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Physical activity behaviours in adolescence: current evidence and opportunities for intervention

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Abstract *(178 words)*

Young people aged 10-24 years constitute 24% of the world's population and investing in their health could yield a "triple benefit": today, into adulthood, and for the next generation. However, in physical activity research this life stage is poorly understood with the evidence dominated by research in younger adolescents (10-14yr), school settings and high-income countries. Globally, 80% of adolescents are insufficiently active, and many engage in ≥2hrs of daily recreational screen time. This paper presents the most up-to-date global evidence on adolescent physical activity and discusses directions for identifying potential solutions to enhance physical activity levels in this population. Adolescent physical inactivity likely contributes to key global health problems, including cardio-metabolic and mental health disorders, but the evidence is methodologically weak. Evidence-based solutions focus on three key components of the adolescent physical activity system: (i) supportive schools, (ii) the social and digital environment, and (iii) multi-utility urban environments. Despite an increasing volume of research focused on adolescents, important knowledge gaps remain and efforts to improve adolescent physical activity surveillance, research, intervention implementation, and policy development are urgently needed.

Key messages

1. Physical activity levels are low and screen use is ubiquitous among adolescents across the globe. Within-country socioeconomic differences vary by country context: adolescents from high socio-economic backgrounds have better activity profiles than those from low socio-economic backgrounds in high-income countries (HIC), with the reverse true for low and middle-income countries (LMIC).

2. Adolescent physical inactivity likely contributes to key global health problems, including cardio-metabolic and mental health disorders, but the evidence is weak. Obesity and mental health problems may become auxiliary drivers of physical inactivity, further increasing the risk of morbidity and mortality.

3. Supportive social and built environments are key drivers of adolescent activity behaviour, and successful policy action should aim for directing change in these areas. Adolescents benefit from built environments that promote a range of activity behaviours (including active travel, play, and sport), and a supportive social environment in- and out-of-school. Access to supportive built environments is unequally distributed, particularly in LMICs.

4. Schools offer an effective avenue to increase physical activity among adolescents but school-based initiatives have had limited success overall and research involving older adolescents (15-19 years) is lacking. There is a need for sustained implementation of multi-component programmes, co-designed with adolescents. Such interventions require context-specific support for schools to ensure effective implementation and sustainability.

5. Many young people across the globe, particularly those aged 15-24 years, are not in educational settings and alternative strategies to reach this population are required. With wide-spread access to the internet and some evidence of effectiveness, the potential contribution of eHealth and mHealth approaches contextualised to adolescents' needs and life circumstances should be explored.

6. The reasons to instigate change are different for decision-makers in health, policy, education, and among adolescents themselves. Understanding the myriad of benefits associated with physical activity, and tailoring messaging around the outcomes most salient to the specific audience will help drive change at multiple levels of a complex system.

7. Observational and interventional evidence on adolescent physical activity behaviours comes largely from HICs and younger adolescents (10-14 years). Increased knowledge from LMICs, those out of school, and older adolescents going through

major life transitions (e.g. starting employment, parenthood) is urgently required to curb rapid rises in the health consequences of physical inactivity.

Introduction

Young people aged 10-24 years constitute 24% of the world's population.[1] This includes, as per the *Lancet Commission on Adolescent Health and Wellbeing*,[2] younger adolescents (10-14 years), older adolescents (15-19 years), and young adults (20-24 years), and will be referred to as such throughout this paper.[3] Both the *Lancet Commission*[2] and the *Global Accelerated Action for the Health of Adolescents (AA-HA!)*[4] concluded that investing in adolescent health and wellbeing will yield a "triple benefit" – today, into adulthood, and for the next generation.[2] While adolescence is generally considered a healthy period, many non-communicable diseases (NCDs) that manifest later are in part the result of modifiable risk behaviours established during this time, such as smoking, unhealthy diet patterns, and low levels of physical activity.[5,6] There have been major global trends in adolescent health in recent decades.[7] Notably, while a decrease in adolescent disease burden has been observed in many countries over the last 25 years, almost one in five (324 million [18%]) adolescents globally now have overweight or obesity[7] and there is an increasing burden of adolescent mental health disorders (including depression and anxiety).[8,9] It is estimated that 962·8 million adolescents (53% globally) now live in multi-burden countries, where they face a "triple burden" of health problems, including infectious diseases, injury and violence, and NCDs.[7] Increased efforts to develop a better understanding of, and potential solutions to, health and well-being during adolescence are therefore encouraged.[2,4,10,11] To support these efforts, *The Lancet* launched the "2020 Campaign on child and adolescent health".[12]

Physical inactivity is associated with many NCDs and substantial economic costs on a global scale.[13,14] It has been estimated to account for 5·3 million deaths per year,[13] and to cost at least $54 billion in direct health care costs of which $31 billion is paid by the public sector.[14] Although physical inactivity is recognized as a global pandemic,[15] much of the evidence has come from studies among adults,[13,16,17] when the effects on NCDs become apparent.[18] Recent evidence, however, suggests marked increases in the prevalence of NCDs (e.g. type 2 diabetes)[19] and NCD risk factors including hypertension[20] and obesity[21] in adolescence. Acknowledging the health risks of long-term neglect of adolescent health and wellbeing, the *Lancet Commission on Adolescent Health and Wellbeing*[2] was launched in 2016, which proposed 12 headline to track progress in adolescent health. However, despite the known health risks of physical inactivity across the life course[13,17,22] and alarmingly low levels of physical activity,[23] no indicator related to physical activity was included. Therefore, physical activity appears to have low priority in adolescent health. It is crucial and timely to refocus the global prevention agenda in adolescence to include physical activity.

It is critical that we develop a better understanding of adolescent physical activity such that effective strategies can be implemented. The implementation of policies and interventions to promote physical activity has the potential to contribute to achieving many of the United Nations' Sustainable Development Goals (SDGs) for 2030.[24] The World Health Organization's (WHO) *Global Action Plan on Physical Activity 2018-2030*[25] and an investigation in the current series[26] demonstrate how the promotion of physical activity can help achieve multiple SDGs. Beyond its direct contribution to SDG-3 (good health and wellbeing),[25] "co-benefits" of adolescent physical activity promotion include contributions to SDG-5 (gender equality) and, based on the increasing evidence linking physical activity to academic performance[27,28] and the critical role of physical education in high quality education, SDG-4 (quality education). This paper provides an overview of up-to-date evidence on adolescent physical activity behaviours, including prevalence, determinants and consequences, and provides recommendations for action in research and practice. The term "physical activity behaviours" is used to capture both physical activity and sedentary behaviour; where evidence is specific to a type of behaviour this is indicated.

Adolescence and young adulthood: A period of transition

Adolescence is a key period of human development, as psychological and biological changes occur rapidly during this phase of life.[4,6] Adolescence and young adulthood represent a significant transition in responsibilities and lifestyles in many cultures as young people shift from school settings to a variety of different pathways, including higher education, family, military, workforce, or unemployment. It is important to be mindful of the global variation in the timings of these pathways. For example, the proportion of adolescents globally not in educational settings is 15·9% in 12-14-year-olds and 36·3% in 15-17-year olds, but figures are as high as 36·6% and 57·8%, respectively, in Sub-Saharan Africa.[29]

In Western countries, young adulthood is characterized by great variability in demographics (income, housing, etc.), self-perceptions, identity exploration, and increased participation in risk behaviours.[11,30] Globally, the age of achieving biological maturation is decreasing.[31,32] At the same time, the age of attaining several "adult" milestones has risen in high-income countries (HICs) (e.g. age of first marriage,[33] mother's age at first birth,[34] and age of completing education[35]). It is unclear if these social trends are mirrored, at least to some extent, in low-and-middle-income countries (LMICs), although global evidence suggests that the prevalence of early marriage[36] and early childbearing[37] have been declining over the past three decades. This expanding period of instability, key life transitions and increasing responsibilities represents an important period where decision-making autonomy increases and lifestyle habits, including physical activity, become established and entrenched, and thereby offers significant opportunities for interventions that can have life-long and inter-generational health implications.[38-40]

Are physical inactivity and sedentary behaviour problems in adolescence?

Physical activity

The WHO recommends that children and adolescents aged <18 years accumulate at least an average of 60 minutes per day of moderate-to-vigorous intensity physical activity, whereas people aged ≥18 years should accumulate at least 150-300 minutes of moderate-intensity physical activity or 75-150 minutes of vigorous-intensity physical activity per week, or an equivalent combination.[41] Similar guidelines have been adopted by many countries across the WHO regions worldwide. The discrepancy reflects the different evidence bases used to develop public health guidelines. In adults, a major focus has been on the prevention of NCDs and premature mortality, while the focus in childhood and adolescence has been on improving fitness, developing coordination and movement control, and maintaining a healthy body weight. It appears unlikely that the dose of physical activity at which health benefits occur changes so dramatically at age 18 years but, as described later, the evidence base to inform quantitative health-related physical activity thresholds over this age range is sparse. This is an important area for future research.

This drastic shift in the recommended levels of physical activity for individuals aged 18 and above also impacts the ability to adequately monitor trends in physical activity compliance across the whole adolescent and young adult age range. For example, global surveillance data indicate that approximately 20% of under-18s, but 73% of adults (≥18 years), are classified as sufficiently active.[42,43] Overall, global data availability is strongest for adolescents attending school. A recent analysis of data of 1·6 million students from 146 countries, territories, and areas,[43] has provided an update on the physical activity prevalence data presented in the first Lancet Physical Activity series.[23] Using self-reported data, it showed that in 2016, 81·0% of 11-17-year-olds were physically inactive, with a lower prevalence in boys compared to girls (77·6% vs. 84·7%, respectively). This constituted a slightly decreased prevalence of physical inactivity for boys (from 80·1% in 2001), but negligible change for girls (from 85·1% in 2001). There was no clear pattern according to country income group. Although within-country socio-economic differences could not be established, wider evidence suggests that these may operate differently across the globe: in HICs the association is equivocal, whereas in Brazil, for example, those from low socio-economic backgrounds have been shown to be more active overall.[44,45] Sources of physical activity also differ, with work/household physical activity contributing more to overall adult physical activity in LMICs, and leisure physical activity contributing more in HICs.[46] The collection of comparable and detailed physical activity data across countries is difficult, given, for example, country-level differences in seasonal variation and school attendance.

Monitoring absolute levels of activity, as opposed to guideline compliance, may provide a better representation of differences in physical activity across the adolescent and young adult age range. Although it can be estimated based on self-report measures, there is a growing list of countries and regions that have begun monitoring physical activity levels using pedometers and accelerometers (Panel 1). Figure 1 presents accelerometry data from American and European 10-24-year-olds. This shows that males are consistently more active than females, and a clear trend for decreasing physical activity with advancing age in early and late adolescence. Levels of physical activity, however, become more stable in young adulthood. This is supported by evidence that activity levels track reasonably well from adolescence into adulthood.[47] Although the mechanisms through which tracking occurs are not well known (e.g., habit formation, early experience and skill development, or self-selection), it emphasises the importance of including a focus on adolescence in physical activity promotion for public health. Figure 1 also demonstrates the critical influence of the changing guidelines on our understanding of physical activity prevalence across adolescence and young adulthood; median values are generally below recommended levels for adolescents, but above recommended levels for adults.

Sedentary behaviour

Over the past decade, time spent sitting and reclining while expanding little energy (sedentary behaviour) and engagement in specific sedentary activities (such as screen-based behaviours) have rapidly emerged as potential additional risk factors for adolescents' health and well-being.[48,49] The WHO does not provide quantitative guidelines for sedentary time.[41] However, country-specific guidelines have been developed. For example, Australia and Canada recommend <2 hours recreational screen time per day for under-18s,[50,51] and the UK recommends that all citizens "minimize the time spent sedentary".[52] These variations together with evidential uncertainties complicate global surveillance of sedentary behaviour. Self-reported global surveillance data on sedentary behaviour are available for adolescents in two large international school-based surveys: the Health Behaviour in School-Aged Children (HBSC) survey and the Global School-based Student Health Survey (GSHS) (details on methods and results:

Appendix 2). Across the 97 countries with information on sitting in GSHS, 25% of boys and 24% of girls aged 13-15 years reported sitting for >3 hours per day in addition to sitting at school and for homework (Figure 2). Although the prevalence was similar across low-, lower-middle, and upper-middle income countries, it was twice as high for boys and girls from HICs as compared to all other income groups. Country prevalence ranged from 9% (Pakistan) to 61% (Kuwait) among boys, and from 7% (Pakistan) to 70% (Barbados) among girls.

In recent years, the ways in which adolescents interact with screens has changed rapidly, posing a challenge for global surveillance of screen-based behaviour. For example, while TV viewing was the main source of US adolescents' screen-time in the late 1970s, in 2016 it only represented 25% of their overall screen use.[53] This indicates that TV viewing and computer use may no longer be appropriate metrics for sedentary behaviour surveillance and that we need more contemporary indicators capturing the multitude of ways in which adolescents use screens. Nevertheless, we drew on the most recent data on adolescent screen use from a range of countries to present prevalence. HBSC assessed TV use and playing computer/video games in up to 38 European countries (Appendix 2). The prevalence of 11-15-year-olds watching TV for ≥2 hours on weekdays was 60% for boys and 56% for girls (Figure 2). Country prevalence ranged from 45% (Switzerland) to 69% (United Kingdom, Wales) among boys, and from 40% (Switzerland) to 72% (Bulgaria) among girls. Prevalence of playing computer/video games for ≥2 hours on weekdays was 51% for boys and 33% for girls, ranging from 32% (Switzerland) to 68% (Denmark) for boys, and from 11% (Finland) to 47% (Netherlands) for girls. Prevalence of both behaviours was consistently higher for boys than girls, but was similar across country income groups. However, as with physical activity, the socio-economical patterning of screen use varies by country context, as demonstrated by a review identified in our umbrella review of correlates and determinants (Appendix 5).[54] Specifically, whereas in HICs adolescents from high socioeconomic backgrounds are less likely to engage in high levels of screen-based behaviour, in LMICs it is the reverse. This demonstrates the importance of context in identifying problems and solutions.

Health consequences of adolescent physical activity behaviours

These high levels of adolescent inactivity and sedentary behaviour come with short- and long-term consequences for health and wellbeing. There is large variation in the consequences considered important to different stakeholders. Whereas evidence on reducing morbidity and health care cost may appeal to health professionals and policy makers, academic performance and mental health may be a priority for educators and parents, while wellbeing, social integration and having fun are more salient for adolescents.[55] In order to instigate action at a variety of levels, high-quality evidence across this broad range of outcomes is required to achieve positive change at individual, population, and systems levels. For example, while evidence of the importance of physical activity for NCD prevention may help push physical activity promotion up the policy agenda, it is unlikely adolescents will change their behaviour for the benefit of distal health consequences. The more immediate benefits of physical activity are likely to be more relatable to adolescents.

The prevalence of obesity increases rapidly during adolescence and young adulthood.[56] Its causes are complex and multifactorial, but evidence suggest prevention is critical as adolescents with overweight or obesity are unlikely to improve their weight status as they progress into young adulthood.[57] Physical activity and sedentary behaviour are considered cornerstones for preventing unhealthy weight gain, with extensive review level evidence available.[58] The magnitude of the associations between adolescent sedentary behaviours and adiposity are very small to small and there is limited evidence that the association is causal[59] or independent from physical activity.[60] Intuitively, higher levels of physical activity prevent gains in adiposity. However, the association is likely to be bi-directional (i.e. high body weight leading to lower physical activity levels).[61] To understand and prevent a potentially vicious cycle of increasing body weight and decreasing activity behaviour and whether weight loss might lead to increases in activity, future research should establish a firm understanding of the causal association between physical activity (of different volumes and intensity) and unhealthy weight gain in adolescence.[62]

To establish the relationship between adolescent physical activity and less frequently studied later cardio-metabolic health outcomes, we systematically reviewed the literature assessing the prospective associations (where assessment of the physical activity behaviour preceded the outcome) with blood pressure, type 2 diabetes and the metabolic syndrome (Appendix 3 for details on methods and results). Only one study examined the association between physical activity in adolescence and type 2 diabetes in adulthood and found no association. Within adolescence and young adulthood (outcome measured at ≤24 years), the evidence for an association between physical activity and the metabolic syndrome and blood pressure was equivocal. The evidence was somewhat stronger for outcomes measured in adulthood (>24 years), with some evidence of a long-term negative association between physical activity and the metabolic syndrome, but not with blood pressure. Physical activity and sedentary behaviours during adolescence may be associated with some medium- and long-term cardio-metabolic health outcomes but the strength of the current evidence is generally low.

Mental health problems are a growing global public health concern in adolescence.[8] Trial-based evidence suggests that physical activity appears to be a promising intervention for those experiencing depression.[63] Many mental health problems have their origins in adolescence, and the role of physical inactivity in its development is poorly understood with a range of neurobiological, psychosocial and behavioural pathways hypothesised.[64] Cross-sectional studies are problematic due to the hypothesised bi-directional association between mental health and physical activity, with evidence suggesting that mental health problems likely lead to decreases in physical activity and increases in sedentary behaviour.[65] We reviewed the literature assessing prospective associations with anxiety and depression in generally healthy adolescents (Appendix 4 for details on methods and results). The results suggest that there is consistent evidence for a lack of prospective association between adolescent physical activity and later symptoms of depression and anxiety, but that the association with sedentary time is more equivocal. These findings may be due to the lack of measurement precision in both the outcome and exposure, and the small effect sizes expected in a generally healthy population. Indeed, a recent large-scale study in *Lancet Psychiatry* showed that an additional hour per day of accelerometer-assessed sedentary time in early adolescence was associated with an 8–11% increase in depression scores at age 18 years.[49] Higher physical activity was negatively associated with later depressive symptoms. These positive findings need to be interpreted cautiously as the benefits may be difficult to achieve; compared to baseline levels, they would require a 14% decrease in sedentary time or a 57% increase in time spent in physical activity, whereas a 22% increase and no change were observed over the 4-year follow-up, respectively.

It is important to note that sedentary behaviour has predominantly been operationalised as engagement in 'traditional' screen-based behaviours. Given the radical shift in the way adolescents interact with screens, there is a need for an improved understanding of the generalisability of these research findings to the present generation. Moreover, a more sophisticated approach to studying screen-based behaviours and their impact on adolescent health and well-being may be warranted, including differentiating between 'quantity' and 'quality' of behaviours and their importance for health. Recent adult-based research suggests that mentally-passive sedentary behaviours (requiring minimal mental demands, e.g. TV-viewing, listening to music) are associated with a higher risk for depression, but not mentally-active behaviours (which increase mental demands, e.g. reading, video gaming).[66] This suggests that not all minutes spent sedentary are equal, and importance of this for adolescent health requires further exploration.

In summary, physical activity behaviours in adolescence may be associated with some medium- and long-term health outcomes, but the evidence base is generally weak. These findings, however, should be interpreted in light of the various limitations of the available evidence: the overall scarcity and lack of global representation of evidence, self-reported exposures, small sample sizes due to attrition, and imperfectly measured or unmeasured confounders. Further high-quality research is urgently needed to strengthen the case for investment in adolescent physical activity behaviours to prevent health problems. This will require large sample sizes, device-based exposure measurement, follow-up within and beyond adolescence, appropriate assessment of confounders, and robust analytical approaches with pre-specified sub-group analyses to establish causality.

Inactive adolescents: correlates, determinants and potential solutions

For decades, research has been dedicated to understanding why some people are more active than others.[67] Such inquiry regarding the correlates and determinants of physical activity behaviours aims to identify subpopulations at risk and understand the modifiable causes of inactivity to inform intervention efforts. Meanwhile, interventions have been tested around the world to identify potential solutions to physical inactivity, with variable success.[68] Recently, physical inactivity has been recognised as a "wicked problem", created and perpetuated by the complex system within which it occurs.[69] As such, identifying solutions requires researchers not to ask whether an intervention 'works', but to identify if and how it contributes to reshaping a system favourably.[70] This paradigm shift led the WHO to adopt a systems framework for their recent Global Physical Activity Action Plan,[25] which aspires to create active societies, environments, people, and systems.[71] Here, we aim to summarise the current literature on the correlates, determinants and interventions with an acknowledgement of the complexity of these issues and the biological and broader social and commercial determinants of health in which they operate and with which they interact. We focus on three key components of the adolescent physical activity system: (i) schools and educational settings, which are particularly important channels and locations for adolescent physical activity promotion, (ii) the social and digital environment, which offers both challenges and potential for behaviour change, and (iii) the urban environment, which is increasingly recognised as a critical and "upstream" strategy to tackling population-level physical inactivity.

The role of schools and other educational settings

Across the globe, schools are considered an important avenue to health promotion, reaching adolescents largely irrespective of their background characteristics. In recognition, WHO and UNESCO recently launched global standards to support their initiative "Making Every School a Health Promoting School".[72] School-based interventions also dominate the adolescent physical activity promotion literature. To better understand the opportunities and challenges this setting provides, we draw on the school-based evidence from our umbrella reviews on correlates and determinants of physical activity behaviours and on interventions to change physical activity behaviours (Panel 2; Appendix 5 and 6 for details on methods and results). Our umbrella review of correlates and determinants identified four reviews considering aspects of the school's policy, social or physical environment.[73-76] Together, this evidence suggests that the availability of within-school sports and activity in specific school areas was positively associated with overall adolescent physical activity. In contrast, access to sports equipment, adult supervision, overall teacher support, and quantity of physical education (PE) provision were not associated with adolescents' physical activity levels. Of note, the most active PE classes were those that fostered a mastery climate (i.e., focusing on individual/team development rather than competition), were conducted outdoors and included team games. PE and after school sport provision are key vehicles for schools to contribute to physical activity promotion. The evidence suggests that the quality and content of these provisions, in addition to the absolute quantity, are critical. Specifically, offering within-school sports competitions and outdoor PE, and fostering of a mastery-focussed motivational climate in PE appear to be salient targets for schools.[77] High quality sport and PE programs are needed to develop adolescents' physical literacy[78] and provide opportunities to develop lifelong physical activity skills to facilitate 'physical activity independence'[79] and long-term enjoyment, although they may not necessarily translate into higher overall activity in the short-term.[80] It is important to note that this evidence is predominantly drawn from younger adolescent populations in HICs. PE is not typically mandated in senior school years,[81] making it difficult for students to maintain physical activity while preparing for their final exams, whereas in LMICs there may be a need for provision of basic conditions (e.g. trained staff, materials and environments).

Overall, the intervention evidence included in our umbrella review suggests that physical activity promotion efforts in schools and universities/colleges have been largely unsuccessful in changing physical activity behaviours (Figure 3). Of concern, larger effect sizes were typically observed in studies using self-report measures compared to those utilising accelerometers, highlighting potential reporting bias. Emerging evidence has identified that poor implementation is a major barrier to the success of school-based interventions.[82-85] This is potentially because 'program drift' and 'voltage drop' occur as interventions progress from efficacy to effectiveness to dissemination,[86] and interdisciplinary research involving behavioural science, implementation science, education, and input from adolescents themselves is needed to optimise intervention effects. Multi-component interventions (i.e., comprehensive school-based physical activity programs)[87,88] appear to be more successful than single component interventions, particularly for adolescent girls, and intra-curricular interventions (those delivered as part of the curriculum) have stronger effects than extra-curricular interventions. Curricular interventions are more closely aligned with teachers' core responsibilities and potentially face fewer barriers to implementation. While there is a need to scale-up multi-component whole-of-school interventions, research should continue to identify implementation strategies and integrate approaches into the realities of the educational system. Although challenging, instigating changes at government policy level could maximize reach and change their mindset that promoting physical activity is incongruent with the educational system's remit. Finally, there is a need for novel interventions targeting and attracting older adolescents and young adults in educational settings as these groups have been largely neglected in previous research.

The challenges and opportunities of the social and digital environment

Adolescence is a period of growing independence, during which peers' and friends' social support becomes increasingly more influential compared to adults' (parents, teachers). Our umbrella review identified three reviews specifically focussed on the role of social support in adolescent physical activity (Appendix 5).[75,76,89] Together, they showed that social support from family and friends is positively associated with physical activity in early and late adolescence, although the effect sizes are small. The association with teacher support was equivocal. Parental support was studied in specific components, showing that encouragement and provision of instrumental support from both parents were positively associated, but the evidence was limited for parental co-participation in physical activity and parental modelling. Few studies investigated associations with friends' support. This demonstrates the ongoing importance of parental social support in adolescence, which should be considered in future adolescent intervention efforts. Moreover, the importance of friends' social networks and the opportunities this offers for interventions should be explored,[90] as well the sources and types of social support relevant for young adults.

The digital revolution of the past decades has radically changed ways of living and communicating, especially in younger generations. In 2015, 95% of 15-year-olds globally had access to the internet at home[91] and in Sub-Saharan Africa 63% of 18-29-year-olds own a smartphone.[92] During this digital revolution, the global prevalence of physical inactivity in adolescents aged 11-17 years has remained relatively stable at around 80%,[43] suggesting that increased digital media access and use may not be a key driver of adolescent physical inactivity. Instead, digital media may be replacing other traditional forms of sedentary behaviour: the percentage of US 16-17-year-olds who read a book/magazine daily declined from 60% in the late 1970s to 16% by 2016, and between 2010 and 2016 13-18-year olds significantly decreased their use of "legacy media" (books, magazines, newspapers, movies, and TV).[53] As noted earlier, greater time spent in mentally-passive sedentary behaviours such as TV viewing may have negative consequences for mental health. This new digital reality provides opportunities for reaching the large proportion of adolescents and young adults not in formal education. Our interventions umbrella review (Appendix 6) identified two reviews focussed on the effectiveness of digitally delivered (eHealth/mHealth) physical activity promotion interventions.[93,94] They demonstrate potential for changing adolescents' activity behaviours in the short-term, particularly when integrated with other intervention components (such as school-based environmental changes), and should be explored further. Critically, these should be sensitive to the social and environmental changes that are natural part of the adolescent transitionary period, tailored to the adolescent's life stage (e.g. starting employment, parenthood), and be mindful of inequalities in mobile phone ownership, particularly in LMICs.[95]

Adolescents in urban environments

Currently 55.3% of the world's population reside in urban environments and this is expected to increase.[96] Improvements to urban environments to facilitate physical activity for transportation and recreation is a recommended strategy for physical activity promotion.[15] Global research in adults has shown positive associations between objectively-ascertained urban environmental attributes and accelerometer-assessed physical activity, specifically for net residential density, intersection density, public transport density, and number of parks.[97] Our umbrella review (Appendix 5) identified a dearth of review-level evidence on environmental influences on adolescents' physical activity published since 2012. One review,[98] including 19 studies in HICs, demonstrated positive effect sizes in both early and late adolescence for built environmental features promoting play (including sports and fitness), those promoting walking, and those promoting both activities. Larger effect sizes were observed for older adolescents, and for those environmental features that promoted both play and walking, suggesting that a multi-utility design of the urban environment is important, particularly as adolescents become older. As also noted by others,[99] the evidence base is mainly cross-sectional and lacks evidence from LMICs where access to positive environments may be more strongly socio-economically patterned. To better inform policy and practice, research needs to move towards longitudinal designs and to consider impacts on adolescent behaviour in natural experimental evaluations of environmental interventions.

