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When does it all go wrong ?: longitudinal studies of changes in moderate-to-vigorous intensity physical activity across childhood and adolescence

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Corresponding and sole author: Prof John J Reilly, University of Strathclyde Glasgow, Physical Activity for Health Group, Glasgow, G1 1XQ, Scotland

john.j.reilly@strath.ac.uk

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When does it all go wrong ? : longitudinal studies of changes in moderate-to-vigorous intensity physical activity across childhood and adolescence

Abstract

There is a widespread belief that moderate-vigorous intensity physical activity (MVPA) declines markedly in adolescence, particularly in girls. This belief has led to substantial research and policy effort aimed at reducing the perceived adolescent decline in MVPA. The main aim of this review is to examine belief in the adolescent decline in MVPA critically, by considering evidence from studies with objective measures of physical activity, systematic reviews of longitudinal studies, insights from recent longitudinal studies, and evidence from the International Children's Accelerometry Database (ICAD). Existing systematic review evidence, four recent longitudinal studies from England, and ICAD data, all fail to support the hypothesis that MVPA declines particularly markedly during adolescence, or that an MVPA decline begins at adolescence, or that adolescent declines in MVPA are greater in girls than boys. Systematic reviews, longitudinal studies, and ICAD data in fact suggest that MVPA begins to decline, and sedentary behaviour begins to increase, from around the age of school entry. Recent longitudinal studies also suggest that increasing sedentary behaviour during adolescence displaces light intensity physical activity. An emerging body of evidence from longitudinal studies which use trajectory analysis is providing important new insights on marked between-individual differences in the trajectories of MVPA across childhood and adolescence. While gaps in the evidence remain, particularly from low-middle income countries, and additional longitudinal studies are required, the present review suggests that efforts to promote and /or maintain MVPA should begin well before adolescence.

Introduction

There is now a substantial amount of evidence, reviewed systematically and appraised critically, that physical activity influences health during childhood and adolescence.[1,2] Moreover, higher moderate-vigorous intensity physical activity (MVPA) during childhood and adolescence has benefits beyond health. For example, recent evidence suggests that higher habitual MVPA can produce meaningful improvements in academic attainment in childhood and adolescence.[3-5]

Physical activity recommendations for school-age children and adolescents are evidence based, and harmonised internationally **(Table 1).** The recommendation in relation to a minimum of 60 minutes of MVPA daily has received most attention, and is the focus of child and adolescent public health surveillance of physical activity. The other two physical activity recommendations are for vigorous intensity physical activity (VPA), and for activities to 'promote muscle and bone health and flexibility' **(Table 1)**. These latter recommendations are important, but have generally received less attention (e.g. in research, and in public health surveillance) than the recommendation for MVPA. Internationally, levels of MVPA among adolescents are typically much lower than recommended: as few as 20% of 13-15 year-olds globally appear to meet the MVPA recommendation.[6] Levels of adherence to the recommendations in relation to VPA, and activities to promote muscle and bone health and flexibility, are less well known because of the lack of surveillance of these behaviours[7,8].

It is generally accepted that there is a marked decline in MVPA during adolescence, and the decline is usually believed to be much more marked in girls than boys. In the UK for example, much policy and research effort has been based on the concept that MVPA declines dramatically during adolescence, with the concept that adolescents, particularly adolescent girls, are a 'high-risk' group for low MVPA.[9-11] Globally, international surveillance programmes for MVPA also focus on adolescents.[6] There has been a tendency among researchers and policymakers in physical activity and health to assume that levels of MVPA among children are relatively high, or at least adequate, and that low MVPA is a problem which emerges in adolescence[9-11].

The view that MVPAdeclines dramatically during adolescence has been extremely influential and is very well-established, but it is worth considering how evidence-based the belief is. The present study, a review of objectively measured evidence, aims to: (1) critique the belief that declines in MVPA begin in adolescence, (2) consider very recent evidence from longitudinal studies on the existence and extent of MVPA declines during adolescence (3) suggest new approaches to understanding the timing and magnitude of changes in MVPA across childhood and adolescence.

