBird study collected annual measures of accelerometry-based PA from 5y-15y in a large number of children. It is well placed to reveal the start, extent and nature of the decline in physical activity, and to determine the type(s) of activity that contributed to the decline and whether certain biological or environmental factors influenced the decline. We have therefore used the EarlyBird data set to explore the trends in PA (total and intensity-specific) from childhood into adolescence according to sex, age (chronological and biological), pubertal stage, and environmental setting (in-school vs out-of-school, higher vs lower area deprivation), and to determine to what extent activity tracks from early childhood through to adolescence.

METHODS

Design, setting and participants

The EarlyBird study is a non-intervention prospective cohort study of 347 healthy children (50% boys, 98% white Caucasian) recruited from 50+ Plymouth primary schools (307 recruited at age 5y in 2000/01, 40 more at age 9y in 2004/05 to redress the sex imbalance prior to puberty). The study's rationale, recruitment procedures and protocol have been reported in detail elsewhere (34). The cohort is measured every 12 months (SD~1.1mo) for PA and every six months (SD~0.7mo) for height, and this report covers the 11 annual time-points from age 5y (SD~3mo) to age 15y (SD~3mo). Written consent of the parent, and assent from the child at each visit, was obtained. Ethical approval was obtained from the Plymouth Local Research Ethics Committee (South & West Devon Health Authority) in 1999.

Physical activity

Physical activity was measured objectively using Actigraph accelerometers (Model:7164 - formerly MTI/CSA - Fort Walton Beach, FL). Actigraph accelerometers are of good technical reproducibility (19) and correlate well (r=0.7-0.9) with free-living activity-related energy expenditure (21,25). The accelerometers were worn around the child's waist, and were set to run continuously for seven days at each annual time-point. Only recordings that captured at least four days' monitoring (defined as at least nine hours wear time each day) - including at least one weekend day - were included in the analyses as this is the minimum number of days required to achieve 70% reliability (2). Each one-minute epoch of activity data was labeled as either sedentary (<1000 counts/min), light intensity (1000-2499 counts/min) or moderate-and-vigorous intensity PA (MVPA: ≥2500 counts/min). The recommended 'counts/min' threshold varies widely among research groups for the term MVPA (22), so for this study the threshold was specific to three METs, deemed by the UK Government to be the lower limit of moderate PA (6). Two studies measuring energy expenditure and Actigraph counts simultaneously in children have shown that three METs is equivalent to ~2500 Actigraph counts/min (21,25). The level is very similar to the 2296 counts/min threshold reported by Trost et. al as being the most appropriate of the five published cut-points (32).

The children and their parents were asked to report the dates, times and activities of when the child removed the accelerometer during waking time, so that false periods of inactivity could be identified. If details on the type of activity were reported, the corresponding zero counts were replaced with activity-specific counts/min values. If no details were provided then the corresponding zero counts were replaced with the mean accelerometer counts recorded at the same clock time on the other days. The same method of replacement was also employed for unreported periods of zero counts lasting 17 consecutive minutes or more. The sensitivity of each accelerometer was measured by a motorized turntable (19) and seasonality was measured by the number of relevant daylight hours (8am - 10pm) specific to Plymouth for the week the accelerometer was worn (31). Accordingly, each measure of physical activity was adjusted for the mean number of daylight hours (10.5 hours/day) and for the mean Actigraph sensitivity.

Biological factors

Biological age was estimated relative to age at peak height velocity (PHV). PHV was determined from averaging every two consecutive rolling six-monthly measurements of height velocity and identifying the age at which this average was at its peak. If a child had not reached PHV by age 15y they were excluded from any analysis that involved biological age. Pubertal stage was assessed from self-report Tanner stage questionnaires completed by the child every year from age 9y to 15y. Children were shown five line drawings of pubic hair development (Tanner Stage 1 to 5, 1 = pre-pubertal: no pubic hair at all, 5 = adult-like: hair is adult like in quantity and type spreading to medial thighs) and asked to indicate which drawings best matched their own development.

Environmental factors

The index of multiple deprivation (IMD) was used as a measure of socio-economic environment. IMD is a post-code-based composite measure of income, employment, health, education, housing, environment and crime in the neighborhood. PA undertaken in a school setting and a non-school setting were obtained by gating the time-stamped activity data into in-school hours (~9.00am–3.00pm Mon-Fri for primary school years, ~9.00am–3.30pm Mon-Fri for secondary school years) and out-of school hours.

Statistical analysis

Patterns and trends of physical activity:

The mean daily number of minutes spent at, and the corresponding counts achieved in, the three intensity levels (sedentary, light, MVPA) were used to describe the pattern of physical activity.

