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Original research

Longitudinal changes in vigorous intensity physical activity from childhood to adolescence: Gateshead Millennium Study

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A B S T R A C T

Objective: The aims of our study were to quantify levels and investigate sex-specific changes and trajectories in VPA longitudinally from age 7 to 15 years.
Design: Longitudinal observational study.
Methods: Participants were part of the Gateshead Millennium Study. Measures were taken at age 7 (n = 507), 9 (n = 510), 12 (n = 425) and 15 years (n = 310). Vigorous physical activity was quantified objectively using ActiGraph GT1 M accelerometers over 5–7 days at the four time-points. Multilevel linear spline random-effects model and trajectory analysis to identify sub-groups were performed.
Results: In boys, average VPA declined across childhood followed by an increase at adolescence, while in girls, average VPA declined across the 8-year study period. In boys, daily VPA decreased from 9-12 years (1.70 minutes/year) and increased from 12-15 years (1.99 minutes/year) (all $p < 0.05$). In girls daily VPA decreased from 7-9 years (1.70 minutes/year) ($p < 0.05$). Three VPA trajectories were identified which differed between the sexes. In boys, one group decreased from an initial relatively high level, one group, initially relatively low, increased, whereas the third one was stable over the 8-year period. In girls, all three groups declined from baseline.
Conclusions: Marked sex and age-specific trajectories in VPA change were observed. These novel findings should help sports and exercise medicine specialists, as well as policy makers, in their effort to maintain or increase VPA in childhood and adolescence.

Practical implications

- Future physical activity promotional strategies for youth should specially target VPA during childhood in their effort to maintain or increase it.
- Children and adolescent boys and girls should not be treated as a whole homogenous group in the attempt to promote VPA.
- Girls should be specially targeted in VPA promotion since they are at highest risk of relatively low and declining VPA across childhood and adolescence.

1. Introduction

Regular physical activity in youth has been positively associated with physical and mental health.[1] However, most children and adolescents accumulate lower levels of physical activity than recommended for their age,[2] while sedentary time increases with age.[3] International physical activity guidelines for children and adolescents recommend 60 minutes of moderate-to-vigorous physical activity (MVPA) per day in order to achieve health benefits, endorsing vigorous physical activity (VPA) generally to 3 days/week.[4–8] However, recent research showed that VPA may have more robust relationships with health indicators like fitness, adiposity, blood pressure or insulin resistance than lower physical activity intensities (i.e., light and moderate physical activity).[9–14]

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Therefore, examining changes in VPA warrants specific attention and might be of importance for future health promotion strategies.

The use of acceleromenters has increased the ability to objectively measure physical activity volume and intensity in epidemiological studies.[15] It is recognized that accelerometry-based VPA levels are highly influenced by the choice of intensity threshold.[16] However, the use of cut-off points to define the intensity of physical activity, which are derived from the analyses of the relationship between accelerometer counts and objectively measured energy expenditure during a set of activities,[17] is the most common method in large-scale accelerometer-based studies.[18] In addition, choice of the appropriate cut-off should provide acceptable accuracy of classification of VPA.[19]

To date, studies investigating changes in physical activity levels in children and adolescents have mostly focused on MVPA, while fewer have examined moderate intensity physical activity and VPA separately and through multi-wave longitudinal studies,[20–22] which may mask important changes within specific intensities of physical activity and between different ages. Nevertheless, a recent cross-sectional study with participants between 5 and 18 years old from different countries suggested that age-related declines in objectively measured VPA during childhood and adolescence are relatively greater than those of moderate intensity physical activity.[20] The only longitudinal study investigating changes in VPA with more than two time measurement periods (2008, 2009, 2011) showed that children spent the least amount of time in VPA compared to moderate and light physical activity intensities.[21] Further, VPA was found to have decreased at a faster pace than other intensities from age 9 to 12 years, with the age-related decline especially marked in girls.[21]

Most of the previous research reporting changes in physical activity levels did not account for heterogeneity of patterns in subgroups of participants. Recent studies suggested that the change in MVPA among children and adolescents is not homogeneous, and subgroups of individuals exhibit dramatically different trajectories of change.[23,24] Modelling longitudinal trajectories of specific physical activity intensities can be useful to identify clusters of individuals who followed a similar progression of physical activity behaviour over time.[25] Nevertheless, to date only trajectories of MVPA have been reported in the existing literature,[23,24] while no specific data exists in relation to trajectories in VPA from childhood to adolescence.