Methods

The present study is a critique based on objectively-measured physical activity evidence derived from: recent systematic reviews of longitudinal studies of changes in MVPA and sedentary behaviour; a synthesis of longitudinal studies published after the most recent systematic reviews; a consideration of insights from the 'International Children's Accelerometry Database' (ICAD).[12]

Results

Systematic review evidence on declines in MVPA during adolescence

The most recent systematic review of declines in physical activity (not specifically MVPA) during adolescence was carried out by Dumith et al.[13] Dumith et al has been highly cited as evidence that MVPA declines during adolescence, and reviewed 26 eligible longitudinal studies (with at least two measures of physical activity). Of the eligible studies, 22/26 were based on questionnaire measures of change, three which used pedometers, and only two were based on accelerometry. Most (16/26) of the eligible studies were from the USA, most (16/26) completed data collection before the year 2000, and the representativeness (or otherwise) of the samples in the eligible studies was usually unclear.[13]

While the systematic review by Dumith et al[13] is a very useful and thorough summary of the evidence base in the area, numerous substantial limitations in the evidence base should be noted. First, the small number of accelerometer studies means that there was in fact almost no longitudinal evidence on the magnitude of declines in MVPA in that review, with accelerometry necessary to have high confidence in the amount and intensity of physical activity.[14] Second, the evidence base is arguably of limited generalisability globally given the dominance of studies from high-income countries, the USA in particular. Third, the dominance of studies with only two time points limits our understanding of the timing of changes in MVPA- an improved understanding of the timing and rate of changes in MVPA will require longitudinal studies with multiple measurement time points. In addition, the limited evidence across both childhood and adolescence revealed by Dumith et al[13] makes it impossible to determine whether age-related declines in MVPA either began during adolescence, or increased during adolescence.

An additional difficulty with the review by Dumith et al[13] is that the evidence base is now so old that it may have reduced generalisability to contemporary populations. Recent and rapid societal changes, notably changes in transportation, in education, and in the technology now widely available to children and adolescents[15], might have changed the timing and/or magnitude of declines in MVPA during adolescence quite markedly in recent years. For example, many new screen-based sedentary behaviors have become popular with young children, and exposure to screen-based sedentary behaviour has probably increased substantially in early childhood[16]. While the impact of these changes on physical activity is unclear, any increase in sedentary time must displace some combination of sleep, light intensity physical activity, and/or MVPA. There is another difficulty with older evidence which applies particularly to settings where the environment has become more 'obesogenic': there is emerging, though not yet conclusive, evidence[17-19], that obesity, and possibly overweight, will reduce MVPA. Prevalence of overweight and obesity is generally higher than in the past, the body fat content of non-overweight, non-obese children, appears to have been going up[20,21], and in recent longitudinal studies of children BMI Z score tends to increase with age, across the distribution of BMI Z score, not just in the overweight and obese[17]. These population-wide changes in body composition predict that MVPA levels of children now will be lower than in even the recent past.

In summary, the lack of good evidence identified by the systematic review by Dumith et al[13] means that there can be little or no confidence on changes in either the amount or timing of MVPA across adolescence at present. The review also provides little or no confidence in the view that MVPA declines begin during adolescence. A brief review of more recent longitudinal studies of changes in MVPA during adolescence, published after the review by Dumith et al,[13] is given below.

Review of recent longitudinal studies of changes in MVPA during adolescence

Four studies of accelerometer-measured longitudinal changes in MVPA (each with two measurement time points) in English adolescents were published after the review by Dumith et al. Two of the cohort studies took place in South-West England and changes were measured using Actigraph accelerometry, though with different accelerometer cut-points. Harding et al[22] (n 363) found no significant changes in MVPA in either boys or girls, born in the mid-late 1990's, between the ages of 12-15 years; Mitchell et al[23] (n 5436) found negligible changes in MVPA in both sexes between 12-16 years in a cohort born in the early 1990's.

In a smaller cohort study by Corder et al[24] in the South-East of England, 480 participants who had been born in the late 1990's were measured by Actigraph accelerometry at age 10 years and were followed up to age 14 years. Corder et al reported small declines in MVPA in both sexes over the four year period, slightly but significantly more marked in boys than girls.[24] In another smaller cohort study in the South-East of England, with baseline measures when participants were age 15 years (n 144; born in the early 1990's), longitudinal declines in accelerometer measured MVPA were small but statistically significant in both sexes between age 15-17 years, with slightly greater declines in boys than girls.[25]

