Age-related change and context of sedentary and screen behaviour in young people

Elli Kontostoli

Doctor of Philosophy

University of East Anglia, UK

School of Health Sciences

March 2022

Abstract

Evidence shows that sedentary and screen behaviour may be associated with physical and mental health. Further evidence suggests that time spent in sedentary and screen behaviours increases from childhood to adolescence. Health behaviours in childhood and adolescence may persist into adulthood; therefore, there is a need to further our understanding of the factors that influence sedentary and screen behaviour and the social contexts in which the behaviours occur. This information is required to support planning for effective interventions to reduce excessive screen time and associated adverse health outcomes. This thesis presents four linked studies that examine age-related change and context of sedentary and screen behaviours, and associations with health behaviours. Chapter 2 is a systematic review and meta-analysis which describes age-related changes in sedentary and screen behaviour during childhood and adolescence and examines whether the magnitude of change varies across social or demographic population groups. Using data from the Study of Cognition, Adolescents and Mobile Phones cohort, Chapter 3 describes changes in time spent in contemporary screen-based behaviours and examines socio-demographic differences in these changes over approximately 2 years in adolescents aged 11 – 15 years. Chapter 4 describes diurnal patterns in adolescents' screen-based behaviours and examines their association with social context on weekdays and weekend days. Chapter 5 examines the association of diary-assessed screen behaviours with physical activity, sedentary behaviour and sleep in adolescents, and explores whether associations vary by sex. Findings suggest sedentary and screen behaviour increase as children and adolescents age, suggesting that interventions may be appropriate to limit these behaviours. However, there is a change in device use as adolescents age and the distribution of time differs across the day, and with particular members of the social context, depending on the behaviour of interest. Screen behaviours may displace time spent in physical activity, sedentary behaviour and sleep, suggesting that targeted strategies to reduce time spent in specific screen-behaviours may be valuable as part of a package of measures to promote physical activity in adolescents.

Contents

Tables

Figures

Acknowledgements

I would first like to thank my supervisors, Dr Andrew Atkin and Prof Andy Jones, for your guidance, support and patience over the past four years. Your insightful feedback has sharpened my thinking over and beyond this research. I have been fortunate to have worked with you. Thank you.

I would also like to thank Dr Natalie Pearson, Dr Louise Foley and Prof Stuart Biddle for the wonderful collaboration. You have been swift to your responses, insightful, supportive and treated me with kindness.

I would like to take this opportunity to thank Prof Afroditi Stathi, whose contribution has been invaluable and undeniable before and during my postgraduate studies. Further, I thank Dr Athanasios Gregoriades, my undergraduate supervisor, for his encouragement and belief in me from the very beginning.

Thanks also to the ladies in room 1.27 who I shared office with. Your support and conversations were always appreciated.

Special thanks to my friends for being a phone call away the past four years. Your understanding, love and humour helped me to complete this work.

Lastly, I would like to thank my family, mum and dad for their unconditional love and support, Stella and the little ones for brightening up some difficult moments.

Publications and statement of authorship

Publications arising from the thesis

Kontostoli, E, Jones, AP, Pearson, N, Foley, L, Biddle, SJH, Atkin, AJ. Age-related change in sedentary behavior during childhood and adolescence: A systematic review and meta-analysis. *Obesity Reviews*. 2021; 22:e13263. https://doi.org/10.1111/obr.13263

This publication can be found at: https://onlinelibrary.wiley.com/doi/10.1111/obr.13263

Kontostoli, E, Jones, AP, Pearson, N, Foley, L, Biddle, SJH, Atkin, AJ. The association of contemporary screen-behaviours with physical activity, sedentary behaviour and sleep in adolescents: a cross-sectional analysis of the Millennium Cohort Study. *International Journal of Behavioral Medicine.* (2022). https://doi.org/10.1007/s12529-022-10077-7

This publication can be found at: https://link.springer.com/article/10.1007/s12529-022-10077-7

Papers under review

Kontostoli, E, Jones, AP, Atkin, AJ. The diurnal pattern and social context of screen behaviours in adolescents: a cross-sectional analysis of the Millennium Cohort Study. BMC Public Health, in review

Statement of jointly authored publications

This piece of research is my own original work. For this work I collaborated with others as follows:

Chapter 1: Written by Elli Kontostoli. Reviewed by Andrew Atkin and Andy Jones.

Chapter 2: Elli Kontostoli was the lead author of a systematic review and meta-analysis published as:

Kontostoli, E, Jones, AP, Pearson, N, Foley, L, Biddle, SJH, Atkin, AJ. Age-related change in sedentary behavior during childhood and adolescence: A systematic review and meta-analysis. *Obesity Reviews*. 2021; 22:e13263. https://doi.org/10.1111/obr.13263

Elli Kontostoli, Andy Jones, Andrew Atkin, Natalie Pearson, Louise Foley and Stuart Biddle designed the protocol and the search strategy which was executed by Elli Kontostoli. Elli Kontostoli screened the records, extracted, and analysed the data from the primary studies. Elli Kontostoli drafted the original manuscript which was critically reviewed by Andy Jones, Andrew Atkin, Natalie Pearson, Louise Foley and Stuart Biddle.

Chapter 3: Elli Kontostoli was the lead author of a longitudinal analysis which will be submitted as:

Kontostoli, E, Jones, AP, Biddle, SJH, Dumontheil, I, Elliott, P, Foley, L, Pearson, L, Röösli, Shen, MC, Thomas, MCS, Toledano, MB, Atkin, AJ. Changes in adolescents' screen-based behaviour over 2-years: Longitudinal results from the Study of Cognition, Adolescents and Mobile Phones.

Elli Kontostoli, Andy Jones, Andrew Atkin, Natalie Pearson, Louise Foley and Stuart Biddle designed the study. Elli Kontostoli conducted the analysis and drafted the original manuscript, which was critically reviewed by Andy Jones, Andrew Atkin, Natalie Pearson, Louise Foley, Stuart Biddle.

Chapter 4: Elli Kontostoli was the lead author of a cross-sectional analysis which is under review as:

Kontostoli, E, Jones, AP, Atkin, AJ. The diurnal pattern and social context of screen behaviours in adolescents: a cross-sectional analysis of the Millennium Cohort Study. BMC Public Health, in review

Elli Kontostoli, Andy Jones and Andrew Atkin designed the study. Elli Kontostoli conducted the analysis and drafted a manuscript which was critically reviewed by Andy Jones and Andrew Atkin.

Chapter 5: Elli Kontostoli was the lead author of a cross-sectional analysis published as:

Kontostoli, E, Jones, AP, Pearson, N, Foley, L, Biddle, SJH, Atkin, AJ. The association of contemporary screen-behaviours with physical activity, sedentary behaviour and sleep in adolescents: a cross-sectional analysis of the Millennium Cohort Study. *International Journal of Behavioral Medicine.* (2022). https://doi.org/10.1007/s12529-022-10077-7

Elli Kontostoli, Andy Jones, Andrew Atkin, Natalie Pearson, Louise Foley and Stuart Biddle designed the study. Elli Kontostoli conducted the analysis and drafted the manuscript which was critically reviewed by Andy Jones, Andrew Atkin, Natalie Pearson, Louise Foley and Stuart Biddle.