The minutes spent at all three intensities were summed to obtain total daily wear time and the counts achieved at each intensity were summed to obtain the total physical activity (TPA) of each child at each annual time-point.

Paired t-tests were performed to determine whether statistically significant changes in TPA occurred between consecutive years. The results of these t-tests, together with a visual inspection of the plots, were used to determine appropriate longitudinal modeling of the data from 5y through to 15y. This initial analysis indicated that the age-related trend in activity from 9y to15y differed from that between 5y and 8y (Figure 1 – bottom panel) so two multi-level models were used to describe the non-linear age-related trend for TPA and its three intensity-specific components. Age, as a continuous variable, was entered into each model as a fixed effect and as a random effect to allow age-related slopes and intercepts for each child. For the period 9y to 15y, age-related trends in activity were modeled separately for chronological age and biological age and then chronological age and pubertal stage were modelled simultaneously. For the simultaneous model, both chronological age (continuous) and pubertal stage (categorical) were entered into the model as fixed effects with age also as a random effect. Age and biological age could not be tested simultaneously because of their high levels of co-linearity (r=0.9). The main sex effect and the 'sex x chronological age' interaction were tested to determine whether age-related changes in physical activity differed between girls and boys.

Multi-level modelling was also used to test whether the age-related trends in TPA differed according to different environmental settings. The 'age x in/out-of-school' interaction term would indicate whether the trends in out-of-school TPA were different from those of in-school

TPA. The 'age x IMD group' interaction term would determine whether the TPA trends differed in those from more affluent area compared to those from deprived areas.

Tracking of physical activity:

Pearson correlation coefficients (r) were calculated separately for each of the 55 possible time-point pairings between the 11 annual measures (5-6y, 5-7y, 5-8y... 5-15y, 6-7y, 6-8y… 6-15y... 13-14y, 13-15y, 14-15y). In addition, the 11 annual measures of PA were averaged for each child according to two distinct periods for both chronological age (primary school years: average TPA 5-11y, secondary school years: average TPA 12-15y) and pubertal stage (pre-pubertal: average TPA at Tanner stage 1, pubertal: average TPA at Tanner stage 2 and above). Tracking between the two periods was assessed by Pearson's correlation and by the proportion of stability (the proportion of children that remained in the same PA tertile) coupled with the corresponding Kappa statistic.

Multi-level modeling was used to quantify the overall tracking of PA across the entire 10 year period using data from all 11 time-points. The data at each time-point were converted into sex-specific z-scores and applied to a model that accounted for between-child variation by allowing intercepts, but not slopes, to vary between children. The proportion of residual variation that could be accounted for by the individual-specific intercepts (compared to a population-specific intercept) was tested for statistical significance using a log-likelihood ratio test. Such a model would explain 100% of residual variation if there was perfect tracking, >50% if strong tracking and >25% if moderate tracking.

RESULTS

Compliance

Each annual visit was attended by between n=249-307 children , with n=347 attending at least one of the 11 visits. (Table 1). Altogether, some n=301 (86%), n=310 (89%) and n=342 (99%) children provided useable PA data at one or more of the annual visits between 5-8y, 9-15y and 5-15y respectively and were therefore included in the analysis. Most children included in the analysis however provided PA on multiple visits (e.g. n=274 [79%] provided PA data on ≥6 visits). Non-compliance was mainly due to children dropping out of the study or insufficient wear time, only ~7% was due to technical faults with the accelerometer. The mean TPA at age 5y was no different in those who subsequently dropped out of the study from those who remained in the study (p=0.34).

Time spent in PA intensities according to chronological age

The mean daily accelerometer wear time increased progressively from 11.8h for both boys and girls at 5y, to 13.2h for boys and 13.1h for girls at 15y. The proportion of wear time that was spent at the three levels of intensity changed with age (Figure 1 - top panels). Children spent a greater proportion of the day sedentary at 15y compared to 5y (boys: 84% at 15y, 73% at 5y; girls: 88% at 15y, 75% at 5y), and a smaller proportion of the day in light intensity activities (boys: 9% at 15y, 20% at 5y; girls: 8% at 15y, 19% at 5y). The proportion of time spent in MVPA changed little from 5y to 15y (boys: 6% at 15y, 7% at 5y; girls 4% at 15y, 6% at 5y). Time spent at each of the three intensity levels correlated strongly with TPA (TPA v sedentary: boys r=-0.71, girls r=-0.63, TPA v light PA: boys r=0.77, girls r=0.80, TPA v MVPA: boys r=0.94, girls r=0.90, all p<0.001).

Proportion meeting the Government recommendations for PA in children

The proportion of boys meeting the international recommendation for children's physical activity - '≥60mins/day of MVPA' - rose slightly from 37% at 5y to 43% by 8y, after which it fell steadily to 32% by 15y. For girls the proportion fluctuated from 18% at 5y to 27%, 14%, 23% at 6y, 7y and 8y respectively, before falling steadily to reach 6% by 15y.