In summary, all 4 recently published longitudinal studies of objectively measured changes in MVPA during adolescence from England do not support the view that marked declines in MVPA occur during adolescence, nor the common view that declines in MVPA during adolescence are more marked in girls than boys. In fact, this emerging evidence from longitudinal studies suggests that declines in MVPA, where they occur, might be greatest in those groups with highest 'baseline' MVPA (and so are likely to be greater in boys than girls). [25]

One notable contrast to the recent evidence from longitudinal accelerometry studies summarised above is the study of Nader et al[26] which reported a phenomenal decline, of over 4 hours per day, in MVPA between age 9-10 and 15-16 years in the USA. This magnitude of change is almost certainly an artefact of the accelerometer cut-points used to define MVPA at the different ages.[14,25]

Evidence on increases in sedentary behavior across childhood and adolescence

One great advantage of longitudinal accelerometry studies of the kind described above is that they can provide a unique insight into the relationships between changes in sedentary behaviour, light intensity physical activity, and MVPA with age. Sedentary behaviour and physical activity are generally regarded as distinct variables, so that an individual can theoretically be both active (ie have sufficient

MVPA) but also sedentary (ie with excess sedentary time). A recent review of largely cross-sectional studies (most of which used subjective measurement methods) found that there was limited evidence of displacement of MVPA by sedentary behavior.[27] However, the recent longitudinal accelerometry studies from England described above show that the increased amount of time spent sedentary as adolescence proceeds displaces physical activity (particularly LPA)[22,23], and may also displace sleep[25].

Tanaka et al[28] recently reported a systematic review of longitudinal studies of changes in accelerometer-measured sedentary behaviour in children and adolescents. They found 10 eligible studies, most from high-income western countries, and most with measures at only two time points. In all of the eligible studies which had measures after the age of school-entry sedentary behaviour increased over time, by an average of 25-30 minutes per day per year. [28] While the review by Tanaka et al found gaps and limitations in the evidence base, it supports the view that sedentary behaviour typically increases from early-mid childhood[28], and this must be displacing physical activity and/or sleep.

Insights from the International Children's Accelerometry Database

The ICAD[12] has, by standardising and pooling accelerometry-measured MVPA from up to 21 studies (of well over 20,000 individuals), provided a number of important insights into levels, correlates, and consequences, of variation in MVPA during childhood and adolescence. In the context of providing an understanding of change in MVPA, the ICAD has limitations, in part because most of the individual datasets are cross-sectional. Despite these limitations, recent evidence from pooled ICAD data[12] quite clearly predict that declines in total volume of physical activity, LPA, and MVPA occur across childhood and adolescence, beginning around the time of school-entry in both sexes, with no obviously marked declines in MVPA during adolescence. ‘Changes’ in MVPA with age across the ICAD dataset are summarised in **Figure 1.**

Large-scale data pooling studies of this kind can also be helpful in providing evidence on why, as well as when, declines in MVPA occur. For example, the extent to which declines in MVPA might be inherent (‘biological’) rather than external (‘environmental’) has been debated[29,30]. The ICAD data demonstrate substantial variation in MVPA between studies/environments, providing support for the view that environment (in the widest sense: policy; built; cultural) is important, and might either increase or decrease changes in MVPA which are mediated by any underlying biological processes.[12]

Insights from the Iowa Bone Development Study

An improved understanding of the timing and magnitude of changes in MVPA will require longitudinal studies, using objective measures, which span both childhood and adolescence and have multiple measurement points (rather than the standard two time points common in the literature to date[13,28]). Such evidence is very scarce[13], but available from the Iowa Bone Development Study[31] which has data on a cohort born in the early 1990’s in the USA, with up to seven accelerometer-measures of MVPA between age 5 and 19 years. Data from the Iowa Bone Development Study support the view that MVPA declines across childhood and adolescence in both sexes, and do not develop at or during adolescence.

The large number of MVPA measures made in the Iowa Bone Development Study also provide an important insight into between-individual variation in both the timing of changes in MVPA, and the magnitude of changes in MVPA. Changes in MVPA over time are often considered in an overly simplistic way, tending to make the implicit assumption that all or most individuals follow the same trajectory of change over time[9-11]. The multiple measures of MVPA in the Iowa Study permit trajectory analysis, identifying sub-groups within the population with very different timing and/or magnitude of change in MVPA across adolescence. These between-group differences in timing and magnitude of MVPA in the Iowa cohort are surprisingly marked, identifying a sub-group with stable MVPA across childhood and adolescence, a subgroup with low and steadily declining MVPA, and a subgroup with high initial MVPA in early childhood and with a dramatically declining MVPA from that point.[31] Such marked differences in the trajectory of MVPA across childhood and adolescence represent a challenge for the prevention of MVPA decline, but greater awareness of the existence of these different trajectories, and evidence on the determinants of the trajectories, should permit much more evidence-informed prevention in future.[31] In summary, recent longitudinal studies which have used accelerometry suggest that it is time for a more nuanced view of age-related changes in MVPA across childhood and adolescence.