Chapter 6: Written by Elli Kontostoli. Reviewed by Andrew Atkin and Andy Jones.

Chapter 1: General Introduction

From a movement perspective, the entirety of daily time-use over a 24-hour period is made up of a combination of sedentary behaviours, physical activity, and sleep. In terms of the amount of movement that are associated with them, these lie on a continuum from almost no movement, for example during sleep, to high movement during vigorous physical activity. High levels of sitting, which may coexist alongside poor adherence to physical activity and sleep, is prevalent in most of the population (Carson *et al.*, 2016). This is of public health importance as a substantial body of evidence links high levels of sedentary behaviour, defined as waking activities characterized by an energy expenditure of ≤1.5 metabolic equivalents (Tremblay *et al.*, 2017), with increased risk of chronic diseases and mortality in adulthood (Biswas *et al.*, 2015).

To gain optimal health, public health recommendations suggest that there should be a balance of physical activity, sleep, sedentary and screen behaviour within a 24-hour period across the life span (Tremblay *et al.*, 2016). The evidence linking device-assessed sedentary behaviour and health appears weaker than the self-reported evidence, and inconsistent to TV viewing. Though there remain important inconsistencies and limitations of the existing research and high quality longitudinal and experimental research is required to understand the links between sedentary behaviour and health in children and adolescents. Yet, children and adolescents spend large amounts of their daily time in sedentary activities, in particular screen time (Arundell *et al.*, 2019; Pearson, Sherar and Hamer, 2019). Evidence shows tracking of sedentary behaviour from early childhood to middle childhood and adolescence (Biddle *et al.*, 2010; Pearson *et al.*, 2017). This is of concern to public health as sedentary behaviour is associated with physical and mental health, independently of level of physical activity (Carson *et al.*, 2016). Carson and colleagues found that few high-quality experimental studies were identified, and most studies were cross-sectional. Furthermore, most studies included self-report or proxy-report measures of sedentary behaviour, which are prone to biases. Finally, a large number of studies focused on TV viewing and did not consider other types of sedentary behaviour, such as non-screen-based measures. The findings from Carson and colleagues, based on very low to moderate quality evidence indicate that different types of sedentary behaviour may have different impacts on different indicators of health. This thesis presents research informed by the Behavioural Epidemiology Framework to gain an understanding of the factors that influence sedentary and screen behaviour in young people (Sallis, Owen and Fotheringham, 2000).

The Behavioural Epidemiology Framework illustrates the spectrum of research needs related to behaviour and health. It proposes six phases of research on sedentary behaviour and their inter-

relationships. The six phases are presented in Figure 1. Research in phases 1 through 5 may be thought of as a logical sequence of evidence; however, all these phases can inform and influence each other. For example, understanding the important influences on specific sedentary and screen behaviours (phase 3) associated with adverse health outcomes (phase 1) will assist interventions to best target such influences (phase 4). As the policy and guidelines on sedentary behaviour are formed (phase 5), research on determinants and/or correlates may require a different focus, and new methods for measuring sedentary behaviour may be proposed (phase 2) and interventions may accommodate the new directions (phase 4). Research presented in this thesis focuses on describing variations in sedentary and screen behaviour in children and adolescents and understanding the factors that influence sedentary and screen behaviour (phase 3) to strengthen the knowledge base underlying interventions. Whilst research presented in this thesis does not directly address phases 2 and 4, this thesis discusses their relevance. This thesis introduces the evidence on the relationships of sedentary behaviour and health (phase 1) and presents the current guidelines in sedentary behaviour (phase 5) in sections 1.3. and 1.4. respectively.

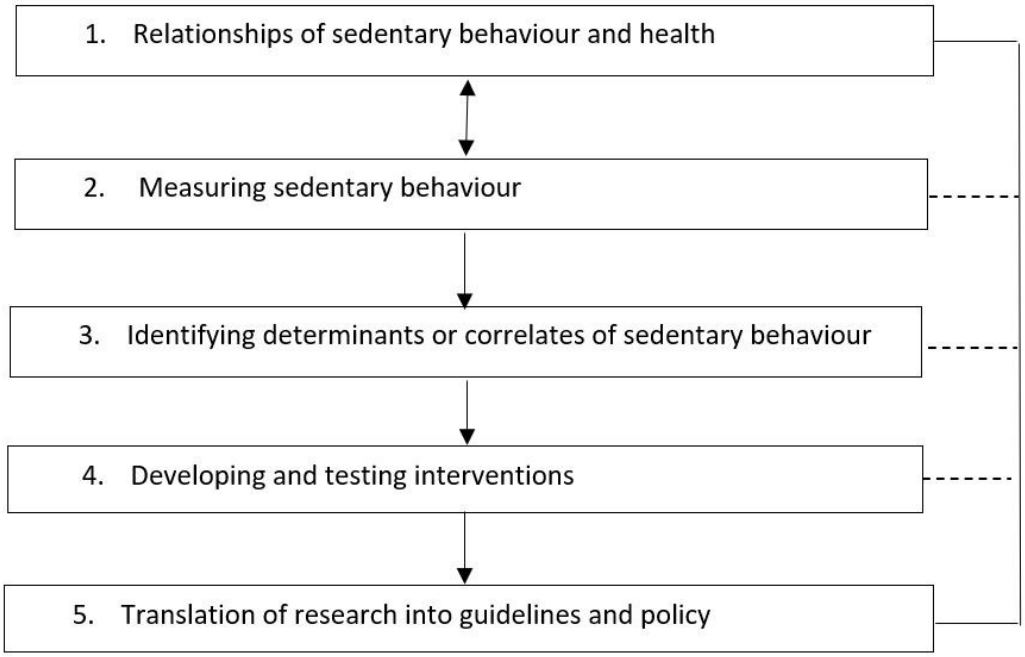


Figure 1 The Behavioural Epidemiology Framework as applied to sedentary behaviour

To guide our understanding of the correlates of sedentary behaviour, the research presented in this thesis draws upon the ecological model (Sallis, Owen and Fisher, 2008). The principal purpose of the ecological model is to illustrate the myriad factors that can influence phenomenon

researchers are interested in. Ecological models can also be used to explore and address health behaviours, such as physical activity, sedentary behaviour, healthy eating etc. The model captures the wide range of factors that may influence behaviour, as shown in Figure 2. For example, sitting may be unavoidable if the social and built environment encourages sitting activities. Therefore, if behaviour change interventions aim to limit sedentary behaviour for individuals, then they should consider whether there is a sufficient amount of support among the social, built and policy environments. For example, interventions should consider including places that encourage activities such as walking by providing walkable destinations rather than motorised vehicle use. Further considerations may include people to be active with, and policies to promote active lifestyles such as walking and cycling to work or limiting screen time in the evening. The application of an ecological model to sedentary behaviour may thus assist guiding future research and identifying intervention targets. This thesis accounts for individual-level factors (i.e., sex, socio-economic position, body weight or BMI and ethnicity) and social environments (i.e., social context) in which behaviour occurs. In doing so it aims to contribute to the knowledge required to achieve changes that are of public health significance. Finally, factors are discussed that include whether sedentary and screen behaviour is associated and coexists with other health behaviours.

