Published by Oxford University Press on behalf of the International Epidemiological Association
International Journal of Epidemiology 2011;40:685–698
doi:10.1093/ije/dyq272

Physical activity change during adolescence: a systematic review and a pooled analysis

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Accepted 20 December 2010

Background It is presumed that physical activity (PA) level declines during the lifespan, particularly in adolescence. However, currently, there is no study that quantifies these changes and pools results for a common interpretation. Therefore, the purpose was to systematically review the international literature regarding PA change during adolescence, and to quantify that change according to a series of study variables, exploring gender-and-age differences.

Methods An electronic search was conducted in the Medline/PubMed and Web of Science databases. Longitudinal studies with, at least, two PA measures throughout adolescence (10–19 years old) or the first PA measure during childhood and the second one during adolescence were selected. From each article, study project name, country, year of the first data collection, sample size, baseline age, follow-up duration, characteristics of the instrument (type, recall time, PA intensity and PA domain), unit of PA measure and report of statistical significance were collected.

Results Overall, 26 studies matched the inclusion criteria. Most were carried out in the USA, assessed PA by questionnaire, and found a decline in PA levels during the adolescence. On average, the mean percentage PA change per year, across all studies, was −7.0 (95% confidence interval: −8.8 to −5.2), ranging from −18.8 to 7.8. The decline was significant according to most sub-groups of variables analysed. Although earlier studies revealed a higher PA decline in boys, the decline has been greater in girls in more recent studies (commenced after 1997). Moreover, although the decline among girls was higher in younger ages at baseline (9–12 years), it was higher in older ages (13–16 years) among boys.

Conclusions The decline of PA during adolescence is a consistent finding in the literature. Differences between boys and girls were observed and should be explored in future studies. Interventions that attempt to attenuate the PA decline, even without an increase in PA levels, could be considered as effective.

Keywords Motor activity, physical activity, exercise, sports, child, adolescent, review, longitudinal studies

Introduction

Physical inactivity has been identified as one of the biggest public health problems of the 21st century.[1] The World Health Organization estimates that ~2 million deaths worldwide annually can be attributable to physical inactivity.[2] In 2002, the World Health Report ranked physical inactivity among the 10 major causes of mortality and disability in the developed world.[3] The health benefits of physical activity (PA) are widely demonstrated by the recent scientific literature.[4] There is strong evidence that regular PA improves body composition, cardiorespiratory and muscular fitness, bone health and metabolic health biomarkers among children and adolescents.[4] Moreover, youth PA can exert both a direct and indirect positive effect on adult health,[5] and track from adolescence to adulthood,[6] which suggests that PA promotion must start early in life.[7]

Despite its health benefits, the world literature suggests that PA level declines across the lifespan, particularly during adolescence.[8] However, at present, there is no evidence based on a systematic review. Previous reviews have mixed study designs and have not been able to pool results across time. A review study from 1993 reported a decline of 2.7% per year among boys and 7.4% per year among girls.[9] This decline was higher for objective PA measures (mainly heart rate).[9] Nonetheless, this review was not systematic and was based only on cross-sectional studies. Another article from 2000, summarizing the results of three investigations, suggested that the decline was higher among boys, vigorous PA and non-organized sports.[10]

Therefore, the aim of this article was to systematically review the international literature about PA change during adolescence, as well as from childhood to adolescence, and to quantify that change according to a series of study variables (such as country, year of initial data collection, sample size, baseline age, follow-up duration, characteristics of the instrument, unit of PA measure), by means of a pooled analysis, exploring gender-and-age differences.

Methods

Eligibility criteria

To be eligible, studies needed to fulfil the following criteria: (i) have a longitudinal design; (ii) have at least two PA measures throughout adolescence (10–19 years), or the first measure in childhood (before 10 years of age) and the second one in adolescence. Studies in which both the first and second PA measures were gathered in childhood were also excluded, since there are few studies only among children and questionnaires may not be applicable to this age group (<10 years).[11] Intervention studies were also considered for selection if they had reported results for the control group (in this case, only the non-intervention group could be included). If not, they were excluded because the aim of the present review was to evaluate the natural change of PA. If there was more than one report with data from the same study, we selected the one where the main objective was to investigate PA change. This decision was taken to avoid overrepresentation of a single study.

Search strategy

The search was conducted in two electronic databases: Medline/PubMed and Web of Science. Four command groups were employed to find articles. Within each group, we used the Boolean operator 'OR' and between the groups we used the Boolean operator 'AND'. In the first group, we included the terms related to PA (physical activity; inactivity; sports; exercise; motor activity; sedentary; sedentarism; sedentariness). In the second one, the terms related to the age group were entered (adolescent; adolescence; young; youth; teenager; teenage; children; childhood; lifespan). In the third group, we added the terms to restrict the study design (longitudinal; cohort; prospective; panel; follow-up). And in the fourth set of commands, we used the PA change terms (tracking; stability; continuity; decline; change; maintenance; adherence; adoption; shift; variability). To broaden the search, a secondary strategy was carried out, replacing the last command group by the following: epidemiology, associated factors; correlates; determinants; predictors; risk factors. During search, no limits were used (i.e. publication date or language). Search was concluded by July 2009.

The article selection process was conducted by the first author of this study (S.C.D.) by a systematic method, which is described in more detail in Figure 1. First, all the references retrieved from the databases were examined and titles were read. Most of the potential articles were excluded in this phase because many did not focus on PA or were clinical investigations. The second step consisted of examination of the abstracts of those papers selected previously. From the 150 papers with abstracts assessed, 76 were selected for reading of the full text, based on the inclusion criteria. Out of these, 41 were excluded. The main reason was the non-report of PA change, accounting for 66% of the papers excluded in this phase. Out of the 35 papers that attained the inclusion criteria, 11 were further excluded by belonging to the same cohort study.[12–22] By the secondary search method, two new studies that were not found by the previous search were included.[23,24] The reference lists of all selected papers were examined to detect other publications eligible for this review, but none was found. Therefore, the present review included data from 26 articles.[23–48]

Data analysis

From each paper, the following information was extracted: study project (if it had an official name),