Translation of evidence on changes in MVPA into policy

Despite the low quality, small quantity, and limited generalisability, of the evidence, there appears to be great and widespread confidence in the belief that MVPA declines markedly during adolescence. In Scotland for example, cross-sectional data from nationally representative surveys of physical activity are available across childhood and adolescence, and these appear to show that levels of MVPA are very high in childhood, declining markedly in adolescence, particularly in girls.[9-11] The apparent decline in MVPA during adolescence has been used as the basis of physical activity policy in Scotland for many years- which targets adolescents, particularly girls.[9-11] The concept of adolescent decline in MVPA has led to many research studentships and grants aimed at understanding why MVPA declines during adolescence. The Scottish survey data which show the apparent decline in MVPA are not without problems however, quite apart from the recent evidence summarised above. The only validation study of Scottish survey methodology to date has shown that the method of physical activity measurement used grossly overestimates MVPA during childhood, by an average of two hours per day, and has no association with accelerometer-measured MVPA.[32] In addition, the main national survey in Scotland (Scottish health Survey) is cross-sectional rather than longitudinal, and the erroneous data on MVPA it produces lead not just to an overestimate of MVPA, but also generate spurious differences in physical activity (e.g. between UK nations, between children and adolescents of high versus low-socioeconomic status) which are not supported by accelerometry studies.[14,33-35] In summary, much of the physical activity policy in Scotland, and probably in other countries, is not as evidence-based as it may appear to be, because the evidence on which it is based is misleading.

The Active Healthy Kids Global Alliance (www.activehealthykids.org) is a new international effort which aims to build capacity in physical activity and health globally, to improve surveillance of child and adolescent physical activity nationally and internationally, and in turn to improve national and international physical activity policy.[8] In Scotland, the Active Healthy Kids Scotland Report Card (www.activehealthykidsscotland.co.uk) is an attempt to highlight limitations in physical activity surveillance, so that future surveillance and policy will be much more evidence-informed.[36] As noted above, recent longitudinal studies with accelerometry are providing new insights into age-related changes in MVPA. Future evidence-based policy, in Scotland and globally, should therefore be based on much better evidence (objective measurement, longitudinal designs) than in the past, and should be able to take advantage of increasing global capacity in physical activity and health.

Gaps in the evidence globally

The present review highlights the need for more longitudinal studies of changes in MVPA, with objective measures made at multiple time points, and which cross childhood and adolescence. Such studies are required urgently, even for high income countries. The summaries of recent evidence above highlight the fact that nearly all of the available longitudinal evidence currently is from high-income or western countries only. Low MVPA appears to be a global problem for adolescents[6], and requires a more global response, but research from many low and middle-income countries is lacking[6], and this should be a high priority. A recent global consensus on priorities for physical activity and health among children and adolescents globally[37] highlighted that the top priority was interventions to improve MVPA, but more evidence on the magnitude and timing of age related declines in MVPA globally would provide a sound basis for such future interventions. New research funding efforts will be required to undertake the new longitudinal studies which are needed so urgently.

Conclusions

The present review suggests that there is little or no sound evidence to support the view that MVPA begins to decline in early adolescence, or the view that MVPA declines particularly markedly during adolescence, or the view that adolescent declines in MVPA are more substantive in girls than boys. It now seems much more likely that MVPA declines and sedentary behaviour increases, in both sexes, from around the age of school entry. These suggestions should be tested by future longitudinal studies which use objective measures of physical activity and sedentary behavior. Future studies should be global because low MVPA is now a global problem.[6,8]