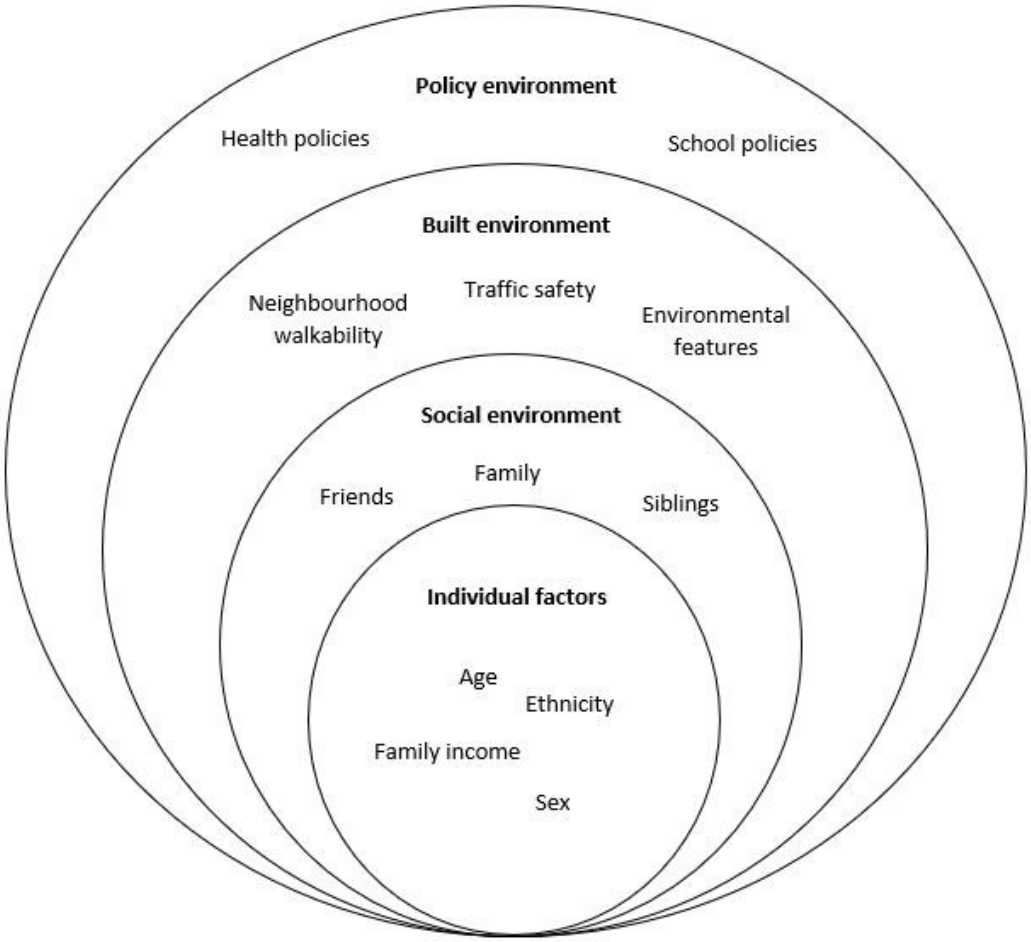


Figure 2 A simplified ecological model of sedentary behaviour

1.1. Definition of sedentary behaviour

The term sedentary behaviour refers to any waking activity characterized by an energy expenditure ≤1.5 metabolic equivalents (METS) while in a sitting or reclining posture (Tremblay *et al.*, 2017). It can take place in various settings, such as in school or the workplace, at home and during transit/transport (i.e., passive modes of travelling). Screen time is a common type of sedentary behaviour. Screen behaviours include television viewing, playing video games and using a computer.

1.2. Evolution of sedentary behaviour and health research

The life of our early ancestors during the Palaeolithic Era was characterised by a highly physically active lifestyle based on hunting and gathering, and a predominantly mobile lifestyle until animal

domestication and advancements in agriculture changed human lifestyles (Katzmarzyk and Mason, 2009). The Industrial Revolution (1820-1840) saw technological development that substantially changed the environment and the lives of people. The Industrial Revolution fundamentally led to an increasingly physically passive lifestyle and introduced sedentary behaviour to all domains of life, leading to a shift in the human energy balance (Panahi and Tremblay, 2018). Changes in the built environment altered workplace settings, and passive modes of transportation contribute to a predominantly sedentary lifestyle (Lieberman, 2007). This is a problem given that human body is designed to be physically active, and it is not designed to sit, at least for extended periods of time.

A landmark study published nearly 70 years ago was the first to indicate that extended periods of sitting may be detrimental to health. Morris and colleagues showed that men in physically active occupations (i.e., bus conductors, mail postmen) were less likely to experience cardiovascular events than those in sedentary occupations (i.e., bus drivers, mail clerks) (Morris *et al.*, 1953). This research gave insight into the relationship between levels of physical activity and heart disease and focused, albeit unintentionally, on the consequences of occupational sitting. In the physical activity literature that followed, researchers have often used the term 'sedentary' to characterise people who were not meeting the recommended levels of physical activity, often termed 'physically inactive', yet without having formally assessed their amount of sedentary behaviour (Paffenbarger *et al.*, 1986; Lowry *et al.*, 2012). This is of concern given that a growing body of evidence has shown that the association between sedentary behaviour and moderate-to-vigorous physical activity is low and that an individual can accumulate substantial amounts of both sedentary behaviour and moderate-to-vigorous physical activity during the day (Healy *et al.*, 2008; Owen *et al.*, 2010). Additionally, studies of time spent in sedentary behaviours show correlates that are distinct from those related to moderate-to-vigorous physical activity (Leatherdale and Wong, 2008). Therefore, too much sitting and too little physical activity represent distinct concepts.