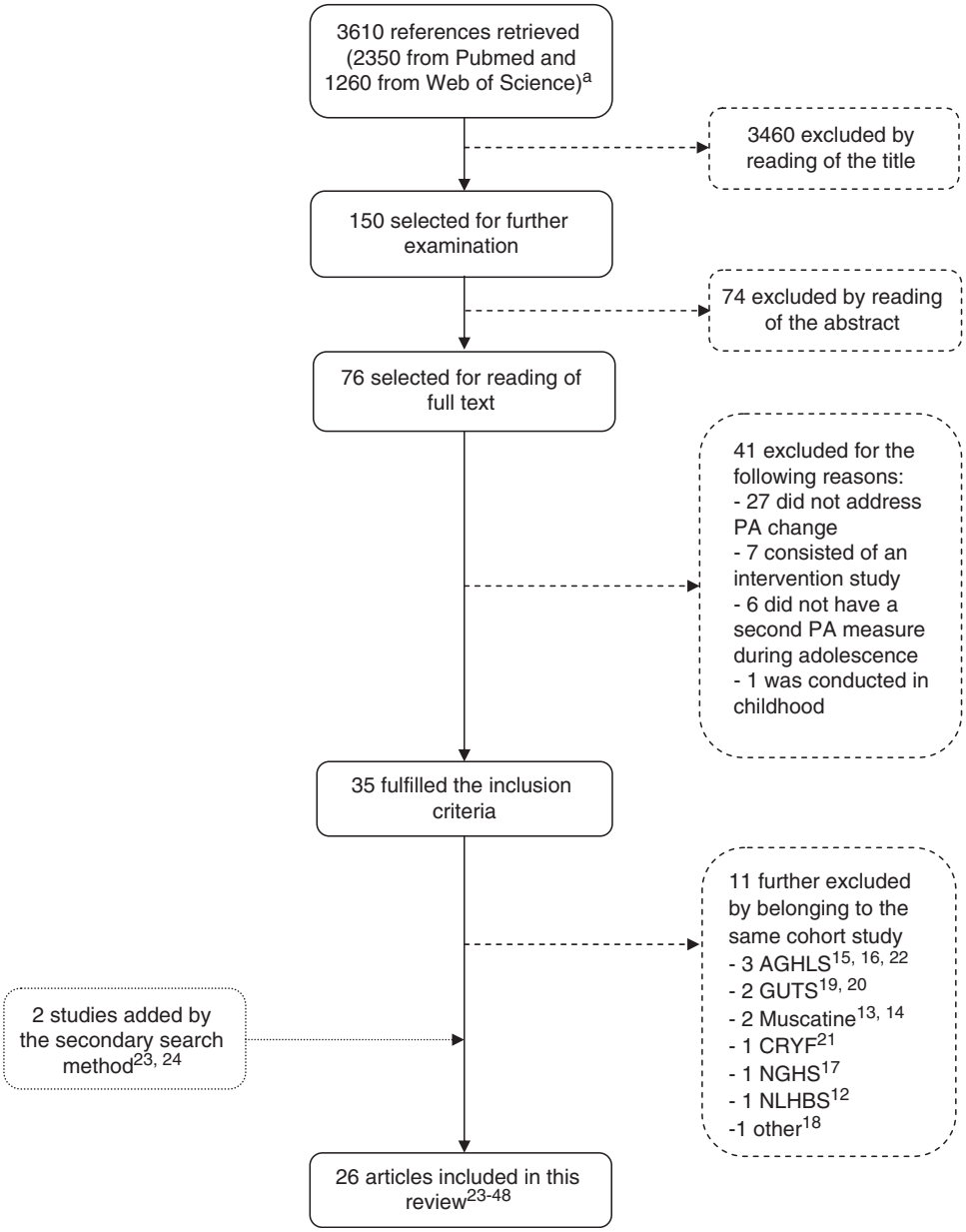

Figure 1 Flow chart of studies selection process. [a]Some references may have overlapped, but were excluded in the next steps. AGHLS, Amsterdam Growth and Health Longitudinal Study; GUTS, Growing Up Today Study; CRYF, Cardiovascular Risk in Young Finns; NGHS, National Heart, Lung, and Blood Institute Growth and Health Study; NLHBS, Norwegian Longitudinal Health Behavior Study.

country and year of initial data collection, sample size, baseline age, follow-up duration, characteristics of the instrument (type, recall time, PA intensity and PA domains), unit of PA measure and report of the results' statistical significance. As the PA measurement unit varied widely across studies, PA outcome was calculated as the percentage PA change during the follow-up, by dividing the difference between the final and the initial value of PA (usually its mean) by the initial value. To enable comparison across studies with different follow-up, we divided the relative change by the follow-up duration (in years), obtaining thus the percentage PA change per year, which is referred as the outcome in this article. Therefore, this approach enabled us to generate a pooled estimate of PA change over all studies.

Because a study could report more than one PA measure, of the 26 studies, we had 38 PA measures (10 studies with two different measures and 1 study with three PA measures). These measures were grouped into the following five categories: duration (min/day; h/day; min/week; h/week); frequency (session/day; block/day; h/week; bout/week); index (MET-min/day; MET-h/day; MET-day; MET-h/week; MET-week;

step/day); percentage (% attaining 1 h/day; 2 h/day; 3 h/week) and number of different types of activities.

For the pooled analyses, differences in percentage PA change per year according to the study characteristics were analysed by the Kruskal–Wallis non-parametric test. To analyse if the mean percentage PA change per year was significant or not, within the categories of each variable extracted, 95% confidence intervals (CIs) were reported (an interval including the zero value means that the difference is not significant). Adjusted analysis, controlling the effect of one variable for each other, was also done, by multiple linear regression. Because the *N* for the analyses was relatively small, and the distribution of the outcome was asymmetric, either a logarithmic or square root transformation was conducted. Additional analyses for both transformed outcomes were run, but the results were basically the same as the non-transformed variable and therefore are not presented.

With the purpose to conduct a meta-regression, we generated a standard error for each PA measure, which corresponded to the inverse probability of its sample size. This procedure was done because only a few studies have reported the standard error of PA change. The heterogeneity across studies was calculated by Cochrane Q-based test. Further, a sensitivity analysis was done for each study characteristic reported above to examine how much of the heterogeneity in the outcome could be explained by each variable. An influence analysis was also taken into account, omitting each study individually from the data set and recalculating the pooled estimation and the sensitivity analysis. Publication bias hypothesis was assessed by inspection of the funnel plot for asymmetry, a scatter plot of individual studies effect against a measure of its precision and by the statistical Begg's test.