Given the emerging results suggesting specific VPA declines in youth, it would be interesting to expand the limited knowledge about the change in VPA from childhood to adolescence through high-quality longitudinal studies with multiple waves and in a contemporary population. In addition, it would be helpful for future promotion of VPA to determine the existence of children and adolescents with different trajectories of change in VPA. Forthcoming recommendations would benefit from having better knowledge about the specific pattern of change in this specific physical activity intensity longitudinally, so that VPA promoting strategies could target populations at critical time points to maintain or increase VPA. Therefore, the first aim of our study was to investigate sex-specific changes in VPA longitudinally from age 7 to 15 years. The second aim was to identify trajectories of VPA over this 8-year follow-up in both boys and girls.

2. Methods

Participants were from the Gateshead Millennium Study (GMS). Details of this cohort study have been published previously.[26] In brief, the GMS is a longitudinal study of a socio-economically representative contemporary cohort from North-East England. Physical activity measurements included in this study were taken for the first time when participants were 7 years of age (October 2006 to December 2007), and were repeated at age 9 (October 2008 to September 2009), 12 (October 2011 to December 2012) and 15 (September 2014 to September 2015). Written parental consent was obtained for all participants included in the study during each data collection period. The study was approved by the Gateshead and South Tyneside Local National Health Service Research Ethics Committee for data collection at 7y and by the Newcastle University Faculty of Medical Sciences Ethics Committee for the 9y, 12y and 15y data collections. This research was performed following the ethical guidelines of the Declaration of Helsinki.

Physical activity was measured at each time point using Actigraph GT1 M accelerometers (ActiGraph Corporation; Pensacola USA). A detailed description of the accelerometer protocol used in the GMS has been described elsewhere.[27] In brief, participants were asked to wear the accelerometer on their right hip during waking hours for 7 days, removing it only during water-based activities (swimming or showering) and during sleep. Participants recorded in a log sheet diary when the monitor had been worn and removed each day. Data were collected in 15-second epochs and included in the analyses if participants had at least 3 days with $\geq$6 hours per day of accelerometer data,[28] though in practice actual wear time was much greater than this minimum (described in Table 1). Non-wear time (including sleep) was removed manually by a trained researcher based on visual inspection of accelerometer output and log sheet diaries as described previously.[3,23,27] Evenson et al. cut points were used to classify epochs as VPA ($\geq$1003 counts per 15s).[29] The Evenson et al. cut-point of 1003 counts per 15 s epoch performs well at classifying physical activities with energy expenditure > = 6 times resting energy expenditure which is commonly accepted as the energy expenditure threshold for VPA.[19,29] Time spent in VPA was expressed as minutes per day and as the percentage of the total monitored time.

Participants were measured at the same time of the year for the 7-, 9- and 12-year measures. However, some variation in measurement time occurred during the 15-year follow-up, therefore analyses were adjusted for seasonality at age 15 years.

Height and weight were measured at each time point using standardized methods. Height was measured to 0.1 cm with a Leicester portable height measure (Chasmors, London, UK) and weight measured to 0.1 kg in light indoor clothing with a Tanita TBF300MA (Chasmors, London UK). Body mass index (BMI) was calculated as weight (kg) divided by height (m) squared.

Data are presented as mean (standard deviation), unless otherwise stated. Differences between sex in physical activity at each time point were analysed by independent T-tests using SPSS V.21.0 statistical software. Multilevel linear spline random-effects model was used to describe the change in VPA with age. As VPA was measured at four time points, models were constructed with two levels: follow-up period (level 1) and within each child (level 2). Knot points were defined at age 9 and 12 years, each with a random intercept and a single-random slope (to capture individual deviation from the average trajectory), across all splines. These time points were chosen as knot points to allow for investigation of change between follow-up periods and following the recommendation that if there are only a small number of data collection time points, the knot points may be placed at the mean follow-up age.[30] The final linear spline random-effects model was adjusted for seasonality and minutes of VPA were corrected for accelerometer wear time. These analyses were performed in STATA 12 (StataCorp, College Station, Texas, USA).