1.3. Sedentary behaviour and health

Numerous cross-sectional and prospective studies have examined the potential obesogenic effect of prolonged sedentary behaviour in children and adolescents, with television viewing being the focus of most of the studies. Findings from cross-sectional studies suggest a positive association between sedentary behaviour and adiposity in children and adolescents. Systematic reviews suggest a positive association between device-measured and self-reported sedentary behaviour, mainly television viewing, and adiposity (Tremblay *et al.*, 2011; Cliff *et al.*, 2016; Zhang *et al.*, 2016). Further, stratified analysis by sex has shown a positive association between television

viewing and adiposity in both boys and girls (Zhang *et al.*, 2016). Review evidence on sedentary behaviours other than television viewing also suggests a positive association between playing video games and adiposity, internet use and Body Mass Index (BMI) but no association between computer use, mobile phones and weight status in adolescents (Prentice-Dunn and Prentice-Dunn, 2012). Conversely, there is limited prospective evidence for a relationship between sedentary time, or changes in sedentary time, with changes in adiposity in young people. A recent meta-analysis showed no association between television viewing, computer use and adiposity (van Ekris *et al.*, 2017). Additionally, review evidence on device-assessed sedentary time showed no association with change in adiposity although one study showed a relationship of increased sedentary time to increased BMI between the ages 9 and 15 years, independent of moderate-to-vigorous physical activity and in girls than in boys (Basterfield *et al.*, 2012; Mitchell *et al.*, 2012; Pate *et al.*, 2013; Tanaka, Reilly and Huang, 2014; van Ekris *et al.*, 2017). There remain important inconsistencies and limitations of the existing research (Biddle, García Bengoechea and Wiesner, 2017; van Ekris *et al.*, 2017; Hashem *et al.*, 2019; Skrede *et al.*, 2019) and further high quality longitudinal and experimental research is required to better understand the links between sedentary behaviour and health in this population.

Since studies with mortality or cardiovascular endpoints cannot typically be carried out in children, the literature is only concerned with cardiovascular markers (i.e., body fatness, blood pressure, fasting triglycerides, high-density lipoprotein (HDL) cholesterol, glucose, and insulin levels) in youth. Cross-sectional studies have shown that television viewing is associated with adverse levels of a range of cardio-vascular risk factors including fasting triglycerides (Ekelund *et al.*, 2006; Martinez-Gomez *et al.*, 2012; Hardy *et al.*, 2014). A pooled analysis of the International Children's Accelerometery Database (ICAD) and analysis of The Avon Longitudinal Study of Parents and Children (ALSPAC) cohort found that device-assessed sedentary time was not associated with any of the examined outcomes, but moderate-to-vigorous physical activity was inversely associated with cardiovascular markers such as body fat, insulin, and cholesterol independently of sedentary time (Ekelund *et al.*, 2012; Stamatakis *et al.*, 2015).

Regarding mental health, the literature suggests an inverse relationship between self-esteem, pro-social behaviour and sedentary behaviour. A review of cross-sectional studies showed that those who watched less television were more emotionally stable, sensitive, imaginative, outgoing, self-controlled, and less likely to be aggressive or to engage in risky behaviour (Tremblay *et al.*, 2011). Sex differences have also been observed; increased television viewing was associated with increased aggression in girls but not boys (Dominick, 1984) whereas increased computer use was associated with behavioural problems in boys but not girls (Sakamoto, 1994; Leatherdale and

Wong, 2008). Recent review evidence on cross-sectional and longitudinal studies indicates strong evidence for a positive relationship between depressive symptoms (i.e., mental disorders and associated symptomatology) and leisure screen time among adolescents (Hoare *et al.*, 2016). There was also some evidence to suggest that low levels of leisure screen time were associated with lower levels of depressed mood, although adverse findings only appeared at more than 2 – 3 hours per day of average of screen time. The authors suggest that few studies examined loneliness, stress, mental well-being, and sadness and considering the pervasive use of new screen technologies this warrants further research.

1.4. Public health guidelines

In light of the evidence that sedentary behaviour is adversely associated with physical and mental health, several countries have provided recommendations on sedentary behaviour for health by incorporating them into their guidelines for physical activity. Recommendations suggest that children and adolescents should limit the amount of time spent being sedentary (UK, Department of Health and Care, 2019; Bull *et al.*, 2020), particularly the amount of recreational screen time, and when physically possible should break up long periods of not moving with at least light physical activity. Australia and Canada provide specific recommendations on sedentary behaviour by quantifying time limits for screen use (Tremblay *et al.*, 2016; Australia, Department of Health, 2021). The recommendations suggest that recreational screen time in children and adolescents should be no more than 2 hours a day.

In addition to the behaviour-specific guidance, Australia and Canada have produced 24-hour movement guidelines for children and adolescents. These acknowledge that all children and young people should get the right mix of physical activity, sedentary behaviour, and sleep in a 24-hour period to support their healthy development. For optimal health benefits, it is suggested that children and young people should get uninterrupted 8 – 11 hours of sleep per night, limit sedentary behaviours with no more than 2 hours of screen time, accumulate of at least 60 minutes per day of moderate to vigorous physical activity and several hours of light physical activity in a variety of environments and contexts. These are the first guidelines to highlight the importance of environmental and social factors which influence time spent in sedentary behaviour, physical activity, and sleep.

Despite the public health guidelines, just 9.7% of British adolescents meet recommendations for sleep, screen time and moderate-to-vigorous physical activity (Pearson, Sherar and Hamer, 2019). This value is higher than that reported for Australian (2%) and American (5%) adolescents (Knell *et al.*, 2019; Scully *et al.*, 2022). As per screen recommendations only, an observational study

shows that 23% of British adolescents meet the screen time guideline (Pearson, Sherar and Hamer, 2019).

1.5. Prevalence of sedentary behaviour

In public health surveillance and epidemiological studies, sedentary behaviours are typically measured using self- or proxy-reported questionnaires or body-worn devices (e.g., accelerometers). It is of interest, therefore, to examine both methods of measurement when exploring sedentary behaviour.

Regarding self- or proxy-reported methods, a recent scoping review of global surveillance data showed that children and adolescents spend approximately 2 hours a day in viewing television, 1.4 hours a day in computer use and 2.4 hours a day using video game consoles (Thomas *et al.*, 2019). Further, time spent in these screen behaviours appear to vary by sex. Boys and girls spent similar amounts of time viewing television; however, boys spent more time using the computer (3.4 hours a day) and video game consoles (2.1 hours a day) compared to girls (2.7 hours and 0.6 hours a day respectively). In addition, girls spend more time using their mobile phone (3.1 hours a day) compared to boys (2.2 hours a day). Narrative review-level data show that time spent in given screen behaviours may also vary by ethnicity and socioeconomic position (Pate *et al.*, 2011). Young people coming from non-White ethnicity and a low socioeconomic background may spend more time in screen-based sedentary behaviour. As per non-screen-based activities, few studies have examined the amount of time spent in non-screen based sedentary behaviours (Olds *et al.*, 2010; Klitsie *et al.*, 2013). In New Zealand, for example, children and adolescents were found to spend 5.7 hours a day (345 minutes) in non-screen based sedentary time (i.e., reading, sitting for socialising, travelling by car/bus) (Olds *et al.*, 2010).

Self-reported measurements in sedentary behaviour (i.e., questionnaires) have focused on TV viewing or other screen-based behaviours. Typically, such measures demonstrate moderate reliability but slight to moderate validity (Atkin *et al.,* 2013). Assessment of sedentary behaviour by self-reports is limited by, among other things, the ubiquitous nature of these behaviours, which may be unremarkable, intermittent, and incidental and therefore difficult to recall. Further, assessment of sedentary behaviour becomes even more perplexed given the rapid changes in the screen media environment which necessitates the development of reliable and valid measurement methods.