Active travel is an important contributor to adolescent physical activity,[100,101] and promoting active travel is one of the opportunities identified in the *Global Action Plan on*

Physical Activity 2018-2030. It also supports achievement of the Paris Agreement (i.e., net-zero emissions), suggested to result in 1.15 million fewer annual deaths due to increased active travel.[102] Figure 2 presents the prevalence of active travel to school amongst 13-15-year-olds across 73 countries in the GSHS (also Appendix 2). An average of 38% of boys and 46% of girls reported *never walking or cycling to school*. While this prevalence increased slightly with country income, differences were very large between individual countries, ranging from 15% (Benin) to 78% (United Arab Emirates) among boys, and from 10% (Vietnam) to 90% (Niue) among girls, indicating substantial scope for improvement in many countries. National-level differences in the social, built and natural environment have likely contributed to this variability, although there is limited evidence exploring this. It is however also important to note that for many adolescents across the globe active transportation remains a necessity and not a choice. Moreover, travel patterns of those not in school have not been captured by this survey. In addition to capturing their travel patterns it may be especially important in LMICs to advance research on adolescents' travel behaviours beyond school travel to other largely overlooked destinations (e.g., friends' and relatives' residence, shops/markets, work, household water collection points, etc.) that may be important contributors to overall activity levels.

Conclusions

Adolescence is a critical life stage in the development of healthy behaviours, but adolescent physical activity behaviours and their association with medium and long-term outcomes are poorly understood. Adolescents are not sufficiently active, and this is unequally distributed globally and within societies. A whole systems approach with radical change at social, environmental and systems levels through multidisciplinary and cross-sectorial collaboration is required to tackle this "wicked problem". Although multi-component programmes, including tailored support for schools, are most likely to be successful, many adolescents across the globe are not in education and alternative strategies to reach this population are required (e.g. changes to the built environment or digital interventions). There is promising observational and interventional evidence on adolescent physical activity behaviours, yet major challenges with implementation remains and more studies from LMICs, those out of school, and older adolescents and young adults going through major life transitions are urgently needed to achieve the promise of the triple benefit of adolescent health promotion.

AUTHOR CONTRIBUTIONS

EvS, UE, DD and PK conceptualised the paper, and EvS drafted the text with critical contributions from all authors. EvS, UE, and DL led the systematic reviews; ICS, AH, and ALO contributed to screening, data extraction, and synthesis. RG and PK led on collation and analysis of surveillance data.

DECLARATION OF INTERESTS

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Panel 1: **Progress and challenges with physical activity surveillance in adolescents**

Increasing physical activity surveillance in adolescents

- There has been a substantial increase in the number of countries with self-reported physical activity surveillance data for adolescents since the *2012 Lancet Physical Activity Series*. Data from 105 countries were available for the 2012 report, compared to 120 countries in 2016, and 146 countries in the latest report.
- Several countries are now integrating device-based measures of physical activity into their population surveillance systems. Some examples of device-based surveillance among adolescents include:
    - Canada has used accelerometers to measure physical activity in the Canadian Health Measures Survey annually since 2007.
    - The U.S. included accelerometers in the National Health and Nutrition Examination Survey in 2003-06 (waist worn), and again in 2011-14 (wrist worn).
    - Australia included pedometers in the Australian Health Survey in 2011-12.
    - Malta used accelerometers to measure physical activity in a nationally representative sample of adolescents in 2012.
    - Portugal used accelerometers to measure physical activity in a nationally representative sample of adolescents in 2006-08.
    - In Norway, accelerometers were used to measure physical activity in nationally representative samples of adolescents in three waves of data collection between 2005-2017.

Challenges and recommendations

- The age span of 10 to 24 years encompasses two sets of aerobic physical activity guidelines (an average of 60 minutes daily up to age 17 years; 150 minutes per week for ages 18 years and over), making comparisons of proportions meeting guidelines problematic. There is no scientific reason why the dose of physical activity at which health benefits occur changes so dramatically at age 18. Strengthening the scientific evidence base upon which to identify quantitative health-related physical activity thresholds during the transition between adolescence and young adulthood is therefore an important area for future research.
- Adolescent physical activity surveillance would benefit from the use of a combination of self-report and device-based assessment. This should consist of repeated cross-sectional surveys at a minimum every five years, conducted throughout the year to account for seasonal variations. Reporting of data should support the monitoring of progress towards reducing inequalities in participation in physical activity (such as by age, sex, geographical location and socio-economic status).
- Current surveillance efforts rely on a variety of self-report questionnaires and devices, making comparison across countries and regions difficult. Moreover, collection of physical activity data across the entire year to account for seasonal variation is complicated by school attendance (versus not) which differs from country to country. Harmonisation of questionnaires and the development of algorithms to generate comparable estimates is paramount.
- Data from low income countries continue to be scarce: only 8 (26%) out of 31 low-income countries contributed self-reported adolescent physical activity data to the latest report. Nationally representative device-based physical activity data are non-existent from low-income countries. Efforts should focus on improving surveillance globally.

- The vast majority of self-reported surveillance data captures adolescents attending secondary school. Surveillance data of those not in schools is generally lacking, and methods to capture this population should be developed.
- Physical activity surveillance should capture domain- and type-specific information to inform interventions. Data on specific aspects of adolescent physical activity, such as sports and walking or cycling for transport, are currently inconsistent and often not comparable across countries, yet important for physical activity promotion.
- Surveillance of screen use has typically focussed on TV viewing and computer use. As the ways in which adolescents interact with screens is changing rapidly, surveys now need to incorporate more contemporary indicators capturing the multitude of ways in which adolescents use screens.
- The use of different intensity cut-points across age when analysing device-based physical activity data makes comparisons across age and between studies difficult. Comparison between studies is further complicated by different wear protocol and data processing decisions, and we encourage the increased use and sharing of raw accelerometer data to enable such comparison.

Panel 2: **Informing solutions: progress in correlates and intervention research into adolescent physical activity behaviours**

In the first Lancet Physical Activity Series, Bauman et al and Heath et al summarised the global evidence on correlates of physical activity, and interventions to promote physical activity, respectively, including evidence on children and adolescents. For this paper on adolescent physical activity, we sought to identify the progress made since the initial publication. We conducted two complementary umbrella reviews addressing the research questions:

- What are the correlates and determinants of physical activity in adolescence?
- What is the effect of interventions to promote physical activity in adolescence?

Data for these reviews were identified by searches in December 2019 of Ovid Medline, Embase, PsycINFO, Web of Science, and Scopus using the search terms related to "adolescents", "physical activity", "systematic review", in addition to terms for "correlates" or "interventions", respectively (see Appendices 5 and 6 for full details). Only articles published from 2012 onwards, providing a (semi-)quantitative synthesis, and including 10-24-year-olds were included.

Correlates and determinants of adolescent physical activity behaviours.

We identified 13 systematic reviews published since 2012. Most had a specific focus, such as an ecological domain of influence (e.g. interpersonal), location (e.g. school), country (e.g. United Arab Emirates), or population (e.g. North American Indigenous populations, Chinese). Across the reviews, 713 papers were included of which 19% reported on longitudinal studies, which constitutes a substantial increase in the proportion of longitudinal studies from 2012 (when 13.5% across the reviews included both cross-sectional and longitudinal evidence) and an improvement to the evidence base. A greater focus on modifiable factors indicates a clear shift from the evidence base in 2012, which was dominated by non-modifiable factors. Reviews included evidence from across the globe, but still predominately from Western-Europe, North America and Australia. Few studies were included from Africa (10 studies) or Central and South America (27 studies, of which 21 were from Brazil). The evidence shows that associations are likely to be context-specific, evidenced by a review showing that the association between socio-economic position and adolescent sedentary behaviour is negative in high-income countries, but positive in low-to-middle-income countries.[52] Transferability of the current evidence base to understudied populations may therefore be limited. More research that aims to understand the context-specific drivers of physical inactivity is required to inform effective intervention development and implementation. Moreover, future research should adopt longitudinal designs, study older adolescent and young adult populations, investigate the relative importance of different factors to identify more targeted action, and focus attention on biological, environmental and policy-level influences (including commercial determinants of health) and how these interact with other correlates. This should include consideration of the diverse impacts of macro-environmental changes such as climate change across the globe.

Interventions to change adolescent physical activity behaviours.

We identified 13 systematic reviews published since 2012. All but one predominantly included studies in early adolescence, with one review focussing on young adults at university/college. The evidence base was largely drawn from HICs, with limited representation of LMICs. Seven reviews focussed specifically on interventions in the school setting, with one additional review investigating the effectiveness of approaches set in universities/colleges, which was also the only review including studies in young adults. In general, previous interventions have had a minimal effect on adolescents' physical activity, especially those that have used objective measures. Based on the evidence identified, we provide the following research recommendations. First, a shift in focus and innovative thinking is required to tackle physical activity behaviours beyond 'early adolescence'. Solutions need to address the challenges faced by young people as they transition into higher education, employment, marriage and/or parenthood. Second, research on school and community-based interventions should focus more on mechanisms of change (mediation), implementation (i.e., adoption, dose delivered, reach, fidelity, and sustainability) and the determinants of implementation (e.g., feasibility, adaptability and acceptability).[81] Poor implementation in original studies likely explains the lack of consistency in the effectiveness of different types of physical activity interventions targeting adolescents, and there is limited evidence on the extent to which interventions have been delivered as intended. Finally, researchers are encouraged to develop, implement and evaluate adolescent physical activity interventions in LMICs.

Panel 3: **Best buys for increasing physical activity in adolescent populations.**

Schools are ideally placed to provide younger and older adolescents with a dose of physical activity while equipping them with the necessary knowledge, skills and confidence to be active across the lifespan. Ideally, schools should implement multi-component interventions that include physical education, physical activity during school hours (e.g., active lunch and recess breaks, and classroom physical activity breaks), physical activity before and after school (e.g., active transportation to school and extra-curricular activities), staff involvement, and family and community engagement. Aligning with the recent WHO/UNESCO initiative on "Making Every School a Health Promoting School",[72] this whole-school approach is known as a comprehensive school-based physical activity programme (CSPAP) and is considered the 'gold standard' for increasing physical activity in youth.[68,83]

In general, school-based physical activity interventions targeting adolescents have been minimally successful. However, interventions involving all or multiple CSPAP components typically result in moderate effect sizes. An example is the Physical Activity 4 Everyone (PA4E1) program, implemented and evaluated in ten Australian secondary schools.[84] PA4E1 included seven CSPAP components: enhanced physical education lessons, individualised student physical activity plans, enhanced school sport program, provision of programs and equipment during breaks, modified school policies to engage low-active students, after school community sport and fitness programs, and parental engagement. Intervention schools were supported to implement PA4E1 using six evidence-based implementation strategies. After two years, students in the intervention schools were engaging in an additional 7 minutes of moderate-to-vigorous physical activity per day, compared to those in the usual care control group. It is important to note that CSPAPs require substantial financial and logistical support, which may not be attainable in many LMICs and HICs.

Many adolescents across the globe are not in formal education, and there is an urgent need for non-school based approaches to physical activity promotion. There is emerging evidence for the efficacy of physical activity interventions involving eHealth (i.e., internet-based) and mHealth (i.e., mobile phone apps and text messaging) technology. Of note, combining eHealth/mHealth technology with traditional intervention strategies, such as school-based environmental change and/or education, appears to be more effective than technology only interventions. Considering the ubiquity of mobile devices and the high levels of internet access amongst adolescents globally, such approaches are likely to have extensive reach and should be explored more widely.

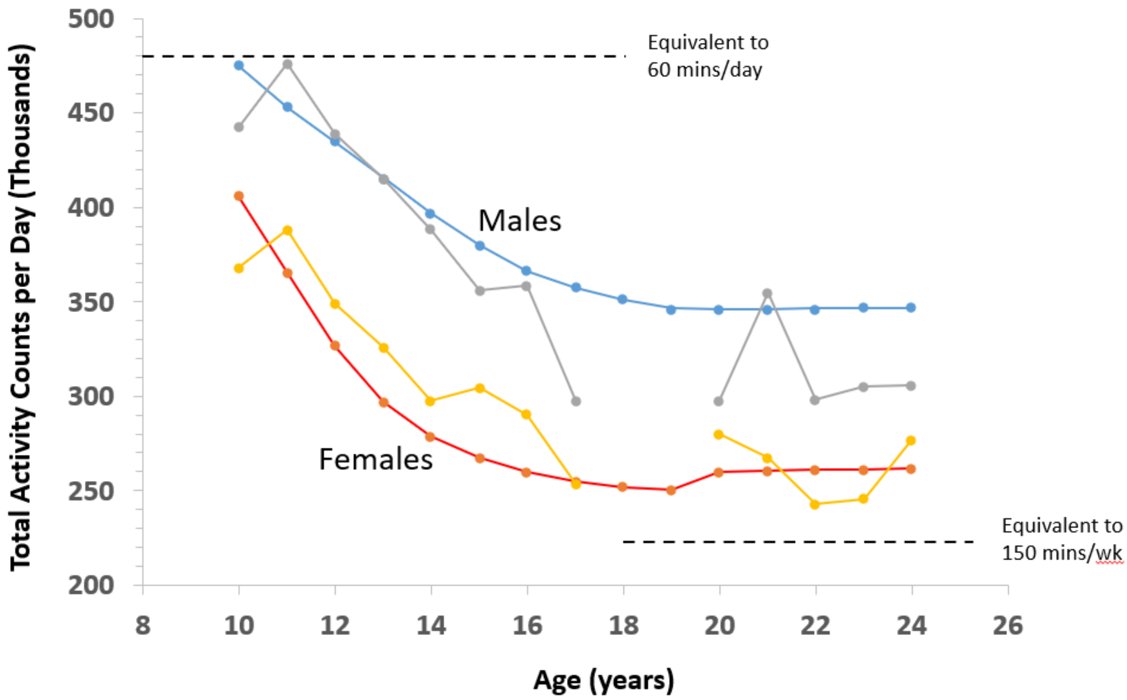

Figure 1: Overall physical activity (expressed as total activity counts) from accelerometry in U.S. and European males and females from 10 to 24 years of age.

Note: Data for U.S. males (blue) and females (red) are smoothed 50th percentiles from NHANES 2003-2006. Data for European males (grey) and females (yellow) are age-specific median values from the Determinants of Diet and Physical Activity Knowledge Hub (DEDIPAC). Dotted lines indicate the estimated total activity counts associated with the adolescent guidelines (60 mins/day) and young adult guidelines (150 mins/week). See appendix 1 for methodological details.

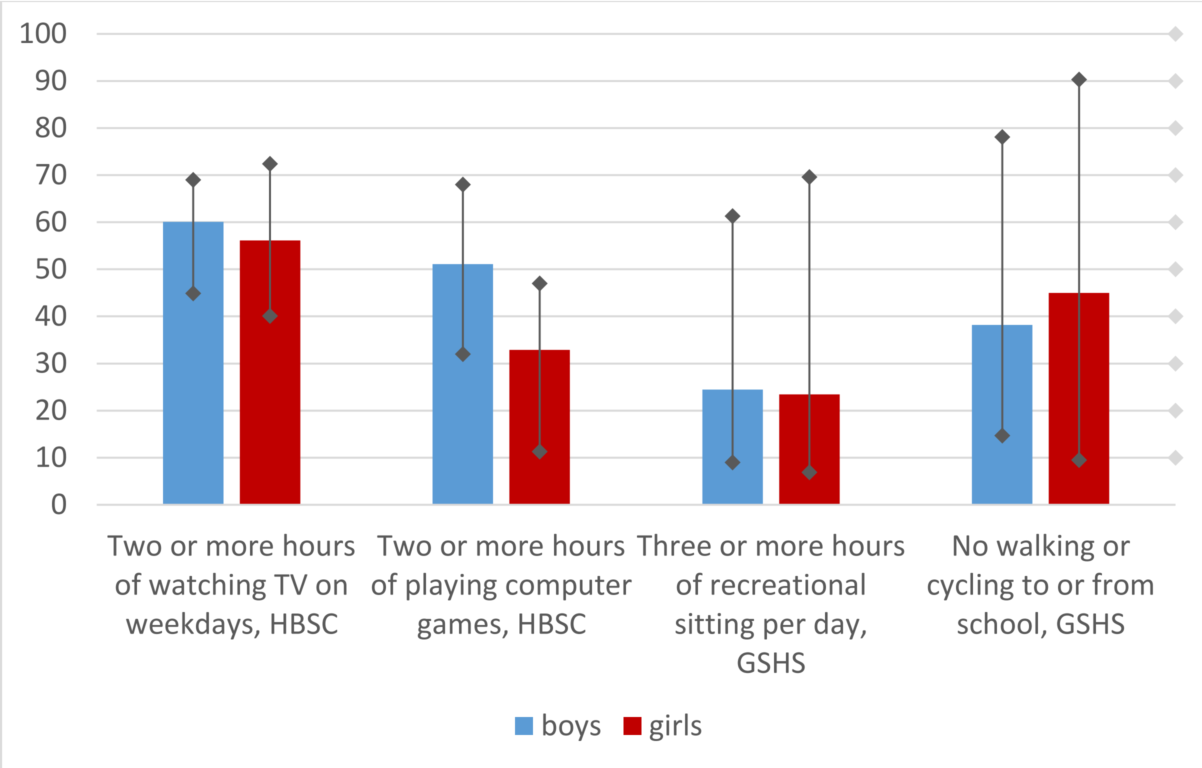

Figure 2: Prevalence of watching TV (HBSC, 37 countries); playing computer games (HBSC, 38 countries); recreational sitting (GSHS, 97 countries); and no walking or cycling to or from school (GSHS, 73 countries).

Note: Data shows prevalence with minimum and maximum country values. HSBC data is from 2014, GSHS data from 2003-2017. See Appendix 2 for methodological details.

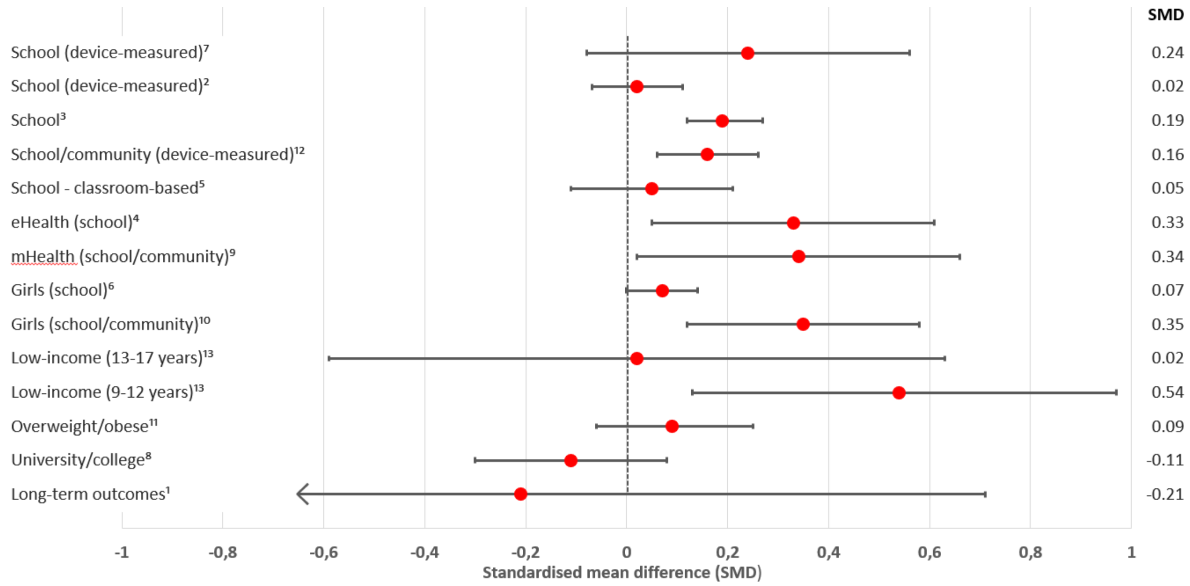

Figure 3: Effects of interventions to promote physical activity or reduce sedentary behaviour in adolescents (standard mean differences from original systematic reviews).

Note: See Appendix 6 for review methods, detailed results, and references.

Supplementary appendix

Supplement to: Van Sluijs EMF, Ekelund U, Crochemore Silva I, et al. Physical activity behaviours in adolescence: current evidence and opportunities for intervention. *Submitted for publication to the Lancet.*

Overview of appendices:

APPENDIX 1: Methods for device-based data presented in Figure 1.

The data presented in **Figure 1** were derived from several sources.

Data for U.S. males and females were obtained from two publications that reported smoothed percentiles for total activity counts from the 2003-2006 U.S. National Health and Nutrition Examination Survey (NHANES).[1,2] Data were collected using an ActiGraph model 7164 accelerometer worn on the right hip during waking hours. Smoothed, sex-specific percentile curves were calculated using the LMS statistical method. The LMS statistical method normalizes a measure across age using a Box–Cox power transformation. The LMS parameters are skewness (L: Box–Cox power), median (M), and coefficient of variation (S). Curves were generated using LMS ChartmakerPro (LMS Chartmaker version 2.54) software, which adjusts for NHANES sample weights.[1,2]

Data for European males and females were obtained from the DEterminants of DIet and Physical ACtivity (DEDIPAC) knowledge hub. Age- and sex-specific median values were obtained by re-analyzing the data previously reported in two publications.[3,4] The DEDIPAC data were derived from pooling 30 studies (from 18 European countries) in adolescents conducted between 1997 and 2014 that used ActiGraph models 7164, GT1M, Actitrainer, or GT3x/3X+,[4] and five population-based studies (from four European countries) in adults conducted between 2001 and 2009 that used either the ActiGraph GT1M or the ActiGraph 7164.[3] The curves for European adolescents have not been smoothed; thus, they appear as jagged lines in comparison to the smoothed U.S. reference data.

Cut-points for total activity counts that correspond to physical activity public health guidelines were obtained using the DEDIPAC data described above. Daily time spent in moderate-to-vigorous intensity physical activity were obtained using cut-points of 2296 counts per minute in adolescents[4] and ≥2020 counts per minute in adults.[3] Linear regression models that predicted total activity counts from daily minutes of moderate-to-vigorous intensity physical activity were developed, and the parameter estimates are presented below:

	Adolescents (10-17 y)	Young Adults (18-24 y)
R^2	0.80	0.83
Intercept	151,191	119,015
MVPA β	5,476	4,829

Current global physical activity recommendations indicate that children and adolescents (<18 years) should participate in an average of 60 minutes of moderate-to-vigorous intensity physical activity daily, while adults (≥18 years) should undertake at least 150-300 minutes per week of moderate-intensity, or 75-150 minutes per week of vigorous-intensity physical activity, or an equivalent combination of moderate- and vigorous-intensity physical activity.[5] In order to estimate the total activity counts associated with meeting the guidelines for adolescents and young adults, we input 60 minutes per day and 21.4 minutes per day (150 minutes per week/7), respectively, into the regression models above. The resulting estimates for total activity counts were 479,751 for adolescents and 222,355 for young adults. These cut-points should be viewed as rough estimates only, as direct comparisons are difficult due to the guideline development process being informed largely by self-reported data, while the results presented here are based on device-measured physical activity.

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APPENDIX 2 - Methods for school survey analysis

We used data from two large international school-based surveys, the Health Behaviour in School-Aged Children (HBSC)[1,2], and the Global School-based Student Health Survey (GSHS)[3]. The target population of both surveys are school going adolescents, with the HBSC collecting data from 11, 13 and 15 year olds, and the GSHS from 13-15 year olds until 2012. After 2012, the GSHS age range was extended to include 13-17 year olds. The HBSC, coordinated by the WHO Office for Europe, covers European and North American countries while the GSHS, coordinated by WHO headquarters in collaboration with the US Centers for Disease Control and Prevention, covers mainly low- and middle-income countries. The HBSC is typically done in waves with simultaneous data collection across participating countries, whereas the GSHS is implemented based on regional and country demand.

The HBSC data presented in our article are from two published HBSC reports[1,2] from the 2013-2014 survey. Each country used random sampling to select a proportion of young people aged 11,13 and 15 years, ensuring that the sample is representative of all in the age range. Around 1,500 students in each HBSC country were selected from each age group. Data are presented for the following indicators:

- Percentage of 11, 13, and 15 year old students who viewed TV for two hours or more on weekdays;
- Percentage of 11, 13, and 15 year old students who played games on a computer or games console for two or more hours on weekdays.

To derive these indicators, adolescents were asked to report on the number of hours spent on these behaviours. Although data on weekend day behaviours were also collected, this was not presented in the reports, and therefore not included here.

We used publicly available data from the GSHS[3] from 2003-2017 for adolescents aged 13-15 years. GSHS surveys are based on representative samples with country sample sizes of typically several thousand students. Data are presented for the following indicators:

- Percentage of 13-15 year old students who spent three or more hours per day sitting and watching TV, playing computer games, or talking with friends, when not in school or doing homework during a typical or usual day;
- Percentage of 13-15 year old students who did not walk or ride a bicycle to or from school.

Where data were reported for several sites in a country with no national estimate being available, we averaged data from the different sites. To produce aggregated estimates by income group[4] (as in previous reports[5]) and for all countries combined,. we weighted country estimates by the respective population size[6].

RESULTS

HBSC

In total, we included 38 countries with HBSC data on screen-based behaviours in the analysis. Of those, 37 countries had information on TV use, and 38 countries on playing computer games. Of the 38 countries included, three were classified as 'lower-middle income', six as 'upper-middle income', and 29 as 'high income' by the World Bank[4] (Table A2.1).

Across the 37 countries with information on TV use, 60% of boys and 56% of girls reported watching TV for two or more hours on weekdays. Prevalence was similar across lower-middle, upper-middle, and high income groups (Figure A2.1). Country prevalence ranged from 45% (Switzerland) to 69% (United Kingdom, Wales) among boys, and from 40% (Switzerland) to 72% (Bulgaria) among girls. In 31 of the 37 countries with data, boys had a higher prevalence of TV watching as compared to girls (Table A2.1), while in only 6 countries, girl's prevalence was slightly higher than the one for boys.

Across the 38 countries with information on playing computer games or using games console for two or more hours on weekdays, the aggregated prevalence was 51% for boys and 33% for girls. Prevalence was similar across lower-middle, upper-middle and high income groups, however, prevalence in all income groups was about 20% higher for boys as compared to girls (Figure A2.2). Country prevalence ranged from 32%

(Switzerland) to 68% (Denmark) for boys, and from 11% (Finland) to 47% (Netherlands) for girls. Prevalence was greater for boys as compared to girls in all of the analysed countries (Table A2.1).

Table A2.1. Percentage of 11, 13, 15 year old boys and girls watching TV for two or more hours on weekdays, and percentage of playing computer games or games console for two or more hours on weekdays, HBSC, 2014.