Whenever possible, the analyses were run separately for boys and girls. To compare the mean PA change between boys and girls, the Wilcoxon signed rank test was used. The overall PA change for studies with results separated for boys and girls was calculated by weighting the data of each gender for their sample size. In three studies, it was necessary to weight the data to obtain a single measure of PA. They were weighted for age,[34] days of week[24] and ethnicity.[46] Additionally, the data from one study[48] were extracted from the graphics, as the absolute values were not described in the text. All the statistical tests were two-sided, and the significance level was set at 5%. The analyses were performed with Stata 10 software (StataCorp, College Station, TX, USA).

Results

Description of studies

The characteristics and main results of the 26 studies included in this review are described in Table 1. The first studies about this subject were published in 1998,[28,29,31] and the large majority were school based. Nevertheless, when we evaluated the onset of data collection, we can see that the first longitudinal study to investigate PA change during adolescence started in 1977, in the Netherlands.[48] The following study also took place in Europe (Finland) in 1980.[47] The first longitudinal study carried out in the USA took place in 1985.[35] Besides North America[23–25,28,30–35,37–43] and Europe,[26,27,36,44–48] a study from New Zealand was found.[29] Four studies comprised only girls,[35,36,39,43] but none was conducted only among boys. The sample size ranged from 97[38,45] to 12 759[32] individuals (mean = 1670; median = 580). The baseline age ranged from 9[24] to 15 years[29,32,46] (mean = 12.4; median = 12.2). The follow-up duration ranged from 1[31,32,36] to 9 years[35] (mean = 3.6; median = 3.0). The age at the end of the study ranged from 12[31,36] to 19 years[26] (mean = 16.0; median = 16.0).

The most often used instrument for PA data collection was questionnaire, administered in 22 studies. Many different questionnaires were used, and only two of them—Godin's Leisure-Time Physical Activity Questionnaire and the 3-Day Physical Activity Recall—were used in two different studies.[41–44] Three studies used pedometers,[30,38,45] and two used accelerometers[24,43] to assess PA level. Regarding the single PA measure, the most common was h/week, reported by four studies.[29,34,41,46] Whenever possible, the initial and final values of PA (usually mean and its standard deviation) are described in Table 1.

A summary of studies according to some study characteristics is presented in Table 2. Analysing the data from 26 studies, 40% ($n = 10$) commenced in the last 11 years, and most (61.5%) were carried out in the USA ($n = 16$). The sample size was evenly distributed among the three groups (<200, 200–999, $\geqslant$1000), and most studies (85%) comprised boys and girls ($n = 22$). In almost two-thirds of the studies (65%), the baseline age was between 9 and 12 years, and in almost three-quarters (73%) the age at the end of study was between 15 and 18 years. Only seven studies (27%) followed the subjects for 5 or more years. Questionnaires were administered in 85% ($n = 22$) studies. The most studied intensity was moderate-to-vigorous PA ($n = 12$; 46%), although four studies (15%) did not mention the PA intensity. More than a half of studies ($n = 17$; 65%) reported significant PA change for at least one gender. However, in six studies (23%) it is not possible to know whether or not the results were significant, because neither the *P*-value nor the CI nor the standard error of PA change was provided. The distribution of the PA measures in the 26 studies ($n = 38$) according the study characteristics was also analysed (data not shown), and was very similar to that observed for the studies (Table 2). Therefore, for the pooled analyses, we considered the PA measure ($n = 38$) as the unit of analysis, rather than the study ($n = 26$).

Table 1 Summary of the articles included in the present review (ordered by author name)

References	Study (project)	Location (country) Year of data collection	*n* (sample size)	Age (years) at baseline	Follow-up duration (years)	Instrument; recall time; intensity; PA domain	Main results †Observation
Aaron *et al.*[25]	Adolescent Injury Control Study	USA 1990	782 (410 boys and 372 girls)	12–15	3 (annually)	Modifiable Physical Activity Questionnaire; past year; light, moderate and vigorous intensity; leisure and competitive activities	Median total PA (min/week) declined 26% (43% boys and 26% girls), $P < 0.001$ †PA declined 56% (7.1 to 3.1), $P < 0.001$
Anderssen *et al.*[26]	Norwegian Longitudinal Health Behavior Study	Norway 1990	557 (262 boys and 295 girls)	Mean = 13.3	3 and 6	Questionnaire (2 questions); Typical month (1st question) and typical week (2nd question); moderate-to vigorous-intensity; exercise and sports outside school	Proportion that achieved at least 2–3 time/week of PA Boys: 85% to 16.5% Girls: 72% to 46% About 55% declined PA level (frequency or duration category) during the study
Belanger *et al.*[23]	Natural History of Nicotine Dependence in Teens (NDIT)	Canada 1999	1293 (608 boys and 685 girls)	12–13 (mean = 12.8)	5 (with 3 months apart each other during the school time, totalizing 20 cycles)	Adapted from the Weekly Activity Checklist; previous 7 days; moderate-to vigorous-intensity; leisure time (outside school and gym class)	Overall change (session/day) = −7.2% (95% CI: −7.5; −6.9) per year
Brodersen *et al.*[27]	Health and Behavior in Teenagers Study	England 1999	4319 (2577 boys and 1742 girls)	11–12 (mean = 11.8)	4 (annually)	Questionnaire (1 question); past week; vigorous intensity; not reported	Decline over the course (day/week) Boys: −1.1 (0.07) Girls: −1.8 (0.07) †*P*-values are not reported
DiLorenzo *et al.*[28]	–	USA 1991	111 (57 boys and 54 girls)	Mean = 11	3	PA interview; three previous school days; moderate-to vigorous-intensity; not reported	Boys (MET/day): 4.54 (3.58) to 3.73 (3.62) Girls (MET/day): 3.27 (2.87) to 2.90 (3.23) †Non-significant changes
Dovey *et al.*[29]	Dunedin Multidisciplinary Health and Development Study (DMHDS)	New Zealand 1987–88	755 (400 boys and 375 girls)	15	3	Adapted from Minnesota Leisure-Time PA Questionnaire; previous year; not reported; School programmes; competitive sports; leisure-time PA	Overall (h/week): 9.7 to 6.1 Boys (h/week): 11.7 to 7.8 Girls (h/week): 7.5 to 4.3 *P*-value < 0.001 Median number of PA: Boys: 7 to 3 Girls: 6 to 3
Duncan *et al.*[30]	–	USA 1999–2000	371 (185 boys and 186 girls)	Mean = 12.1	4 (annually)	Questionnaire adapted from Youth Risk Behavior Survey; and Pedometer; last week (at least 20 min of hard PA) and a typical week (at least moderate PA); moderate-to vigorous-intensity; not reported	Questionnaire (day/week) Hard PA: 3.50 (1.94) to 2.95 (2.03) Typical PA: 3.99 (1.88) to 3.64 (1.83) Pedometer (step/day): 1.04 (0.42) to 0.98 (0.44) †Significant decrease
Garcia *et al.*[31]	–	USA 1992–93	132 (56 boys and 76 girls)	Not reported (estimated to be 11.5 years transition to high school)	1	Child/Adolescent Activity Log for 7 consecutive days; prior day; not reported; not reported	Boys (index): 12.8 (11.0) to 11.0 (9.6) Girls (index): 8.5 (7.4) to 7.4 (5.6) †Non-significant changes
Gordon-Larsen *et al.*[32]	The National Longitudinal Study of Adolescence Health (Add Health)	USA 1995	12 759 (6288 boys and 6471 girls)	11–19 (mean = 15.9)	1	Questionnaire (adapted from other instruments); not reported; moderate-to vigorous-intensity; not reported	Change (bout/week) All: −0.19 (0.03) Boys: −0.25 (0.03) Girls: −0.17 (0.03)