References cited

1. Timmons BW, LeBlanc AG, Carson V et al. Systematic review of physical activity and health in the early years. Appl Physiol Nutr Metab. 2012; 37: 773-792.
2. Janssen I, LeBlanc AG. Systematic review of the health benefits of physical activity and fitness for school-aged children and youth. Int J Behav Nutr Phys Act. 2010; 7:40.
3. Booth JN, Leary SD, Joinson C et al. Associations between objectively measured physical activity and academic attainment in adolescents from a UK cohort. Br J Sports Med. 2014; 48: 265-270.
4. Donnelly JE, Greene JL, Gibson CA et al. Physical activity across the curriculum: RCT to promote physical activity and diminish overweight and obesity in elementary school children. Prev Med 2009; 49: 336-341.
5. Davis CL, Tomporowski PD, Boyle CA et al. Effect of aerobic exercise on overweight children's cognitive function: RCT. Prev Med 2009; 49: 336-341.
6. Hallal PC, Andersen LB, Bull FC et al. Global physical activity surveillance: progress, pitfalls, and future prospects. Lancet 2012; 380: 240-246.
7. Reilly JJ. The pandemic of low physical activity in children and adolescents. Aspetar Sports Medicine Journal. 2015; 4:234-238.
8. Tremblay MS, Gray CE, Akinroye K et al. Physical activity of children: a global matrix of grades comparing 15 countries. J Phys Act & Health. 2014; 11 (suppl 1) s113-s125.

9. Scottish Health Survey 2014 (SHeS; www.scotland.gov.uk/Topics/Statistics/Browse/Health/scottish-health-survey). (accessed 31st March 2016).

10. Let's Make Scotland More Active: Five Year Review of A Strategy for Physical Activity. www.healthscotland.com/uploads/documents/9159-1150-HS%20PA%5yr%20Review%20Final.pdf (accessed 17th August 2013).

11. Murray A, Calderwood C, O' Connor N et al. Scotland's progress in putting policy about physical activity into practice. Br J Sports Med. 2016; 10.1136/bjsports-2015-095744.

12. A Cooper, A Goodman, JJ Reilly et al. Objectively measured physical activity and sedentary time in youth: the International Children's Accelerometry Database (ICAD). Int J Behav Nutr Phys Act. 2015; 12:113.

13. Dumith SG, Gigante DP, Domingues MR et al. Physical activity change during adolescence: a systematic review and pooled analysis. Int J Epidemiol. 2011; 40: 685-698.

14. Reilly JJ, Penpraze V, Hislop J et al. Objective measurement of physical activity and sedentary behaviour: review with new data. Arch Dis Child. 2008; 93:614-619.

15. Pratt M, Sarmiento OL, Montes F et al. The implications of megatrends in global communication technology and transportation for changes in global physical activity. Lancet 2012. 380: 282-293.

16. Christakis DA. Interactive media use at younger than the age of two years. JAMA Pediatrics. 2014. 168: 399-400.

17. Basterfield L, Pearce MS, Parkinson KN et al . Longitudinal study of physical activity and sedentary behavior in children. Pediatrics. 2011; 127:e24-e30.

18. Hughes AR, Stewart L, Chapple J . Randomized controlled trial of a best-practice, individualized, behavioural program for treatment of childhood overweight: Scottish Childhood Overweight Treatment Trial (SCOTT). Pediatrics. 2008; 121: e539-3546.

19. Bauman AE, Reis RS, Sallis JF et al. Correlates of physical activity. Lancet . 2012; 380: 258-271.

20. Wells JC, Coward WA, Cole TJ et al. The contribution of fat and fat-free tissue to BMI in contemporary children and the reference child. Int J Obes 2002; 10: 1323-1328.

21. Ruxton CHS, Reilly JJ, Kirk T. Body composition of healthy 7-8 year olds and comparison with the 'reference child'. Int J Obes. 1999; 23:1276-128.

22. Harding SK, Page AS, Falconer C et al. Longitudinal changes in sedentary time and physical activity during adolescence. Int J Behav Nutr Phys Act 2015; 12: 44.

23. Mitchell JA, Pate RR, Dowda M et al. A prospective study of sedentary behaviour in a large cohort of youth. Med Sci Sports Exerc 2012; 44: 1081-1087.

24. Corder K, Sharp SJ, Atkin AJ et al. Change in objectively measured physical activity during the transition to adolescence. Br J Sports Med 2015; 49: 730-736.

25. Collings PJ, Wijndaele K, Corder K et al. Magnitude and determinants of changes in objectively measured physical activity, sedentary behaviour,

and sleep duration from ages 15 to 17.5 years in UK adolescents. Int J Behav Nutr Phys Act 2015; 12: 61.