Group-based modelling of longitudinal data to identify distinct trajectories of age-related changes in VPA was performed using the Traj module plug-in in STATA developed by Nagin.[31] Given potential differences in trajectories of physical activity change between the sexes, they were modelled separately for boys and girls. The tra-

Table 1
Vigorous physical activity values by sex and wave of data collection.

	Boys				Girls			
	7 y n = 255	9y n = 245	12y n = 198	15y n = 144	8 y n = 252	9y n = 265	12y n = 227	15y n = 166
Age (years)	7.5 (0.5)	9.3 (0.4)	12.5 (0.3)	15.2 (0.3)	7.5 (0.4)	9.3 (0.4)	12.5 (0.3)	15.2 (0.4)
Anthropometry								
Height (cm)	125.4 (5.7)	135.9 (6.4)	153.9 (8.4)	171.3 (8.3)	124.4 (5.5)	135.4 (6.4)	155.2 (7.3)	163.1 (6.2)**
Weight (Kg)	26.5 (5.4)	33.0 (7.2)	48.5 (11.9)	62.8 (14.3)	26.2 (5.0)	34.0 (7.9)	50.6 (12.3)	61.6 (14.1)
BMI (kg/m^2)	16.7 (2.4)	17.7 (2.8)	20.3 (3.8)	21.3 (4.0)	16.8 (2.2)	18.4 (3.0)*	20.8 (3.9)	23.1 (4.5)**
Accelerometer								
WearT (min/day)	673.8 (71.2)	674.6 (76.8)	714.1 (84.9)	730.5 (79.2)	667.5 (67.0)	671.4 (74.2)	721.0 (80.2)	721.2 (85.5)
Days worn	6.5 (0.9)	5.9 (1.2)	5.9 (1.3)	5.5 (1.3)	6.3 (1.0)	6.0 (1.2)	5.9 (1.3)	5.6 (1.3)
MPA (min/day)	49.6 (14.4)	45.1 (14.2)	38.0 (14.7)	27.7 (11.4)	41.2 (12.0)**	36.9 (11.2)**	33.0 (13.0)**	26.1 (10.4)
MPA (%)	7.4 (2.1)	6.7 (2.0)	5.3 (2.0)	3.9 (1.8)	6.2 (1.8)**	5.5 (1.6)**	4.6 (1.9)**	3.7 (1.5)
VPA (min/day)	26.0 (13.6)	25.1 (12.4)	22.4 (13.3)	24.9 (15.2)	22.6 (11.0)*	19.2 (10.3)**	14.7 (10.1)**	15.0 (10.9)**
VPA (%)	3.9 (2.0)	3.7 (1.8)	3.2 (1.9)	3.5 (2.1)	3.4 (1.7)*	2.8 (1.5)**	2.0 (1.4)**	2.1 (1.5)**

Data is shown as mean (standard deviation). BMI, body mass index; WearT, wear time; MPA, moderate physical activity; VPA, vigorous physical activity. * Indicates significantly different from boys at same age.
* p<0.01.
** p<0.001

jectories were modelled using quadratic, cubic or linear trends. In a step-by-step manner, we developed several distinct trajectories by comparing fit statistics as defined by the Bayesian Information Criterion (BIC) to be lowest and by evaluating the posterior probabilities for each model for tenability. The process of specifying the number of distinct trajectories and selection of linear, quadratic or cubic trend for each trajectory was carried out until there was no substantial improvement in the model. Using a maximum probability assignment rule, each participant was classified under a trajectory for which posterior membership probability was the highest. Trajectories and the 95% confidence intervals (CIs) surrounding each trajectory were plotted.