Patterns and trends in PA according to chronological age

Mean TPA was relatively stable between 5-8y in both sexes (linear trend from multi-level modeling: boys p=0.10, girls p=0.09), and was consistently lower in girls (all p<0.05). TPA subsequently decreased progressively from 9-15y by ~20% in boys and ~30% in girls (boys: -16334; girls: -22654 counts/day/year, both p<0.001, 'sex x age' interaction p<0.01), (Figure 1 - bottom panels, and Table 2). The fall in light PA accounted for about half the decrease in TPA counts from 9-15y, while decreases in MVPA and sedentary counts each accounted for 20-30%.

Patterns and trends in PA according to biological age and pubertal stage

When analyzed according to biological age, the trends in TPA were very similar to those reported for chronological age (Figure 2 – top panels). There was no significant decline in TPA until three years before PHV (boys: p=0.21, girls: p=0.10), and continued to decrease until two or three years after PHV (boys: -16079 counts/day/year p<0.001, girls: -22511counts/day/year p<0.001).

In the simultaneous model, pubertal stage was associated with changes in physical activity independently of chronological age (Figure 2 –bottom panels). For any given age, TPA in boys tended to be significantly lower in pre-puberty than in early-puberty (pubic hair stage 1 – pubic hair stage 2 = -42727 counts/day, p=0.02) though there were no differences in TPA between early- and late-puberty. In girls, TPA was lower in the later pubertal stages than in the pre-to-mid pubertal stages (e.g. stage 5 - stage 3 = -47112 counts/day, p=0.01). Pubertal stage did explain much of the steeper TPA decline of girls compared to boys from 9-15y (age-related slope coefficients adjusted for pubertal stage: boys: -17220, girls: -20501 counts/day/year, both p<0.001, 'sex x chronological age' interaction p=0.51).

Trends in PA according to in-school and out-of-school settings

There were no significant differences in the rate of TPA decline from 9-15y between in-school and out-of-school settings (boys: -8042 and -8214 counts/day/year respectively, both p<0.001, 'age x in/out-of-school' interaction p=0.93; girls: -10012 and -12596 counts/day/year respectively, both p<0.001, interaction p=0.06).

Trends in PA according to the socio-economic environment

There were no significant differences in the rate of TPA decline from 9-15y between the categories of area deprivation (boys: IMD<30 = -17265 and IMD≥30 = -13004 counts/day/year, both p<0.001, 'age x IMD group' interaction p=0.32, girls: IMD<30 = -22192 and IMD≥30 = -22453 counts/day/year, both p<0.001, interaction p=0.95).

Tracking of PA

The degree of PA tracking from baseline at 5y was (predictably) highest one year later, and decreased thereafter with time (Pearson's correlation for 5-6y, 5-7y, 5-8y, 5-9y, 5-10y, 5-11y, 5-

12y, 5-13y, 5-14y and 5-15y was r=0.47, 0.43, 0.41, 0.41, 0.34, 0.39, 0.28, 0.27, 0.24 and 0.27 respectively for TPA and r=0.46, 0.39, 0.39, 0.39, 0.29, 0.30, 0.24, 0.25, 0.15 and 0.16 respectively for MVPA). Similarly, the tracking between any two time-points was highest when the measures were only one year apart and decreased steadily as the interval between them lengthened (mean Pearson's correlation when PA measured one, two, three, four, five, six, seven, eight, nine and ten years apart was r=0.50, 0.46, 0.41, 0.40, 0.39, 0.32, 0.34, 0.32, 0.26 and 0.27 respectively for TPA and r=0.54, 0.47, 0.42, 0.35, 0.37, 0.32, 0.35, 0.30, 0.18 and 0.16 respectively for MVPA). The magnitude and pattern of these correlations were similar for boys and girls.

Tracking of TPA from primary school years to secondary school years was moderate-to-strong (r=0.55, p<0.001 - Figure 3). Thus, 50% of children remained in the same tertile for PA from one period to the next (Kappa statistic=0.25, p<0.001). Tracking was of similar magnitude between pre-pubertal and pubertal years (r=0.58, p<0.001, 55% remained in same tertile, Kappa statistic=0.32, p<0.001)

Multi-level modeling also implied moderate-to-strong tracking of PA from 5y through to 15y. Allowing intercepts to vary at the individual level resulted in a decrease in residual variation of 40% for TPA and 35% for MVPA (log-likelihood ratio test: both p<0.001).