In terms of device-assessed sedentary time, a review showed that of all the cohorts included in, the US National Health and Nutrition Examination Survey which is the largest, reported that young people aged 6–11, 12–15 and 16–19 years recorded mean sedentary time (hours per day) 6.1, 7.5

and 8.0 in 2003-2004, respectively (Pate *et al.*, 2011). In the same review, boys and girls in the age of 10 years old in the UK spent 7.5 and 7.7 hours per day, respectively, in sedentary behaviour. Device measured sedentary time appears higher in girls than in boys (Matthews *et al.*, 2008; Colley *et al.*, 2011; Cooper *et al.*, 2015). For example, in Canada, boys accumulated an average of 507 minutes per day in sedentary behaviour, whereas girls accumulated 524 minutes per day (Colley *et al.*, 2011). Modest differences by ethnicity are also apparent, but they may vary by age and sex. For example, mean sedentary time was greater (8.3 hours a day) in 16–19 years old boys of Black ethnicity compared with their peers of Mexican American ethnicity (7.4 hours a day) (Whitt-Glover *et al.*, 2009). Conversely, it was lower in 6 –11 years old girls of Black ethnicity compared with same-aged girls of White or Mexican American ethnicity (Matthews *et al.*, 2008). The evidence is mixed on the amounts of time spent in sedentary time by socioeconomic position and BMI (Pate *et al.*, 2011).

It is evident that device-assessed and self- or proxy-reported sedentary time may increase with age, with older children spending more time in screen and non-screen behaviours than their younger counterparts. In the Gateshead Millennium cohort in the UK, median daily accelerometer-assessed sedentary time increased from approximately half of waking hours at age 7 years to three quarters of waking hours at age 15 years, with the steepest increase occurring between the ages of 9 and 12 years (Janssen *et al.*, 2016). In accordance with this literature, a systematic review of longitudinal studies reported an increase of 10–20 min/day/year in device-measured sedentary time and screen-based sedentary behaviour during the transition from primary to secondary education (Pearson *et al.*, 2017). However, there was no published systematic review to quantify the change in sedentary behaviour during childhood and adolescence. This is addressed and presented in **Chapter 2: Age-related change in sedentary behaviour during childhood and adolescence: a systematic review and meta-analysis**. The review presented in this chapter provides an understanding of the timing of changes and demographic variation in sedentary behaviour change to help with the targeting of behaviour change interventions.

1.6. Influences on sedentary behaviour

As mentioned earlier, factors at the individual level of the ecological model are one component within the multiple levels that influence sedentary behaviour. Strategies to reduce sedentary behaviour aimed at highlighting the influences on behaviour at multiple levels are likely to be an effective public health approach.

1.6.1. Individual level influences

Non-modifiable factors highlight groups that can be targeted in intervention designs. Age has been the most consistent determinant (Stierlin *et al.*, 2015), with increasing age being associated with greater sedentary behaviour prevalence, including screen time (Arundell *et al.*, 2016b). Evidence concerning associations between sex and sedentary and screen behaviour appears to vary by measurement methods. As noted earlier, there is a consistent association between sex and device-assessed sedentary behaviour; however, no evidence has been reported for an association between sex and self- or proxy-reported screen time (Arundell *et al.*, 2016b).

Although sedentary behaviour varies by socioeconomic status (Hoyos Cillero and Jago, 2010; Pate *et al.*, 2011; Downing, Hnatiuk and Hesketh, 2015), this relationship is not consistent across all behaviours. For example, lower socioeconomic status is associated with more hours of television viewing (Hoyos Cillero and Jago, 2010) but not with time spent in computer and video game play (Olds, Ridley and Dollman, 2006) or recreational computer use (Babey, Hastert and Wolstein, 2013). However, the inverse has been reported in a UK study. Young people coming from families with a higher socioeconomic position showed greater increases in accelerometer-measured sedentary time during after-school hours and on weekend days (Atkin *et al.*, 2013). It is important to note that socioeconomic position can be captured in lots of different ways, including income, parent education, and this at least partially accounts for different findings between studies. Finally, there is limited evidence on ethnicity as a correlate of sedentary behaviour (Pate *et al.*, 2011).

Our understanding of the correlates of sedentary behaviour is typically limited to traditional forms of screen use, such as television viewing, across studies due to a failure to consider new screen devices, which are popular among adolescents. The proliferation of screen devices, including smartphones and tablets, has led to concerns that the current generations of young people, and adolescents in particular, spend a large proportion of their awake time in sedentary behaviour. Using a large and ethnically diverse sample of adolescents in the UK, this is addressed in **Chapter 3: Changes in adolescents' screen-based behaviour over 2-years: Longitudinal results from the Study of Cognition, Adolescents and Mobile Phones.**

1.6.2. Social context influences and the diurnal patterning

As noted in the introduction to this chapter, sedentary behaviour is likely influenced by factors across all levels of the ecological model. The social environment is one of the many levels that can influence sedentary behaviour. The home and school environment are important settings in which young people spend most of their time. For example, at home, systematic reviews have reported

an inverse relationship between parental rules around screen use and sedentary behaviour in children and early adolescents (Hoyos Cillero and Jago, 2010; Verloigne *et al.*, 2012; Maitland *et al.*, 2013). Both settings have been extensively examined in the literature. Further, the persons with whom young people spend time are important but less frequently studied in the literature. Children who participated in sedentary behaviour with their parents spent more time in sedentary behaviour compared to those who did not spend time with their parents (Maitland *et al.*, 2013). The majority of after-school and weekday evening time was spent with family or siblings, with less than 1% spent with friends. Similarly, friends and peers may also influence health behaviours, particularly as young people get older (Sawka *et al.*, 2013). A recent meta-synthesis of qualitative studies reported that the absence of peer social support networks promoted screen time (Minges *et al.*, 2015). The evidence suggests that although a variety of social correlates (parental rules, screen limits) have been examined, specific social contexts (i.e., family members, friends) have been too rarely studied for conclusions to be drawn. Moreover, screen time is commonly derived as a composite measure rather than by specific activity, potentially masking true variation, and making it difficult to draw clear conclusions about specific behaviours occurring at specific contexts. There is a need to better understand the social contexts in which screen behaviours take place if interventions to address them are to be targeted precisely.

In addition to understanding the social context of screen-based activity, understanding its distribution across the day may also be informative for intervention design, highlighting periods of the day when specific behaviours are likely to occur. Previous research has shown that accelerometer measured time spent sedentary was greater after-school than before or during school (McLellan *et al.*, 2019). Evidence also suggests that the afternoon and evening period during weekends represents the largest accumulation of sedentary time (McLellan *et al.*, 2019). In a study of temporal patterning of sedentary behaviour across weekdays and weekend days in adolescents, Biddle and colleagues reported that television viewing was most likely to occur in the middle to late evening (Biddle *et al.*, 2009). There are two potential limitations in the evidence. Firstly, accelerometer data do not provide information on the type of the behaviour being undertaken making it difficult to draw clear conclusions about specific behaviours occurring at specific time points. Secondly, as noted earlier, the rapid changes in the screen media environment necessitate evidence on diurnal patterns of new screen behaviours. Therefore, there is limited evidence examining whole-day contemporary screen behaviour patterns.