Country (subnational area)	WHO region	World Bank Income Group	2+ hours of TV/day, boys	2+ hours of TV/day, girls	2+ hours of computer games/day, boys	2+ hours of computer games/day, girls
Albania	Europe	Upper middle income	63	64	47	26
Armenia	Europe	Lower middle income	61	57	38	23
Austria	Europe	High income	56	50	48	30
Belgium (Flemish)	Europe	High income	59	59	43	24
Belgium (French)	Europe	High income	57	52	49	38
Bulgaria	Europe	Upper middle income	69	72	66	46
Canada	Americas	High income	No data	No data	56	42
Croatia	Europe	Upper middle income	60	57	43	19
Czechia	Europe	High income	63	55	60	24
Denmark	Europe	High income	65	61	68	34
Estonia	Europe	High income	61	58	64	25
Finland	Europe	High income	61	55	50	11
France	Europe	High income	58	53	48	29
Germany	Europe	High income	58	52	47	33
Greece	Europe	High income	63	59	48	26
Hungary	Europe	High income	55	51	51	30
Iceland	Europe	High income	52	44	56	28
Ireland	Europe	High income	52	49	38	31
Israel	Europe	High income	67	70	56	47
Italy	Europe	High income	54	47	45	33
Latvia	Europe	High income	66	62	58	27
Lithuania	Europe	High income	60	58	58	34
Luxembourg	Europe	High income	57	50	46	31
Malta	Europe	High income	59	50	57	44
Netherlands	Europe	High income	68	69	63	47
North Macedonia	Europe	Upper middle income	53	52	46	27
Norway	Europe	High income	59	52	53	32
Poland	Europe	High income	60	59	48	21
Portugal	Europe	High income	56	53	40	22
Republic of Moldova	Europe	Lower middle income	65	67	50	30
Romania	Europe	Upper middle income	69	66	59	36
Russian Federation	Europe	Upper middle income	62	58	55	35
Slovakia	Europe	High income	66	64	60	32
Slovenia	Europe	High income	56	49	41	15
Spain	Europe	High income	53	48	37	29
Sweden	Europe	High income	65	62	63	32
Switzerland	Europe	High income	45	40	32	21
Ukraine	Europe	Lower middle income	60	58	51	29
United Kingdom (England)	Europe	High income	61	62	53	39
United Kingdom (Scotland)	Europe	High income	68	60	65	46
United Kingdom (Wales)	Europe	High income	69	65	65	40

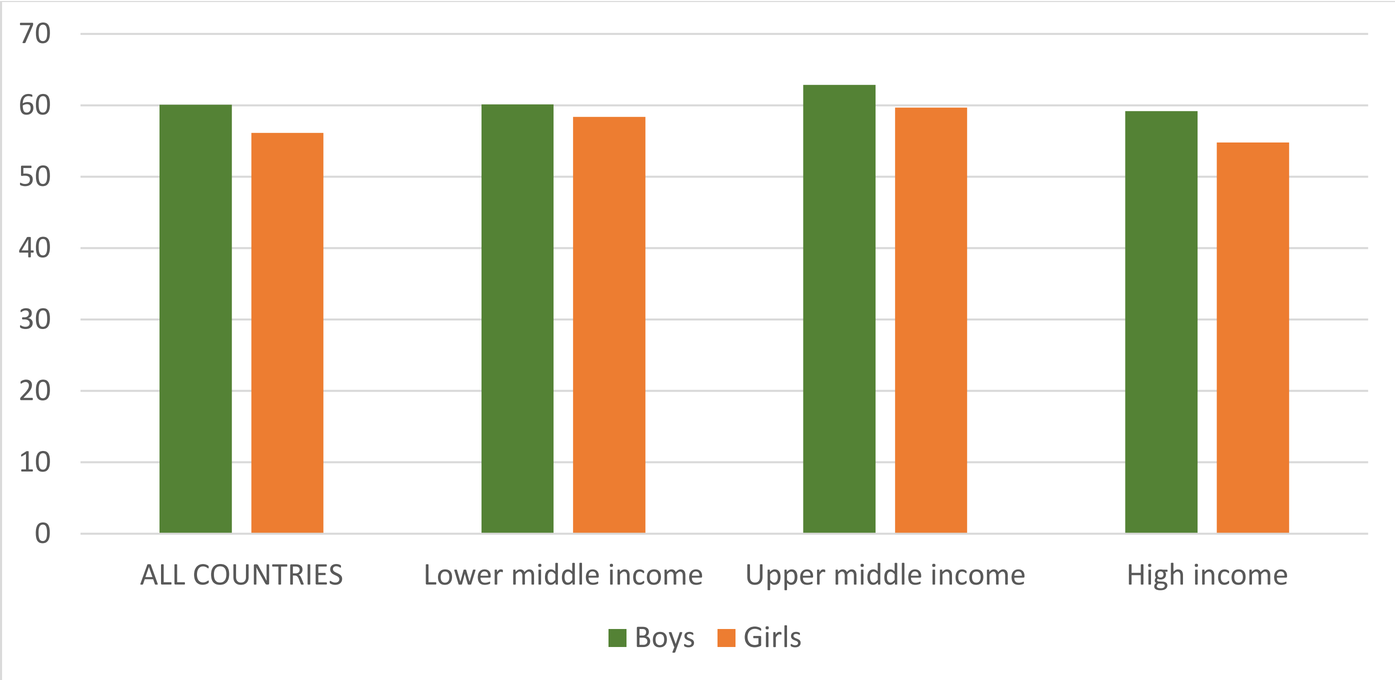

Figure A2.1. Percentage of 11, 13, 15 year old boys and girls watching TV for two or more hours on weekdays, all countries and by income group, HBSC, 2014.

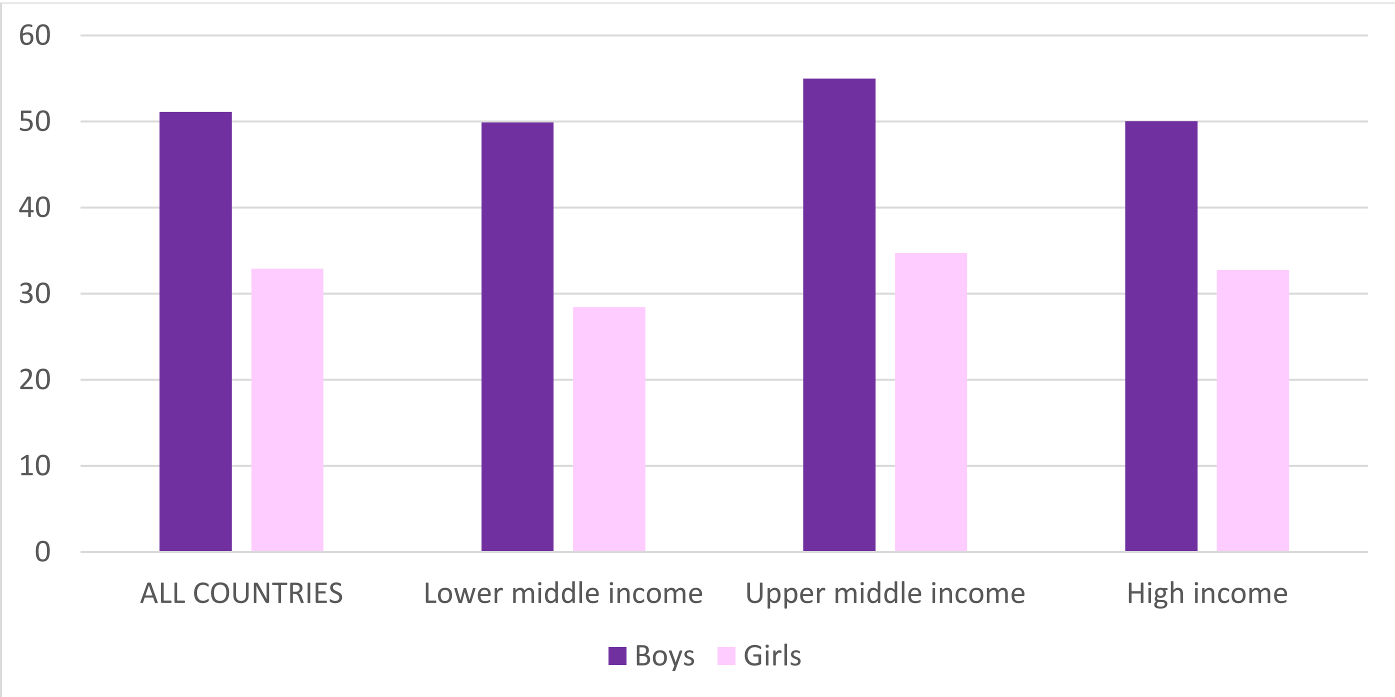

Figure A2.2. Percentage of 11, 13, 15 year old boys and girls playing computer games or games console for two or more hours on weekdays, all countries and by income group, HBSC, 2014.

GSHS

In total, we included 98 countries with GSHS data on physical activity in the analysis that conducted a survey between 2003-2017. Of those, 97 countries had information on sitting, and 73 countries on active transport behaviour. Of the 98 countries included, ten were classified as 'low income', 33 as 'lower-middle income', 31 as 'upper-middle income', 18 as 'high income', and six were not classified into any income group by the World Bank[4] (Table A2.2).

Across the 97 countries with information on sitting, 25% of boys and 24% of girls reported sitting for three or more hours per day in addition to sitting at school and for homework. Prevalence was similar across low-, lower-middle, and upper-middle income groups, however, it was more than double for 13-15 year old boys and girls from high-income countries as compared to all other income groups (Figure A2.3). Country prevalence ranged from 9% (Pakistan) to 61% (Kuwait) among boys, and from 7% (Pakistan) to 70% (Barbados) among girls (Table A2.2).

Across the 73 countries with information on walking or riding a bike to or from school, 38% of boys and 46% of girls reported not using active school transport. While prevalence increased only slightly with country income, there were very large differences between individual countries, ranging from 15% (Benin) to 78% (United Arab Emirates) among boys, and from 10% (Viet Nam) to 90% (Niue) among girls (Table A2.2).

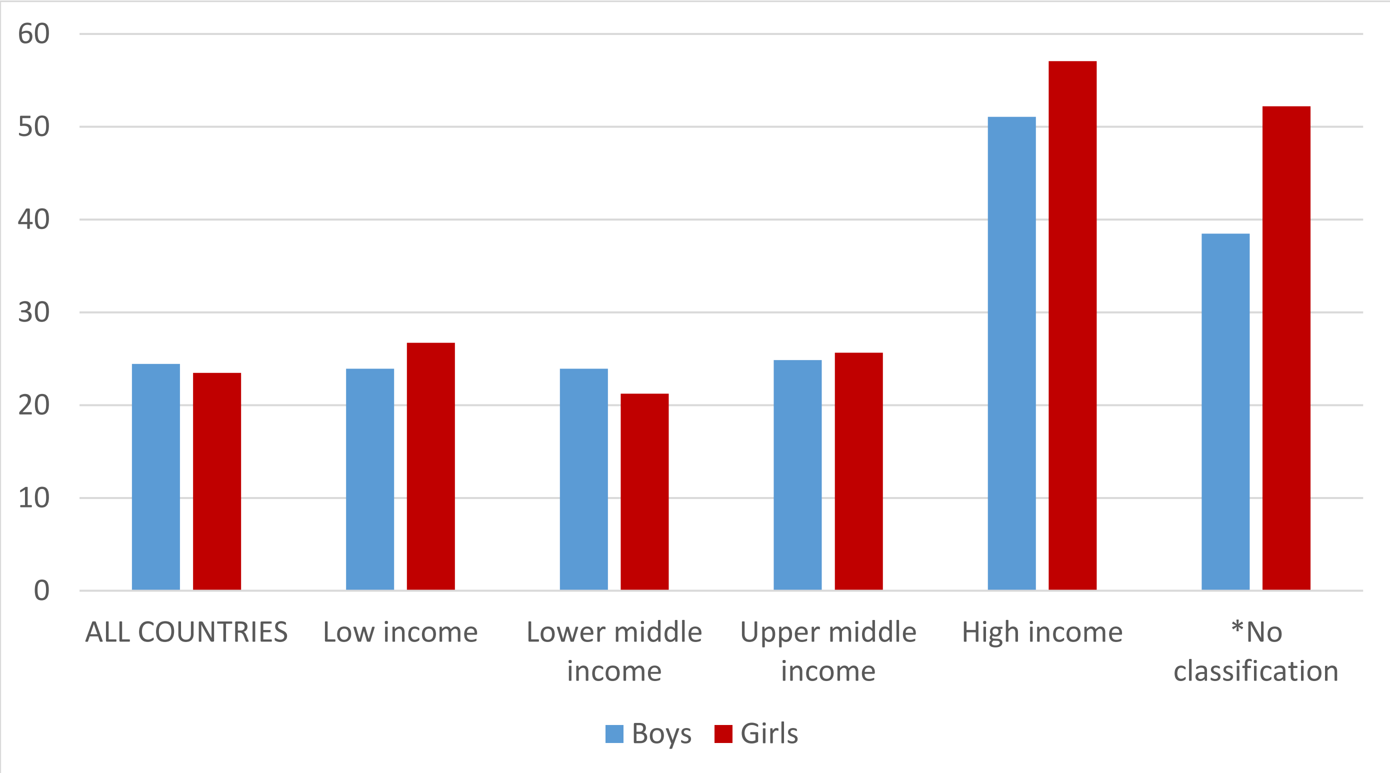

Figure A2.3. Percentage of 13-15 year old boys and girls sitting three or more hours per day in addition to sitting at school or for homework, all countries and by income group, GSHS, 2003-2017.

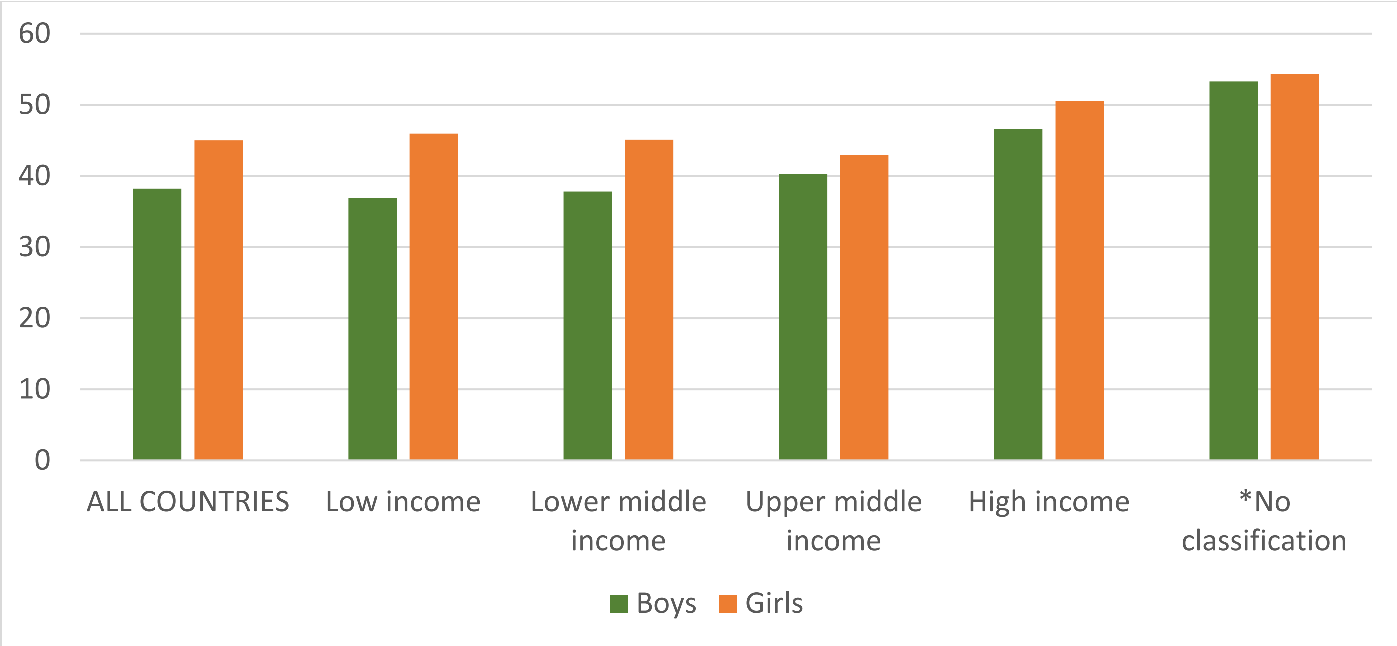

Figure A2.4. Percentage of 13-15 year old boys and girls not walking or riding a bike to and from school, all countries and by income group, GSHS, 2003-2017.

Table A2.2. Percentage of 13-15 year old boys and girls sitting three or more hours per day in addition to sitting at school or for homework, GSHS, 2003-2017, and percentage of 13-15 year old boys and girls not walking or riding a bike to and from school, GSHS, 2003-2017.

Country (subnational area)	WHO region	World Bank Income Group	Survey year	3+ hours of sitting/day, boys	3+ hours of sitting/day, girls	No waking/cycling to/from school, boys	No waking/cycling to/from school, girls
Algeria	Africa	Upper middle income	2011	30	26	40	40
Benin	Africa	Low income	2016	25	27	15	14
Botswana	Africa	Upper middle income	2005	35	34	no data	no data
Ghana	Africa	Lower middle income	2012	18	20	36	45
Kenya	Africa	Lower middle income	2003	40	36	no data	no data
Liberia	Africa	Low income	2017	25	19	no data	no data
Mauritania	Africa	Lower middle income	2010	39	40	30	34
Mauritius	Africa	Upper middle income	2017	35	42	no data	no data
Mozambique	Africa	Low income	2015	34	49	43	60
Namibia	Africa	Upper middle income	2013	35	39	46	58
Senegal	Africa	Low income	2005	29	21	no data	no data
Seychelles	Africa	High income	2015	48	56	54	58
Sierra Leone	Africa	Low income	2017	22	25	no data	no data
Uganda	Africa	Low income	2003	27	28	no data	no data
United Republic of Tanzania	Africa	Low income	2014	21	20	48	52
Zambia	Africa	Lower middle income	2004	33	33	no data	no data
Zimbabwe (Bulawayo)	Africa	Low income	2003	43	42	no data	no data
Zimbabwe (Harare)	Africa	Low income	2003	43	45	no data	no data
Zimbabwe (Manicaland)	Africa	Low income	2003	39	42	no data	no data
Antigua and Barbuda	Americas	High income	2009	50	60	55	52
Argentina	Americas	Upper middle income	2012	47	53	31	32
Bahamas	Americas	High income	2013	50	60	64	68
Barbados	Americas	High income	2011	60	70	73	80
Belize	Americas	Upper middle income	2011	31	43	40	44
Bolivia (Plurinational State of)	Americas	Lower middle income	2012	25	24	38	34
Chile	Americas	High income	2013	52	56	33	33
Colombia (Bogotá)	Americas	Upper middle income	2007	51	52	no data	no data
Colombia (Bucaramanga)	Americas	Upper middle income	2007	46	51	no data	no data
Colombia (Cali)	Americas	Upper middle income	2007	49	54	no data	no data
Colombia (Manizales)	Americas	Upper middle income	2007	51	60	no data	no data
Colombia (Valledupar)	Americas	Upper middle income	2007	38	48	no data	no data
Costa Rica	Americas	Upper middle income	2009	41	48	44	44
Dominica	Americas	Upper middle income	2009	no data	no data	60	66
Ecuador (Guayaquil)	Americas	Upper middle income	2007	31	33	no data	no data
Ecuador (Quito)	Americas	Upper middle income	2007	34	31	no data	no data
Ecuador (Zamora)	Americas	Upper middle income	2007	29	28	no data	no data
El Salvador	Americas	Lower middle income	2013	34	39	40	44
Grenada	Americas	Upper middle income	2008	43	43	no data	no data
Guatemala	Americas	Lower middle income	2015	21	26	41	43
Guyana	Americas	Upper middle income	2010	35	36	50	63
Honduras	Americas	Lower middle income	2012	31	30	33	42
Jamaica	Americas	Upper middle income	2017	47	59	64	68
Paraguay	Americas	Upper middle income	2017	32	35	41	44
Peru	Americas	Upper middle income	2010	28	30	30	29
Saint Kitts and Nevis	Americas	High income	2011	52	64	52	57

Country (subnational area)	WHO region	World Bank Income Group	Survey year	3+ hours of sitting/day, boys	3+ hours of sitting/day, girls	No waking/cycling to/from school, boys	No waking/cycling to/from school, girls
Saint Lucia	Americas	Upper middle income	2007	57	54	no data	no data
Saint Vincent and the Grenadines	Americas	Upper middle income	2007	42	38	no data	no data
Suriname	Americas	Upper middle income	2016	44	45	47	56
Trinidad and Tobago	Americas	High income	2017	43	54	no data	no data
Uruguay	Americas	High income	2012	56	60	31	34
Venezuela (Bolivarian Republic of) (Barinas)	Americas	Upper middle income	2003	23	19	no data	no data
Venezuela (Bolivarian Republic of) (Lara)	Americas	Upper middle income	2003	29	31	no data	no data
Afghanistan	Eastern Mediterranean	Low income	2014	20	27	23	38
Bahrain	Eastern Mediterranean	High income	2016	50	68	63	79
Djibouti	Eastern Mediterranean	Lower middle income	2007	32	33	no data	no data
Egypt	Eastern Mediterranean	Lower middle income	2011	36	20	39	37
Iraq	Eastern Mediterranean	Upper middle income	2012	28	23	35	52
Jordan	Eastern Mediterranean	Lower middle income	2007	36	40	no data	no data
Kuwait	Eastern Mediterranean	High income	2015	61	65	65	73
Lebanon	Eastern Mediterranean	Upper middle income	2017	43	44	57	67
Libya	Eastern Mediterranean	Upper middle income	2007	30	27	no data	no data
Morocco	Eastern Mediterranean	Lower middle income	2016	29	27	33	37
Oman	Eastern Mediterranean	High income	2015	40	37	64	76
Pakistan	Eastern Mediterranean	Lower middle income	2009	9	7	28	54
Qatar	Eastern Mediterranean	High income	2011	44	55	30	36
Sudan	Eastern Mediterranean	Lower middle income	2012	22	17	59	65
Syrian Arab Republic	Eastern Mediterranean	Lower middle income	2010	24	27	45	44
Tunisia	Eastern Mediterranean	Lower middle income	2008	22	28	no data	no data
United Arab Emirates	Eastern Mediterranean	High income	2016	48	63	78	86
Yemen	Eastern Mediterranean	Lower middle income	2014	17	23	47	72
North Macedonia	Europe	Upper middle income	2007	49	51	no data	no data
Anguilla	No WHO Member State	No classification	2016	50	67	69	70
British Virgin Islands	No WHO Member State	High income	2009	59	65	64	64
Cayman Islands	No WHO Member State	High income	2007	51	63	no data	no data
Curacao	No WHO Member State	High income	2015	60	60	49	57
French Polynesia	No WHO Member State	High income	2015	40	43	47	52

Country (subnational area)	WHO region	World Bank Income Group	Survey year	3+ hours of sitting/day, boys	3+ hours of sitting/day, girls	No waking/cycling to/from school, boys	No waking/cycling to/from school, girls
Montserrat	No WHO Member State	No classification	2008	51	45	no data	no data
Tokelau	No WHO Member State	No classification	2014	43	43	52	25
Wallis and Futuna	No WHO Member State	No classification	2015	30	42	52	54
West Bank and Gaza Strip (Gaza)	No WHO Member State	Lower middle income	2010	42	44	30	32
West Bank and Gaza Strip (West Bank)	No WHO Member State	Lower middle income	2010	34	34	35	32
Bangladesh	South-East Asia	Lower middle income	2014	17	11	28	39
Bhutan	South-East Asia	Lower middle income	2016	27	30	54	54
India	South-East Asia	Lower middle income	2007	25	21	no data	no data
Indonesia	South-East Asia	Lower middle income	2015	27	26	55	57
Myanmar	South-East Asia	Lower middle income	2016	17	15	17	17
Nepal	South-East Asia	Low income	2015	12	10	39	44
Sri Lanka	South-East Asia	Lower middle income	2016	36	34	34	44
Thailand	South-East Asia	Upper middle income	2015	51	53	50	46
Timor-Leste	South-East Asia	Lower middle income	2015	17	15	54	67
Brunei Darussalam	Western Pacific	High income	2014	51	58	72	79
Cambodia	Western Pacific	Lower middle income	2013	11	10	24	25
China (Beijing)	Western Pacific	Upper middle income	2003	21	23	no data	no data
China (Hangzhou)	Western Pacific	Upper middle income	2003	22	28	no data	no data
China (Wuhan)	Western Pacific	Upper middle income	2003	22	16	no data	no data
China (Wurumqi)	Western Pacific	Upper middle income	2003	21	23	no data	no data
Cook Islands	Western Pacific	No classification	2015	34	51	42	42
Fiji	Western Pacific	Upper middle income	2016	28	29	55	56
Kiribati	Western Pacific	Lower middle income	2011	15	13	38	44
Lao People's Democratic Republic	Western Pacific	Lower middle income	2015	19	19	48	47
Malaysia	Western Pacific	Upper middle income	2012	42	44	46	48
Mongolia	Western Pacific	Lower middle income	2013	38	43	20	17
Nauru	Western Pacific	Upper middle income	2011	31	36	40	52
Niue	Western Pacific	No classification	2010	26	43	67	90
Philippines	Western Pacific	Lower middle income	2015	31	31	48	47
Samoa	Western Pacific	Upper middle income	2011	43	32	33	43

Country (subnational area)	WHO region	World Bank Income Group	Survey year	3+ hours of sitting/day, boys	3+ hours of sitting/day, girls	No waking/cycling to/from school, boys	No waking/cycling to/from school, girls
Solomon Islands	Western Pacific	Lower middle income	2011	27	28	49	51
Tonga	Western Pacific	Upper middle income	2017	23	19	46	50
Tuvalu	Western Pacific	Upper middle income	2013	17	10	59	69
Vanuatu	Western Pacific	Lower middle income	2011	23	16	16	27
Viet Nam	Western Pacific	Lower middle income	2013	34	36	15	10

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APPENDIX 3: Methods and results of the systematic review on the prospective associations between physical activity behaviours and blood pressure, metabolic syndrome and type 2 diabetes.

DESCRIPTION OF REVIEW METHODS

We conducted a systematic review of original studies aimed to address the question "What is the prospective association between physical activity in adolescence and cardiovascular risk later in life?" To specify the outcomes of interest we first scoped the available literature to identify outcomes with sufficient evidence available to warrant evidence synthesis. We considered blood pressure/hypertension, insulin resistance, incident diabetes, HDL cholesterol, metabolic syndrome, triglycerides, carotid intima media thickness, and inflammation (IL-6, fribinogen, CRP). Based on the results of the preliminary searches, we identified three outcomes for the systematic review. We specifically searched for studies examining blood pressure, the metabolic syndrome (including clustered metabolic risk) and type 2 diabetes as outcomes. We systematically searched five databases (Ovid Medline, Embase, PsycINFO, Web of Science, and Scopus) on 5th Dec 2019 for literature published since inception. A librarian at the University of Cambridge medical library developed a search strategy focused on population (terms related to adolescence and young adulthood), behaviour (terms related to physical activity in general, specific activity behaviours, sitting, and screen-based behaviours), study type (prospective, longitudinal observational), and outcomes (terms related to blood pressure, the metabolic syndrome and type 2 diabetes). The search strategy as applied to Ovid Medline is presented in Textbox A3.1, search strategies in other databases are available upon request from the lead author (EvS).