DISCUSSION

Summary of findings

Three novel observations emerge from this study: First, the decline in PA which begins around age 9y is attributable mostly to a reduction in light intensity activity, rather than a reduction in the more intense activities. This could have important implications for intervention, as light activities are more likely to be habitual, and MVPA is more likely to be structured. Again, attribution to the decline in TPA was much the same in school (largely structured time) as it was out of school (largely free time), and did not differ according to socio-economic status. Second, the decline in PA that started around 9y in both sexes was unrelated to puberty, although puberty accounted for the steeper age-related decline in PA among girls. Finally, physical activity tracks well throughout childhood, such that those who are inactive in early childhood tend to remain inactive in adolescence.

Strengths and limitations

Strengths: No other study, to our knowledge, has measured PA objectively every year in a single cohort over the course of childhood and adolescence. The narrow age range (±3m) helped to resolve age-related trends, and the design unusually distinguished all categories of PA intensity. Tracking coefficients derived from measures at just two time-points are vulnerable to measurement error and regression toward the mean. The current study was able to minimize these effects with up to 11 repeated measures of PA. The study was also able to analyze PA in relation to two markers of biological/pubertal development (years from the attainment of peak height velocity and pubic hair development respectively). Here, peak height velocity was identified objectively by averaging every two consecutive six-monthly measurements of height velocity. While the tempo of growth and maturation approaching PHV will vary from child to child, this is certainly a more precise approach than that used in cross-sectional studies where age at PHV is estimated from equations that use standing height, sitting height, leg length and age measured at one single time-point. Pubic hair development was used as a marker of pubertal development using self-reporting Tanner staging. While it is a subjective measure, it has been shown to have high concordance with a physician's assessment according to a review of validation studies (mean weighted kappa coefficient: boys~0.71, girls~0.74) (5). Self-report measures of testes/scrotum size are less reliable (5) and were therefore not analyzed. Limitations: The accelerometers were removed for water-based activities so that activity levels during swimming lessons, for example, could not be measured directly. Although it did record socio-economic status – a broad environmental measure – the study was unable to collect information on specific environmental factors shown by others to be associated with activity (e.g. green space/parks, sports centers, neighborhood walkability) which may have been important (35). However, the study did collect in-school and out-of-school PA data for each participant, which allowed for a paired comparison of the trajectories of PA undertaken in two very different settings/environments. A small proportion (8%) of children had not reached PHV by the age 15y visit and therefore the average age at PHV reported in Table 1 slightly under-estimates the true age at PHV by ~0.5y and ~0.2y in boys and girls respectively. The cohort was almost exclusively White Caucasian and geographically limited, so that the findings may not be widely generalizable.

Comparison with other studies

We are not aware of other studies that have measured PA longitudinally from 5-15y, but comparison can be made with the small number that cover the period of decline in PA (9-15y). Thus, Jago and colleagues found that total activity in 384 Danish children decreased by ~4.9% per year between the ages 9y and 15y, similar to the 3.7% that we report over the same period (13). Similar annual decreases in total PA were recorded by two larger studies that measured objectively-measured PA on just two occasions – at 12y, and again at 14y (Baggett 2008 ~ -3.5%, Riddoch 2009 ~ -5.5% per year)(1,23). Nader et al, on the other hand, reported a much greater decrease (~12.5% per year) in the MVPA of some 600 US children between 9y and 15y (20). The discrepancy is likely to result from the lower thresholds employed by Nader and colleagues to define MVPA (~900 counts/min at 9y and ~1700 counts/min at 15y). Similarly, a higher threshold (of 2802 counts/min) might explain why the proportion of children exceeding the recommended 60mins/day was so low (7% of boys, 0% of girls) in the Health Survey for England (NHS information). Although no other longitudinal study has to our knowledge reported age-related changes in children's light intensity PA, despite it accounting for 30-40% of total daily activity, cross-sectional data from the 'Health Survey for England 2008' did suggest that the time spent in light PA was lower in older children than younger children (28). These studies were concerned more with the description of changes in activity levels among children than with the cause.

A review by Sherar et al. reported a relationship in six studies, but no relationship in five others, between biological maturation and physical activity (26). Few of the studies, however, controlled for chronological age, which is crucial to determining whether the change in PA is related to biological change or is simply reflecting non-biological, age-related change. Importantly, the present study showed that PA was influenced by pubertal stage in both boys and girls even after controlling for chronological age. Interestingly, three different studies of Canadian children have examined PA in relation to biological age - biological age being estimated from cross-sectional measures of height, sitting height and leg length in two and calculated from longitudinal height data in one (3,27,29). Two of the studies found that the age-aligned gender difference in PA disappeared when PA was aligned on biological age (27,29). The findings of the other study did not show this but did show that biological age explained the steeper PA decline seen in girls (3). This finding was consistent with our own study which found that differences in pubertal stage explained the steeper PA decline of girls, but not their lower levels.