From the perspective of intervention design, knowledge of diurnal pattern and time-specific associations with social factors can be used to determine the most appropriate times to intervene and point toward potential intervention strategies. This issue is addressed and presented in

Chapter 4: The diurnal pattern and social context of screen behaviours in adolescents: a cross-sectional analysis of the Millennium Cohort Study.

1.7. Inter-relations between health behaviours

Although not typically included within conceptualisations of the ecological model, it is likely that health behaviours interact and influence each other. Recently, there has been increased interest in how the various movement-related behaviours (i.e., sleep, sedentary behaviour, and physical activity of all intensities) that make up the whole day interact to influence health (Tremblay *et al.*, 2016). Sedentary behaviour is therefore best seen as part of a continuum of 'movement' behaviours. The displacement hypothesis asserts that if a person is undertaking one behaviour (e.g., sedentary behaviour), then they cannot be doing another (e.g., physical activity) (Mutz, Roberts and Vuuren, 1993). A meta-analysis showed that sedentary behaviours are inversely associated with physical activity, but associations were small (Pearson, Braithwaite, S. J H Biddle, *et al.*, 2014). This was somewhat dependent on the measurement method and study quality, but this association may also be relevant on the screen activity of interest. Since the amount of time in a day is fixed at 24 hours then increased time spent sedentary must inevitably displace time spent in physical activity or time spent asleep. This is not always reflected in the evidence due to error in the measurement methods. Sedentary behaviour measurement methods fail to capture every single behaviour. There is a disconnection between the displacement theory and what can be measured in devices. Most recent data show that smartphone and tablet use may be negatively associated with self-reported PA, though the strength of this association may vary with age and sex (Kenney and Gortmaker, 2017; Raustorp *et al.*, 2019). For example, an inverse association between mean steps per day and smartphone and tablet use was found among 14 years old girls but not in boys. Similarly, previous studies have found that screen time (mainly television-viewing and video games) (Espinoza and Juvonen, 2011; Foley *et al.*, 2013) and engagement in social media use (social networking or messaging sites or Apps on the internet) (Scott, Biello and Woods, 2019) are associated with late sleep onset. Nevertheless, there remains limited evidence of how contemporary screen behaviours (such as time spent in social networking sites and email/texts) may associate with overall sedentary time, or on time spent active or sleeping. A clearer understanding of how these behaviours interact may help to inform the content of behaviour change interventions. This is addressed and presented in **Chapter 5: The associations of contemporary screen-behaviours with physical activity, sedentary behaviour and sleep in adolescents: a cross-sectional analysis of the Millennium Cohort Study.**

1.8. Thesis methods and structure

This thesis consists of four interlinked studies, asking different research questions, using varied methods and reported in separate chapters. In combination, the learning from each study complements each other and builds evidence to improve understanding of age-related change and context of screen and sedentary behaviour in young people. They have either been published or are under review at the time of completion of this thesis as outlined in the publications and statement of authorship section. The method for each study is separately explained within each chapter.

Chapter 2: This study quantifies age-related change in sedentary behaviour during childhood and adolescence. The primary aim of this review and meta-analysis was to synthesise existing evidence on age-related changes in sedentary and screen behaviour during childhood and adolescence. A secondary aim was to examine whether the magnitude of change varied across social or demographic population groups.

Chapter 3: Findings from chapter 2 indicated that further research is needed to better understand how the duration of time spent in newer screen-based behaviours changes over time. The aim of this study was to describe changes in time spent in screen-based behaviours (including portable and non-portable devices) and examine socio-demographic differences in these changes over approximately 2 years in a cohort study of adolescents aged 11 – 15 years. Data were derived from the Study of Cognition, Adolescents and Mobile Phones (SCAMP).

Chapter 4: Findings from Chapter 3 indicated a shift in screen use preference from television to mobile phone use which may be accompanied by a change in the social and environmental context in which the behaviour is undertaken. The study in Chapter 4 describes the diurnal pattern and social context of screen behaviours in adolescents using time use diary data taken from the sixth wave (2015/2016) of the Millennium Cohort Study. The aim of this cross-sectional analysis was to describe diurnal patterns in adolescents' screen-based behaviours and examine the association of social context with these behaviours at weekdays and weekend days.

Chapter 5: In addition to social context being associated with screen behaviours, there remains limited evidence of how contemporary screen behaviours (such as time spent in social networking sites and email/texts) may impact on overall sedentary time, or on time spent active or sleeping. This study used data from the sixth wave (2015/2016) of the Millennium Cohort Study. The aim of this cross-sectional analysis was to examine the association of diary-assessed screen behaviours with overall physical activity, moderate-to-vigorous physical activity (MVPA), sedentary behaviour and sleep in adolescents and explore whether these associations vary by sex.

Chapter 6: This chapter summarises the principal findings and concludes the thesis. It also provides some critical reflections on the methods used.

Chapter 2: Age-related change in sedentary behaviour during childhood and adolescence: a systematic review and meta-analysis

Background

There is evidence that sedentary behaviour during childhood may be associated with several adverse health outcomes, independently of physical activity (Carson *et al.*, 2016). Device-measured total sedentary time and self-reported screen-based sedentary behaviour may be associated with higher risk of obesity and low cardiorespiratory fitness (Tremblay *et al.*, 2011; Mitchell and Byun, 2013). Total sedentary time may also be associated with poor academic achievement and social interactions (Tremblay *et al.*, 2011), depression and low self-esteem (Hoare *et al.*, 2016; Vancampfort *et al.*, 2018; Rodriguez-Ayllon *et al.*, 2019). This evidence is reflected in public health guidelines suggesting that sedentary behaviour be limited, though there remain important inconsistencies and limitations of the existing research (Biddle, García Bengoechea and Wiesner, 2017; van Ekris *et al.*, 2017; Hashem *et al.*, 2019; Skrede *et al.*, 2019) and further high quality longitudinal and experimental research is required to better understand the links between sedentary behaviour and health in this population.

Several studies have shown that sedentary behaviour is highly prevalent in young people. Global surveillance data showed that approximately half of children and adolescents spend more than 2 hours a day in screen-based activities (Thomas *et al.*, 2019). A systematic review found that device-measured sedentary time accounted for almost half of the after-school time in children and over half of the after-school time in adolescents (Arundell *et al.*, 2016a). Another review found that device measured sedentary time accounted for 6.4 hours a day in children and 7.3 hours a day in adolescents (Pate *et al.*, 2011). Informed by this evidence, public health recommendations advise that children and adolescents should minimize the amount of time they spend sedentary (UK, Department of Health and Care, 2019), or limit the duration of specific sedentary behaviours, such as recreational screen time (Tremblay *et al.*, 2016).