3. Results

Participant characteristics and physical activity data stratified by sex are described in Table 1. At 7 years, 9 years, 12 years and 15 years of age a total of 507, 510, 425 and 310 participants provided valid accelerometer measurements, respectively. Compliance was high at each age, with participants wearing the accelerometer on average between 5.5 and 6.5 days for 673.8 and 730.5 minutes per day across the four time-points. Daily VPA mean values for boys and girls respectively were: 26.0 (13.6) min/day and 22.6 (11.0) min/day at age 7; 25.1 (12.4) min/day and 19.2 (10.3) min/day at age 9; 22.4 (13.3) min/day and 14.7 (10.1) min/day at age 12; 24.9 (15.2) min/day and 15.0 (10.9) min/day at age 15. VPA was significantly higher in boys at all time-points ($p < 0.01$) (Table 1). A total of 199 participants provided data at all four time points, and 326 provided data at two or three of the time points. Attrition across the 8 year period was not differential, since, as previously shown, there were no significant differences between those retained versus those lost to follow-up for height, weight, BMI or SES.[3] Furthermore, the statistical analysis used is very robust to loss to follow-up[3], and there was no significant difference in VPA at baseline and follow up between those followed up versus those lost to follow up.

Changes in VPA for boys and girls over the follow-up are shown in Table 2. Linear spline modelling estimates showed that in boys daily VPA significantly decreased from 9-12 years by 1.7 minutes per year (0.32% of the accelerometer wear time) and significantly increased from 12-15 years by 2.0 minutes per year (0.31% of the accelerometer wear time) (Table 2). In girls, daily VPA significantly decreased from 7-9 years by 1.7 minutes per year (0.29% of the accelerometer wear time) (Table 2). Supplementary Fig. 1 displays the change in minutes of VPA over the 8-year study period by sex based on the linear spline modelling estimates.

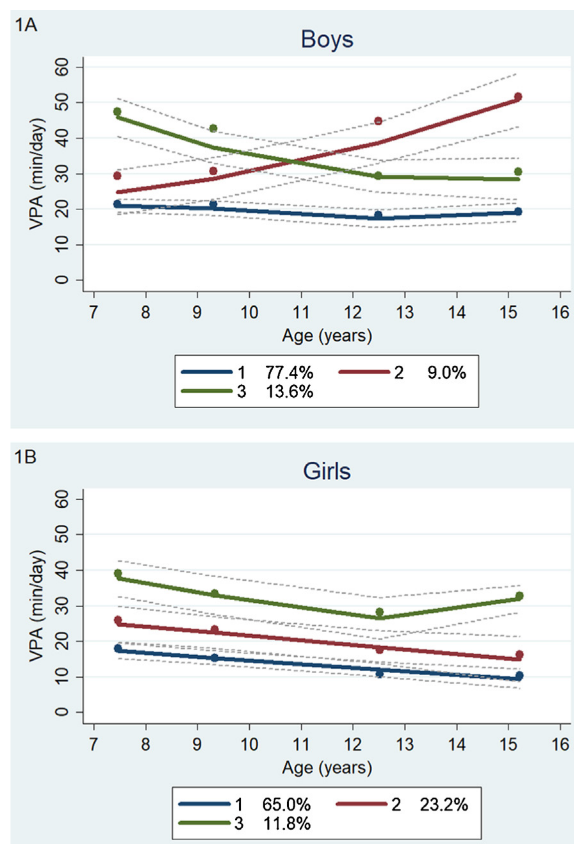

Fig. 1. Change in vigorous intensity physical activity in boys (A) and girls (B) based on trajectory analysis. The numbers 1, 2 and 3 designate the three different trajectories found by sex and the values in brackets represent the percentage of participants following this specific VPA trajectory.

Group-based modelling revealed three distinct trajectory groups for VPA for boys and girls as shown in Fig. 1. In boys the three trajectories were characterized by: group 1 being consistently relatively low in VPA from age 7 years to 15 years (77% of the sample); group 2 initially relatively low but gradually increasing from age 7 years (9% of the sample); group 3 initially relatively high but

Table 2
Changes in VPA minutes and VPA percentage of the total wear time over the follow-up based on linear spline model estimates.