(continued)

Table 1 Continued

References	Study (project)	Location (country) Year of data collection	*n* (sample size)	Age (years) at baseline	Follow-up duration (years)	Instrument; recall time; intensity; PA domain	Main results †Observation
Janz *et al.*[33]	Muscatine Study	USA 1991	110 (53 boys and 57 girls)—pre-pubertal students	7–12 (mean = 10.5)	4 (annually)	3-day sweat recall; previous 3 days; vigorous; all domains	Number of events lasting roughly 20–90 min Boys: 3.5 to 5.0 (median) Girls: 2.5 to 3.0 (median) †Increase among boys but no significant change among girls
Kahn *et al.*[34]	Growing Up Today Study (GUTS)	USA 1997	10 250 (4460 boys and 5790 girls)	10–16	2 (annually)	Questionnaire with 18 activities; previous year; all intensities; leisure time and sports teams	Boys (h/week): 10.89 to 9.91 Girls (h/week): 10.13 to 9.77 †*P*-values are not reported
Kimm *et al.*[35]	National Heart, Lung, and Blood Institute Growth and Health Study (NHGS)	USA 1985	2014	9–10	9 (annually)	3-Day Activity Diary; Habitual Activity Patterns Questionnaire; past year; all intensities; all domains	Daily PA (MET-min/day): 446.8 to 292.1 Habitual PA (MET-time/week): 29.3 to 4.9 †*P*-values are not reported
Knowles *et al.*[36]	–	Scotland 2006	150 (only girls)	Mean = 11.8	1	Physical Activity Questionnaire for Children (PAQ-C); school year (7 days recall); all intensities; not reported	PA score (ranging 1 to 5): 3.06 (0.7) to 2.78 (0.6), $P < 0.01$
McMurray *et al.*[37]	Cardiovascular Health in Children Study (CHIC)	USA 1990	1064 (535 boys and 529 girls) with data available for at least 3 years follow-up	9–13 (mean = 11)	2, 3, 4, 5	Questionnaire with 32 activities (nothing more is reported)	Boys (MET/day): 328 (53) to 160 (72) Girls (MET/day): 310 (52) to 145 (66) †*P*-values are not reported
Morgan *et al.*[38]	–	USA 2006	97 (35 boys and 62 girls)	Mean = 13.5	2.25 (27 months)	Pedometer; 4 weekdays (baseline) and 8 weekdays (follow-up); all intensities; all domains	Boys (step/day): 13 204 (3488) to 12 845 (3145) Girls (step/d): 11 769 (2761) to 11 830 (2889) †Non-significant changes
Must *et al.*[39]	MIT Growth and Development Study	USA 1990–3	156 (only girls), non-obese and pre-menarcheal	8–12 (mean = 10)	Mean = 7.5 (4 years after the menarche)	Questionnaire; Typical day; moderate-to vigorous-intensity; leisure and sports	Mean time (h/day): 4.13 (1.59) to 3.67 (1.79), $P = 0.043$ Mean index (MET-h/day): 15.4 (6.9) to 12.1 (6.2), $P < 0.001$
Nader *et al.*[40]	Child and Adolescent Trial for Cardiovascular Health (CATCH)	USA 1994	1400 (number of each gender is not reported, estimated in 50%)	Not reported (estimated to be 11 years)	3 (annually)	Self-administered PA checklist (SAPAC); previous day; not reported; not reported	Vigorous PA (min/day): 45.5 (1.9) to 22.1 (1.4) Total PA (min/day): 163.2 (3.1) to 125.4 (2.6) †*P*-values are not reported
Nader *et al.*[24]	National Institute of Child Health and Human Development (NICHHD) Study of Early Child Care and Youth Development	USA 2000	604 (324 boys and 280 girls)	9	2, 3 and 6	Accelerometer; 7 days (2 weekend days and 5 weekdays); moderate-to vigorous-intensity; all domains	Min/day All: 180.9 to 45.2 Boys: 188.9 to 53.9 Girls: 173.3 to 34.9 % 1 h/day: 99.0 to 26.7 †Data weighted for weekdays and weekends
Nelson *et al.*[41]	EAT (Eating Among Teens)	USA 1998–99	806 (366 boys and 440 girls)	11–15 (mean = 12.8)	4	Adapted from Godin Leisure-Time Exercise Questionnaire; usual week; moderate-to vigorous-intensity; leisure time	Boys (h/week): 6.7 (0.3) to 6.6 (0.3), $P = 0.687$ Girls (h/week): 5.9 (0.2) to 4.9 (0.2), $P < 0.001$