In public health surveillance and epidemiological studies, sedentary behaviours are typically measured using body-worn devices (e.g., accelerometry) or self- or proxy-reported questionnaires. Despite some overlap in content, the correlation between device- and questionnaire-assessed sedentary behaviour is typically low, and they appear to be differentially associated with health markers (Dowd *et al.*, 2018; Guo, Key and Reeves, 2019). It is of interest, therefore, to examine both methods of measurement when exploring changes in sedentary behaviour over time. A recent systematic review of longitudinal studies reported an increase of

10-20 minutes per day per year in device-measured sedentary time and screen-based sedentary behaviour during the transition from primary to secondary education (Pearson *et al.*, 2017). This is consistent with cross-sectional data from the International Children's Accelerometry Database (ICAD), which showed that device-measured sedentary time increased progressively from the age of 5 years (Cooper *et al.*, 2015). Previous research has shown that sedentary behaviour may be higher in non-white children, those with a higher body mass index (BMI) (Pate *et al.*, 2011; Pearson *et al.*, 2017), and those from families of lower socio-economic position (Fairclough *et al.*, 2009; Coombs *et al.*, 2013), suggesting that age-related change in sedentary behavior may also vary in these sub-groups. Understanding of social and demographic variation in sedentary behavior change will help with the targeting of behavior change interventions.

It is understood that health behaviours in childhood and adolescence may persist into adulthood (Malina, 2001), highlighting the need to establish the timing of changes in sedentary behaviour during this period, as well as the population groups that may be most at risk. There is a published systematic review that showed device-based measured sedentary time increases with age in school-aged children and adolescents, by approximately 30 minutes per year (Tanaka *et al.*, 2014). However, this review focused on device-based sedentary behaviour and did not conduct a meta-analysis. Therefore, the aim of this review was to synthesize existing evidence on age-related changes in sedentary behavior during childhood and adolescence. A secondary aim was to examine whether the magnitude of change varied across social or demographic population groups.

Methods

The review protocol was registered with the International Prospective Register of Systematic Reviews ((PROSPERO) CRD42018106948). The review is reported in accordance with The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (PRISMA checklist is available in Appendix 1) and Meta-analysis Of Observational Studies in Epidemiology (MOOSE) (Stroup *et al.*, 2000; Liberati *et al.*, 2009).

Search strategy

Ten electronic databases were searched (PsycINFO, CINAHL, Web of Science, MEDLINE, Embase, Scopus, LILACS, Cochrane Library, Allied and Complementary Medicine Database (AMED), and Applied Social Sciences Index and Abstracts (ASSIA)) in September 2018 with no chronological limits set. Searches were re-run in June 2020. Manual searches of the reference lists of published systematic reviews and related articles were also completed to identify potentially relevant articles. The searches were focused on three groups of keywords: sedentary behaviour, study

design and study population. Key terms were used in combination with relevant MeSH-headings. The search strategy was developed in conjunction with an academic librarian. An example search strategy is provided in Appendix 2. The search was conducted by EK.

Inclusion and exclusion criteria

Studies were included if they 1) used an observational study design or a provided data for the control arm in an experimental study; 2) provided a quantitative estimate of duration of at least one sedentary behaviour with data collected at ≥2 time points (minimum of 1-year between baseline and follow-up); 3) included children and/or adolescents aged ≥5 and ≤18 years at baseline and follow-up; 4) were published in an English language peer-reviewed journal. Commentaries, conference papers, qualitative studies, pilot studies and trials without a no-treatment control group were excluded, as were studies in clinical populations.

When the same study was reported in multiple papers, the following prioritisation was applied to select papers for inclusion: 1) the article with the most follow-up assessment points; 2) the article with a variety of activities (i.e., most sedentary behaviours) for self-reported data; 3) the paper with the biggest sample size; 4) stratification for boys/girls, week/weekend days.

Identification of relevant studies

Covidence review management software (www.covidence.org) was used for the screening and selection of records retrieved from electronic and manual searches, including the removal of duplicates. Articles were selected by screening the titles, the abstracts, and if abstracts were not available or did not provide enough data, the entire article was retrieved and screened to determine whether it met the inclusion criteria. Articles that were not available through open access publication were obtained through university library subscription, email request to the author or inter-library loan as appropriate. Screening of titles, abstracts and full-texts was undertaken by the lead author (EK). A second reviewer (AJA) independently screened 10% of titles and abstracts with disagreements resolved by discussion. Ninety-two percent agreement was achieved at this stage. Ten percent of full texts were also screened by a second reviewer (NP). There was an agreement of 96% at this stage. Disagreements were solved by discussion and when uncertainties were raised, adjudication was made by AJA.

Data extraction

Data were extracted on forms developed specifically for this review. Extracted data included 1) author name, year of publication, country and study name (if applicable) 2) study design 3) aim(s) of the study 4) follow-up duration 5) sample size 6) baseline age, gender, ethnicity, socioeconomic position, weight status, BMI, BMI z-score 7) age at follow-up 8) methods utilised for device-based

(counts, epochs, time and days needed for inclusion) and self- or proxy reported assessments 9) duration of sedentary behaviour for each assessment or change between assessments 10) attrition rates. Data were extracted for the smallest reported independent sub-sample (*k*). Data extraction was conducted by EK and extracted data for 10% of papers were checked for accuracy by AJA.

Methodological quality assessment

Included studies were appraised for methodological and reporting quality using a scale adapted from previous reviews of observational longitudinal research (Tooth *et al.*, 2005; Jones *et al.*, 2013; Tanaka, Reilly and Huang, 2014). The following domains were assessed: study population and participation rate (2 items); study attrition (3 items); data collection (3 items); and data analysis (1 item). An additional item, pertaining to report of cut-point used in data processing, was included in appraisal of studies that assessed sedentary time by accelerometer (Appendix 3). Published methods papers were reviewed alongside included studies where necessary. The lead author (EK) undertook quality appraisal. A second reviewer (LF) conducted duplicate quality appraisal in a 10% subsample of papers and disagreements were resolved by discussion. Each item for the included studies was assessed with a 1 or 0 score. The overall quality of a study was determined by the sum of positively scored items and by converting to a percentage. Studies were rated high quality if score was ≥71%, moderate quality if score was 41%≥ and ≤70%, and low quality if score was ≤40%.