Textbox A3.1 – Cardiovascular risk factors review search strategy in Ovid Medline

1 (adolescen* or teen* or student* or ((young or early or emerging) adj adult*) or youth* or (young adj (people or person)) or freshman or freshmen or freshwoman or freshwomen or mid-adolescen*).ti,ab. or exp students/ or exp adolescent/ (2346958)
2 ((physical* adj activ*) or (active adj (transport or travel)) or exercis* or sport* or cycle or cycling or walk* or (energy adj expenditure) or sedentary or sitting or TV or television or inactiv* or (screen adj time) or screentime).ti,ab. or exp exercise/ or exp sedentary behavior/ or exp screen time/ or exp bicycling/ (1353213)
3 (longitudinal or cohort* or prospective* or follow-up* or followup* or (follow* adj up*)).ti,ab. or exp longitudinal studies/ or exp prospective studies/ or exp follow-up studies/ or cohort studies/ (2496787)
4 diabet*.ti,ab. or exp diabetes mellitus/ (663004)
5 ("clustered cardio-metabolic risk" or "metabolic syndrome").ti,ab. or exp metabolic syndrome/ (52674)
6 (((pressure* or mean) adj aterial) or (blood adj pressure*) or hyperten* or hypoten* or normotens* or ((venous or monitor* or diastolic* or pulse or systolic) adj pressure*)).ti,ab. or exp blood pressure/ or exp hypertension/ or exp hypotension/ (823479)
7 4 or 5 or 6 (1390725)
8 1 and 2 and 3 and 7 (2844)

All records retrieved were uploaded into the Covidence review software, and duplicates removed. Textbox A3.2 outlines the in- and exclusion criteria applied. Title and abstract screening were conducted by single reviewers; all records considered for full text screening were double screened by an independent reviewer, as was 10% of the excluded abstracts. Two reviewers independently screened full texts for inclusions, with discrepancies resolved by a third reviewer. Data extraction of all included papers was conducted by a single reviewer, with a 100% check by a second reviewer. Data extracted included: citation, objective, study type and name, baseline year and follow up time, analytical sample size and participants, setting and context, exposure and outcomes details, analyses performed and summary of results.

Textbox A3.2 Inclusion and exclusion criteria	
Inclusion	Exclusion
- Population: generally healthy participants aged 10-24y at baseline (or mean age between 10-24y) - Exposure: physical activity behaviour (any type measure) - Outcomes: blood pressure, incident diabetes, metabolic syndrome. - Study type: prospective observational analysis (min 1y follow-up to assess medium-to-long term effects) (including observational analyses of trial data). - Relevant quantitative data available related to the research question - Any publication date	- Exposure assessed outside of adolescent period - Cross-sectional study - Trial analyses of experimental studies - Prospective studies with <1yr follow-up - Studies of non-ambulatory participants, hospitalized patients, or samples with pre-existing chronic health conditions

RESULTS

We retrieved 8370 records of which 5419 were retained. Following title and abstract screening 5324 records were removed and 95 full text papers screened of which 61 were excluded (main reasons: adult populations, wrong outcomes, wrong study design) Thus, we extracted data from 35 papers, mainly from HIC with the exception from two studies conducted in Brazil and one study from China.

Table A3.1 provides a descriptive overview of the included studies and a summary of the results. Results highlighted in red refers to no association and those highlighted in green a significant association. The results in the Table is presented by outcome (Blood pressure, type 2 diabetes and the metabolic syndrome). Studies assessing exposures by self-report are presented first and thereafter those that assessed exposures using devices (i.e. accelerometry). Medium-term outcomes were measured within the adolescent and young adulthood period (10 to 24 years) and long-term outcomes in adulthood (i.e. >24 years of age).

Table A3.1: Description of studies included in review of prospective associations between physical activity behaviours and blood pressure, metabolic syndrome and type 2 diabetes in adolescents.

Blood pressure (BP) – Physical activity and sedentary behaviour self-reported									
Short citation	**Objective**	**Study type and name**	**Baseline year and follow up time**	**Analytical N and participants**	**Setting and context**	**Exposure details**	**Outcome details**	**Analyses**	**Results**
Barnekow-Bergkvist 2001 [1]	Investigate how physical activity at age of 16 are related to adult biological risk factors for cardiovascular diseases	Observational Prevention and Incidence of Asthma and Mite Allergy (PIAMA) Study	1974 18 years	N=278 15-18 year (mean age 16.1) old boys	Sweden Six secondary schools randomly selected from six regions	Questionnaire; leisure time sport and membership of sports club	SBP	Bivariate relative risk (>139 mmHg) and multiple logistic regression	No significant association between sport participation and SBP
Berentzen 2014 [2]	Examine the association between screen time and cardiometabolic risk and the mediating role of snacks, physical activity and adiposity.	Observational	2008-2009 1.4 years	N=144 11 to 14 years (mean age 11.3)	The Netherlands Population-based birth cohort	Questionnaire of TV viewing and computer time (h/week); PA number of days/week being active for >1 h	BP assessed by Omron Monitor after 5 min quiet sitting	Sex stratified multiple linear regression (screen time and BP)	No associations between screen time and SBP and DBP
Boreham 2002 [3]	Examine relationships between levels of activity (including sports participation) later CVD risk status	Observational Young Hearts Project	1989-1990 8 years	N=488 12 y old (135 boys; 119 girls) and 15 y old (114 boys and 120 girls)	Northern Ireland; school based random, stratified sample	Questionnaire (PA score 0 to 100 for everyday PA based on intensity, frequency and duration) and sport participation score from 0 to 10 based on extracurricular sports	BP was measured twice using a random-zero sphygmomanometer	Linear regression analysis (the biological CVD risk factors being the dependent variables) controlling for social class and sexual maturity	No significant associations between total daily activity and SBP and DBP
Boreham 1999 [4]	Examine relationships between longitudinal development of biological risk factors for CHD in tandem with the development of key risk behaviours	Observarional Young Hearts Project	1989-1990 3 years	N=459 12 y old (229 boys; 230 girls)	Northern Ireland; school based random, stratified sample,	Questionnaire (PA score 0 to 100 for everyday PA based on intensity, frequency and duration) and sport participation score from 0 to 10 based on extracurricular sports	BP was measured by random-zero sphygmomanometer,	Longitudinal associations analysed by generalised estimating equations (univariate for each exposure and outcome adjusting for SES and sexual maturity) stratified by sex	Activity score significantly inversely associated with SBP (standardized regression=-0.12; P=0.012) in boys; No associations in girls

Dasgupta 2006 [5]	Examine sex differences in the early determinants of high SBP	Observational Nicotine Dependence in Teens Study	NA 5 years	N=703 Mean age 12.8 (341 boys; 362 girls)	Canada (Montreal); school-based from all grade 7 classes in a convenience sample of 10 secondary schools.	Self-reported 7-day recall (20 surveys) Frequency (per week) participating in approx. 30 activities (continuous estimate summing all activities); Sedentary time (h/week) from TV, video and Internet use	BP measured with an oscillometric device; SBP values at or above the 90th percentile (sex, age and height specific) = high BP	All available data on SBP and candidate correlates were collapsed across the 3 assessments. Sex specific logistic regression. For physical activity and sedentary behaviour, we report associations with high SBP according to increments of 5 activities weekly on the 7-day physical activity recall and according to increments of 5 hours weekly of sedentary behaviour. Models were additionally adjusted for resting heart rate	Sedentary behaviour (OR, 1.17; 95% CI, 1.04 to 1.33) demonstrated positive associations with high SBP values; Physical activity was inversely associated with the presence of high SBP (OR, 0.92; 95% CI, 0.84 to 1.00)
Dong 2017 [6]	Determine the longitudinal associations of screen time, and leisure time sports with increasingly prevalent CMD risk factors	Observational repeated surveys China Health and Nutrition Survey	2004 to 2009 NA	N=1154 Mean age 12.6 (55% boys)	China (nine provinces); multistage, random-cluster design,	7-day recall; MET-h for all activities/week; Leisure time sport dichotomized (Yes/No); Screen time spent watching television or videotapes, playing video games, and using a computer at home	Elevated BP defined as an SBP z score or a DBP z score >90th percentile or an SBP >120 mm Hg or a DBP >80 mm Hg,	Random effects logistic regression models to examine the associations of lagged screen time, and PA with elevated BP at follow-up, adjusted for snacking and weight to height ratio	Adolescents who had >2 h/d (compared with <1 h/d) of screen time in the previous survey were more likely to have elevated BP at follow-up (OR: 1.54; 95% CI: 1.03, 2.31) in the fully adjusted model. Lagged leisure time sport participation not associated with BP.
Ford 2008 [7]	Test the independent influences of adolescent physical activity/inactivity on young adult cardiovascular risk factors	Observational National Longitudinal Study of Adolescent Health (Add Health)	1995 6 years	N=14322 Students in grade 7 to 12 (11 to 19 years)	US Nationally representative sample	Self-reported sport and exercise previous week (coded as low=0 to 2 times/w; medium=3 to 4 times/w; high=5 or more times/w); Sedentary assessed as hours/w watching TV, videos and computer use (Low=0 to 10 h/w; medium=11 to 24 h/w; high more than 25 h/w)	Self-reported "Have you ever been diagnosed with high BP?"	Bi- and multivariate models adjusted for other risk factors at follow up (i.e. BMI, tobacco use, activity/sedentary)	No association between baseline physical activity or sedentary with self-reported high BP at FU.

Gooding 2016 [8]	Examine associations of adolescent physical activity with optimal physiologic cardiovascular health (CVH) in adulthood	Observational National Longitudinal Study of Adolescent Health (Add Health)	1995 13 years	N=12139 Students in grade 7 to 12 (11 to 19 years)	US Nationally representative sample	Self-reported sport and exercise previous week (moderate/vigorous activity 5 vs. <5 day/week)	BP measured using an approved automatic device	Weighted logistic regression models to estimate odds of having young adult optimal BP defined as <120/80 mmHg	Adolescent physical activity did not predict high BP in young adulthood
Kvaavik 2009 [9]	Examine the influence of childhood physical activity on later cardiovascular disease risk factors	Observational Oslo Youth Study	1979 2 to 27 years	N=706 (age 13 y); 463 (age 15 y); 276 (age 25 y); 195 (age 40 y) Mean age 13 (11 to 15 years)	Norway (Oslo) School based (6 schools in socially disparate areas)	Self-report leisure-time physical activity (6 categories from seldom to every day)	Resting BP was ascertained using a random-zero sphygmomanometer	Linear regression adjusted for sex, SES and physical fitness	No significant associations between leisure time PA and BP at any of the follow-ups
Lefevre 2002 [10]	Analyse the relationship between cardiovascular risk factors at adult age (40 years), and sports participation during youth and physical activity during adulthood	Observational Leuven Longitudinal Study on Lifestyle, Fitness and Health	1969 to 1974 23 years	N=166 13 to 18 year-old boys	Belgium (Leuven) School based (6 schools in socially disparate areas) based on a cohort of 8963 boys	Questionnaire sport activities during the last year (global hrs/week computed; mean of annual assessments between 13 and 18 years)	SBP and DBP	Pearson correlations between adolescent sport participation and adult BP	No significant correlations observed (e.g. -0.11 for SBP)

Maximova 2009 [11]	Assess the potential association between physical activity and BP in adolescents and to assess whether this potential association was mediated by changes in adiposity	Observational Nicotine Dependence in Teens Study	1999 2 and 4 years	N=799 Mean age 12.7 (Girls; N=410) 12.8 (boys; N=389)	Canada (Montreal); school-based from all grade 7 classes in a convenience sample of 10 secondary schools.	7-day recall; number of MVPA sessions/week as the sum of 23 activities (> 5min duration and >4.8 METs)	BP was measured with an automated oscillometric device	Each student's pattern of number of MVPA sessions over time were derived from individual growth models. The estimates were then used as predictors of BP at the end of early (mean age = 15.2 years) and late (mean age = 17.0 years) adolescence. Sex specific linear regression models including estimates of initial level and rate of decline in the number of MVPA sessions per week; initial (baseline) SBP; initial BMI; initial height, change in height, and interaction between initial height and change in height; age at the time of SBP measurement; and smoking	Initial level of MVPA significantly and inversely associated with SBP at follow-up (beta between -0.10 to -0.12 in girls and between -0.02 and -0.05 in boys. In early adolescence, a decline of 1 MVPA session per week with each year of age was associated with 0.29-mm Hg and 0.19-mm Hg higher SBPs in girls and boys, respectively. In late adolescence, a decline of 1 MVPA session per week with each year of age was associated with 0.40-mm Hg and 0.18-mm Hg higher SBPs in girls and boys, respectively. The magnitude of the association between initial level and rate of decline in the number of MVPA sessions per week and SBP remained unchanged in late adolescence in girls after adjustment for changes in BMI, waist circumference, or skinfold thickness. The association was attenuated in boys
Mielke 2019 [12]	Examine the joint effects of screen time (ST), as an indicator of sedentary behaviour, and physical activity (PA) on indicators of cardio-metabolic risk during adolescence	Observational birth cohort Pelotas birth cohort study 1993	2004 and 2008 7 years (11 to 18 y) and 3 years (15 to 18 y)	N=3613 Mean age 11 years (Boys N=1768; Girls N=1845)	Brazil (Pelotas) Birth cohort including approx. 69% of all born in 1993	Questionnaire time spent watching television, playing video games and with a computer, in a typical day (h/day); PA assessed by questionnaire. Daily PA score was calculated and categorized as active (≥60 min per day) or inactive (< 60 min/day). To evaluate the joint effects of PA and ST, a variable including four mutually exclusive groups was created	BP was measured using a digital monitor	Multivariate linear regression was used to examine the associations between four mutually exclusive PA/ST groups: 1) active (≥1 h/day PA) and low ST (< 5 h/day ST); 2) active (≥1 h/day PA) and high ST (≥5 h/day ST); 3) inactive (< 1 h/day PA) and low ST (< 5 h/day ST); 4) inactive (< 1 h/day PA) and high ST (≥5 h/day ST) at each age, and outcomes at age 18	No association between any of the combinations of SED and PA with BP

Pouliou 2012 [13]	Establish the role of physical activity and sedentary behaviour at different life stages on BP in mid-adulthood (age 45 years)	Observational birth cohort 1958 British Birth cohort	1969 34 years	N=9297 Mean age 11	England, Wales and Scotland including all born in in 1 week in March 1958 followed through to adulthood.	Self-reported (or parentally reported) at ages 11, 16, 23, 33, 42 and 45 years. sports and leisure activities. (h/day that individuals spent in moderate or vigorous activity (>3MET) was estimated separately for leisure and worktime. A binary variable was generated (i.e. more vs. <150 min/week)	BP was measured at 45 years using an automated digital oscillometric sphygmomanometer	Linear regression models were applied for SBP and DBP and logistic regression for hypertension separately for men and women. 1) simple associations of adult BP (SBP, DBP and hypertension) with each physical activity (or sedentary behaviour) measure separately at different ages. Thereafter adjusted for covariates (i.e. lifestyle and social class) and BMI	No association between physical activity in childhood (11 and 16 years) and adult BP and no associations were observed for television-viewing at 11 and 16 years. In men, the odds ratios (ORs) for hypertension associated with activity at 23 years was 0.79 (0.70, 0.90) after adjustment including BMI; In women, associations with activity at 23 years seen for SBP and DBP were attenuated after adjustment for covariates
Rangul 2012 [14]	Examine whether differences in physical activity patterns from adolescence to young-adulthood showed different associations with subsequent cardio-metabolic risk factors in young-adulthood	Observational Norwegian Nord-Trøndelag Health Surveys (HUNT2 and 3)	1995 to 1997 11 years	N=1869 individuals (n = 838 male; N=1070 female) Mean age 16 years	Norway (Nord Trondelag) Population based sample;	Physical activity assessed by self-report PA were dichotomised into; "inactive" if response was <2-3 days/week "active" if response was ≥2-3 days/week; Four groups created	BP measured with a Dinamap based on oscillometry	Linear regression to investigate associations between physical activity and BP. First, physically active maintainers (AMs) were compared to inactive maintainers (IMs), unadjusted and adjusted for age and gender, Second, we grouped 'relapsers', 'adopters' and 'IMs' by comparing them against 'AMs' to investigate the relationship with BP. In addition, we also separately examined the linear relationships by comparing 'adopters' against 'AMs' and 'adopters' against the common group of 'IMs' and 'relapsers'	DBP; Examining the Active Maintainers against all others, females showed favourable diastolic BP (B=−1.05; −2.07, 0.03). Adopters did not show a favourable profile compared to inactive maintainers and relapsers

Twisk 2000 [15]	Examine the longitudinal relationships between physical activity and BP.	Observational Amsterdam Growth and Health Longitudinal Study	1977 24 years	N=181 Mean age 13.1	The Netherlands (Amsterdam) healthy subjects secondary school	Interviewer administered questionnaire past 3 months; total time spent on all habitual physical activities (expressed as the number of metabolic equivalents (METs) per week)	BP was measured with a sphygmomanometer	Longitudinal linear regression (Generalised estimating equations) adjusted for time, gender, biological age, and other lifestyle parameters, i.e., dietary intake, alcohol consumption, and smoking behaviour and subsequently body fatness (skinfolds)	No longitudinal associations between physical activity and BP
Twisk 2002 [16]	Analyse the relationship between physical activity (between 13 and 16 years of age) and cardiovascular disease (CVD) risk factors at adult age (32 years)	Observational Amsterdam Growth and Health Longitudinal Study	1977 20 years	N=277 and N=182 (pending on number of measurements between ages 13 and 16) Mean age 13.1	The Netherlands (Amsterdam) healthy subjects secondary school	Interviewer administered questionnaire past 3 months; total time spent on all habitual physical activities (expressed as the number of metabolic equivalents (METs) per week)	BP was measured with a sphygmomanometer.	linear regression analyses with the physical activity as separate determinant, correcting for gender and biological age. 1) the relationship between physical activity at 13 years of age and CVD risk factors at 32 years of age and 2) the relationship between “maintained” exposure to physical activity during adolescence (between 13 and 16 years of age)	No association between physical activity during adolescence and BP in young adulthood

Twisk 1997 [17]	Analyse which lifestyle parameters discriminate people at high risk from those at low risk of CHD spanning adolescence and young adulthood	Observational Amsterdam Growth and Health Longitudinal Study	1977 15 years	N=181 Mean age 13.1 (98 female and 83 male)	The Netherlands (Amsterdam) healthy subjects secondary school	Structured interview past 3 months of activities >4 METs; combined into a score (METs/week)	DBP and SBP were measured sphygmomanometer participants with DBP > 82 mmHg were classified as being at risk. For the ages 21 and 27 years, a threshold value of 90 mmHg was used. For SBP the threshold value was 126 mmHg between 13 and 16 years of age and 140 mmHg for 21 and 27 years of age	Generalised estimating equations; odds ratios (OR) were calculated which indicated the relationship over the entire longitudinal period. ORs were calculated for a one-unit change difference in the standardized value of the particular predictor variable, adjusting for biological maturity (13 to 16 years) and sex	No longitudinal associations between physical activity and risk for high BP
Twisk 1997 [18]	Investigate the relationship between daily physical activity from 13-29 years of age ("long-term exposure") and BP at the age of 29 years	Observational Amsterdam Growth and Health Longitudinal Study	1997 15 years	N=181 Mean age 13.1 (98 female and 83 male)	The Netherlands (Amsterdam) healthy subjects secondary school	Structured interview past 3 months of activities >4 METs; combined into a score (METs/week). Averaged over three time periods (13-16 yr; 13 to 21 yr and 13 to 29 yr)	DBP and SBP were with a sphygmomanometer	For each of the three time periods under consideration the same analyses were carried out. BP was related to PA (only under correction of gender) by univariate linear regression analysis	No association between PA during any of the three periods and BP
Hancox 2004 [19]	Examined the association between child and adolescent television viewing and a range of adult health indicators	Observational birth cohort	1977-78 21 years	N=980 Baseline assessments between ages 5 and 15 years	New Zealand (Dunedin) Birth cohort including all children	Questionnaire; parental report ages 5 to 11 years and self-report at ages 13 and 15 years. Computed as mean hours of TV viewing per weekday between 5 and 15 years	BP measured with a random zero sphygmomanometer	Linear regression adjusted for sex, SES, BMI at age 5 years,	No association between youth TV viewing time and SBP at age 26 years

BP – Physical activity and sedentary behaviours device-based measure									
Short citation	**Objective**	**Study type**	**Baseline**	**Analytical N**	**Setting & context**	**Exposure details**	**Outcome details**	**Analyses**	Results
Bell 2018 [20]	Describe associations of current and longer-term physical activity and sedentary time with detailed traits related to systemic metabolism	Observational Avon Longitudinal Study of Parents and Children	2003 3.7 years (for PA/SED modelled as exposure at age 12 years)	N=1826 mean age 15.4 at FU (1015 girls; 811 boys)	UK (Bristol); Birth cohort	PA and sed assessed by accelerometry (CPM, and min/d) at three time points	SBP; DBP measured at age 15 y	Linear regression (with robust SE); 1) x-sectional associations; 2) long-term (mean of PA/SED across 3 time points); 3) change in PA/SED (15y minus 12 y)	PA/SED not associated with current SBP/DBP; change in MVPA weakly and significantly positively (<+0.1 SD change for 1 SD change in MVPA) associated with DBP
Carson 2014 [21]	to determine the longitudinal associations between different PA intensities and cardiometabolic risk factors in a sample of Canadian youth	Observational Healthy Hearts Prospective Cohort Study of Physical Activity and Cardiometabolic Health in Youth	2008 2 years	N=315 Mean age 12.2 y (128 boys; 187 girls)	Canada; convenience sample from eight middle or high schools in the Black Gold Regional School District	PA by accelerometry (Actical); time (min/d) spent sedentary, light, moderate and vigorous intensity derived using published cut points and categorised into quartiles	SBP according to the American Heart Association guidelines for pediatrics. High-normal systolic BP was classified as 90th percentile for age, sex and height	Multiple linear regression models. All models were adjusted for age, sex, and diet quality, wear time and other intensities. Models also adjusted for baseline of BP and FU BMI (z-score). Logistic regression examined different intensities of PA at baseline and incident high-normal BP of PA	No association between baseline LPA, MPA or VPA and SBP.
Hallal 2011 [22]	To explore cross-sectional and longitudinal associations between PA and BP between 11 and 14 years of age and to evaluate whether objectively-measured and questionnaire-based PA are differently associated with BP in adolescence	Observational birth cohort Pelotas Birth Cohort 1993	2004 3 years	N=427 Mean age 11.3	Brazil (Pelotas) Birth cohort including approx. 10% of all born in 1993	Questionnaire; last 7 days (sport and other activities; duration and frequency) at age 11 (baseline), 12 and 14 years, Total score in min/week; PA measured by accelerometry at age 12 years	BP measured with wrist-mounted digital sphygmomanometer	Unadjusted and adjusted analyses for the associations between PA (categorized into terciles) and systolic and diastolic BP (continuous) were performed using linear regression models; model 1, adjustment for sex, socioeconomic level, puberty status, sum of triceps and subscapular skinfolds and height; adjusting for PA at 14 years, model 3, adjusted for baseline values of BP	Objectively measured PA at 12 years was significantly independently and inversely associated with DBP at 14 years of age in the finally adjusted model (-1.56 mmHg (-3.09; -0.04) in the most active third compared with the least active (referent)), Questionnaire based PA not associated with BP

Diabetes – **Physical activity and sedentary behaviours self-reported**									
Short citation	**Objective**	**Study type**	**Baseline**	**Analytical N**	**Setting & context**	**Exposure details**	**Outcome details**	**Analyses**	Results
Lee 2014 [23]	Identifying the association between physical activity (PA) and sedentary behaviour (SB) patterns during adolescents on the future increase in BMI and risk of diabetes during young adulthood	Observational National Longitudinal Study of Adolescent Health (Add Health)	1994 to 1995 13 years	N=3717 Grade 7 to 12 (11 to 21 years at baseline)	US Nationally representative sample	Questionnaire self-reported activities from in total 25 items including PA and sedentary activities	Type 2 diabetes defined as fasting glucose > 7.0 mmol/dL, (2) non-fasting glucose >11.1 mg/dL, (3) hemoglobin A1c >48 mmol/mol (or 6.5%), (4) self-reported history of diabetes, or (5) reported taking anti-diabetic medication.	k-means cluster analysis was used to identify the number of physical activity and sedentary behaviour patterns in the sample using 25 physical activity and sedentary behaviour variables. All these variables were standardized to a mean and a standard deviation of 0 and 1 respectively using wave-specific means and standard deviations to equalize their importance. Three clusters identified ('low physical activity, high sedentary behaviour'; '(low physical activity, low sedentary behaviour'; 'high physical activity, low sedentary behaviour'). Incidence of diabetes were adjusted for age, sex, smoking and drinking habits at Waves I and III, education level of parent-in-home, and parental history of diabetes, using logistic regression	Participants in the 'low PA/high SED' cluster, the 'high PA/low SED' cluster, and the 'low PA/low SED' cluster had a diabetes incidence of 11.7% (95% CI = 5.8%,23.5%), 6.1%(95% CI = 3.0%,12.1%), and 6.9% (95% CI = 3.7%,12.9%) respectively. Compared with the 'low PA/low SED' cluster, the 'low PA/high SED' cluster had significantly greater odds for developing diabetes (OR = 1.69, 95% CI = 1.04,2.75, P= 0.03), whereas no significant difference was found for the 'high PA/low SED' cluster (OR = 0.87, 95% CI = 0.52,1.47, P= 0.61).