(continued)

Table 1 Continued

References	Study (project)	Location (country) Year of data collection	*n* (sample size)	Age (years) at baseline	Follow-up duration (years)	Instrument; recall time; intensity; PA domain	Main results †Observation
Nigg[42]	–	USA 1995	400 (181 boys and 219 girls)	Mean = 14.9	2.7	Godin's Leisure Time Exercise Questionnaire; usual week; mild, moderate and strenuous intensity; not reported	Exercise index (MET/week): 65.2 (40.9) to 49.8 (30.9) †Significant decline
Pate *et al.*[43]	Trial of Activity for Adolescent Girls (TAAG)	USA 2001	501 (only girls)	Mean = 12	2	3-Day PA Recall; previous 3 days; moderate-to vigorous-intensity; all domains;; accelerometer; 6 days; moderate-to vigorous-intensity; all domains	Questionnaire (number of 30 min-block/day): 1.95 to 1.42 ($P < 0.001$) Accelerometer (MET-min/day) 151.2 to 142.0 ($P < 0.01$)
Raudsepp *et al.*[44]	–	Estonia 2003	345 (176 boys and 169 girls)	Mean = 12.3	1.75 (22 months, four occasions, two at each school year)	3 Day Physical Activity Recall (3DPAR); 3 previous days (2 weekdays); light, moderate and vigorous intensity; not reported	MET/day (all intensities) Overall: 75.5 (7.8) to 65.1 (6.8) Boys: 79.3 (7.3) to 71.5 (6.5) Girls: 71.7 (6.8) to 58.7 (6.4) Block/day (moderate-to-vigorous PA) Overall: 4.5 (3.4) to 3.7 (3.0) Boys: 4.8 (3.2) to 4.4 (3.2) Girls: 4.2 (3.3) to 3.0 (3.1) †Significant decline
Raustorp *et al.*[45]	–	Swedish 2000	97 (46 boys and 51 girls)	12–14 (mean = 12.7)	3 and 5	Pedometer; 4 consecutive week-days; all intensities; all domains	Boys (step/day): 15 633 (3683) to 11 398 (3783) Girls (step/day): 13 276 (2818) to 12 286 (3523) †Significant decline only among boys
Sagatun *et al.*[46]	Oslo Health Study	Norway 2000–01	2489 (1112 boys and 1377 girls)	15–16	3	Questionnaire (1 question); typical week; moderate-to vigorous-intensity; outside school	Boys (h/week): 5.28 to 4.56 Girls (h/week): 3.67 to 3.25 Prevalence of ⩾3 h/week: Boys: 74.4% to 64.3% Girls: 57.2–51.0% †Significant decline †Data were weighted for ethnicity
Telama and Yang[47]	Cardiovascular Risk in Young Finns	Finland 1980	1687 (748 boys and 939 girls), total with data for the entire follow-up	9, 12, 15	3, 6 and 9	Questionnaire; not reported; not reported; leisure time, sports, competition	Percentage of 2 times/week declined 26.4% (boys) and 14.0% (girls). Considering only MVPA, the decline was 15.2% (boys) and 12.4% (girls). †Period considered: 12–15 years †Significant decline
Van Mechelen *et al.*[48]	Amsterdam Growth and Health Study (AGHS)	Netherlands 1977	182 (84 boys and 98 girls)	13	1, 2, 3	Semi-structured interview; 3 months; moderate-to vigorou-s-intensity; all domains	PA (min/week) Boys: 610 to 510 Girls: 540 to 520 PA (MET/week) Boys: 5000 to 3700 Girls: 3800 to 3400 †Values are approximated (based on the article graphics) †Significant decrease only among boys Prevalence of 1 h/day: Boys: 82.9 to 60.8% Girls: 65.6 to 74.5%

Table 2 Description of studies and distribution of PA change, according to study characteristics

Variable	*n* (%)	Annual change (%)	95% CI	*P*-value[a]
Beginning of the study (year)				0.60
1977–87	4 (15.4)	−7.4	−12.0 to −2.9	
1988–97	11 (42.3)	−7.5	−11.4 to −3.6	
1998–2007	11 (42.3)	−6.4	−8.7 to −4.1	
Country				0.61
USA	16 (61.5)	−6.8	−9.5 to −4.1	
Other[b]	10 (38.5)	−7.3	−9.7 to −5.0	
Sample size (*n*)				0.04
<200	8 (30.8)	−3.6	−7.2 to −0.1	
200–999	9 (34.6)	−9.5	−12.5 to −6.5	
⩾1000	9 (34.6)	−7.1	−9.6 to −4.6	
Gender				0.60
Both	22 (84.6)	−7.2	−9.3 to −5.1	
Only female	4 (15.4)	−6.2	−10.4 to −2.0	
Age at baseline (years)				0.88
9–12	17 (65.4)	−6.7	−9.0 to −4.6	
13–16	9 (34.6)	−7.5	−10.7 to −4.2	
Age at end of study (years)				0.23
11–14	7 (26.9)	−7.9	−12.9 to −3.0	
15–19	19 (73.1)	−6.7	−8.6 to −4.8	
Follow-up duration (years)				0.78
1.0–2.9	8 (30.8)	−7.5	−10.7 to −4.3	
3.0–4.9	11 (42.3)	−6.6	−9.9 to −3.3	
5.0–9.0	7 (26.9)	−7.3	−10.2 to −4.4	
Instrument				0.36
Questionnaire/diary	22 (84.6)	−7.3	−9.3 to −5.3	
Pedometer/accelerometer	4 (15.4)	−5.5	−11.2 to 0.2[c]	
PA intensity				0.13
Low/moderate/vigorous	7 (26.9)	−7.4	−10.6 to −4.1	
Moderate-to-vigorous	12 (46.2)	−5.8	−7.7 to −3.8	
Only vigorous	3 (11.5)	−5.8	−37.2 to 25.5[c]	
Not reported	4 (15.4)	−11.7	−17.8 to −5.6	
PA measure[d]				0.22
Duration	10 (26.3)	−7.3	−11.1 to −3.5	
Frequency	7 (18.4)	−5.6	−12.0 to 0.8[c]	
Index (MET)	14 (36.8)	−6.1	−8.3 to −3.9	
Percentage	5 (13.2)	−6.4	−12.8 to −1.0	
Number of activities	2 (5.3)	−18.4	−24.1 to −12.6	
Significant PA change ($P < 0.05$)				0.15
No	3 (11.5)	−6.2	−22.6 to 10.2[c]	
Yes	13 (50.0)	−7.2	−9.6 to −4.9	
Only in boys or girls	4 (15.4)	−1.6	−8.4 to 5.2[c]	
Not available	6 (23.1)	−9.1	−12.5 to −5.7	
Total	26 (100)	−7.0	−8.8 to −5.2	–