The degree of PA tracking reported here is similar to that reported in other objectively-measured studies (15,16). Kwon and Janz reported the level of tracking from five studies (5021 children altogether) involved in the International Children's Accelerometry Database (ICAD). The follow-up periods were relatively short - between one and four years - and the correlations for MVPA across this period ranged from r=0.43 to 0.61 (16).

Possible explanations and implications

It seems unlikely that the age-related decline in PA reported in the current study can be explained by a period effect, given the reported absence of any decline in youth activity levels over the past two decades (9). There is, furthermore, no clear reason why the decline in PA should be accounted for mainly by light intensity PA, though it may reflect a natural down-regulation in spontaneous, non-exercise/unstructured activity. The decline in predominantly light PA and the relative stability of higher intensity PA may have important implications for public health, as strategies often target the higher intensities.

The sex differences, age-related trends and tracking of physical activity in the current data were systematic, and systematic variation implies control. Whether such control is biological and/or environmental/socio-environmental is unclear. The argument for socio-environmental factors, however, was not supported by our data, where PA decreased at the same rate during in-school and out-of-school hours and in children from areas of higher deprivation compared with those from lower deprivation areas. Neither did the transition from primary school to secondary school (at ~11y) influence the progressive decline in PA from 9-15y. The argument for biological control was supported by our data as physical activity was significantly associated with pubertal stage independently of chronological age. The biological control of PA has received much attention over the last decade (8,24,30). The review by Eisenmann and Wickel and the review by Thorburn and Proietto both point to the link between genes and PA as primary support for biological control, particularly trials in rodents where there are no potential psycho-social and environmental confounders (e.g. mice selectively bred for high voluntary wheel running produced many generations of 'more active' offspring) (8,30). The review of the genetic evidence was not limited to animal studies, Eisenmann and Wickel summarized the heritability of PA in humans which varied from 18-69% (8). Both Thorburn and Proietto, and Rowland discussed the notion that spontaneous PA is biologically controlled to achieve energy homeostasis and/or regulate optimum body weight (24,30). The term 'activitystat', first coined by Rowland, is used to describe one such compensatory mechanism. It is used to conceptualize a neuro-humoral feedback loop set by the individual's hypothalamus which could monitor physical activity and regulate it accordingly (10,11,24,36). A review by Gomersall et al. was inconclusive regarding the 'activitystat', although it did find that over half - 15/28 - of the studies showed evidence of PA compensation (11). Importantly for health strategists concerned with the childhood obesity epidemic, such compensation may be one reason why the interventions designed to increase PA have little impact on the activity of children (18).

Conclusions

The downward trends in activity are consistent across different settings, are attributable to falls in light-intensity - possibly habitual behaviour - and are influenced by pubertal development. Together these findings imply that the inactivity of adolescence may, in part, be a biologically driven event. Contemporary teenagers, especially girls, are deemed inactive and are often targeted by activity interventions, but the effectiveness of such interventions may be limited if much of the decline in the activity from childhood to adolescence is a natural occurrence.

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Figure 1. Patterns and trends in physical activity by chronological age (boys - left panels, girls - right panels, mins/day - top panels, counts/day - bottom panels).

* TPA is significantly different ($p<0.05$) from the previous year according to a paired t-test.

Trend for TPA between 5y and 8y was not significant (boys p=0.10, girls p=0.09) but was highly significant between 9y and 15y (boys $p<0.001$, girls $p<0.001$) according to multi-level modelling.

Figure 2. Patterns and trends in physical activity by biological age[a] (top panels) and pubertal stage[b,c] (bottom panels) (boys - left panel, girls - right panel).

[a] the number of years from the attainment of peak height velocity

[b] self-reported Tanner stage for volume of pubic hair (PH)

[c] for pubertal stage only, the results are independent of chronological age

* TPA is significantly different ($p<0.05$) from the previous year according to a paired t-test. According to multi-level modelling the trend for TPA between biological ages -7y and -4y was not significant (boys p=0.21, girls p=0.10) but was highly significant between -3y and +2y for boys ($p<0.001$) and -3y and +3y for girls ($p<0.001$).