Metabolic Syndrome – **Physical activity and sedentary behaviours self-reported**									
Short citation	**Objective**	**Study type**	**Baseline**	**Analytical N**	**Setting & context**	**Exposure details**	**Outcome details**	**Analyses**	Results
Ferreira 2005 [24]	Analysing if the longitudinal development of lifestyle variables from the age of 13 years to the age of 36 years determined the occurrence of the metabolic syndrome	Observational Amsterdam Growth and Health Study	1997 24 years	N=363 Mean age 13.1 (175 men and 189 women)	The Netherlands (Amsterdam) healthy subjects secondary school	Structured interview of activities >4 METs; Time (min/week) spent in light (4-7 METs), moderate (7-10 METs) and hard (>10 METs)	MetS according to the National Cholesterol Education Program Adult Treatment Panel III	Generalized estimating equations with activity as a continuous variable adjusted for sex and potential confounder/mediator variables	Very hard physical activity significantly different (approx. 30 min/week) between those who developed METs at age 36 years compared with those who did not. These differences were attenuated following adjustment for sum of 4 skinfolds (Fatness) and maximal oxygen uptake.
Grontved 2014 [25]	Examine the association of TV viewing, computer use, and total screen time in adolescence, and change in these behaviours, with cardiovascular disease (CVD) risk factors in young adulthood.	Observational European Youth Heart Study-Denmark	1997/98 and 2003/04 6 and 12 years	N=435 (224 with 6 year FU and 191 with 12 -y FU) Mean age 15.6	Denmark; School-based (schools randomly selected and students within these schools randomly selected)	Computer based questionnaire TV and computer use (hours/d) at baseline. A daily screen variable (hours/day) were computed	Clustered metabolic syndrome score (Z-score) including WC, the mean of DBP and SBP, triglycerides, HDL (inverted), fasting glucose, and fasting insulin	multiple linear regression with baseline levels of respective risk factors included as a covariate; adjustments for parental educational level, current smoking, family history of CVD, frequency of intake of soft drinks, intake of fruit and vegetables, and MVPA (measured by accelerometry);	In multivariable-adjusted models, for each 1-hour increment in TV viewing time in adolescence the METs score increased by 0.45 (95% CI 0.14 to 0.76) SD. Total screen time was significantly associated with the metabolic syndrome z-score 0.35 (0.08 to 0.62).
Hasselstrom 2002 [26]	Analyse if physical activity during adolescence predicted CVD risk factor levels in young adulthood	Observational Danish Youth and Sports Study	1983 8 years	N=193 Mean age 17.1 (N=79 men; 114 women)	Denmark; school-based, randomly selected	Questionnaire (Sport and other activities) Mean time spent on sports per week	CVD risk score calculated for men and women separately and recoded into quintiles for each of the risk factors and the risk score was calculated as the sum of SBP, total cholesterol, HDL/TC-ratio, triglycerides, and percent body fat from skinfolds.	Linear regression	No association between physical activity at baseline and CVD risk score

Jaaskelainen 2012 [27]	Examine the associations between childhood lifestyle factors (i.e., the frequency of consumption of vegetables, fruit, fish, and meat, butter use on bread, and physical activity) and MetS in adulthood	Observational Young Finns Study	1980 27 years	N=2128 Mean age 11.2 at baseline (3 to 18 year old)	Finland (5 cities) prospective follow-up study of people 3, 6, 9, 12, 15, and 18 years of age in 1980. randomly selected from the Finnish national population register Follow ups in 1983, 1986 and 2007	PA assessed by questionnaire (parentally reported in 3 to 6 year old). Frequency and intensity assessed and a PA index calculated	MetS (3 of 5 of the following; WC >102 cm for males and >88 cm for females; 2) triglycerides >1.7 mmol/L 3) HDL cholesterol <1.0 mmol/L in males or <1.3 mmol/L in females; 4) BP >130/85 mmHg or treatment of previously diagnosed hypertension, and 5) fasting plasma glucose >5.6 mmol/L or previously diagnosed type 2 diabetes.	the average of PA measurements taken in 1980, 1983, and 1986 used in age- and sex adjusted multivariable logistic regression	Physical activity index not associated with adult METs (OR=0.85 (0.91 to 1.14)
Mitchell 2013 [28]	Examine the longitudinal associations between television viewing and CVD risk factors, using quantile regression, in a sample of girls as they age from 9 to 19	Observational NHLBI Growth and Health Study	1987 2, 4 , 6 and 9 years	N=1702 Mean age 10.0 at baseline	US (Berkeley, Cincinnati, and Washington, DC) black and white girls; socioeconomically representative of each location	Self-reported TV viewing (H/week); Leisure time physical activity reported in the past year (MET-h/week)	Clustered risk score summing the z-scores for sum of 4 skinfolds, SBP, triglycerides, LDL-cholesterol and the ratio (TC:HDL-C)	Quantile regression; the association between television viewing and the CVD risk factors at the 10th, 25th, 50th, 75th, and 90th percentiles are presented. The CVD risk factors were modeled as the dependent variables with age and television viewing included as independent variables (model 1). In model 2, maturation, sleep patterns, household income, total caloric intake, and percent intake from carbohydrates were also included as independent variables, and in model 3, physical activity level was included	There was no associations observed between television viewing hours per week and clustered metabolic risk scores in the black girls. However, for the white girls a positive association was observed between television viewing and clustered metabolic risk score at the 50th percentile. No association between leisure time physical activity and the clustered metabolic risk score.

Stamatakis 2012 [29]	Examine the longitudinal associations between a key indicator of sedentary behaviour (TV viewing) in early adulthood and comprehensive cardiometabolic risk profiles in early middle age.	Observational birth cohort 1958 British Birth cohort	1981 21 years	N=5972 Baseline age 23 years (Men N=2947; Women N=3025)	England, Wales and Scotland including all born in in 1 week in March 1958 followed through to adulthood.	TV viewing was assessed by an interview-administered questionnaire and reported as weekly frequency quantified as ≥5, 3–4 and ≤2 times per week	A continuous clustered cardiometabolic risk score (Z-score) was calculated from (HbA1c, triacylglycerol, total cholesterol, HDL cholesterol, fibrinogen, CRP, BP, waist circumference)	Generalised linear models and multiple linear regression. Different models were adjusted for: (1) sex; (2) additionally for smoking, alcohol, CVD medication and social class at age 44 years; and (3) additionally for exercise at age 23 years, and MVPA and TV viewing times at age 44 years. Generalised linear model coefficients indicate mean between the reference category (two or fewer times a week) and each of the other TV viewing groups at age 23 years	All examined risk markers and the clustered cardiometabolic risk score showed sex-adjusted associations with TV viewing frequency at age 23 years. Once analyses were adjusted for potential confounders, and for TV viewing and physical activity at age 44 years, these associations persisted for systolic (1.4 mm HG (95% CI; 0.3 to 2.5)) higher in >5 times TV per week compared with 2 or less time) and diastolic BP, and clustered cardiometabolic risk score (0.055; 95% CI 0.016, 0.095).
Twisk 1999 [30]	Investigate the relationship between lifestyle parameters and clustering of CVD risk factors	Observational Young Hearts Project	1989 to 1990 3 years	N=459 Mean age 12 years	Northern Ireland; school based random, stratified sample,	Questionnaire A physical activity score ranging from 0 to 100 for everyday physical activities (method of travelling to and from school, activities during breaks in the school day and participation in sports after school)	Clustered risk score calculated based on the distribution of DBP, total cholesterol/HDL ratio, sum of skinfolds (highest quartile) and number of laps 20-m shuttle run (lowest quartile)	Longitudinal log-linear regression analysis. The longitudinal regression coefficients (i.e. ones that can be transformed into rate ratios) were estimated with generalized estimating equations. Analyses conducted stratified by sex and adjusted for biological maturity and SES	No longitudinal association between physical activity and clustering of CVD risk

Twisk 2001 [31]	Investigate the longitudinal relationship between daily physical activity, smoking and a biological CHD risk factor clustering score	Observational Amsterdam Growth and Health Longitudinal Study	1977 15 years	N=181 Mean age 13.1 (98 female and 83 male)	The Netherlands (Amsterdam) healthy subjects secondary school	Structured interview past 3 months of activities >4 METs; combined into a score (METs/week).	Clustered risk score; For the TC:HDL ratio, MABP and SSF the highest quartile was defined as the 'high risk' quartile, while for VO2-max the lowest quartile was defined as the 'high risk' quartile. Clustered risk score calculated as summary of belonging to 'high risk' group at each time point	Logistic generalised estimating equations; with physical activity as a continuous variable. (adjusted for age and sexual maturity)	Daily physical activity was significantly inversely related to the clustering score (risk ratio 0.89; 0.84, 0.95; P=0.01). This association remained significant following inclusion of all lifestyle factors in the model (OR=0.89 (0.84; 0.95).
Wennberg 2013 [32]	Investigate whether TV viewing and low leisure time physical activity in adolescence predict the metabolic syndrome in mid adulthood.	Observational The Northern Swedish Cohort	1981 27 years	N=888 (464 men and 424 women) 16 years old	Sweden (Luleå) all school leavers of the 9th (final) grade of the Swedish compulsory school in 1981	Self-report TV viewing (categorised into 3 groups; Leisure-time physical activity (sport activities or exercise) during the last 12 months, with six response options: daily, several times per week, once a week, several times per month, once a month, and seldom. The last three categories were collapsed	MetS defined according to the International Diabetes federation guidelines 2 diabetes	Logistic regression was used to estimate odds ratios (ORs) and 95% CIs. Multivariate models included TV viewing and leisure-time physical activity in the same model and a model with additional adjustment for sex, socioeconomic disadvantage, family history of diabetes, BMI, intake of sweets/pastries, alcohol consumption, and smoking at age 16 years	TV viewing and low leisure-time physical activity in adolescence were associated with the metabolic syndrome adjusted for covariates (model 2). Adjustment for PA at age 43 years attenuated the association for TV viewing somewhat, but the P for trend (P = 0.008) across the TV-viewing categories as well as the OR for several shows per day versus one show per week or less remained significant (OR 1.96 [95% CI 1.13–3.42]), the association for low leisure-time physical activity was more markedly attenuated and no longer significant (P for trend=0.064).

Yang 2009 [33]	Explore the effect of organized youth sport on metabolic syndrome (MetS) in adulthood	Observational Young Finns Study	1980 21 years	N=1493 participants (704 males and 789 females) Baseline age between 3 and 18 years	Finland (5 cities) prospective follow-up study of people 3, 6, 9, 12, 15, and 18 years of age in 1980. randomly selected from the Finnish national population register Follow ups in 1983, 1986 and 2007	Questionnaire; 'How many times a week do you usually engage in training sessions organized by a sport club?' recoded into three categories: no participation or less than once a week, once a week and more than once a week. The second asked 'Do you participate in sports competitions?' and had four response categories: no participation, sport-club level, regional level and national level. The two items were summed into three levels. Additionally, to examine persistent youth sport participation between 1980 and 1983 three groups were created ('persistent', 'starter', and 'leaver'	Continuous MetS score by summing the z-scores A categorical variable indicating the presence of MetS was constructed according to the European Group for the Study of Insulin Resistance (EGIR) definition	Comparisons of the adult MetS score between the groups at the 3-year follow-up (between 1980 and 1983) were performed with ANOVA. To study the effect of sustained participation in sport during youth on MetS in adulthood, youth sports activities were assessed by calculating the average of the four measurement points taken from 1980 to 1989. Linear regression was taken to relate the mean score of youth sport to the continuously distributed outcome variable of the adult MetS score adjusted for baseline covariates such as age, smoking, caloric intake and baseline-clustered risk for MetS in those 9 to 18 years. Logistic regression analysis was used to assess whether participation in and persistence of organized youth sport during the 3-year period were related to the prevalence of MetS in adulthood.	Sustained youth sport over 3 years and the prevalence of EGIR MetS showed a significant relationship, which seemed to be linear in both males and females ($P=0.05$). The persistent athletes were less likely to have MetS in adulthood than the non-athletes. Starters in both sexes had a lower risk for MetS than their non-athletic counterparts ($P<0.05$). Persistent athletes were also less likely to have MetS than the leavers ($P<0.05$ for males, $P<0.01$ for females). Mean youth sport level emerged as a significant predictor of MetS in men (beta= 0.149, $P=0.001$) and women (Beta=0.118, $P=0.005$). Males who dropped out from organized sport during the 3 years had higher prevalence of the MetS compared with persistently athletic counterparts ((OR = 4.52, 95% CI 1.29, 15.84)

Metabolic Syndrome - **Physical activity and sedentary behaviours device-based measured**									
Short citation	**Objective**	**Study type**	**Baseline**	**Analytical N**	**Setting & context**	**Exposure details**	**Outcome details**	**Analyses**	Results
Stamatakis 2015 [34]	Examine the prospective associations between accelerometer-measured ST and MVPA at age 11 to 12 years and a broad range of cardiometabolic risk markers in adolescence (age 15–16 years)	Observational birth cohort ALSPAC	2002 to 2003 4 years	N=1075 Baseline age 11 years	UK (Bristol); Birth cohort	Accelerometry for 7 days. Time (min/d) in MVPA and sedentary	A standardized continuous clustered cardiometabolic score (CM score) was also calculated (body fat mass, SBP, DBP, triglycerides, HDL-C, C-reactive protein, glucose, insulin, total cholesterol, and LDL-C)	Multiple linear regression examined associations between ST and MVPA and cardiometabolic outcomes, adjusting for covariables (gender; birth weight (kilograms); maternal BMI; paternal occupational social class, total energy intake at age 10 years; Tanner puberty stage at age 11 years and age; age (months) at the time of assessment of cardiometabolic markers; accelerometer wear time (minutes/d) at age 11 years; time in months between accelerometry at age 11 years and measurement of cardiometabolic outcomes at age 15 years; baseline adiposity (BMI), body fat mass (%), and waist circumference (centimeters); and SBP and DBP at age 11 years	No evidence of an association between baseline ST and BP or the clustered CM score at follow up. There was evidence of an inverse association between baseline MVPA and SBP (-0.276 (–0.490 to –0.061)), and CM score (-0.029 (–0.041 to –0.018)). Associations and CM score (attenuated by 50% but statistically significant) were attenuated following adjustment for covariates.

Ried-Larsen 2014 [35]	Investigate the association between physical activity (PA) intensity across childhood and sub-clinical atherosclerosis in adolescence.	Observational European Youth Heart Study – Denmark	2003 to 2004 6 years	N=254 Mean age at baseline 9.8 years (Boys N=107; Girls (N=147)	Denmark; School-based (schools randomly selected and students within these schools randomly selected)	Physical activity assessed by accelerometry for at least 5 days. MVPA and VPA (min/day)	CVD risk z-score included HOMA, triglyceride, total cholesterol to HDL ratio, the sum of four skinfold, cardio-respiratory fitness (inverted) and SBP	Associations between the outcomes and cumulative exposure to or changes in exposures across childhood were analyzed using multiple linear regression analyses. Analyzing the mean exposure across childhood, we performed an analysis adjusted for gender and biological maturation at follow-up. Using changes in exposure level we further adjusted for baseline exposure level.	A one-SD (6.3 min) increment in the cumulative exposure to vigorous PA was associated with a 0.19 SD lower clustered risk z-score. Baseline vigorous PA was significantly associated to adolescent metabolic CVD risk z-score (beta= -0.06 (95%CI; -0.17 to -0.01) p<0.05).

BMI, Body Mass Index; BP, blood pressure; CHD, Coronary Heart Disease; CVD, Cardio Vascular Disease; CM, Clustered Metabolic (score); CRP, C-Reactive Protein; DBP, Diastolic Blood Pressure; HDL, High Density Lipoprotein; HOMA, Homeostatic Model Assessment; LDL, Low Density Lipoprotein; MET-h, Metabolic Equivalents in hours per week, MetS, Metabolic Syndrome; MVPA, moderate-to-vigorous intensity physical activity; PA, Physical Activity; SBP, Systolic Blood Pressure; SD, Standard Deviation; SES, Socio-Economic Status; SSF, Sum of Skinfolds; ST, Sedentary Time; TC, Total Cholesterol; VPA, Vigorous Intensity Physical Activity; WC, Waist Circumference

SYNTHESIS OF EVIDENCE

- Evidence is derived from high income countries with the exception for Brazil (2 studies from the same cohort) and China (1 study).
- The 35 retrieved papers comprised 20 unique cohorts.

Physical activity

- There is mixed evidence for a medium-term association between physical activity and blood pressure (4 of 9 studies).
- There is mixed evidence for a medium-term association between physical activity and improved metabolic profile defined as clustered metabolic risk (2 of 4 studies).
- There is no evidence for a long-term association between physical activity and blood pressure (0 of 11 studies where the same study was used in 4 different publications)
- There is currently no evidence for long-term associations between physical activity and the development of type 2 diabetes (data restricted to one study).
- There is some evidence for a long-term association between physical activity and metabolic syndrome/metabolic risk (4 of 7 studies).

Sedentary behaviours

- There is limited evidence for a medium-term association between sedentary behaviours (TV-viewing/screen time) and BP (2 of 6 studies)
- There is mixed for a medium-term association between sedentary behaviours (TV-viewing/screen time) and metabolic syndrome/clustered metabolic risk (2 of 4 studies).
- There is no evidence for a long-term association between sedentary behaviours (TV-viewing/screen time) and BP (0 of 2 studies)
- There is no data on the long-term association between sedentary behaviours (TV-viewing/screen time) and type 2 diabetes.
- There is some evidence for a long-term association between sedentary behaviours (TV-viewing/screen time) and metabolic syndrome/clustered metabolic risk (4 of 7 studies).

Considerations

- There was substantial heterogeneity in exposure measurements.
- We noted a high risk of reporting bias due to self-reported measures of physical activity and sedentary behaviours in most studies.
- The studies had a high risk of bias due to poorly measured or unmeasured confounders, especially baseline levels of the outcome variable in most studies. Adiposity may be an important mediator or confounder of the associations, but only 14 studies (40%) included measures of adiposity in their analyses and to what extent this led to an attenuation of the association could not be established.
- The studies had a high risk of type 2 error due to small sample size (50% of studies included <500 participants).
- Studies from LMIC are non-existent and only three studies from high middle-income countries (Brazil and China) identified.

Future direction

Given the drastic decline in physical activity and increase in sedentary time during adolescence, long-term prospective studies with adequate sample size, device-measured exposure variables preferably at multiple time points, appropriate statistical models including adjustment for multiple confounding factors are warranted. In particular, adiposity is a strong determinant of cardio-metabolic health and examining the confounding or mediating effect of adiposity is needed to quantify the independent prospective associations between physical activity and sedentary behaviours and later cardio-metabolic outcomes. The paucity of data from LMIC is especially concerning given the rapid epidemiological transition in these countries.

CONCLUSION

Physical activity and sedentary behaviours during adolescence may be associated with some medium- and long-term cardio-vascular health outcomes although the strength of the current evidence is generally low.

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APPENDIX 4: Methods and results of the systematic review on the prospective associations between physical activity (including sedentary behaviours) and mental health outcomes in adolescence.

DESCRIPTION OF REVIEW METHODS

We conducted a systematic review of original studies aimed to address the question "What is the prospective association between physical activity and later depression/anxiety in adolescence?" As per the *Lancet Commission on Adolescent Health and Wellbeing* definition of adolescence we included all evidence from within the adolescent and young adulthood period (10 to 24 years). We systematically searched five databases (Ovid Medline, Embase, PsycINFO, Web of Science, and Scopus) on 2nd Dec 2019 for literature published since inception. A librarian at the University of Cambridge medical library developed a search strategy focused on population (terms related to adolescence and young adulthood), behaviour (terms related to physical activity in general, specific activity behaviours, sitting, and screen-based behaviours), study type (prospective, longitudinal observational), and outcomes (terms related to depression and anxiety). The search strategy as applied to Ovid Medline is presented in Textbox A4.1, search strategies in other databases are available upon request.

Textbox A4.1 – Mental health review search strategy in Ovid Medline

1 (adolescen* or teen* or student* or ((young or early or emerging) adj adult*) or youth* or (young adj (people or person)) or freshman or freshmen or freshwoman or freshwomen or mid-adolescen*).ti,ab. or exp students/ or exp adolescent/

2 ((physical* adj activ*) or (active adj (transport or travel)) or exercis* or sport* or cycle or cycling or walk* or (energy adj expenditure) or sedentary or sitting or TV or television or inactiv* or (screen adj time) or screentime).ti,ab. or exp exercise/ or exp sedentary behavior/ or exp screen time/ or exp bicycling/

3 (Depress* or anxious* or anxiety).ti,ab. or exp depression/ or exp anxiety/

4 (Longitudinal or cohort* or prospective* or follow-up* or followup* or (follow* adj up*)).ti,ab. or exp longitudinal studies/ or exp prospective studies/ or exp follow-up studies/ or cohort studies/

5 1 and 2 and 3 and 4

All records retrieved were uploaded into the Covidence review software, and duplicates removed. Textbox A4.2 outlines the in- and exclusion criteria applied. Title and abstract screening were conducted by single reviewers; all records considered for full text screening were double screened by an independent reviewer, as was 10% of the excluded abstracts. Two reviewers independently screened full texts for inclusions, with discrepancies resolved by a third reviewer.

Textbox A4.2 Inclusion and exclusion criteria	
Inclusion	Exclusion
- Population: generally healthy participants aged 10-24y at both baseline and follow-up (or mean age between 10-24y) - Exposure: physical activity behaviour (any type/measure) - Outcome: Depression or anxiety - Study type: prospective observational analysis (min 1y follow-up) (including observational analyses of trial data). - Any publication date - Ability to extract quantitative data relevant to the research question	- Exposure and/or outcome assessed outside of adolescent period - Other mental health outcomes - Cross-sectional study - Trial analyses of experimental studies - Prospective studies with <1yr follow-up - Studies of non-ambulatory participants, hospitalized patients, samples with pre-existing chronic health conditions, or exclusively including obese populations, or athletes.

Where multiple papers reported on data from the same study, we only included the separate papers when they reported on unique exposure/outcome combinations. In all other cases, we selected the paper with (1) longest follow-up; (2) largest sample size; (3) most valid measure of outcome/exposure. Data extraction of all included papers was conducted by a single reviewer, with a 100% check by a second reviewer. Data extracted included: citation, objective, study type and name, baseline year and follow up time, analytical sample size and participants, setting and context, exposure and outcomes details, analyses performed and summary of results. The results were scored by two independent reviewers on a 5-point scale ("statistically significant association in hypothesised direction", "association in hypothesised direction at p<0.20", "no association", "association not in hypothesised direction at p<0.20", "statistically significant association not in hypothesised direction"). We hypothesized that higher physical activity was negatively associated with later (risk of) depression/anxiety, and that sedentary behaviour was positively associated with later (risk of) depression/anxiety. Where multiple relevant exposure or outcomes were reported, we used the most comprehensive measure where possible, or assigned a score where 2/3rds of the associations were in the same direction. Data were extracted and scored separately for males/females where appropriate. Disagreements were resolved by discussion.

RESULTS

We retrieved 4,900 records of which 2,816 were retained. Following title and abstract screening 2,718 records were removed; 98 full text papers screened of which 65 were excluded (main reasons: wrong age group, wrong study design, cross-sectional analyses). We extracted data from 33 papers; results from 2 papers were combined as they presented similar analyses with different follow-up in the same populations. Of 32 papers, 10 recruited participants in late adolescence, and five in young adulthood. The studies were mainly conducted in North America (9) and Europe (16), but we identified additional studies from Australia (4), Japan (2), Bangladesh (1), and China (1). One study was conducted in Germany and China. No studies were available from Africa or South America. In all but two studies, physical activity behaviours were assessed with self-report measures which were mostly not validated. A variety of validated tools was used to assess depression and anxiety; versions of the Center for Epidemiologic Studies Depression Scale (CES-D) were most frequently used to establish depressive symptoms. Sample sizes were >1,000 participants in 18 of the included studies (55%).

Table A4.1 provides a descriptive overview of the included studies and a summary of the results for each study. Results highlighted in red refer to no association, orange to a trend towards association (p<0.20, and those highlighted in green present a significant association.

Table A4.1: Overview of studies included in review of prospective association between physical activity behaviours and depression/anxiety in adolescence.

Short citation	Objective	Study type and name	Baseline year and follow up time	Analytical N and participants	Setting and context	Exposure details	Outcome details	Analyses	Results
Ashdown-Franks 2017 [1]	To examine the longitudinal associations between sport participation during high school and symptoms of panic disorder, GAD, social phobia and agoraphobia in young adulthood.	Observational Nicotine Dependence in Teens Study	1999 8 years	N=781 12-13 year, 44.8% male	Canada 10 high schools, Montreal area	Physical activity Questionnaire on sport participation. Total sport participation was coded as 0 = no sports to 5 = at least one sport in every year of high school.	Anxiety Three self-reported items for generalized anxiety disorder symptoms (coded (1) if they endorsed one or more symptom for the subtype).	Multinomial logistic regression model.	No significant association between sport participation and anxiety (OR for 0 years of sports vs. 5 years: 1.01 (95%CI: 0.6-1.69)
Bickham 2015[2]	To investigate association between media use (both receptive and interactive) and symptoms of depression in adolescents.	Observational Measuring Youth Media Exposure Project	2009 1 year	N=103 Mean age=14.04 years (range 12.56-15.94), 46.8% female, 45.2% non-white race	USA Public schools, after school programs and summer camps	Sedentary behaviour Media use survey questions (hrs/day), time use diaries (hrs/day) and ecological momentary assessment (EMA) (moments of use over 2 weeks).	Depression Beck Depression Inventory for primary care (excluding question about suicidality)	Linear regressions.	No association between any measure of computer use, listening to music and playing video games and later depressive symptoms. Positive associations between some measures of TV viewing and of mobile phone use and later depressive symptoms (e.g. TV viewing (EMA): beta=0.205, p<0.03; mobile phone use (EMA): beta=0.220, p<0.02)
Birkeland 2009[3]	To test the hypothesis that early leisure-time physical activity is associated with later low levels of depressed mood (protection hypothesis)	Observational Norwegian longitudinal behaviour study	1990 10 years	N=924 Mean age=13.0, 55% boys	Norway Secondary schools	Physical activity Leisure-time physical activity assessed frequency per week doing activities that caused sweat or lose breath (from "every day" (scored 7) to" Never" (0))	Depression Seven-item inventory (Alsaker and Olweus) to measure general depressed mood.	Latent curve modelling	Baseline levels of LTPA do not predict later changes in depressed mood.

Briere 2013[4]	To determine whether sports participation independently predicts lower depressive symptoms, social anxiety and loneliness the following year.	Observational New Approaches New Solutions dropout prevention programme	2007 1 year	N=17,550 Mean age=14.4y, 54% female, 85% Canadian-born Caucasian	Canada 71 schools, Quebec	Physical activity Self-reported sports participation (times per week). Dichotomised into no or any sport participation.	Depression 20-item Center for Epidemiological Studies-Depression (CES-D) questionnaire, items were summed (max=60).	Linear regression model	No significant association between sports participation and later depressive symptoms (beta: -0.01 (95%CI: -0.03 to 0.01).
Brunet 2013[5]	To assess longitudinal and cross-sectional associations of past moderate-to-viogorous physical activity and involvement in team sports during secondary school with depressive symptoms in early adulthood.	Observational Nicotine Dependence in Teens Study	1999 10 years	N=816 Mean age=12.71 (0.51), 53.2% female	Canada 10 high schools, Montreal area	Physical activity MVPA was assessed from survey cycles 1 through 20 using a past 7-day recall activity checklist Involvement was categorized as “never involved”, “sporadic involvement” and “sustained involvement”.	Depression 10-item Major Depression Inventory (max=50).	Multiple hierarchical linear regression	No significant association between MVPA and later depressive symptoms (unstandardised betas (SE): baseline MVPA: 0.004 (0.03), p=.90; change in MVPA: 0.17 (0.30), p=0.41)
Flotnes 2011[6]	To examine the associations of physical activity, sports participation and body composition on the risk of symptoms of mental health problems.	Observational Young HUNT study	1995/97 4 years	N=2,000 12-19 years; 50% female	Norway Middle schools (12-16 y) and high schools (16-19 y)	Physical activity LTPA questionnaire with questions related to frequency, duration and intensity of training, and activity type (operationalized into days and hours per week).	Depression Hopkins Symptoms Check List (mean score was calculated)	Log-binomial models, stratified by sex	Some evidence of positive association between physical activity and depression in boys for days per week (p-value for trend: 0.02) and hours per week (0.16). No significant association in girls (days per week (0.34), hours per week (0.16).
Grontved 2015[7]	To examine the associatation between screen time and adolescence and depressive symptoms in young adulthood.	Observational European Youth Heart Study	1997/98 & 2003/04 Mean: 8.6y	N=435 Mean age=15.6 (0.4)	Denmark Secondary schools	Sedentary behaviour Computer-based questionnaires; summary variable of daily hours TV viewing and using a computer were derived and added to obtain total screen time.	Depression Major Depression Inventory scale (significant depressive symptoms: MDI $\geq$20)	Mixed linear and logistic regression models	Total screen time (hrs/day) was positively associated with depressive symptoms (1.05; 95%CI: 0.50-1.59) and significant depression (OR 1.58; 1.18-2.12). TV viewing time was positively associated with depressive symptoms (1.36; 0.73-1.98) and significant depression 1.64; 1.18-2.27), but not computer use (0.01; -1.06-1.08 and 1.28; 0.73-2.25, respectively)

Gunnell 2016[8]	To examine the relationship between physical activity, screen time, and symptoms of anxiety and depression over time during adolescence.	Observational Research on Eating and Adolescent Lifestyles Study	2006/10 Up to 7 years	N=1,160 Mean age = 13.54 (1.12), 39.5% female, 74.1% Caucasian	Canada Secondary schools, Ottowa	Physical activity & Sedentary behaviour Physical activity: 3-item Leisure Time Exercise Questionnaire (total continuous PA score) Sedentary: total screen time from questionnaire querying hours per day TV viewing, video game playing, and computer use.	Depression & Anxiety Depression: 27- item Children's Depression Inventory (CDI) (max= 54). Anxiety: 10-item Multidimensional Anxiety Scale for Children-10 (MASC-10).	Latent growth modelling and regression models	Baseline sedentary behaviour or physical activity did not predict changes in symptoms of depression or anxiety.
Henchoz 2014[9]	To assess the health impact of changes in sport and exercise levels during adolescence.	Observational Cohort study on substance use risk factors (C-SURF)	2010 & 2012 15 months	N=4,846 Mean age = 19.95 (1.19), 100% male	Switzerland 3 of 6 national military recruitment centers	Physical activity Single question. Regular exercise was defined as participating in sports or exercising almost every day.	Depression 10-item Major Depressive Inventory (MDI)	Cross-lagged path analysis	Regular exercise was negatively associated with later depressive symptoms (beta: 0.036, p<0.01).
Hoare 2016[10]	To examine cross-sectional and longitudinal associations between obesogenic risk factors, weight status, and depressive symptomatology	Observational Australian Capital Territory It's Your Move project	2012 2 years	N=634 Mean age = 13.1 (0.6), 53.3% female, 68.5% European-Australian	Australia Government schools, Canberra, Australia	Physical activity Questionnaire. Classified as inactive/low physical activity or moderately active/highly active (played active games at least once during last school day and participated in sport, dance or active games).	Depression 13-item Short Mood and Feelings Questionnaire (max=26; >10 = depressive symptomatology).	Multivariate regression models, stratified by sex	Significant association for males (inactive-active vs. active-active: beta: 2.55; 95%CI: 0.78-4.32). No significant associations for females (-0.39; -2.19 - 1.41).