[a]Kruskal–Wallis test.
[b]Canada, England, Estonia, Finland, Netherlands, New Zealand, Norway (two), Scotland and Swedish.
[c]Non-significant change ($P > 0.05$).
[d]A given study could have more than one PA measure.

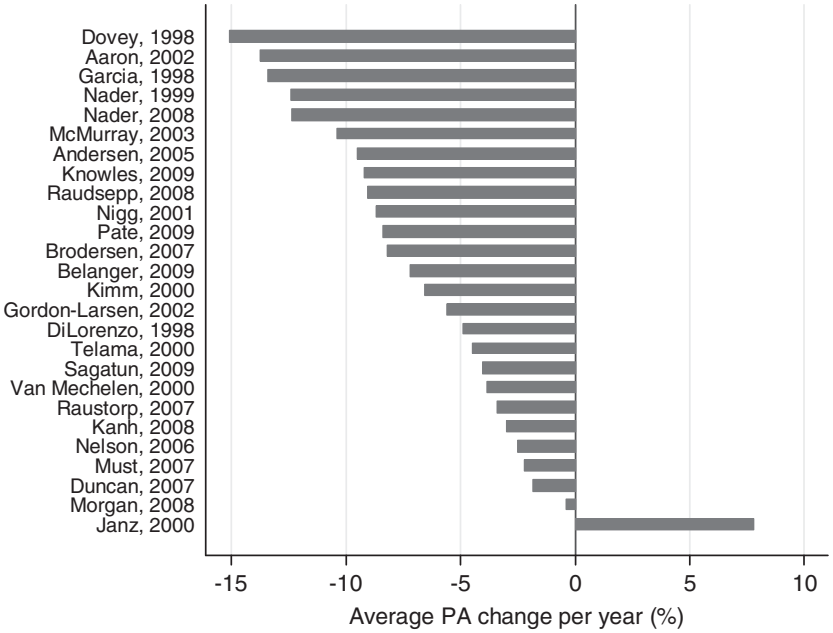

Figure 2 Description of annual average PA change according to each study

Pooled analyses

The combination of all sample sizes summed 43 341 individuals (19 548 boys and 23 883 girls). The results of each study, in terms of annual percentage PA change, are illustrated in Figure 2. Among all studies, only one reported an increase of PA level from baseline to follow-up, being significant only among boys.[33] Three studies did not find significant changes,[28,31,38] and the remaining found a decline in PA level. However, one study detected a decline only among girls,[41] and in two studies it was significant only among boys.[45,48]

The overall percentage PA change per year ranged from −18.8 to 7.8 (mean = −7.0; median = −6.8). The 95% CI ranged from −8.8 to −5.2, whereas the 99% CI ranged from −9.4 to −4.6. If in the combined measure only the PA measure that yielded the smallest decline (for those studies with more than one PA measure reported) was considered, the mean change would be −5.7 (95% CI: −7.5 to −3.8), ranging from −13.4 to 7.8. In the same way, if in the combined measure only the PA measure that yielded the highest decline was considered, the mean change would be −7.7 (95% CI: −10.0 to −5.2). The median decline was close to the mean in both simulations (−5.3 and −7.7, respectively). Mean PA change weighting data for sample size were −6.2 (95% CI: −7.5 to −4.9).

To explore if the average percentage PA change by year could be extrapolated to the overall adolescence period, we tested the global PA change (considering the entire follow-up duration) according to the total follow-up duration. On average, the studies with 1 and 2 years of follow-up showed an overall change of −12.4% (95% CI: −18.5 to −6.3); those with 3 and 4 years of follow-up showed an overall change of −20.1% (95% CI: −30.5 to −9.7) and those with 5 or more years of follow-up presented an overall change of −46.1% (95% CI: −64.5 to −27.6). The Spearman correlation between global PA change and follow-up duration was 0.43, with a beta coefficient of −5.6 (95% CI: −9.0 to −2.1; $P = 0.002$). This association was independent of age at baseline (adjusted beta = −5.9; 95% CI: −9.6 to −2.3; $P = 0.002$). Therefore, it means that for each year of follow-up, the PA (adjusted for age at baseline) declined, on average, 5.9% per year, which is similar to the mean decline obtained by our analytical approach (mean decline = 7.0; 95% CI: 5.2 to 8.8).

Differences between genders

Some studies reported PA change separately for boys and girls. Among boys, mean PA change was −7.0 (95% CI: −9.6 to −4.5), ranging from −19.0 to 10.7. Among girls, mean PA change was −6.3 (95% CI: −8.4 to −4.1), ranging from −16.7 to 5.0. There was no gender difference ($P = 0.41$). Even considering the least decline, the PA change would be −6.1 for both genders (95% CI: −9.7 to −2.6). When comparing the mean change of studies that included only girls with the mean change among girls of studies that encompassed both genders, the results were basically the same (−6.2 vs −6.3, respectively, with a P-value = 0.98).