[#2] TPA is significantly lower ($p<0.05$ from multi-level model) compared to PH2

[#1,3] TPA is significantly lower ($p<0.05$ from multi-level model) compared to PH1 and PH3

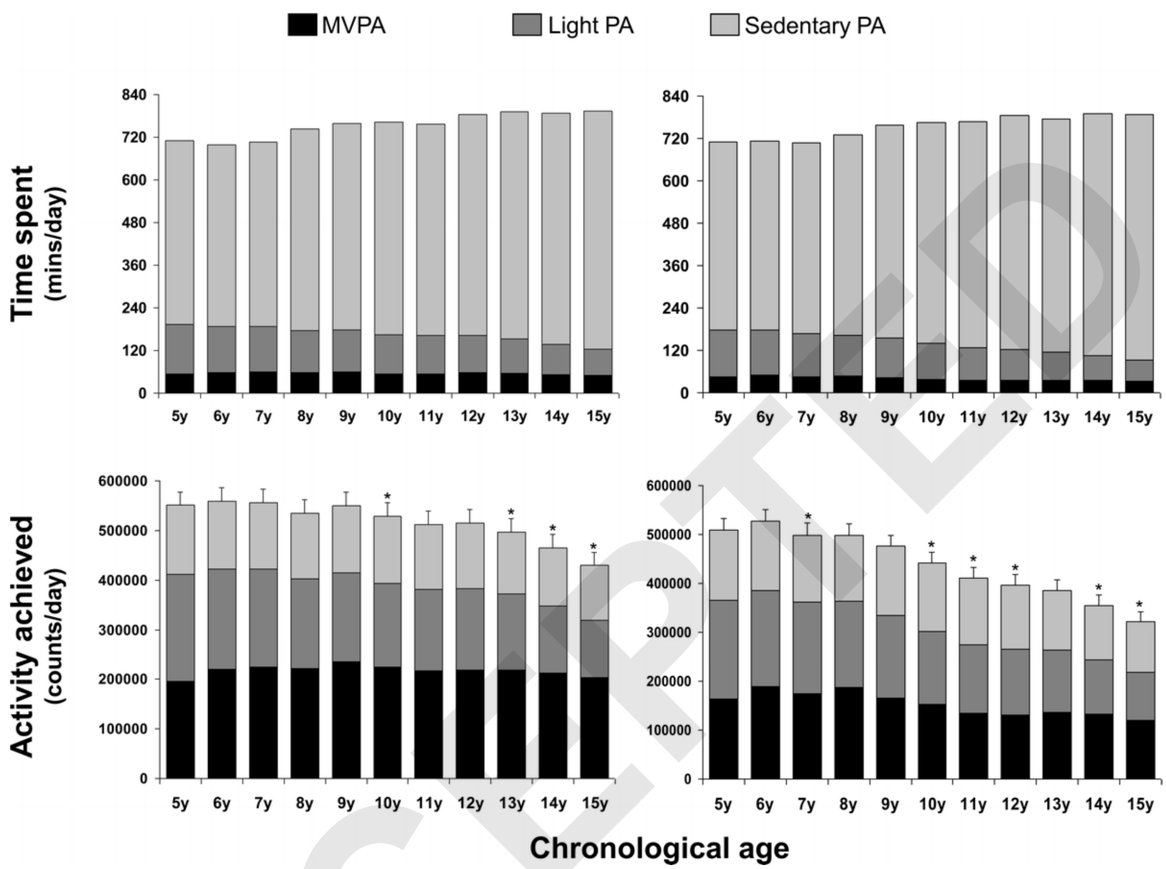
[#1,2,3] TPA is significantly lower ($p<0.05$ from multi-level model) compared to PH1, PH2 and PH3

Figure 3. Tracking of total physical activity from primary school years[a] to secondary school years[b].

[a] the mean TPA (total physical activity) calculated from seven annual time-points (5-11y)