Exposure variable	Mean predicted (95% CI) intercept and slopes in boys	p-value	Mean predicted (95% CI) intercept and slopes in girls	p-value
Percentage				
VPA at 7y	3.28 (2.99; 3.57)	**<0.001**	3.00 (−0.59; 0.02)	0.07
VPA change 7y–9y	−0.21 (0.47; −0.04)	0.11	−0.29 (−0.51; −0.06)	**0.01**
VPA change 9y–12y	−0.32 (−0.48; −0.16)	**<0.001**	−0.09 (−0.26; 0.07)	0.26
VPA change 12y–15y	0.31 (0.05; 0.58)	**0.02**	−0.06 (−0.24; 0.12)	0.52
Minutes				
VPA at 7y	22.17 (20.02; 24.32)	**<0.001**	19.76 (−4.74; −0.09)	**0.041**
VPA change 7y–9y	−1.29 (−3.00; 0.42)	0.139	−1.70 (−3.18; −0.22)	**0.025**
VPA change 9y–12y	−1.70 (−2.67; −0.73)	**0.001**	−0.62 (−1.60; 0.35)	0.211
VPA change 12y–15y	1.99 (0.61; 3.36)	**0.005**	−0.61 (−1.62; 0.39)	0.234

95%CI: 95% Confidence Interval; VPA: vigorous physical activity. All estimates adjusted for season. Minutes of VPA were corrected for accelerometer wear time. Significant results are highlighted in bold.

progressively declining from age 7 across the follow-up (14% of the sample). In girls, three distinct trajectories of VPA were also found: group 1 initially relatively low with modest decline from age 7 years to 15 years (65% of the sample); group 2 with slightly higher VPA at age 7 years and with a gradual decline over time to 15 years (23% of the sample); group 3 initially relatively high but progressively declining from age 7 to 12 years, then slightly increasing from age 12 to 15 years (12% of the sample).

4. Discussion

The present study revealed a markedly different pattern of decrease in objectively measured VPA between boys and girls from age 7 to 15 years old, showing that: 1) in boys the decline in mean VPA stops by early adolescence and then increases after age 12 years; 2) VPA declines from a lower baseline level in girls, and 3) three trajectories could be identified in both boys and girls, with a consistent relatively low VPA group predominant in both sexes. Our results contribute to the scarce current literature reporting objectively measured VPA levels and sex-specific longitudinal changes in children and adolescents. In addition, we report different VPA trajectories for the first time. These VPA data may be especially timely considering the increasing evidence suggesting associations between VPA and cardiometabolic health.[14]

Our findings showed that for boys, on average, daily VPA significantly decreased in later childhood, from age 9 to 12 years old, but then increased during adolescence from age 12 to 15 years, almost returning to the baseline level of age 7 years. Over the 8-year period, therefore, average VPA appeared rather stable. Our observation that VPA increased in boys during adolescence is novel. For girls daily VPA significantly decreased earlier during childhood, between age 7 and 9 years of age, and it remained steadily low throughout adolescence. Girls' VPA remained lower than boys' throughout the follow-up period, which agrees with the limited previous research investigating sex-specific levels of objectively measured VPA.[20–22] However, the mean sex-specific minutes of decrease per year reported by these studies[20–22] were slightly higher than in our findings. The direct comparison in the magnitude of VPA change between studies is hindered by methodological aspects such as age of the participants at baseline and number of follow-ups, as well as the different accelerometer cut-points used in such studies.

The between-sex differences in VPA change found in our study could be related to the sex-specific trajectories of change observed. Trajectory analyses showed that the highest proportion of participants were in the relatively stable, but low, VPA group both in boys and girls (77% and 65%, respectively). However, it is of note that 9% of boys tended to increase VPA over the 8 years, even though they had a low initial level. This is an important finding and suggests that interventions could be designed to support an increase in VPA. In the remaining 14% of boys with relatively high initial VPA, this decreased to same level of the lowest VPA group over the 8-year period, and in the girls all three groups showed a general trend to decreased VPA.