However, an interaction of gender PA change with year of data collection and baseline age was detected. Although PA decline among boys is becoming smaller (9.9% in studies beginning up to 1987 to 5.4% in studies beginning after 1997), among girls it seems to be increasing, especially based on studies from the last decade (4.8% for the period 1988–97 to 8.2% for the period 1998–2007). When this

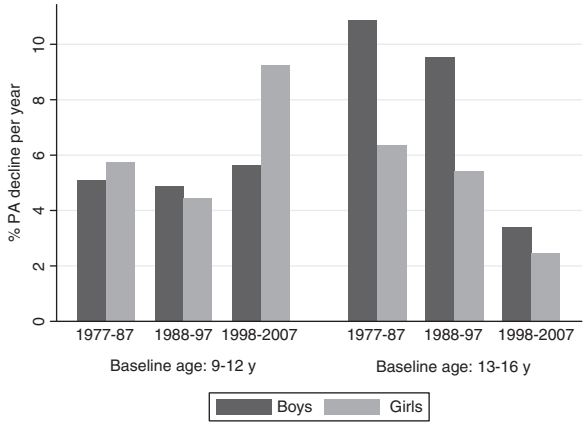

Figure 3 Annual percentage PA decline among boys and girls, according to the year of study (baseline data collection) and age at baseline

information is combined with the baseline age, it becomes evident that the increase in PA decline among girls has occurred only in the younger (baseline age = 9–12 years) (Figure 3). Among younger boys, it seems to be stable over the years. Nevertheless, among older adolescents (baseline age = 13–16 years), we can see a decrement in PA decline, which was steeper in boys than in girls (Figure 3). Similar patterns were verified using only the smallest or largest decline for studies with more than one PA measure.

Differences across study characteristics

The results of the pooled analyses according to each study characteristic are presented in Table 2. In summary, PA showed a decline for the categories of all variables, except for: objective measure (mean = −5.5; $P = 0.05$), vigorous intensity PA (mean = −5.8; $P = 0.51$), frequency as PA measure (mean = −5.6; $P = 0.08$) and no significant results for PA change (mean = −6.2; $P = 0.24$) or significant only for one gender (mean = −1.6; $P = 0.55$). Nevertheless, it is important to mention that the number of observations for each of these groups was small, ranging from three to seven. Comparing the categories of each variable, there were significant differences in percentage PA change per year only for the sample size ($P = 0.04$). However, this difference disappeared when this variable was controlled for PA measure ($P = 0.06$). With the adjustments for each variable in the table, the other results were basically the same, and therefore are not shown. Moreover, the mean PA change weighted for sample size yielded similar results, except that the variability (95% CI) became narrower.

Meta-regression

The analyses presented in Table 2 were also run through a meta-regression, considering the inverse probability of sample size as the standard error of each study. As the *P*-value for heterogeneity was very small ($P < 0.001$), a random effect model was applied. This approach yielded very similar results (data not shown) and allowed estimation of the characteristics that explained most of the heterogeneity across studies. Sample size, PA intensity and PA measure explained between 17% and 22% of the differences in PA change estimate. A model including all these three variables explained almost a half (44%) of the heterogeneity across studies. Influence analysis, omitting each study individually, did not affect the results, neither the global measure nor the sensitive analyses for each study characteristic. Either the observation of the funnel plot or the formal statistical test (data not shown) allowed the conclusion that there was no indication of publication bias, as results for studies with lower precision (small sample size) seemed to have the smallest PA change.

Discussion

This is the first study to systematically review the literature regarding PA change throughout adolescence. This study has some strength that deserves to be highlighted. First, the elaboration of this article was based on MOOSE (Meta-Analysis of Observational Studies in Epidemiology) guidelines.[49] Second, the data comprised the entire adolescence period (10–19 years), which is known to be a critical phase in life regarding PA change.[8] Third, only longitudinal studies were included, since cross-sectional data are subject to a cohort effect and do not reflect changes experienced by a single individual. Fourth, several descriptors were used to search articles and no limits were employed, making this process widely sensitive. Fifth, the use of a single measure (percentage PA change per year) enabled us to quantify the PA change and to analyse this outcome according to various sub-groups of variables, even though the diversity of PA measures along studies.

There are some limitations that also should be mentioned. As the search process was conducted by only one person (the principal investigator of this article), one could argue that some important article might not be identified. However, apart from the search carried out in two large databases (PubMed and Web of Science), the reference list of all articles included in this review was examined, and no additional study has been found. Besides this, the reference list of two review papers investigating the correlates of PA[10,50] was also assessed, but we did not detect any other paper not retrieved or identified by our search method. Another point consisted of the lack of a methodological evaluation of the articles included. For example, some of them reported a high attrition rate, whereas others did not address this issue. Moreover, the original estimate of PA change variability (e.g. standard error) of each study should be preferable to the meta-regression analyses, rather than our estimate based on the sample size. Our results

suggest that the PA decline during adolescence is a consistent finding in the literature. Only one study has reported an increase in PA level, which was significant only among boys.[33] Nevertheless, this study was restricted to pre-pubertal subjects and analysed the number of vigorous events lasting at least 20 min. These characteristics could explain that finding, since PA seems to have a greater decline after discernible physical maturation,[30] and involvement in vigorous PA may increase during adolescence, even in the presence of an overall decline in PA.[47] Three studies found no significant changes, but two of them could have been affected by sample size limitations, since the PA change in one was −4.9% per year[28] and in the other it was −13.4%.[31] The third one actually did not find any change (−0.4% per year),[38] but PA was measured by pedometers. The other two studies that used steps/day as PA measure also reported small changes (−1.5 and −3.4% per year).[30,45] The significance of PA change was not reported in eight studies, although the results ranged from −3.0 to −17.9% per year (mean = −9.1; 95% CI: −12.5 to −5.7), and sample size was higher than 500 individuals for all of them.[24,26,29,34,35,37,40,46] Moreover, it is worth emphasizing that PA level presented a decline according to most sub-groups of variables analysed.

Because we found a mean decline of 7% per year in PA level, we could infer that global PA change throughout adolescence would be ~60–70%. That finding is comparable to the study with the largest follow-up duration (9–10 to 18–19 years) that found an overall decrease of 83% (9.2% per year) considering the habitual PA (MET-time/week), although results were obtained only among girls.[35] Another study that followed individuals from 9- to 15-years old, with accelerometry, found a decrease of 75% (12.5% per year),[24] which is higher than our result and might suggest that our estimate is somewhat conservative. In this same study, most individuals (99%) achieved the goal of one daily hour of moderate-to-vigorous PA recommended for children and adolescents, when they were 9 years of age.[4,51] Nevertheless, at the end of study (15 years old) only 26.7% achieved such recommendations,[24] meaning that, if PA had continued decreasing at the same rate, at the end of adolescence no one would be considered active. However, after the age 18 years, PA recommendation changes to 30 min daily,[4] which might cause significant changes in this scenario.