26. Nader PR, Bradley RH, Houts RM et al. Moderate-vigorous physical activity from ages 9-15 years. JAMA. 2008; 300: 295-305.
27. Pearson N, Braithwaite RE, Biddle STH et al. Associations between sedentary behaviour and physical activity in children and adolescents: a meta-analysis. Obes Rev 2014. 15: 666-675.
28. Tanaka C, Reilly JJ, Huang WY. Longitudinal changes in objectively measured sedentary behavior and their relationship with adiposity in children and adolescents: systematic review and evidence appraisal. Obes Rev. 2014; 15: 791-803.
29. Wilkin TJ. Can we modulate physical activity in children ? No. Int J Obes 2011. 35: 1270-1276.
30. Reilly JJ. Can we modulate physical activity in children ?. Int J Obes 2011; 35: 1266-1269.
31. Kwon S, Janz KF, Letuchy EM et al. Developmental trajectories of physical activity, sports, and TV viewing during childhood to young adulthood. JAMA Pediatr 2015. 169: 666-672.
32. Basterfield L, Adamson AJ, Parkinson KN et al. Surveillance of physical activity in the UK is flawed: validation of the Health Survey for England physical activity questionnaire. Arch Dis Child. 2008; 93: 1054-1058.
33. WHO Europe 2015. United Kingdom of Great Britain and Northern Ireland Physical Activity Factsheet.
34. British Heart Foundation. Physical Activity Statistics 2015. www.bhf.org.ukaccessed31st March 2016.

35. UK Association for Physical Education. Health Position Paper 2015.

36. Reilly JJ, S Dick S, McNeill G et al. Results from the Scottish Report Card on Physical Activity for Children and Youth. J Phys Act & Health. 2014; 11 (suppl 1), s93-s97.

37. L Gillis, G Tomkinson, T Olds et al Research priorities in child and adolescent physical activity and sedentary behaviour: a global perspective using a twin-panel Delphi Procedure. Int J Behav Nutr Phys Act. 2013;10: 112. www.ijbnpa.org/content/10/1/112.

Table 1 Physical Activity Recommendations for School-Age Children & Adolescents[7]

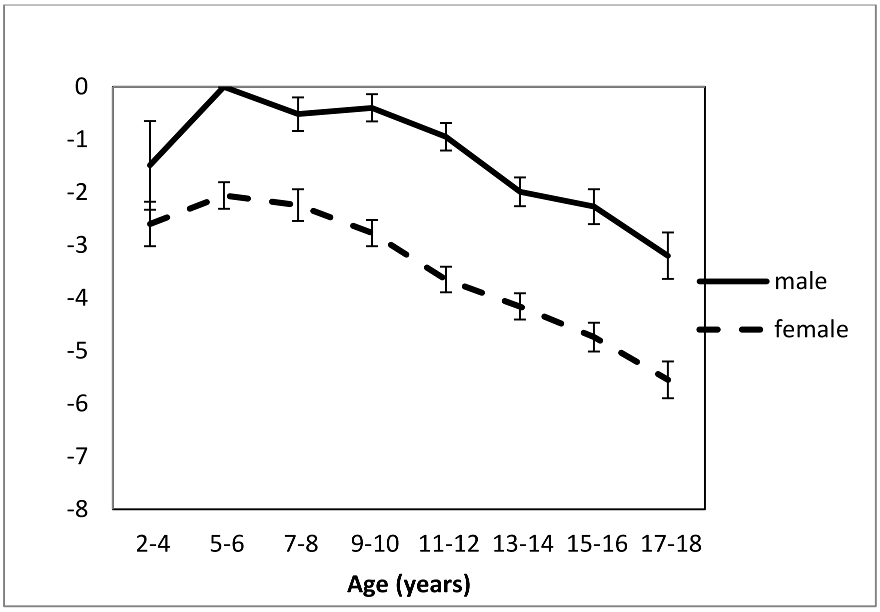
1. Accumulate at least 60 mins/d, preferably more, MVPA on a daily basis
2. Incorporate vigorous intensity activities on at least 3 days/week
3. Include activities that strengthen muscle & bone, and promote flexibility, on at least 3 days/week

Figure Legends

Figure 1

Percentage ‘decline’ in moderate-to-vigorous physical activity by age group across childhood and adolescence from ICAD[12] Int J Behav Nutr Phys Act. 2015; 12:113.

Figure 1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Age (years)
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