Hossain 2019[11]	To investigate the impacts of the socio-cultural environment and lifestyle on the pscychological health of the university students in Bangladesh.	Observational NA	2016 15 months	N=897 Mean age = 19.49 (0.86), 58% male.	Bangladesh First year students, Jahangirnagar University, Dhaka	Physical activity & Sedentary behaviour Physical activity: questionnaire: moderate activity (walking or meditation/yoga ≥30 min/day), vigorous activity (jogging etc. ≥60 min/day) or low/inactivity (occasional or no) Sedentary behaviour: screen use questionnaire: excessive (>4 h/day, high (>2 h/day) or low (≤2 h/day).	Depression & Anxiety Depression: PHQ-9 questionnaire (max=27). Anxiety: GAD-7 questionnaire (max=21).	Multivariate linear regression models	No significant association between PA level and depressive symptoms, with only statistically significant association between day/week of PA and depressive symptoms (vs. 3 d/w: none: beta: 1.358; 95%CI: 0.131 - 2.585). Significant association between screen time and depressive symptoms (vs. low: excessive: 1.745; 0.794 - 2.696). No significant association between PA level and days/week of PA and anxiety. Significant association between screen time and anxiety (vs. low: excessive: 1.216; 0.381 - 2.052).
Houghton 2018[12]	To evaluate whether there are associations between screen use and subsequent depressive symptomatology or between depressive symptomatology and subsequent screen use.	Observational N/A	2013 2 years	N=1,749 Age = 10-17, 47% female	Australia 38 secondary schools, Perth	Sedentary behaviour Questionnaire: online Screen Based Media Use Scale (SBMUS), total time spent on screens (incl. use both inside and outside of school).	Depression Children's Depression Inventory 2	Cross-lagged panel model	Statistically significant association between total screen use and later depressive symptoms (beta (SE): 0.128 (0.057), p=0.024). No statistically significant association between separate screen behaviours (social media, gaming, passive screen use), apart from web use.
Howie 2016[13]	To identify unique organized sport trajectories from early childhood to late adolescence.	Observational Western Australia Pregnancy Cohort Study (Raine)	1989/91 3 years	N=1,679 5-17 years, 49% girls; 85-87% White	Australia All expecting mothers 1989-1991, recruited from Tertiary women's hospital	Physical activity Questionnaire, parent-reported organised sport participation from age 5 to age 17y (5 time points) to create trajectories.	Depression & Anxiety Mental health: Depression Anxiety Stress Scales (each 7 items, max=21 per scale).	Generalised linear models with negative biomial link function, stratified by sex.	Depression: No statistically significant association in girls, in boys dropouts vs. consistent participators had higher depressive symptoms: IRR: 1.4 (1.1-1.8). Anxiety: No statistically significant association between pattern of PA and later anxiety in boys or girls.

Khouja 2019[14]	To examine associations between screen time measured at 16 years and anxiety and depression at 18	Observational Avon Longitudinal Study of Parents and Children (ALSPAC)	2007/08 2 years	N=1,869 16 years, 51% male	UK Recruited pregnant mothers living in and around Bristol, England	Sedentary behaviour Questionnaire, 6 screen use questions; categorised <1 hour, 1-2 hours or 3+ hours. Separate weekend and weekday use.	Depression & Anxiety Anxiety and Depression: self-administered, computerised version of revised Clinical Interview Schedule. Categorised as no anxiety/depression; symptoms but no diagnosis; diagnosis.	Logistic regression models	Depression: No statistically significant association with weekend or weekday TV viewing, or weekday computer use. Statistically significant association with weekend computer use (3+ hours vs. <1hr: beta: 1.35; 95%CI: 1.10, 1.65). Anxiety: No statistically significant association with weekend or weekday TV. Statistically significant association with computer use on weekdays (1.3; 1.10, 1.55) and weekends (1.28; 1.03, 1.58).
Nagamatsu 2010[15]	To investigate the influence of sport activities over 15 months on the mental health of adolescents.	Observational N/A	2008 15 months	N=553 15-16 year, male only	Japan Private high school	Physical activity Frequency (day/week) of extracurricular sport activity and community sport activity. Dichotomosied into non-activity; sport activity	Depression & Anxiety 65-item Profile of Mood States (POMS) .	General linear model repeated measurement	Depression: depression scores increased over time in both groups, but the degree of change was less in the Sport Activity group (p-value for interaction: 0.039). Anxiety: No difference in change in anxiety scores between sports groups (p-value for interaction: 0.485).
Pisarska 2018[16]	To analyse the risk and protective factors that limit the development of internalising problems in teenagers at late-stage adolescence (18- to 19-year-olds).	Observational N/A	2013 2 years	N=511 16-17 years, 34.4% female	Poland Randomly selected classes from public high schools (19), non-public high schools (3), technical high schools (9), basic vocational schools (3).	Physical activity 2-item questionnaire on participation in organised or unorganised sports activities (hours/week).	Depression 4-item Center of Epidemiologic Studies Depression Scale (CES-D)	Generalised linear models (GENLIN) with gamma variation	Statistically significant association between physical activity and later depressive symptoms (beta: -0.097, p< 0.001).

Poulsen 2016[17]	To examine whether a high level of leisure time physical activity (LTPA) during adolescence reduces the risk of future poor mental health as a 20/21 year old.	Observational Project VestLiv	2005 6 years	N=1589 14-15years, 56% female	Denmark Regional cohort people born in 1989.	Physical activity 1-item questionnaire on hours/week of usual exercise or sports. Categorised into low/high, low/high/very high, and change (reduction/persistent low level, increase/persistent high level)	Depression 4-item (abbreviated version) Center for Epidemiologic Studies Depression Scale for Children (CES-DC)	Adjusted logistic regression, stratified by sex	Statistically significant association in girls for low vs. high PA (OR=1.63, 95%CI=1.23-2.17) and for reduction/persistent low vs. increase/persistent high (1.44, 1.06-1.95). No significant association between boys' PA and later depressive symptoms: binary (1.19, 0.85-1.66), change (1.36, 0.95-1.93).
Primack 2009[18]	To assess the association between electronic media exposure in adolescence and subsequent development of depressive symptoms in young adulthood.	Propspective cohort National Longitudinal Study of Adolescent Health (Add Health)	1995 7 years	N=4142 14-15 year, 52.5% female; 67.8% White, 23.7% African American	USA A nationally representative sample of US adolescents in grades 7 through 12.	Sedentary behaviour Reported total hours/day of exposure to each 4 types of electronic media (television, videocassettes, computer games, radio); created total media	Depression 9-item Center for Epidemiologic Studies Depression Scale (CES-D) (max=27). Threshold for depression: >= 11 (female), >= 10 (male).	Multiple logistic regression	Positive association with baseline media exposure and later depression for: total media (OR=1.05, 95%CI=1.00-1.10), and TV (1.08, 1.01-1.16. No significant association for videocassettes (1.03, 0.86-1.25), video games (1.04, 0.89-1.22), or radio (0.97, 0.92-1.03).
Raudsepp 2016[19] & Raudsepp 2019[20]	To examine longitudinal and bidirectional associations between girls' sedentary behaviour and depressive symptoms in transition from early to late adolescence.	Observational NA	2010 4 & 6 years	N=234 & 341 Mean age 12.1 (0.4), 100% female	Estonia 15 public schools in Tartu	Sedentary behaviour Ecological Momentary Assessment (EMA) for 4 days (watching TV, using computer, sedentary hobbies, doing homework, sum of sedentary behaviours).	Depression 20-item Center for Epidemiologic Studies Depression Scale (CES-D) (max=60)	Latent growth models	Baseline sedentary behaviour was not associated with later depressive symptoms at 4-yr and 6-yr follow-ups.
Raudsepp 2019[21]	To examine longitudinal and bidirectional associations between physical activity, sedentary behaviour and depressive symptoms in adolescent girls.	Observational NA	2015 2 years	N=173 Mean age: 13.2 (0.4), 100% female	Estonia 4 middle public schools in Tartu	Physical activity 3-Day Physical Activity Recall (3DPAR)	Depression 20-item Center for Epidemiologic Studies Depression Scale (CES-D) (max=60)	Latent growth models	Baseline physical activity was not associated with later depressive symptoms.

Rothon 2010[22]	To examine the relationships between depression and physical activity.	Observational Research with East London Adolescents: Community Health Survey (RELACHS)	2001 2 years	N=2093 11-14 years, 49% female, 26.7% White, 41.4% South-East Asian, 20.4% Black	UK 3 Local Education Authority (LEA) boroughs in East London	Physical activity 1-item of Health Education Authority survey on hours/week of exercise outside school hours (responses: 0-7)	Depression 13-item Short Moods and Feelings Questionnaire (SMFQ); ≥8 presence of depression.	Multivariable logistic regression, stratified by sex	No significant association between physical activity and later depression in boys (OR=0.99, 95%CI=0.89-1.10) or girls (0.95, 0.87-1.04).
Stavrakakis 2012[23]	To investigate patterns in the association between physical activity and depressive symptoms to determine whether changes in physical activity precede, follow, or co-occur with changes in depressive symptoms in healthy adolescents.	Observational The Tracking Adolescents Individual Lives Survey (TRAILS)	2001/02 4-7 years	N=2230 Mean age: 11.11 (0.55), 51% female.	Netherlands NR	Physical activity Frequency of physical exercise (responses: 0=never to 4=5-6 times/week)	Depression Modified 12-item Affective Problems scale of the Youth Self-Report (YSR) & parent-reported Child Behaviour Checklist (CBCL)	Structural equation modelling: cross-lagged panel model	Significant association between physical activity and later depressive symptoms.
Strohle 2007[24]	To examine whether regular physical activity at baseline is prospectively associated with decreased risks of incident mental disorders in adolescence and young adulthood.	Observational The Early Developmental Stages of Psychopathology (EDSP)	1995 4 years	N=2548 14-17 years (45.88%) & 18-24 years (54.12%), 49.1% female	Germany Representative sample in metropolitan Munich and surrounding counties	Physical activity 4-item questionnaire (scored into: regular (daily and several times/week), non-regular (1-4 times/month), no (< once/month, no exercise at all)	Depression & Anxiety Munich Composite International Diagnostic Interview (DIA-X/M-CIDI)	Multiple multinomial logistic regression	Depression: indication of association between physical activity and later major depressive disorder (regular vs. no activity: OR=0.73, 95%CI=0.50-1.04), and dysthymia (0.34, 0.16-0.74) Anxiety: statistically significant association between physical activity and later anxiety disorder (regular vs. no activity: 0.52, 0.37-0.74)

Suetani 2017[25]	To examine the prospective relationship between physical activity engagement during adolescence and multiple mental health outcomes in young adulthood.	Observational The Mater-University of Queensland Study of Pregnacy	1995/97 7 years	N=3493 Mean age: 13.9 (0.3), 53% female	Australia Birth cohort recruited in Queensland, Australia between 1981 and 1983.	Physical activity Questionnaire on PA frequency; scored into: frequent, infrequent, or no PA	Depression & Anxiety Composite International Diagnostic Interview (CIDI)	Multiple logistic regression	Depression: indication of association between PA and later affective disorder in males (no vs. frequent PA: OR=2.17, 95%CI=0.98-4.82) and females (1.69, 0.81-3.53; Anxiety: no association between PA and later anxiety disorder in females (no vs. frequent PA: 0.56, 95%CI=0.24-1.29). Statistically significant association in males (2.24, 95%CI=1.10-4.57).
Sund 2011[26]	To examine the cross-sectional and 1-year longitudinal relationships beween physical and sedentary activities in regard to depressive symptom levels.	Observational The Youth and Mental Health Study	1998 1 year	N=2360 Mean age: 13.7 (0.58), 50.5% girls	Norway Private or public schools in two counties in the middle of Norway	Physical activity & Sedentary behaviour Physical activity: 2 items on vigorous exercise, non-vigorous PA. Sedentary behaviour: 1 item (e.g., homework, reading, walking TV, games). Hours/week	Depression 34-item Mood and Feelings Questionnaire (MFQ) (max=68; high: ≥ 25).	Multiple hierarchical logistic regression analysis	Physical activity: Statistically significant association between vigorous activity and high depression score (reverse coded: OR=1.23, 95%CI=1.01-1.49). Sedentary behaviour: Statistically significant association between sedentary time and high depression score (1.22, 1.02-1.47).
Toseeb 2014[27]	To investigate the association between objectively measured physical activity and depressive symptoms during 3 years of adolescence.	Observational ROOTS study	2005 3 years	N=736 Mean age: 14.5 (0.5), both sexes	UK Secondary schools in 2 counties.	Physical activity Actiheart (heart rate & movement sensing) for 4 consecutive days. Variables: weekend MVPA, weekday MVPA, weekend PA energy expenditure (PAEE), weekday PAEE.	Depression 33-item Mood and Feelings Questionnaire. Face-to-face assessment of major depressive disorder (MDD) using Schedule for Affective Disorders and Schizophrenia for School-Age Children-Present and Lifetime Version (diagnosis: yes/high clinical index, no).	Multivariable linear regression model	No significant association between any physical activity variable and later depressive symptoms, or major depressive disorder.

Van Dijk 2016[28]	To investigate the association between changes in physical activity and changes in mental health in adolescents.	Observational GOALS study	2011/12 1 year	N=158 Mean age: 13.6 (1.13), 62.4% female	Netherlands Secondary schools of senior general secondary education or university preparatory education in south of Netherlands	Physical activity ActivPAL3 for 4 valid days (incl. 2 weekend days); variables: volume: steps/week; change in PA.	Depression 20-item Centre for Epidemiologic Studies Depression Scale (CES-D) (max=60)	Structural equation modelling	Physical activity at baseline did not predict change in depressive symptoms.
Velten 2018[29]	To evaluate the predictive values of lifestyle choices for positive mental health and mental health problems in German and Chinese students.	Observational The Bochum optimism and mental health studies (BOOM-studies)	2012/16 1 year	N= 15,396 Germany: mean age: 21.69 (4.07), 58.9% female. China: mean age: 20.59 (1.58), 61.9% female.	Germany & China 1 German and 3 Chinese universities	Physical activity 1-item of the frequency of physical activities (responses: 0=none to 3=> 4 times/week).	Depression 21-item (7-subscale) of the Depression Anxiety Stress Scales-21 (DASS-21) (max=63)	Multi group path analysis	No significant association between physical exercise and later depressive symptoms (β=-0.02, SE=0.02, p=0.335).
Wu 2016[30]	To examine the relationships between screen time and mental health problems (anxiety, depression and psychopathological symptoms).	Observational N/A	2013 1 year	N=2521 Mean age: (male) 18.53 (1.0), (female) 18.34 (0.91); 52.9% female.	China 6 randomly selected colleges	Sedentary behaviour Questionnaire on time spent on computer use (not school work) and watching TV/video; scores dichotomised into: ≤2 hrs/day, >2 hrs/day; change: reduced/maintained constant vs. increased.	Depression & Anxiety Depression: 20-item Centre for Epidemiologic Studies Depression Scale (CES-D), high: >16. Anxiety: 20-item Self-Rating Anxiety Scale (SAS), high: >50.	Multiple logistic regression	Depression: Statistically significant association with later high depressive symptoms (>2hrs/day, increased vs. ≤2hrs/day, reduced/maintained: OR=1.98, 95%CI 1.28-3.05). Anxiety: Statistically significant association with later high depressive symptoms (>2hrs/day, increased vs. ≤2hrs/day, reduced/maintained: 1.77, 1.12-2.79.

Yasuda [31]	To examine the effect of physical activity on the development of depressive symptoms in children by using longitudinal data.	Observational N/A	2008 1 year	N=1,319 9-14 year, 48.6% female	Japan Elementary and junior high schools	Physical activity & Sedentary behaviour Physical activity: 1 item on hours/week of exercise; scored as low, middle, high (based on grade and gender). Sedentary: time spent using videogames (hrs/day); category: 0 hr, 30 min-1.5hrs, ≥2hrs.	Depression 18-item Birleson Depressive Self-rating Scale for Children (DSRS-C) (max=36; depression >16).	Multivariate logistic regression, stratified by sex	Physical activity: Statistically significant association between physical activity and risk of depression in boys (high vs. low: OR=0.37, 95%CI 0.12-0.95), but not in girls (1.05, 0.54-2.04). Sedentary: some indication of higher screen time associated with lower risk of depression in boys (0 vs. ≥2hrs/day: 0.56, 0.17-2.05), and girls (0.41, 0.12-1.24).
Zhang 2018[32]	To test the predictive validity of 4 health-related factors for new onsets of major depressive disorder.	Observational The Dresden Predictor Study (DPS)	1996/97 17 months	N=1,196 Mean age: 21.03 (1.73), 100% female	Germany NR	Physical activity Questionnaire on PA frequency (responses: 1= several times/week to 5= never); categories: regular, non-regular, no.	Depression Diagnostic interview for mental disorders research version (DSM-IV Axis I disorders); Major depressive disorder	Multiple logistic regression with bootstrap-corrected 95% confidence intervals	Statistically significant association between regular physical activity and later depression (regular vs.no: OR=0.48, bootstrap 95%CI 0.20-0.94).
Zink 2019[33]	To estimate the reciprocal (bidirectional) associations between self-reported time spent in television viewing or computer/videogame use and significant symptomatology of 4 emotional disorders	Observational Happiness and Health (H&H) study	2013 1 year	N=2,325 Mean age 14.6 (0.40), 56.2% female, 47.2% Hispanic/Latino, 16.4%White	USA High schools in the Los Angeles area	Sedentary behaviour 2 items on TV viewing and computer use/videogaming from Youth Risk Surveillance System (YRBSS); categories: ≥4 and < 4 hrs/day.	Depression & Anxiety 33-item Revised Children's Anxiety and Depression Scale (RCADS) (major depressive symptoms, generalised anxiety disorder)	Multiple logistic regression	Depression: No significant association between high TV viewing (OR=1.09, 95%CI 0.80-1.48) or computer use (1.23, 0.96-1.57) and later depression. Anxiety: No significant association between high TV viewing and later anxiety disorder (1.23, 0.96-1.57). Statistically significant association with high computer use (1.54, 1.23-1.94).

Abbreviations: 95%CI: 95% confidence interval; GAD: generalized anxiety disorder; IRR:incidence rate ratio; LTPA: leisure-time physical activity; MVPA: moderate-to-vigorous physical activity; PA: physical activity; OR:odds ratio; SE: standard error; TV: television; UK: United Kingdom; USA: United States of America

SYNTHESIS OF EVIDENCE

- Only two studies from LMIC were identified: one from Bangladesh and one from China. Another study was conducted in both Germany and China.
- Physical activity and sedentary behaviour were assessed using self-report measures in all but two studies.
- Sedentary behaviour was generally operationalized as recreational screen-time.
- More than half of studies (55%) had a sample size of >1000 participants.
- Only three studies were published before 2010.
- Thirteen studies had a follow-up longer than 2 years.
- A synthesis of the associations between physical activity / sedentary time and depression / anxiety is presented in Figure A4.1.

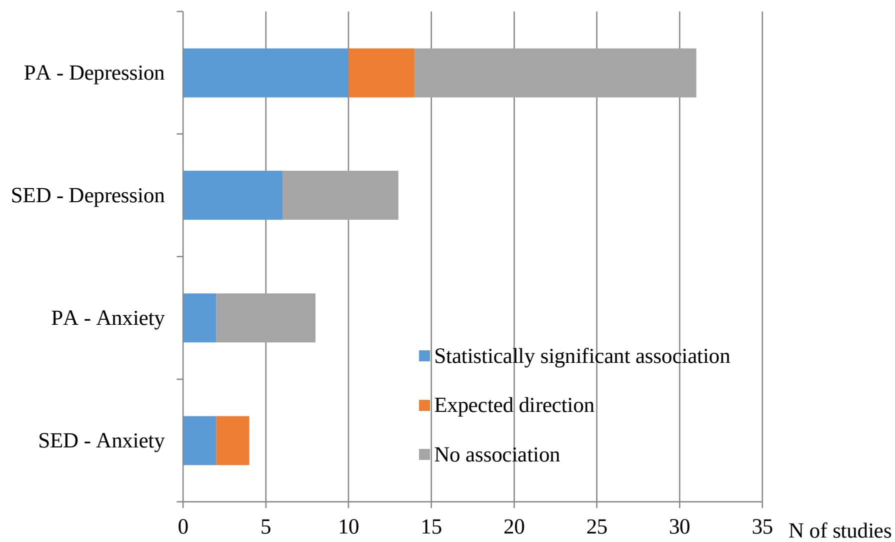

Figure A4.1: Synthesis of published evidence on prospective association between adolescent physical activity behaviours (physical activity [PA] and sedentary behaviour [SED]) and depression and anxiety.

Physical activity

- There is consistent evidence of a lack of prospective association between adolescent physical activity levels and later symptoms of depression, with 21/31 studies showing no statistically significant association.
- There is consistent evidence of a lack of prospective association between adolescent physical activity levels and later symptoms of anxiety, with 6/8 studies showing no statistically significant association.
- Associations did not differ by sex for depression or anxiety.

Sedentary behaviour

- More than half of the studies (7/13) found no association between sedentary behaviour and depression.
- There was weak evidence for a positive association between adolescent sedentary behaviour, generally operationalized as screen-based behaviours, and later anxiety: two studies showed statistically significant associations, and two statistically non-significant associations in the expected direction.
- There was some evidence of adolescent sedentary behaviour-specific associations (e.g. stronger associations for TV viewing or computer use), although these were not consistent across studies.
- There were no clear differences in associations by sex.

Considerations

- There was a high risk of reporting bias due to un-validated self-reported measures of physical activity and sedentary behaviours in most studies. Additionally, there was diversity in the types of behaviours assessed (e.g. sports participation, leisure-time physical activity)
- Outcome assessment of anxiety/depression was conducted using standardised assessments in most studies.

- This review excluded studies focused on those with pre-existing mental health disorders. Small effect sizes are expected in a generally healthy population suggesting the need for large-scale studies with precise assessment of exposure, outcomes, and confounders. Pre-specified sub-group analyses should explore differences in association by baseline clinical status, and demographic characteristics such as age, sex, and ethnicity.

CONCLUSION

There is currently no evidence that physical activity during adolescence is associated with later depressive symptoms or anxiety. There is weak evidence that adolescent sedentary behaviour, in particular screen-based behaviour, is associated with later anxiety, but not depressive symptoms. As the prevalence of mental health problems is increasing, a thorough investigation of the role of physical activity and sedentary behaviour in its aetiology and prevention is required. There is a paucity of data from LMIC, which is especially concerning given the rise in mental health problems in these countries. Future studies should employ long-term follow-up with adequate sample size, and use a combination of device-measured and self-reported exposure variables at multiple time points. Considering the social context of physical activity (e.g. team vs. individual activities) and mental requirements of sedentary activity (such as video gaming vs. TV viewing) are important avenues to inform preventative efforts.

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APPENDIX 5: Methods and results of umbrella review of correlates and determinants of physical activity and sedentary behaviour in adolescence.

DESCRIPTION OF REVIEW METHODS

To address the question "What are the correlates and determinants of physical activity in adolescence?" we conducted a review of reviews, aiming to update the data presented by Bauman et al (2012). We systematically searched five databases (Ovid Medline, Embase, PsycINFO, Web of Science, and Scopus) on 4th Dec 2019 for literature published since 2012. A librarian at the University of Cambridge medical library developed a search strategy focused on population (terms related to adolescence and young adulthood), behaviour (terms related to physical activity in general, specific activity behaviours, sitting, and screen-based behaviours), study type (Systematic review or meta-analysis), and exposures (terms related to correlates, determinants, and types of exposures e.g. psychosocial, environmental). The search strategy as applied to Ovid Medline is presented in Textbox A5.1, search strategies in other databases are available upon request from the lead author (EvS).

Textbox A5.1 – Correlates and determinants review search strategy in Ovid Medline

1 (adolescen* or teen* or student* or ((young or early or emerging) adj adult*) or youth* or (young adj (people or person)) or freshman or freshmen or freshwoman or freshwomen).ti,ab. or exp students/ or exp adolescent/
2 ((physical* adj activ*) or (active adj (transport or travel)) or exercis* or sport* or cycle or cycling or walk* or (energy adj expenditure) or sedentary or sitting or TV or television or inactiv* or (screen adj time) or screentime).ti,ab. or exp exercise/ or exp sedentary behavior/ or exp screen time/ or exp bicycling/
3 ((systematic* adj review) or meta-analys* or metaanalys*).ti,ab. or review.pt. or systematic review.pt. or exp *"Systematic Review"/ or exp *"Review"/
4 (determin* or correlat* or demograph* or biologic* or psychosocial* or environment*).ti,ab.
5 1 and 2 and 3 and 4

All records retrieved were uploaded into the Covidence review software, and duplicates removed. Textbox A5.2 outlines the in- and exclusion criteria applied. As per the *Lancet Commission on Adolescent Health and Wellbeing* definition of adolescence we included all evidence from within the adolescent and young adulthood period (10 to 24 years). Title and abstract screening were conducted by single reviewers; all records considered for full text screening were double screened by an independent reviewer, as was 10% of the excluded abstracts. Two reviewers independently screened full texts for inclusions, with discrepancies resolved by a third reviewer. Data extraction of all included papers was conducted by a single reviewer, with a 100% check by a second reviewer. Data extracted included: citation, review objective, number of databases searched, date range of search, study designs included, quality assessment instrument used (if so, what), number of relevant original studies included + country of origin, summary of participant details (e.g. age range, sex), summary of settings (e.g. school-based, regional), outcomes reported of relevance to umbrella review, synthesis method, and other comments.