The analysis stratified by gender revealed an interesting finding that should be further explored. There was an interaction between PA decline and gender with year of study and age at baseline. It is difficult, however, to state if the PA decline is actually becoming greater in girls and smaller in boys, or if this trend is an effect of the instruments used in the most recent studies, which could be more sensitive in measuring the female PA than the first instruments. One recent study that objectively measured PA level, by accelerometer, found only a small difference in the decline between boys and girls (11.9 vs 13.1, respectively).[24] When we explored these differences according to age at baseline, increment in the decline among girls was verified only in the most recent studies with 9- to 12-year-olds at baseline. Among older girls (13–16 years) a slight reduction in the decline was identified. Among younger boys (9–12 years), there was a slight increment in the decline in the most recent studies, but a steep decrease among older boys (13–16 years). One reason for a decrease in decline might be that the boys in more recent years start from a lower level of PA and therefore there is less to decline from.[29,46] Therefore, whereas girls declined more in their PA levels at younger ages (mean = 7.1% per year vs 5.1% per year among boys), boys had a higher decline at older ages (mean = 8.6% per year vs 5.3% per year among girls). That result might be an effect of sexual maturation, which usually happens earlier in females, although other factors may also be suggested. Independently of this, it is important to mention that the differences in absolute PA level between genders at the beginning of the adolescence, when PA is usually higher among boys, in general, became smaller or even reversed.[47,48]

Although the decline in PA levels is consistent in the literature, it is not clear yet what are the factors related to this change. The authors of one study described herein attributed that decline to the number of physical activities, rather than the time spent in each PA.[25] In fact, the number of physical activities was the measure that presented the highest decline, and although only two studies have analysed this sub-group, their findings were consistent (an overall decline of 54% in one and 56% in the other during 3 years of follow-up).[25,29] The type of PA, however, presented contradictory results between two studies: whereas one described a higher decline in organized sports,[47] the other attributed the decline to the reduction of participation in non-organized sports.[48] PA intensity is another inherent component that deserves further investigation, because its definition and instrument varied widely across studies. At present, it is therefore unclear what kind of PA intensity has the greatest variability during adolescence, although all of them have presented a decline. Nevertheless, it is important to mention that the PA decline was basically the same (21%) between self-reported (questionnaire) and objective (accelerometry) measure in an analysis of a sub-sample of adolescents from 11–12 to 13–14 years old.[35] Finally, the decrease in PA may be positively associated with its baseline level,[17] although a possible effect of regression-to-the-mean phenomenon may not be ruled out. That is, those with high levels of baseline PA can potentially present a large decrease in PA levels, compared with those who start with lower PA levels.

With regard to the external factors, there are few studies that investigated the predictors of PA change

among adolescents. The largest body of evidence comes from cross-sectional studies[10,50] that are useful for investigating the correlates, but not the predictors of PA.[52] Moreover, it is relevant to state that a determinant of behaviour is not the same as a determinant of behaviour change.[53] Among the limited longitudinal researches, there seems to exist an inverse association between PA change and sedentary behaviour change,[44] and with body mass index change.[18] In addition to that, the decline seems to be higher in adolescents of low socio-economic level,[24,46] and lower in adolescents with more social friend support.[18,30] No difference according to ethnicity was reported by one study.[27] The seasonal effects should also be considered, because PA level tends to decrease more in the winter and in the presence of adverse weather conditions (e.g. snowfall).[23] Another external factor related to PA decline could rely on secular changes. Secular changes could occur with overall PA levels declining over time. Although possible, a recent study did not find any secular change in PA level of two adolescent cohorts within 5 years of follow-up (from 1999 to 2004).[41]

The decline in PA levels has also been demonstrated in studies with animals,[54] suggesting that there is a biological plausibility for the occurrence of this phenomenon. However, PA is a multi-dimension behaviour that can be influenced by physiological, developmental, environmental, psychological, social and demographic factors.[55] Therefore, our challenge consists in determining how the environment can modify the biological tendency to PA decline with age.[8]

Based on the current findings, some recommendations are pointed out for future research and interventions. Considering that all studies located are from developed countries, particularly the USA, evidence from developing and undeveloped countries is warranted to clarify if the present results can be generalized to distinct settings. Attempts to improve the validity and comparability of instruments across studies are also necessary. There is an imperative need to standardize PA definition in terms of light, moderate and vigorous intensity, due to its considerable contribution to the heterogeneity across studies. Moreover, whenever possible, we recommend aggregation of self-reported and objective PA measures (e.g. accelerometry) to increase the accuracy of the estimate. Regarding the gender-and-age-specific differences in decline of PA, it is recommended to intervene at earlier ages among girls, and to stimulate involvement in a variety of physical activities among both genders after childhood. More investigations addressing the predictors of PA change are also needed, as the current knowledge is not sufficient to create a body of evidence concerning this issue.

Conclusions

The decline of PA during adolescence is a consistent finding in the literature and does not vary according to several study characteristics. However, differences between boys and girls in the pattern of PA change over time, as well as an interaction with age, were observed and should be explored in future research. Interventions that attempt to attenuate the PA decline, even without an increment in PA levels, could be considered as effective, and are of great importance to improve adolescent health and, in consequence, the health of future generations.

Funding

We would like to thank the Brazilian Federal Agency for Support and Evaluation of Graduate Education (CAPES) and the National Council of Technological and Scientific Development (CNPq).

Conflict of interest: None declared.

KEY MESSAGES

- It was presumed that physical activity level declined during the lifespan, particularly in adolescence. However, there were no studies quantifying this change or pooling results for a common interpretation.
- Having conducted a systematic review of the international literature, we found consistent evidence showing that physical activity declines over adolescence.
- On average, the mean percentage physical activity decline per year, across all studies reviewed, was −7.0% (95% CI: −8.8 to −5.2).
- Although earlier studies revealed a higher physical activity decline among boys, the decline has been greater among girls in more recent studies. Moreover, although the decline among girls was greater at younger ages (9–12 years old), among boys it was greater at older ages (13–16 years old).
- Interventions that attempt to attenuate the physical activity decline, even without an increase in physical activity levels, could be considered as effective.

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