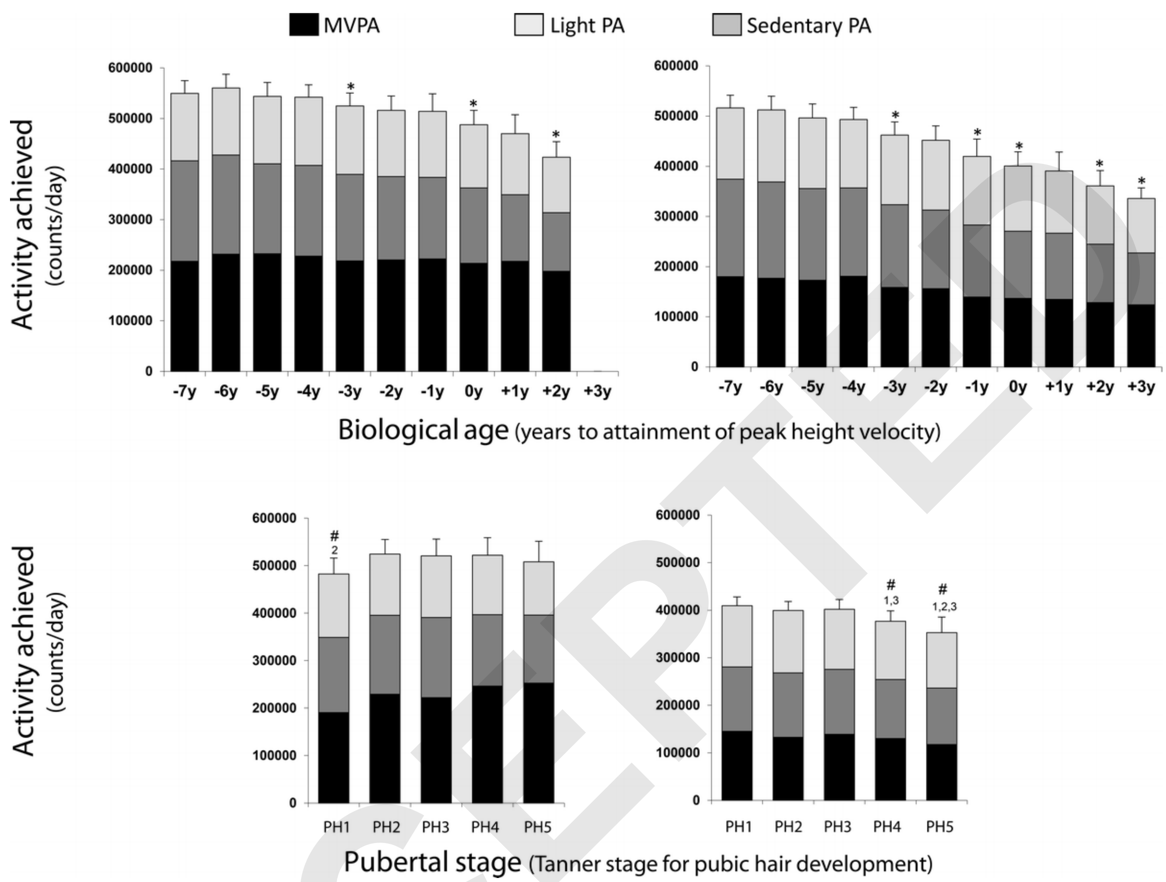
[b] the mean TPA (total physical activity) calculated from four annual time-points (12-15y)

Figure 1



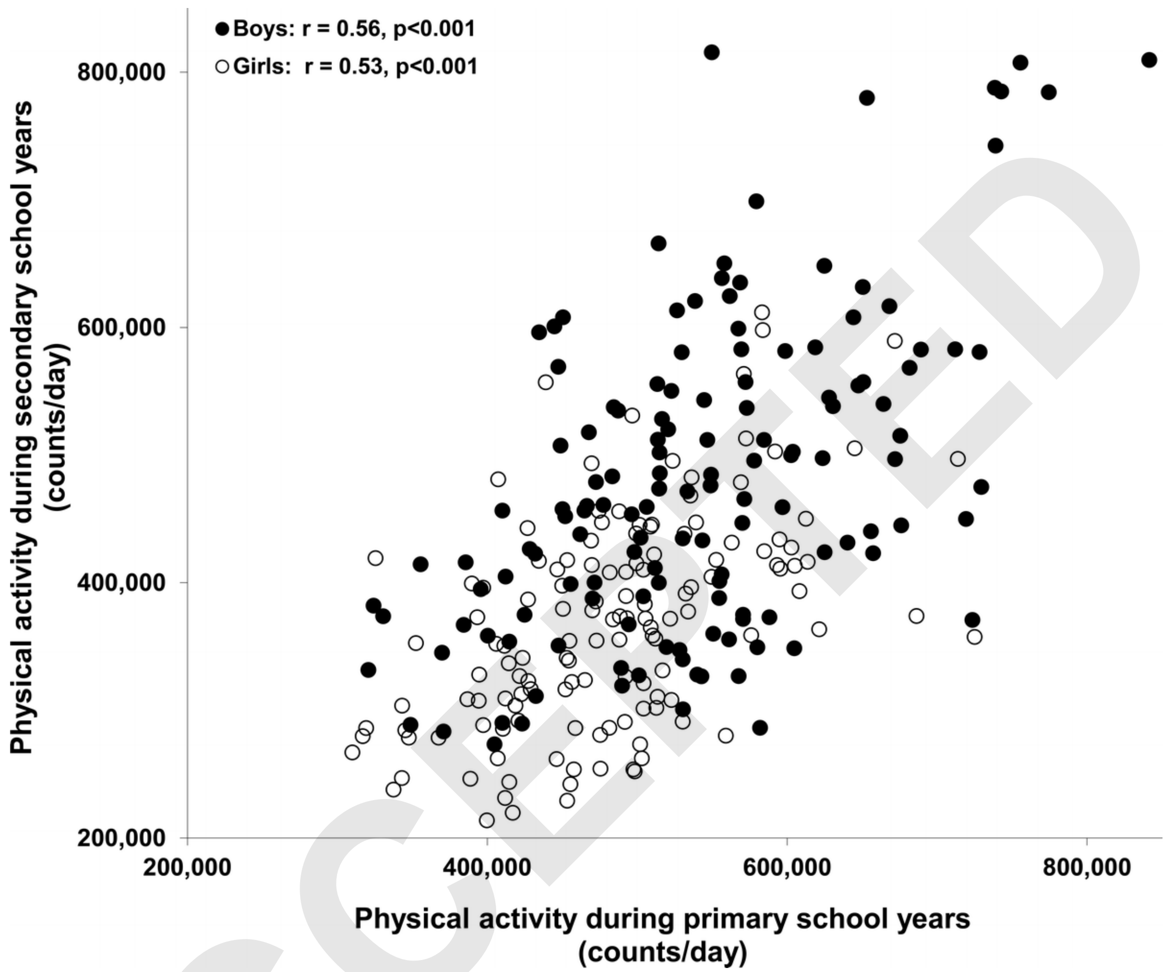
MVPA
Light PA
Sedentary PA
Time spent
(mins/day)
840
720
600
480
360
240
120
0
5y 6y 7y 8y 9y 10y 11y 12y 13y 14y 15y
Activity achieved
(counts/day)
600000
500000
400000
300000
200000
100000
0
Chronological age