The VPA trajectories found in the current study could be related to variations in organized sport participation, since sport has been reported to increase daily VPA achievement.[32,33] Indeed, previous research reported higher participation in organized sports in child and adolescent boys compared to girls, as well as different sport trajectories between sexes.[34] Howie et al.[34] showed that while no group of girls increased participation in sports across childhood and adolescence, a group of boys did so. Therefore, we could speculate a similarity between the trajectories in sports participation and the VPA results found in the present cohort. On the other hand, engaging in insufficiently intense unstructured active play during children and adolescent's free time could be related to the high percentage of boys and girls showing a trajectory of stable low or decreasing level of VPA. Indeed, it has been shown that children at primary school, especially girls, spend the lowest percentage of time in VPA during the recess period[35,36] and that VPA time significantly decreased in favour of increased sedentary or light physical activities over time.[35]

Thus, it may be critical to promote higher VPA participation before 7 years, especially in girls, as well as to develop preventive strategies to tackle the decline in VPA at this age, so that they could achieve as high VPA levels as possible. VPA should be encouraged early in life in any of the context where children can engage in VPA (i.e. organized sport, outdoor active play or curriculum-based physical activity). Schools, families and policy makers should facilitate outdoor play in accessible and secure playground areas with green surfaces, providing fun and accessible materials or recreational structures that encourage running, jumping and skilful activities.[35,37] Moreover, fitness-oriented enjoyable tasks should be planned during physical education classes with teacher interaction, which have been found to promote participation in VPA during and after school.[38]

Although VPA trajectories have not been reported previously, limiting the comparison with our results, it has been previously shown that MVPA change is not homogeneous from childhood to adolescence.[23,24] From a public health point of view, our and previous research[23,24] suggest that children and adolescents should not be treated as a whole homogenous group in the attempt to promote physical activity, especially when targeting VPA, since trajectories are not uniform and VPA may have different determinants from lower intensities of physical activity.[39] Future studies should investigate the determinants of the different VPA trajectories, so that interventions to promote VPA can be developed.

The main strengths of this study were the methodological design: longitudinal with multiple follow-up data collection points throughout childhood and adolescence and VPA measured objectively using what are currently understood to be the most appropriate accelerometer cut-points, as well as the inclusion of a contemporary cohort (born in 1999-2000) which was socio-economically representative of North-East England.[26] In addition, the data analysis is innovative, since no multilevel linear spline models and trajectories in VPA by sex from childhood to adolescence have been reported previously. However, the sample size of the study decreased over the 8 years of data collection, but participants who provided data at least twice had similar physical activity at baseline compared with those who had missing or invalid accelerometer data [23] and the trajectory analyses are relatively robust to missing data. We used the cutpoints developed by Evenson et al.[29] as recommended by Trost et al.[19] due to their accuracy for physical activity measurement in children and adolescents. In addition, previous research from our group and others have shown that a minimum of 3 wear days is a valid accelerometer-measurement period which provides reasonable reliability[15,28]. However, this accelerometer protocol may have influenced our findings and variability in the results could be obtained with different accelerometer procedures. Additionally, more frequent physical activity measurements might have provided more evidence on the precise timing of changes across childhood and adolescence. Our data could be influenced by the physical, social and/or policy environments; thus, further longitudinal research with larger cohorts, and from other populations, will be necessary to determine if the findings of the present study are generalizable. It remains to be elucidated how the patterns and trajectories of VPA observed influence health outcomes. Moreover, since there are currently no specific recommendations for levels of VPA that children and adolescents should achieve daily, we cannot comment on the adequacy of VPA levels in this cohort. Therefore, we would like to point out that when referring to “relatively low” or “relatively high” in the manuscript, these are descriptive levels relative to the other trajectory groups statistically determined, not based on judgements about the absolute amounts of VPA observed.

5. Conclusions

Our findings suggest that VPA in boys decreases in childhood then increases in adolescence, with an overall declining pattern in girls. Our findings also suggest that sex-groups follow distinct trajectories of VPA change which vary substantially, with girls being at highest risk of relatively low and declining VPA across childhood and adolescence. An emerging body of evidence shows marked cardiometabolic health- benefits particularly associated with VPA,[9–14] and so a better understanding of levels, changes, and trajectories of change in VPA should be useful to inform future physical activity promotional strategies for youth, and possibly also informing future VPA guidelines. Since sport may increase VPA specifically,[32,33] it might be useful to base future strategies aimed at increasing or maintaining VPA across childhood and adolescence around sport, as well as promoting outdoor play and planned physical education tasks.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jsams.2018.10.010.

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