Textbox A5.2: In- and exclusion criteria for correlates and determinants review

Inclusion criteria:
- Study type: Systematic review of quantitative observational studies (cross-sectional or prospective)
- Population: generally healthy participants aged 10-24y at baseline (or mean age 10-24y at baseline)
- Outcome: physical activity behaviour (any type/measure)
- Exposure: correlate/determinant (individual, social, environmental)
- Synthesis type: (semi-)quantitative
- Published from 2012 onwards

Exclusion criteria:
- Baseline age outside of adolescent period, or no age-specific results presented.
- Not systematic review
- Outcome not physical activity behaviour
- Reviews of non-ambulatory participants, hospitalized patients, or samples with pre-existing chronic health conditions
- Review of experimental or qualitative studies.
- Only narrative synthesis

RESULTS

We retrieved 4,820 records, of which 3,194 unique records were retained. Title/abstract screening removed 3,107 records and 87 full text papers were screened of which 74 were excluded (main reasons: no adolescent-specific results, only qualitative synthesis, wrong outcomes, umbrella review). Table A5.1 provides a descriptive overview of the 13 included reviews; Table A5.2 provides a summary of their results.

Table A5.1: Descriptive overview of systematic reviews on correlates and determinants of adolescent physical activity and/or sedentary behaviour.

Brief review objective (reference)	N databases searched & date range	Study designs included	Quality assessment & synthesis method	N of relevant studies & countries of origin	Summary of participants details & settings	Outcomes reported
To systematically review the correlates of children's and adolescents' after-school sedentary behavior organized according to an ecological framework ***Arundell 2016* [1]**	9 (Academic Search Complete; CINAHL Complete; Education Research Complete; MEDLINE; MEDLINE Complete; PsycARTICLES; Psychology and Behavioral Sciences Collection; PsycINFO; SPORTDiscus); to Oct 2015	Cross-sectional (n=8), Cohort (n=1)	Yes (McMaster University Quality Assessment Tool for Quantitative Studies); semi-quantitative synthesis	N=8; United States (n=5), United Kingdom (n=2), combined countries of Denmark, Portugal, Estonia and Norway(n=1)	N=81- 2670; Age= 10 - 16 yrs; Female %= 46-100%; after-school setting	Overall sedentary behaviours; TV-viewing; non-screen based sedentary behaviours; screen-based sedentary behaviour; computer/DVD/video game
To determine the association between physical activity and physical self-concept in young people and examine potential moderators of the association ***Babic 2014*[2]**	6 (MEDLINE; CINAHL; SPORTDiscus; ERIC; Web of Science; Scopus); to Aug 2013	Cross-sectional (n=46), Longitudinal (n=12), Experimental (n=4)	Yes (Adapted Items from previous studies); meta-analysis	N=62; United States (n=15), England (n=12), Australia (n=7), Canada (n=5), United Kingdom (n=4), Spain (n=2), Finland (n=2), Sweden (N=2), all n=1: Taiwan, Hong Kong, Mexico, Norway, Germany, Scotland, Cyprus, Poland, Jamaica, Greece, Estonia, Italy, China	N=45,871; Age = 10-19 yrs, Female (N=245,030); setting not reported	Leisure time physical activity
To systematically review the literature on socio-ecological correlates of total and domain-specific sedentary behaviours in university students ***Castro 2018*[3]**	12 (Academic Search Ultimate; CINAHL; Education Research Complete; ERIC; PsycARTICLES; Psychology and Behavioral Sciences Collection; PsycINFO; SPORTDiscus; Web of Science; MEDLINE; Scopus; and SciELO); to Jan 2018	Cross-sectional (n=109), Cohort (n=16), qualitative (1)	Yes (The Cochrane Collaboration's Tool for Assessing Risk of Bias); semi-quantitative synthesis	N=124; USA (n=33), Spain (n=11), India (n=5), Turkey (n=5), Colombia (n=5), China (n=5), Canada (n=5), Saudi Arabia (n=4), Brazil (n=4),United Kingdom (n=4), South Africa (n=3), United Arab Emirates (n=3), Nigeria (n=2), Egypt (n=2), Poland (n=2), Belgium (n=2), New Zealand (n=2), Pakistan (n=2), Japan (n=2), Thailand (n=2), Bahrain (n=2), all n=1: Algeria, Somalia, Ukraine, Portugal, Italy, Ireland, Mexico, Germany, Bangladesh, Greece, Sweden, Sudan, Romania, Malaysia, Lebanon, South Korea, Costa Rica, Peru, Israel, Czech Republic	N= 99,071; Age= 17 - 24yrs , Female%=32 - 100%; university setting	Screen time, total sedentary behaviour or sitting time, occupational sedentary behaviour, passive transportation

Brief review objective (reference)	N databases searched & date range	Study designs included	Quality assessment & synthesis method	N of relevant studies & countries of origin	Summary of participants details & settings	Outcomes reported
To examine screen time behaviour among North American Indigenous populations and compare behaviours across subgroups ***Foulds 2016*** [4]	14 (MEDLINE; EMBASE; CINAHL; PsychINFO; Cochrane Libraray; SPORTSDiscus; Sociological Abstract; SocINDEX; Scopus; Social Services Abstract; Academic Search Premier; WorldCat; Web of Science; Clinicaltrial.gov); to Aug 2015	Cross-sectional (n=20), Prospective cohort (n=6), randomized control trial (n=1)	Yes (Downs and Black Scoring system); meta-analysis	N=27; USA (n=16), Canada (n=11)	N= 21,278; Age= 5 - 18 yrs; Female% =not reported; setting not reported	Overall screen time, television viewing, computer video game use
To systematically review and meta-analyse the relationship between social support and physical activity in adolescent girls ***Laird 2016*** [5]	14 (MEDLINE; PsychINFO; EMBASE; CABabstracts; Global Health; Science Citation Index; ERIC; Allied and Complementary Medicine; CinAHL; SPORTDiscus; Social Science Citation Index; Cochrane library; Dissertations and Theses A&I; International Bibliography of the Social Sciences) to Aug 2016	Cross-sectional (n=68), Longitudinal (n=16)	Yes (The Critical Appraisal Skills Programme for cohort studies tool); meta-analysis	N=73; USA (n=37), Australia (n=10), Canada (n=6), UK (n=6), Estonia (n=3), Brazil (n=2), all n=1: Iran, Japan, China, Singapore, India, Taiwan, Norway, France, Hungary	N=22 - 15737; Age= 10 - 19 yrs; Sex= 100% female; setting not reported	MVPA, sport, active transport, Total PA
To systematically review the factors related to physical activity in Chinese children and adolescents ***Lu 2017*** [6]	2 (Web of Sciences; Pubmed) to Aug 2017	Cross-sectional (n=33), Longitudinal (n=9)	Yes (Adapted items from Strengthening The Reporting of Observational studies in Epidemiology (STROBE) statement and Evaluation of the Quality of Prognosis Studies in Systematic Reviews (QUIPS)); semi-quantitative	N=20; China (n=13), Hong Kong (n=5), Taiwan (n=2)	N=91 - 29139; Age=13 - 18 yrs; female=42.8 - 100%; setting not reported	Leisure time physical activity, MVPA, MPA, VPA
To conduct a systematic review and metaanalysis of studies linking aspects of the built environment with youth moderate-vigorous activity, including walking ***McGrath 2015*** [7]	4 (PubMed; Embase; CINAHL; Active Living Research Database); to Aug 2018	Cross-sectional (n=10); Longitudinal (n=9)	Yes (researchers' developed instrument); meta-analysis	N=19; USA (n= 9), Australia (n= 3), England (n= 4), all n=1: Canada, Belgium, New Zealand	N= 24 - 1525, Age= 10 - 18 yrs); female%= 0 - 100%; SES= (mixed, low, mid, high); school recruitment	MVPA, play, exercise, sports, walking

Brief review objective (reference)	N databases searched & date range	Study designs included	Quality assessment & synthesis method	N of relevant studies & countries of origin	Summary of participants details & settings	Outcomes reported
To synthesize the results of studies on the association between physical activity and social support in adolescents ***Mendonca 2014***[8]	8 (Adolec; ERIC; LILACS; PubMed; SciELO; Scopus; SportDiscus; Web of Science); to Apr 2011	Cross-sectional (n= 64), Longitudinal (n= 9), Intervention (n= 2)	Yes (new instrument based on STROBE, Downs and Black checklist, and CONSORT); semi-quantitative	N=75; USA (n=42), Norway (n=3), Australia (n=6), China (n=2), Brazil (n=2), China and Australia (n=1), UK (n=4), Israel (n=1), Canada (n=5), Belgium (n=2), all n=1: Estonia, New Zealand, Denmark, Cyprus, South Korea, Singapore, Iran	N=<100 to >5000; Age= 10-19; both sexes=76%, male only=1.3%, female only=22.7%; setting not reported	Any type of physical activity
To examine the SES correlates of sedentary behaviour in adolescents ***Mielke 2017***[9]	8 (Academic Search Premier, CINAHL, Cochrane, PubMed, Scopus, SocIndex, SPORTDiscus, and Web of Science); to Mar 2015	Cross-sectional (n=35); Longitudinal (n=2); Surveillance(n=2)	Not done; meta-analysis	N=39; Brazil (n=12), the USA (n=8), Australia (n=4), China (n=3), England (n=3), Norway (n=2), all n=1: Palestine, Denmark, Estonia, Finland, Thailand	N= <500 to >50000; mean age= between 10 and 19; low-middle income countries=46%; male+female=82%; not reported	Screen-based sedentary behaviour (TV and/or video game and/or computer time together; TV-viewing; “other” (computer and/or video game time and/or time spent studying, but not including TV time)
To provide information on what school environment factors are associated with adolescent physical activity and sedentary behaviour ***Morton 2016***[10]	4 (PubMed; Web of Science; PsycINFO; ProQuest [including British Education Index; Australian Education Index; ERIC]); to Jun 2014	Cross-sectional (n=46), prospective (n=11), experimental (n=11)	Yes (modified tool appropriate for mixed-studies reviews); semi-quantitative	N=68 quantitative studies; USA (27), Canada (7), Australia (7), Norway (4), Spain (3), Belgium (1), New Zealand (3), UK (3), Singapore (2), all n=1: China, Sweden, Vietnam, Greece, Hong Kong, Finland, South Korea, UK+Greece+Poland+Singapore (1), Estonia, the Netherlands	N=<100 to >10000; secondary school=54%; school recruitment	Reported and objective assessment. total PA, MVPA, vigorous PA, light PA, leisure time PA, sedentary time, TV viewing
To search for more accurate data on the prevalence of PA among adolescents and young adults in UAE ***Yammine 2017***[11]	7 (MEDLINE, Embase, SciELO, AMED, AUSPORT, SPORTDiscus, and Google Scholar); to May 2015	Cross-sectional (n=5)	Not done; meta-analysis	N=5; UAE (5)	N=206 to 9916; Age=12 to 24; setting not reported	Overall PA
To provide a cohesive and comprehensive examination of the parental correlates, and potential moderators, of child PA ***Yao 2016***[12]	10 (EBSCO (Academic Search Complete, Academic Search Premier, CINAHL, Health Source, MEDLINE, PsycINFO, Social Sciences, SPORTDiscus, PubMed, and ISI Web of Science); Jan 1970 to Nov 2014	Cross-sectional (n=94), prospective (n=21)	Yes (Downs and Black’s 22-item assessment tool); meta-analysis	N=47 adolescent studies (out of 112 in total); USA, Hungary, Portugal, Canada, Australia, Korea, Norway, Finland, Brazil, France, Sweden, Spain, Japan, Estonia, UK, Denmark, Belgium, New Zealand, China, Cyprus, UK+Estonia+Finland+Hungary	N=45 to 12,812; adolescent age range defined as 12.5 to 18yrs; setting not reported	Structured (e.g., organized sports, lessons) and unstructured PA (e.g. leisure time PA, play)

Brief review objective (reference)	N databases searched & date range	Study designs included	Quality assessment & synthesis method	N of relevant studies & countries of origin	Summary of participants details & settings	Outcomes reported
To systematically summarise studies on the correlates of secondary school students' MVPA during PE classes ***Zhou 2019***[13]	6 (ERIC, SPORTDiscus, PubMed, PsycINFO, Academic Search Premier, and Web of Science); to May 2018	Cross-sectional (n=38) and prospective longitudinal (n=5) quantitative studies	Yes (instrument based on STROBE and McMaster Critical Review Forms); semi-quantitative	N=43; USA (23), UK (4), Spain (4), Finland (2), Hong Kong (2), other country (8)	N=<100 to >500; participant age in included studies= 10-18 years old; school recruitment	MVPA during secondary school PE lessons

Table A5.2: Summary of results of included systematic reviews on correlates of adolescent physical activity and/or sedentary behaviour

Ref	Brief review objective	Summary of results	Socio-ecological domains
Arundell[1]	To systematically review the correlates of children's and adolescents' after-school sedentary behavior organized according to an ecological framework	No consistent evidence for all associations (<4 studies per correlate): - *Overall SED:* male sex (+), age (+), BMI (+/-), non-Caucasian (+), body fat % (+), time supervised after school (+), time alone after school (+), rainfall (0) - *TV viewing:* male sex (0), BMI (+/0), non-Caucasian (+/0), child behaviour autonomy (+/0), high vs. low father income (-/0), medium vs. low father income (0), high/medium vs. low mother income (0), TV environment (+), N TV sets at home (+/0), TV in bedroom (0), country (+) - *Computer/DVD/Video games:* male sex (0), non-Caucasian (+/-/0) - *Non-screen based SED:* male sex (0)	All
Babic[2]	To determine the association between physical activity and physical self-concept in young people and examine potential moderators of the association	Effect sizes estimates (r) for association with PA: - *General physical self-concept*: r=0.26 (0.15-0.37) in early adolescence; r=0.22 (0.04-0.40) in late adolescence. - *Perceived competence*: r=0.35 (0.26-0.42) in early adolescence; r=0.31 (0.10-0.41) in late adolescence - *Perceived fitness*: r=0.31 (0.24-0.37) in early adolescence; r=0.28 (0.13-0.42) in late adolescence - *Perceived appearance*: r=0.19 (0.13-0.24) in early adolescence; r=0.07 (0.01-0.13) in late adolescence	Psychological
Castro[3]	To systematically review the literature on socio-ecological correlates of total and domain-specific sedentary behaviours in university students	Correlates of SED investigated in ≥4 low risk of bias studies: - *Total sitting time:* female gender (0, 13 studies), MET min physical activity per week (-, 5 studies) - *TV time:* obesity markers (?, 7 studies) - *Overall screen time:* female gender (0, 4 studies),	All
Foulds[4]	To examine screen time behaviour among North American Indigenous populations and compare behaviours across subgroups	Indigenous male youth have greater screen time than female youth (3.27±1.36 vs. 2.65±1.19 h/day)	Demographic
Laird[5]	To systematically review and meta-analyse the relationship between social support and physical activity in adolescent girls	Effect size estimates (r) for social support on PA behaviour in adolescent girls (73 cross-sectional studies) - *Total social support:* all providers: r=0.237 (0.150-0.321); parents: r=0.192 (0.108-0.273); family: r=0.136 (0.081-0.191); mother: r=0.223 (0.163-0.280), father: r=0.161 (0.101-0.219), friend: r=0.135 (0.096-0.173); teacher: r=0.062 (-0.051-0.174). - Encouragement: parents: r=0.103 (0.032-0.173); mother: r=0.194 (0.111-0.275), father: r=0.211 (0.153-0.266)	Intrapersonal

Ref	Brief review objective	Summary of results	Socio-ecological domains
		- Instrumental support: parents: r=0.169 (0.131-0.206), mother: r=2.14 (0.060-0.359); father: r=0.234 (-0.011-0.452) - Modelling: parents: r=0.130 (0.049-0.209); mother: r=0.079 (-0.004-0.160), father: r=0.144 (0.054-0.232), friends: r=0.161 (0.074-0.245) - Co-participation: parents: r=0.033 (-0.102, 0.168) Longitudinal studies (n=16): - Total social support: 10/12 studies reported a positive longitudinal relationship. - Encouragement: 1/2 studies reported positive longitudinal relationship - Instrumental support: 1 study reported positive longitudinal relationship - Modelling: 5/12 studies reported positive longitudinal relationship, 6 no association, and 1 a negative relationship - Co-participation: 2/3 studies reported positive longitudinal relationship.	
Lu[6]	To systematically review the factors related to physical activity in Chinese children and adolescents	Association with PA in Chinese adolescents: male gender (+), mother's PA (+), father's PA (+), self-efficacy (+), urban vs. rural (?), weight status (?), SES (0), parental education (0), age (?), intention (0)	All
McGrath[7]	To conduct a systematic review and metaanalysis of studies linking aspects of the built environment with youth moderate-vigorous activity, including walking	Association of built environment features promoting play (e.g., play facilities, play grounds, parks, etc) and walking (e.g., sidewalks, walking tracks, path lighting, etc) with PA: - Play features (including sports & fitness): 12-y olds: r=0.17±0.10; 15-y olds: r=0.35±0.17 - Walking features: r=0.26±0.16 - Both play and walking features: 12-y olds: r=0.16±0.11, adolescents: 0.61±0.20	Environment
Mendonça[8]	To synthesize the results of studies on the association between physical activity and social support in adolescents	Association between social support and PA: overall (+), parents (+), father (+), mother (?), friends (+), family (+), siblings (?), teacher (0)	Intrapersonal
Mielke[9]	To examine the SES correlates of sedentary behaviour in adolescents	OR of high SED in the highest vs. lowest SES - All outcomes: overall: 0.89 (0.81–0.98); HIC: 0.67 (0.62-0.73); LMIC: 1.18 (1.04-1.30) - Screen-based: overall: 0.77 (0.66-0.90); HIC: 0.68 (0.62-0.74); LMIC: 1.06 (0.76-1.47) - TV viewing: overall: 0.86 (0.77-0.95); HIC: 0.58 (0.49-0.69); LMIC: 1.08 (0.97-1.20) - Computer/Video games/study time (not TV): overall: 1.32 (1.06-1.66); HIC: 1.15 (0.87-1.52); LMIC: 1.38 (1.07, 1.79)	Demographic
Morton[10]	To provide information on what school environment factors are associated with adolescent physical activity and sedentary behaviour	Correlates of PA/SED behaviour investigated ≥4 studies: - *Whole school environment:* activity setting (+); PA facilities (?), field/PA area size (?), access to sports/PA equipment (0), perceived school PA climate/support (overall) (?),perceived school PA climate/support (teacher) (+), adult supervision (0), extracurricular PA activities (?), school offers intramural sports (+), PE provision (0). - *PE environment:* autonomy support (+), perception of learning/mastery climate (+).	Intrapersonal Environmental
Yammine[11]	To search for more accurate data on the prevalence of PA among adolescents and young adults in UAE	Male vs female adolescents from United Arab Emirates: OR for participation in mild PA: 0.82 (0.698-0.961), moderate PA: (1.23 (1.126-1.349), high PA (2.6 (2.137-3.139)	Demographic
Yao[12]	To provide a cohesive and comprehensive examination of the parental correlates, and potential moderators, of child PA	Association with adolescent (12.5-19y) PA (fixed effects): - Parental modelling: r=0.08 (-0.07-0.22) - Overall/composite parental support: r=0.42 (0.29-0.55) - Parental encouragement: r=0.34 (0.21-0.45)	Intrapersonal
Zhou[13]	To systematically summarise studies on the	Correlates of MVPA during secondary school PE lessons investigated ≥3 studies:	All

Ref	Brief review objective	Summary of results	Socio-ecological domains
	correlates of secondary school students' MVPA during PE classes	- *Demographic and biological:* male sex (+), school level (0), grade (?), overweight vs. normal weight (0), white ethnicity (+) - *Instruction*-related: class size (0), boys only PE (+), co-educational PE (?), girls-only PE (-), team games (+), individual games (0), movement activities (-), individual activities (0), fitness activities (?), free play (0), game play (?), skill drills (0), management (0), knowledge (-), male teacher (0) - *School physical environment:* lesson outdoors (+) - *Psychological:* intrinsic motivation (0), identified regulation (0), external regulation (0), amotivation (0), competence (0), expectancy beliefs (+), subjective task values (+), self-efficacy (?), enjoyment (+)	

Notes: +/0/-/?: positive/null/negative/indeterminate association; interpretation of effect sizes: <0.20: trivial, 0.20-0.59: small, 0.60-1.19: moderate: ≥1.20: large (Hopkins et al, MSSE 2009); HIC: high income countries; LMIC: low-middle-income countries; OR: odds ratio

SYNTHESIS OF EVIDENCE

- 13 systematic reviews were identified, of which three focused on specific populations (adolescents in China and United Arab Emiratis, and North American Indigenous populations). Four review exclusively focused on sedentary behaviour and one considered both physical activity and sedentary behaviour; all others focused on physical activity behaviour.
- Evidence is predominantly based on studies from North America, Western Europe and Australia, although further global evidence is included (including from Iran, Poland, China, Brazil, Palestine, Korea, Sudan).
- Summary of evidence within ecological domains (based on conclusions from ≥4 studies where possible):
    - Demographic and biological:
        - Overall, adolescent males are more active and less sedentary than females, both overall and during PE. This difference between males and females is less clear in young adults.
        - The association between socioeconomic position (SEP) and adolescents' physical activity and time spent sedentary is ambiguous. Opposite associations for time spent sedentary are observed in HICs and LMICs, with evidence suggesting that adolescents from low SEP are less sedentary than adolescents from high SEP in LMICs, whereas in HICs adolescents from low SEP are more sedentary.
    - Psychological:
        - Higher levels of physical activity are associated with greater general physical self-concept and higher self-efficacy, but effect sizes are small.
    - Behavioural
        - Higher levels of physical activity are associated with lower levels of total sedentary time in university students.
    - Intrapersonal:
        - The intrapersonal domain was most prominent in the evidence-base with three reviews specifically focused on the role of social support in adolescent physical activity.
        - Social support from family and friends was positively associated with adolescent physical activity, although effect size estimates were small. The association with teacher support was equivocal. Overall, encouragement and instrumental support from both mothers and fathers showed positive associations, but the evidence was limited for an association with parental co-participation in physical activity and parental modelling.
    - Environmental:
        - Combined effect of neighbourhood built environmental features promoting play (i.e., play facilities, play grounds, parks, beaches, sports venues, recreational facilities and gym) and walking (i.e., sidewalks, walking tracks, path lighting, traffic calming, high connectivity streets and local destinations) was associated with increased adolescent physical activity.
        - Two reviews focused on correlates within the school and PE environment. These showed that the motivational climate within PE classes were positively associated with PE-based physical activity (specifically autonomy support and fostering enjoyment). Moreover, adolescents in PE classes that were delivered outdoor, to boys only, and included team games were more active. In contrast, girls only classes were less active, whereas the association was indeterminate for co-educational PE classes.
        - At the whole-school level, factors that showed no association included hours of PE provision and access to sports equipment. However, the offer of intramural sports, the perceived school PA climate created by teachers and the activity setting (i.e. the type and location for specific activities, e.g. baseball field, indoor gym) were positively associated.

Considerations

- Limitations of the underlying evidence in the reviews includes the predominant use of self-reported behaviour as outcome, the overwhelming focus on individual and social factors, the dominance of cross-sectional evidence, and the lack of studies in older adolescents and young adults, and from LMICs.

- No reviews reported on associations with biological determinant beyond sex, age and adiposity. Further research is needed on the importance of genetics and the process of maturation for adolescent physical activity behaviour, and how these may interact with the psychosocial, intrapersonal and environmental factors identified.
- The limitations of the reviews included are also worth noting. They include the failure to distinguish between cross-sectional and longitudinal associations in evidence synthesis, and a lack of assessment of the relative importance of, and interactions between, different factors at different levels of the socio-ecological model.

CONCLUSION

Review-level evidence shows that adolescent physical activity and sedentary behaviour are associated with a range of factors from the demographic, psychological, intrapersonal and environmental domain, The evidence was strongest for gender, social support from friends and family, multi-utility activity-supportive built environments, features of the PE environment, and, at the whole school level, intramural sports and the school PA climate. Future research should aims to understand the context-specific drivers of PA behaviours, adopt longitudinal designs, study older adolescents, young adults and populations from LMICs, investigate the relative importance of different ecological factors, and study biological, environmental, commercial and policy-level influences and how these interact with other correlates.

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APPENDIX 6: Umbrella review of physical activity and sedentary behaviour interventions in adolescents: methods and results.

DESCRIPTION OF REVIEW METHODS

We conducted a review of reviews to address the question "What is the effect of physical activity and sedentary behaviour interventions in adolescent populations?" As per the *Lancet Commission on Adolescent Health and Wellbeing* definition of adolescence we included all evidence from within the adolescent and young adulthood period (10 to 24 years). We systematically searched five databases (Ovid Medline, Embase, PsycINFO, Web of Science, and Scopus) on 4th December 2019 for literature published since 2012. A librarian at the University of Cambridge medical library developed a search strategy focussed on population (terms related to adolescence and young adulthood), behaviour (terms related to physical activity in general, specific activity behaviours, sitting, and screen-based behaviours), study type (systematic review or meta-analysis), and exposures (interventions, programs, policies). An example search strategy for the Ovid Medline database is presented in Textbox A6.1. Search strategies for the other databases are available upon request.

Textbox A6.1 – Search strategy in Ovid Medline

1 (adolescen* or teen* or student* or ((young or early or emerging) adj adult*) or youth* or (young adj (people or person)) or freshman or freshmen or freshwoman or freshwomen).ti,ab. or exp students/ or exp adolescent/
2 ((physical* adj activ*) or (active adj (transport or travel)) or exercis* or sport* or cycle or cycling or walk* or (energy adj expenditure) or sedentary or sitting or TV or television or inactiv* or (screen adj time) or screentime).ti,ab. or exp exercise/ or exp sedentary behavior/ or exp screen time/ or exp bicycling/
3 ((systematic* adj review) or meta-analys* or metaanalys*).ti,ab. or review.pt. or systematic review.pt. or exp *"Systematic Review"/ or exp *"Review"/
4 (promot* or intervention* or campaign*).ti,ab. or exp health promotion/
5 1 and 2 and 3 and 4

All records retrieved were uploaded into the Covidence review software, and duplicates removed. Textbox A6.2 outlines the inclusion and exclusion criteria applied. Title and abstract screening were conducted by single reviewers; all records considered for full text screening were screened by an independent reviewer, as was 10% of the excluded abstracts. Two reviewers independently screened full texts for inclusions, with discrepancies resolved by a third reviewer. The reference lists of included reviews were checked for additional papers. Data extraction of all included papers was conducted by a single reviewer, with 100% checked by a second reviewer. We extracted the following data from the included reviews: objectives, number of databases searched, quality assessment instrument used (if so, what), number of relevant original studies included + country of origin, summary of participant details (e.g. age range, sex), summary of settings, outcomes reported of relevance to review, synthesis method, and other comments. The meta-analysis summary effects (i.e., standardised mean difference and 95% confidence intervals) for MVPA and moderators of interest (i.e., sex, socio-economic status, type of physical activity measure, intervention strategy, and study duration,) were extracted from all included reviews. If a review did not report an MVPA effect size, results for total physical activity were extracted.