Figure 2



MVPA
Light PA
Sedentary PA
Activity achieved (counts/day)
600000
500000
400000
300000
200000
100000
0
-7y -6y -5y -4y -3y -2y -1y 0y +1y +2y +3y
Biological age (years to attainment of peak height velocity)
PH1 PH2 PH3 PH4 PH5
Pubertal stage (Tanner stage for pubic hair development)

Figure 3



Boys: r = 0.56, p<0.001
Girls: r = 0.53, p<0.001
800,000
600,000
400,000
200,000
Physical activity during secondary school years (counts/day)
200,000
400,000
600,000
800,000
Physical activity during primary school years (counts/day)

Table 1. The number, age and pubertal stage of the children that provided physical activity data.

	Boys			Girls		
Visit	5y	9y	15y	5y	9y	15y
Age (y)	4.9 (0.3)	8.9 (0.3)	14.8 (0.3)	4.9 (0.3)	8.8 (0.3)	14.8 (0.3)
Attendance (n)	170	151	141	137	150	137
Attended ≥1 of the annual visits between 5-15y (n)	174			173		
Compliance to the measurement of PA						
Provided PA data: n(%)	153 (90%)	128 (85%)	116 (82%)	120 (88%)	131 (87%)	106 (77%)
Provided PA data between 5-15y on:						
≥1 annual visit: n(%)	173 (99%)			169 (98%)		
≥6 annual visits: n(%)	144 (83%)			130 (75%)		
Pubertal development						
Age at peak height velocity (y)	13.1 (0.7)			11.6 (1.1)		
Peak height velocity reached by 15y visit: n(%)	101 (87%)			103 (97%)		
Puberty (pubic hair development):						
PH=1 at age 9y: n(%)	123 (96%)			119 (91%)		
PH≥4 by age 15y: n(%)	100 (86%)			83 (78%)		

Age and age at peak height velocity are presented as means (SD), all other data is presented as n or n(%). y = years, PA = physical activity, PH=1 = no public hair, PH≥4 = pubic hair resembles that of adult pubic hair though may cover a smaller area.

Table 2. Age-related trends in physical activity from 9-15y with and without adjusting for pubertal stage.

	Gender	TPA (counts/day/year)	MVPA (counts/day/year)	Light PA (counts/day/year)	Sedentary PA (counts/day/year)
Age-related trends (unadjusted)	Boys (n=154)	-16334*** (-19630 to -13038)	-2996* (-5656 to -336)	-9683*** (-10782 to -8583)	-4060*** (-4620 to -3500)
	Girls (n=156)	-22654*** (-26057 to -19250)	-6087*** (-8828 to -3346)	-10405*** (-11542 to -9267)	-6317*** (-6896 to -5739)
	Gender interaction	p<0.01	p=0.11	p=0.37	p<0.001
Age-related trends (adjusted for puberty)	Boys (n=154)	-19267*** (-25823 to -12711)	-7201** (-12438 to -1965)	-9491*** (-11729 to -7254)	-3341*** (-4438 to -2243)
	Girls (n=156)	-18454*** (-25579 to -11329)	-3612 (-9284 to +2060)	-9337*** (-11730 to -6945)	-5661*** (-6834 to -4489)
	Gender interaction	p=0.87	p=0.36	p=0.93	p<0.01

* p<0.05, ** p<0.01 and *** p<0.001 for age-related slope coefficients obtained from multi-level modeling. PA physical activity, TPA total physical activity, MVPA moderate-or-vigorous physical activity.