Textbox A6.2: Inclusion and exclusion criteria.

Inclusion criteria:
- Study type: Systematic review of controlled trials (RCT or quasi-experimental)
- Population: generally healthy participants aged 10-24y at baseline (or mean age 10-24y at baseline)
- Outcome: physical activity behaviour and sedentary behaviour (including screen-time)
- Exposure: physical activity interventions in any setting (as sole focus or part of multi-component)
- Synthesis type: quantitative
- Published from 2012 onwards

Exclusion criteria:
- Baseline age outside of adolescent period, or no age-specific results presented.
- Not systematic review
- Outcome not a physical activity behaviour
- Reviews of non-ambulatory participants, hospitalized patients, or samples with pre-existing chronic health conditions
- Review of cross-sectional, longitudinal or qualitative studies
- Only narrative or semi-quantitative synthesis
- Published pre-2012
- Conference papers, abstracts, non-peer-reviewed publications

RESULTS

We retrieved 5,015 records, of which 3,293 unique records were retained (an additional paper was identified from the reference list of included studies). Title/abstract screening removed 3,144 records and 150 full text papers were screened of which 137 were excluded (main reasons: no adolescent-specific results, no quantitative synthesis and wrong outcomes). A total of 13 reviews were included. Table A6.1 provides a descriptive overview of the included reviews, whereas Table A6.2 provides a summary of the results. The mean effect-size estimates from the 13 original systematic reviews are depicted in Figure A6.1.

Table A6.1: Characteristics of included systematic reviews

Review	Brief review objective	Databases searched (N and date range)	Quality assessment instrument used (if so, what)	Setting(s)	Intervention type	Countries and studies in meta-analysis	Participant details (N, age, sex)
Borde et al (2017)[7]	Determine the impact of school-based interventions on objectively measured PA among adolescents	7 databases (CINAHL® Plus with Full Text, The Cochrane Library, EMBASE®, Ovid MEDLINE®, PsychINFO®, Scopus and SPORTDiscus™) Date range: NR	Yes (customised tool)	Schools	Single and multiple components	7 studies (Total PA) 12 studies (MVPA) 13 studies: Australia (5) Belgium (1) Ecuador (1) Denmark (1) Hong Kong (1) Norway (1) USA (3)	(i) N = 2,323 (Total PA) and 4,803 (MVPA) (ii) Mean age = 12.4 (11-16: range) years (iii) Sex: mixed
Chang et al (2019)[13]	Examine the effectiveness of interventions to increase PA in youth from low-income and ethnic minority families	8 databases (PubMed, CINAHL Plus, SPORTDiscus, ERIC, PsycINFO, Scopus, ProQuest, and The PA Index) Date range: Up to Feb 2018	Yes (modified version of the Downs and Black Checklist for the Risk of Bias)	No setting limitations	Single and multiple components	12 studies (9-12 years) 6 studies (13-17 years) 15 studies (3 had 2 datasets included): Australia (6) USA (9)	(i) N = NR (ii) Age range = 9-12 or 13-17 years (iii) Sex: mixed
Champion et al (2019)[4]	Review the effectiveness of eHealth school-based interventions targeting multiple lifestyle risk behaviours	5 databases (Ovid, MEDLINE, Embase, PsycINFO, and the Cochrane Library) Date range: Up to June 2017	Yes (Cochrane Collaboration's Risk of Bias tool)	Schools	eHealth- single and multiple components	2 studies (objective PA) 7 studies (self-report PA) 3 studies (self-report ST) Belgium (1) Netherlands (1) USA (6)	(i) N = 5,045 (ST), 324 (objective PA), 10,399 (self-report PA) (ii) Mean age = 13.4 (1.5: SD) years (iii) Sex: mixed
Love et al (2019)[2]	Systematically review and meta-analyse data on the effectiveness of school-based interventions on accelerometer-assessed daily minutes of MVPA	6 databases (ERIC, EMBASE, OVID MEDLINE, PsycINFO, Scopus, and SPORTDiscus) Date range: Up to Feb 2017	Yes (Cochrane Collaboration's Risk of Bias tool)	Schools	Single and multiple components	17 studies (objective PA) Australia (4) Belgium (1) Denmark (1) Ecuador (1) Northern Ireland (1) Norway (2) Sweden (2) Switzerland (1) UK (3) USA (1)	(i) N = NR (ii) Mean age: 10·6 (11.2: median) years (iii) Sex: mixed

McMichan et al (2018)[5]	Review classroom-based PA and SB interventions within early secondary/middle/ high school settings	6 databases (Medline (OVID), EMBASE, ERIC, SportDiscus, PsycInfo, and Web of Science) Date range: Up to July 2017	Yes (EPHPP quality assessment tool)	Schools	Classroom-single component	5 studies (self-report and objective PA) 2 studies (sedentary behaviours) China (2) UK (1) USA (3)	(i) N = NR (ii) Age range: 12.0 to 15.3 years (iii) Sex: mixed
Metcalf et al (2012)[12]	Determine whether, and to what extent, PA interventions increase the overall activity of children	Four databases (Embase, Medline, PsycINFO, and SPORTDiscus) Date range: Jan1990 to Mar 2012	Yes (Customised tool)	Schools, home, primary care	Single and multiple components	13 studies (objective PA) Australia (2) Belgium (1) Canada (1) New Zealand (1) Sweden (1) UK (1) USA (6)	(i) N = NR (>10 years) (ii) Age range: 10.0 to 13.1 years (iii) Sex: mixed
Owen et al (2017)[6]	Systematically review school-based PA interventions involving adolescent girls and quantify their effect through meta-analysis	4 databases (PubMed, Web of Science, SPORTDiscus and PsychInfo) Date range: Up to Dec 2016	Yes (Modified from existing tool)	Schools	Single and multiple components	17 studies (self-report and objective PA) Australia (4) Belgium (1) Cyprus (1) Iran (1) Poland (1) UK (3) USA (6)	(i) N = 10,755 (ii) Mean age = 12.9 years (iii) Sex: girls
Pearson et al (2015)[10]	Quantify the effectiveness of interventions that aimed to increase PA among adolescent girls	6 databases: (Science Direct, PubMed, PsychINFO, Web of Science, Cochrane Libraries, and EPPI Centre) Date range: Up to May 2013	Yes (The Cochrane Collaboration tool for Assessing Risk of Bias)	School, after school, community and family	Single and multiple components	45 studies (34 independent samples- self-report and objective PA) Australia (5) Belgium (1) Canada (1) France (1) Iran (1) Poland (2) UK (2) USA (20)	(i) N = 5,680 (ii) Age range = 12-18 years (iii) Sex: girls

Plotnikoff et al (2015)[8]	Examine the effectiveness of interventions aimed at improving PA in university/college students	5 databases: (MEDLINE, PsychINFO, CINAHL, ERIC and ProQuest) Date range: Jan 1970 to April 2014	Yes (Academy of Nutrition and Dietetics Quality Criteria Checklist: Primary Research Tool assessing criteria)	University or college	Single and multiple components	5 studies (self-report PA) 5 studies (total PA) Taiwan (1) UK (1) USA (3) 5 studies (VPA and MPA) USA (5) Combined (total PA + VPA + MPA) Taiwan (1) UK (1) USA (6)	(i) N = 1,848 (total PA), 1,108 (vigorous PA), 1,108 (moderate PA) (ii) Age range = 18-22 years (iii) Sex: mixed
Ruotsalainen et al (2015)[11]	Examine the effects of PA interventions on subsequent PA for overweight and obese adolescents	3 databases: (CINAHL, MEDLINE (Ovid) and PsycINFO) Date range: 1950 to Aug 2013	Yes (The Cochrane Collaboration tool for Assessing Risk of Bias)	Home, community, primary care and eHealth	Single and multiple components	14 studies (self-report and objective PA) Australia (1) Germany (1) New Zealand (1) Sweden (1) Tunisia (2) UK (1) USA (7)	(i) N = 1,321 (ii) Mean range = 13.6 (10-18, range) years (iii) Sex: mixed
Shin et al (2019)[9]	Evaluate the effectiveness of mobile phone intervention in promoting a healthy lifestyle among adolescents	6 databases (MEDLINE, Embase, Cochrane Library, Cumulative Index to Nursing and Allied Health Literature, KoreaMed, and Research Information Sharing Service Date range: Up to Oct 2018	Yes (Cochrane Collaboration tool for Assessing Risk of Bias)	School and home	Mobile phone-single and multiple components	6 studies (Self-report and objective PA (5 included in meta-analysis) Australia (2) New Zealand (1) USA (2) 5 studies (self-report screen-time) Australia (3) New Zealand (1) USA (1) Combined: Australia (3) New Zealand (1) USA (2)	(i) N = 1,472 (ii) Age range = 10-18 years (iii) Sex: mixed

Sims et al (2015)[1]	Examine PA intervention effects measured at least six months post-intervention	7 databases (PubMed, MEDLINE, EMBASE, PsychINFO, ScienceDirect, SportDiscus and Google Scholar) Date range: Jan 1991 to Nov 2014	Yes (Methodology Checklist for Randomised Controlled Trials)	School, primary care, scout group and community	Single and multiple components	6 studies (self-report and objective PA) Australia (1) China (1) Portugal (1) UK (1) USA (2)	(i) N = NR (ii) Mean age = 10.67 (± 1.91) years (iii) Sex: mixed
Van de Kop et al (2019)[3]	Identify effectiveness of prevocational school-based PA interventions in adolescents	7 databases (PubMed, Embase.com, The Cochrane Library (via Wiley) and (via EBSCO) CINAHL, SPORTDiscus, PsycINFO, and ERIC) Date range: Jan 2000 to Nov 2018	Yes (Cochrane Collaboration tool for Assessing Risk of Bias)	Schools	Single and multiple components	40 studies (self-report and objective PA) Australia (6) Austria (1) Belgium (3) Denmark (1) Germany (1) Greece (1) Hong Kong (2) USA (17) Netherlands (2) UK (2) Canada (2) France (1) Portugal (1) Finland (1) South Africa (1) Thailand (1) Note. 1 study was conducted in 4 countries (Austria, Belgium, Germany, Greece)	(i) N = 32,696 (ii) Age = NR (iii) Sex: mixed

Note. PA = physical activity; MVPA = moderate-to-vigorous physical activity; ST = screen-time; NR = not reported

Table A6.2: Outcomes from included meta-analyses

Review	Brief review objective	Outcomes
Borde et al (2017)[7]	Determine the impact of school-based interventions on objectively measured PA among adolescents	*Main analysis* (i) Objective total PA, SMD = 0.02, 95% CI [-0.13 to 0.18] (ii) Objective MVPA, SMD = 0.24, 95% CI [-0.08 to 0.56] *Sub-group analyses* (ii) Objective total PA (<13 years), SMD = 0.08, 95% CI [-.06 to 0.22] (iii) Objective total PA (≥13 years), SMD = -0.26, 95% CI [-0.50 to 0.02]
Chang et al (2019)[13]	Examine the effectiveness of interventions to increase PA in youth from low-income and ethnic minority families	*Main analysis* (i) Total PA (9-12 years), SMD = 0.54, 95% CI [0.13 to 0.97] (ii) Total PA (13-17 years), SMD = 0.02, 95% CI [-0.59 to 0.63] *Sub-group analyses* (iii) Duration (<13 weeks), SMD = 0.56, 95% CI [0.12 to 1.00] (iv) Duration (13 to 47 weeks), SMD = 0.18, 95% CI [-0.21 to 0.57] (v) Duration (>47 weeks), SMD = 0.31, 95% CI [-0.44 to 1.05] (vi) Teacher delivered, SMD = 0.18, 95% CI [-0.11 to 0.48] (vii) Specialist delivered, SMD = 0.68, 95% CI [0.25 to 1.11]
Champion et al (2019)[4]	Review the effectiveness of eHealth school-based interventions targeting multiple lifestyle risk behaviours	*Main analysis* (i) Objective PA, SMD = 0·33, 95% CI [0·05 to 0·61] (ii) Self-report PA, SMD = 0·14, 95% CI [0·05 to 0·23] (iii) Self-report ST, SMD = –0·09, 95% CI [–0·17 to –0·01] *Sub-group analyses* (iv) Boys' objective PA, SMD = 0.67, 95% CI [0.21 to 1.13] (v) Girls' objective PA, SMD = 0.14, 95% CI [-0.14 to 0.42] (vi) Self-report PA (≥13 years), SMD = 0.23, 95% CI [0.10 to 0.36] (vii) Self-report PA (<13 years), SMD = 0.03, 95% CI [-0.03 to 0.09]
Love et al (2019)[2]	Systematically review and meta-analyse data on the effectiveness of school-based interventions on accelerometer-assessed daily minutes of MVPA	*Main analysis* (i) Objective MVPA, SMD = 0.02, 95% CI [−0.07 to 0.11] *Sub-group analyses* (ii) Girls' objective MVPA, SMD = 0.07, 95% CI [−0.07 to 0.21] (iii) Boys' objective MVPA, SMD = 0.05, 95% CI [−0.09 to 0.19] (iv) Low SEP objective MVPA, SMD = -0.02, 95% CI [−0.16 to 0.12] (v) Middle SEP objective MVPA, SMD = -0.06, 95% CI [−0.17 to 0.05] (vi) High SEP objective MVPA, SMD = -0.01, 95% CI [−0.13 to 0.11]
McMichan et al (2018)[5]	Review classroom-based PA and SB interventions within early secondary/middle/ high school settings	*Main analysis* (i) Total PA, SMD = 0.05, 95% CI [-0.11 to 0.21] (ii) Total SB, SMD = -0.11, 95% CI [-0.25 to 0.04] *Sub-group analyses* NR
Metcalf et al (2012)[12]	Determine whether, and to what extent, PA interventions increase the overall activity of children	*Main analysis* (i) Total PA, SMD = 0.16, 95% CI [0.06 to 0.26] (ii) Objective MVPA, SMD = 0.16, 95% CI [0.06 to 0.26] *Sub-group analyses* No significant study level covariates
Owen et al (2017)[6]	Systematically review school-based PA interventions involving adolescent girls and quantify their effect through meta-analysis	Main analysis (i) Total PA, SMD = 0.07, 95% CI [−0.00 to 0.14] *Sub-group analyses* (ii) Single component interventions, SMD = 0.02, 95% CI [-0.09 to 0.14] (iii) Multi-component interventions, SMD = 0.09, 95% CI [0.01 to 0.18] (iv) Duration (≤6 months), SMD = 0.22, 95% CI [-0.06 to 0.50] (v) Duration (>6 months), SMD = 0.06, 95% CI [-0.02 to 0.14] (vi) Girls only interventions, SMD = 0.06, 95% CI [-0.02 to 0.13] (vii) Mixed sex interventions, SMD = 0.28, 95% CI [-0.05 to 0.61]
Pearson et al (2015)[10]	Quantify the effectiveness of interventions that aimed to increase PA among adolescent girls	*Main analysis* (i) Total PA, SMD 0.35, 95% CI [0.12-0.58] *Sub-group analyses* (ii) Objective PA, SMD = 0.29, 95% CI [-0.28 to 0.86] (iii) Self-report PA, SMD = 0.38, 95% CI [0.13 to 0.65] (iv) Educational interventions, SMD = 0.23, 95% CI [-0.01 to 0.50] (v) Environmental interventions, SMD = 0.37, 95% CI [-0.30 to 1.05] (vi) Multi-component interventions, SMD = 0.62, 95% CI [0.20 to 1.04] (vii) Theory-based interventions, SMD = 0.42, 95% CI [0.15 to 0.70] (viii) A-theoretical interventions, SMD = 0.18, 95% CI [-0.24 to 0.60] (ix) Girls only interventions, SMD = 0.44, 95% CI [0.16 to 0.72] (x) Mixed sex interventions, SMD = 0.24, 95% CI [0.08 to 0.55]

Plotnikoff et al (2015)[8]	Examine the effectiveness of interventions aimed at improving PA in university/college students	*Main analysis* (i) Total PA, SMD = −0.11, 95% CI [−0.30 to 0.08] (ii) Vigorous PA, SMD = 0.28, 95% CI [−0.08 to 0.63] (iii) Moderate PA, SMD = 0.18, 95% CI [0.06 to 0.30] *Sub-group analyses* NR
Ruotsalainen et al (2015)[11]	Examine the effects of PA interventions on subsequent PA for overweight and obese adolescents	*Main analyses* (i) PA promotion, SMD = 0.09, 95% CI [-0.06 to 0.25] *Sub-group analyses* (ii) Supervised exercise, SMD = -0.01, 95% CI [-0.42 to 0.45] (iii) Supervised exercise and PA promotion, SMD = 0.08, 95% CI [-0.14 to 0.30]
Shin et al (2019)[9]	Evaluate the effectiveness of mobile phone intervention in promoting a healthy lifestyle among adolescents	*Main analyses* (i) Total PA, SMD = 0.34, 95% CI [0.02 to 0.66] (ii) Total ST, SMD = -0.20, 95% CI [-0.32 to -0.8] *Sub-group analyses* (iii) Health app interventions for PA, SMD = 0.24, 95% CI [-0.07 to 0.54] (iv) Text message interventions for PA, SMD = 1.01, 95% CI [0.25 to 1.77] (v) Short-term interventions for PA, SMD = 0.67, 95% CI [0.16 to 1.19] (vi) Long-term interventions for PA, SMD = 0.03, 95% CI [-0.12 to 0.18] (vii) Multiple component interventions for PA, SMD = 0.27, 95% CI [-0.14 to 0.67] (viii) Single component interventions for PA, SMD = 0.46, 95% CI [0.06 to 0.86] (ix) Health app interventions for ST, SMD = -0.27, 95% CI [-0.41 to 0.12] (x) Text message interventions for ST, SMD = -0.04, 95% CI [-0.25 to 0.18] (xi) Short-term interventions for ST, SMD = -0.36, 95% CI [-0.96 to 0.24] (xii) Long-term interventions for ST, SMD = -0.19, 95% CI [-0.31 to 0.05] (xiii) Multiple component interventions for ST, SMD = -0.25, 95% CI [-0.48 to 0.02] (xiv) Single component interventions for ST, SMD = -0.06, 95% CI [-0.53 to 0.41]
Sims et al (2015)[1]	Examine PA intervention effects measured at least six months post-intervention	*Main analyses* (i) Total PA, SMD = -0.21, 95% CI [-1.12 to 0.71] *Sub-group analyses* NR for adolescents
Van de Kop et al (2019)[3]	Identify effectiveness of prevocational school-based PA interventions in adolescents	*Main analyses* (i) Total PA, SMD = 0.19, 95% CI [0.12 to 0.27] *Sub-group analyses* (ii) Intra-curricular PA interventions, SMD = 0.43, 95% CI [0.19 to 0.68] (iii) Intra-curricular with staff interventions, SMD = 0.37, 95% CI [0.16 to 0.58] (iv) Tailored intra-curricular interventions, SMD = 0.35, 95% CI [0.13 to 0.58] (v) Duration (6-8 weeks), SMD = 0.21, 95% CI [0.5 to 0.38] (vi) Duration (8-26 weeks), SMD = 0.26, 95% CI [0.11 to 0.41] (vii) Duration (>26 weeks), SMD = 0.15, 95% CI [NR]

Note. MVPA = moderate-to-vigorous physical activity; NR = not reported; PA = physical activity; SEP = socio-economic position; SB = sedentary behaviour; SMD = standardised mean difference; ST = screen-time, 95% CI = 95% confidence interval

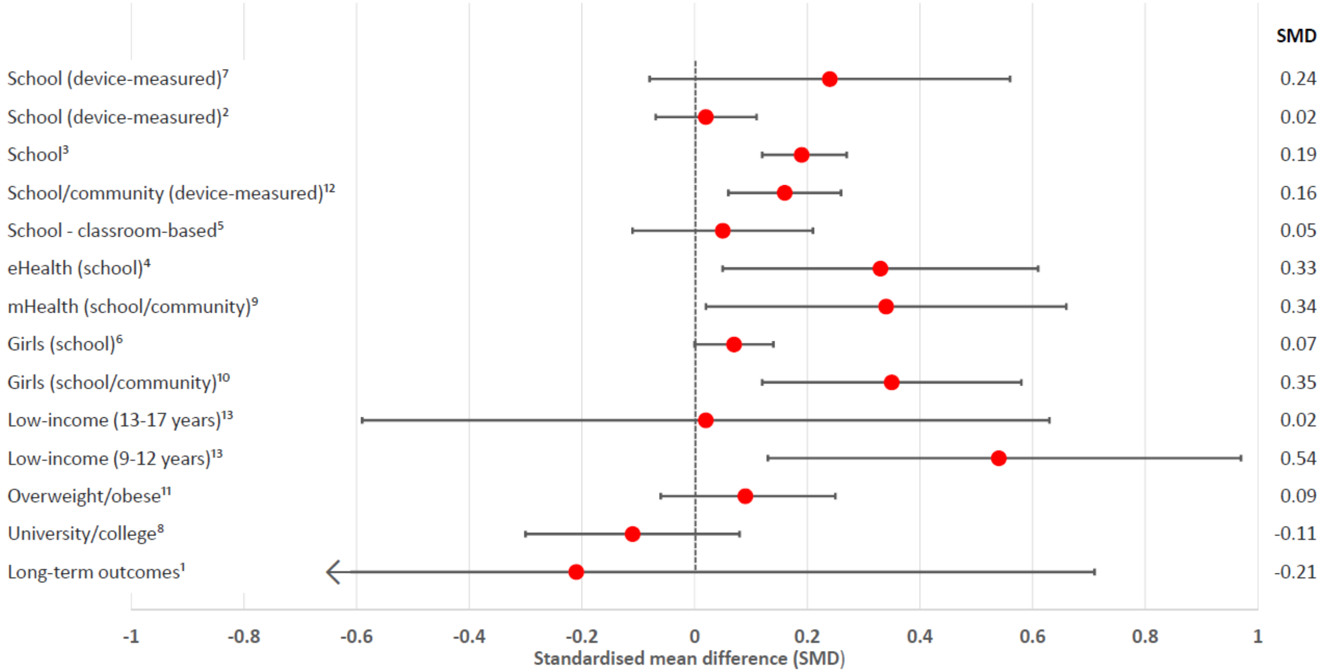

Figure A6.1: Mean effect size estimates from original systematic reviews

SYNTHESIS OF EVIDENCE

Types of reviews

- Seven reviews focused specifically on interventions delivered in school settings.[1-7]
- Only one review focused on physical activity interventions in universities/colleges.[8]
- Two reviews focused on eHealth interventions (one specifically school-based).[4 9]
- Two reviews focused on adolescent girls.[6 10]
- One review examining the effects of interventions conducted with overweight and obese adolescents.[11]
- One review of school- and community-based interventions that had used an objective measure of physical activity.[12]
- One review examining the sustained effects (i.e., >6 months from intervention) of adolescent physical activity interventions.[1]
- One review focused on interventions targeting adolescents from low-income and ethnic minority families.[13]

Overview of findings

Physical activity

- Effect sizes were generally small and non-significant, especially for studies that assessed physical activity using objective measures (e.g., accelerometers).
- The majority of interventions were evaluated in HICs, while fewer LMICs were included in the reviews.
- The majority of interventions targeted younger adolescent populations (i.e., 10 to 14 years) and were delivered in school-based settings. Multi-component school-based interventions (i.e., comprehensive school physical activity programs) appear to be more successful than single component interventions. Intra-curricular interventions (those delivered as part of the curricular) appear to have stronger effects than extra-curricular interventions.
- Few consistent moderators of intervention effects (i.e., similar effects for boys and girls, adolescents from different socio-economic backgrounds). However, short-term intervention effect sizes were larger than those observed over longer study durations.
- Evidence for the effectiveness of single sex versus mixed sex interventions was inclusive. Owen and colleagues found that school-based interventions targeting girls were less effective (SMD= 0.06), than mixed sex interventions (SMD = 0.28).[6] Alternatively, Pearson and colleagues found the opposite to be true (single sex, SMD = 0.44 versus mixed sex, SMD = 0.24).[10]
- Evidence from a small number of studies suggest that eHealth interventions can increase adolescents' activity levels in the short-term.

Sedentary behaviour

- Two reviews provided evidence for eHealth interventions reducing adolescents' screen-time.[4,9]

Policy-relevant messages

- There is a need to design, implement and disseminate comprehensive school physical activity programs in secondary schools.
- The inclusion of targeted intervention strategies within comprehensive school physical activity programs may help address the decline in physical activity that is typically larger in adolescent girls, compared to boys. For example, organising lunch-time sporting competitions and recreational physical activity (e.g., dance and fitness) for adolescent girls. Moreover, involving adolescents in the design and provision of activities is important and may enhance their autonomous motivation to be physically active within and beyond schools.
- Setting-based interventions should focus on increasing opportunities for adolescents to participate in physical activity by creating new opportunities (e.g., physical activity breaks in or between classes), maximising existing opportunities (e.g., increasing students' activity levels in PE) and extending existing opportunities (e.g., increasing the length of school breaks).[14]

- Older adolescents (15-19 years) are under-represented in physical activity intervention research. Physical education (and physical activity in general) is not typically mandated in senior school years. As students prepare for their final examinations, they need to be physically active.
- There is a need for physical activity interventions in post-school settings, such as universities, vocational training centres and workplaces. Such interventions may require similar strategies to those used to target adult behaviour in the workplace.
- Innovative and time efficient physical activity interventions are needed. For example, the 2018 Physical Activity Guidelines Advisory Committee Scientific Report highlighted the potential utility of high intensity interval training as a health promotion strategy. [15]
- Greater accountability for schools in regards to physical activity promotion. Based on findings from the recent Global Matrix 3.0 Physical Activity Report Card for Children and Youth, a few HICs are leading the way. For example, Slovenia who obtained the highest grade for overall physical activity, has a national school-based surveillance system that is focused on measuring children and adolescents' physical fitness. Japan also scored highly in the Global Matrix 3.0, with the best grades for Active Transportation (A−) and Physical Fitness (A). Japan has an established walking-to-school policy which has been successful at promoting active transportation among children and youth. It is unclear if such strategies will be effective in increasing adolescents' physical activity levels. However, there is a clear need for schools to implement policies and interventions effectively.
- Schools require on-going support (and funding) to effectively implement interventions. Previous research has identified 'voltage drop' as interventions progress from efficacy to effectiveness to dissemination.[16 17] Focusing implementation strategies may help to maximise intervention potency.

CONCLUSION

Interventions designed to increase physical activity and/or reduce sedentary behaviour in adolescent populations have been largely unsuccessful. There is some evidence suggesting that multi-component school-based physical activity interventions can reduce the decline in activity that is typically observed during adolescence. The majority of interventions have targeted younger adolescents (i.e., 10 to 14 years) in HICs, while little is known regarding the efficacy of interventions in LMICs. There is a need for interventions in the senior school years and post-school settings, such as universities, vocational training centres and workplaces, as older adolescents (15-19 years) and young adults (20-24 years) are under-represented in physical activity behaviour intervention research.

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