Data synthesis

The unit of analysis was independent sub-sample (*k*), defined as the smallest sub-sample for which relevant data were reported. Data on device-measured sedentary time and self- or proxy-reported screen behaviours were synthesised by meta-analysis. It was opted to meta-analyse screen-based behaviours due to prominence of those in children and adolescents and inclusion in public health guidelines. In order to prepare data for meta-analysis, conversion for reports of device-based and self- or proxy- reported data were undertaken as follows. The metric chosen was the original unit reported in most of the studies (i.e., min/day during the week (Monday to Sunday)). When studies reported sedentary time separately for Saturday and Sunday, the mean and SD of those values was calculated to provide mean sedentary time for the weekend. Conversions were also made for studies reporting minutes per day separately on a weekday and minutes per day on a weekend; in those cases, the mean value was calculated to provide mean weekly sedentary time ((5 x weekday) + (2 x weekend) / 7). For studies reporting hrs/day or hrs/week, data was converted to min/day. For studies reporting data in medians, interquartile range (IQR) and standard error, data were converted to mean and standard deviation (SD) following published methods (Hozo, Djulbegovic and Hozo, 2005). For self- or proxy methods, studies were grouped according to whether they

reported on a single sedentary behaviour (e.g., television viewing only) or a composite of multiple behaviours in various combinations (e.g., television viewing, computer use and video games).

It was opted not to meta analyse data on non-screen-based behaviours due to limited number of studies providing this data, the heterogeneity in questionnaire content and the limited evidence of associations with health and well-being. None of the studies tested statistically for change over time. Findings are summarised in the table but omitted from the synthesis.

Statistical analysis

Data on change in sedentary behaviour were combined using random effect meta-analysis, conducted in STATA 16.0 (Stata Corporation, Texas, USA). Data included in the meta-analysis were converted to a common metric, non-standardised weighted mean differences (WMD). Studies were meta-analysed according to the duration of follow-up (e.g., 1 year, 2 years, 3 years and 4+ years) except for video games and computer use for which meta-analysis was conducted for 1 year, 2 years and 3+ years of follow-up due to the limited number of studies that assessed change over 4 or more years (video games N=2, computer use N=3). Heterogeneity was quantified using the I^2 statistic (Higgins, 2011). Meta-regression was used to explore the impact of possible effect modifiers (gender, age span, study's location and quality). Candidate moderators were selected based on the data extracted and potential to inform behaviour change interventions. Age range referred to either childhood (age from 5 to 10 years old) or adolescence (age 11 to 18 years old) at baseline. Study location was summarised as: Europe, North America, South America, Australia & New Zealand, Africa or Asia. Annual change in sedentary behaviour (min/day/year) was estimated by subtracting baseline sedentary behaviour from follow-up and dividing by duration of follow up (years) (Higgins, 2011). Standard deviation of annual change was calculated according to methods described by Higgins, assuming a correlation of 0.5, consistent with previous research (Farooq *et al.*, 2019). Eggers test for publication bias was conducted for all meta-analyses (Egger *et al.*, 1997).

Results

The literature search returned 17,265 references (Fig. 3). After removal of duplicates, 14,341 titles and abstracts were screened, from which 834 full-text papers were assessed for eligibility. Of those, 722 were excluded due to not meeting the inclusion criteria. Subsequently, a further 27 papers were excluded as they included duplicate data available in other papers. Eighty-five papers were included in the review, of which 10 were identified in the updated search in June 2020.

Most studies were conducted in Europe (N=36) or in North America (N=23), had a sample size of >1000 participants (N=33) and had a follow-up duration of ≤3 years (N=51). The majority (N=63; k

independent samples=129) used self-reported instruments to measure television viewing, video games, computer use, doing homework, or travelling by car/bus, either separately or in combination. Thirty studies (k=52) used device-based methods to assess total sedentary time. Eight papers reported data for both device-based and self- or proxy- assessment. Methodological characteristics of included studies are summarized in Table 1, stratified by method of measurement. A study-level summary of included studies is presented in Appendix 4a and Appendix 4b.

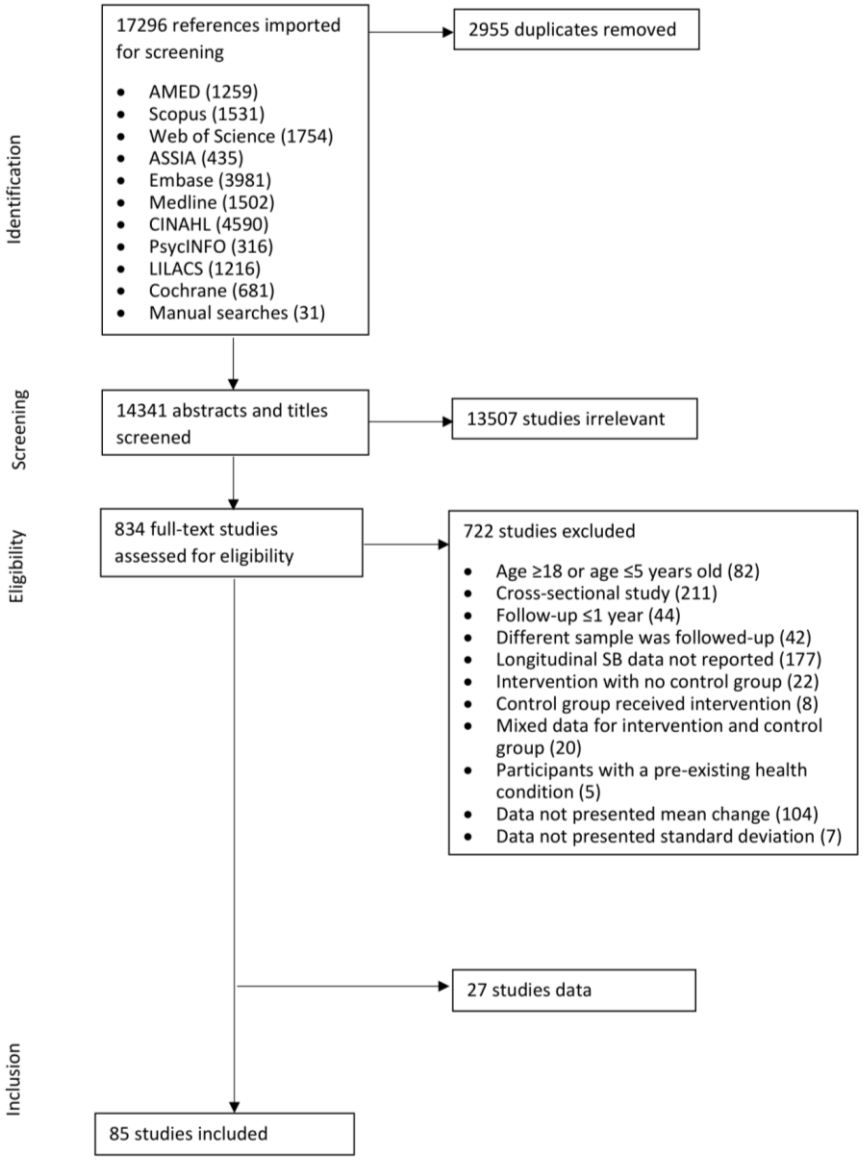


Figure 3 Literature search and article screening process

Methodological quality scores for each study are provided in Appendix 5. An 84% agreement was achieved on bias scoring between reviewers, and discrepancies were resolved via discussion. Of the 85 included studies, 63% were rated high quality, 32% were rated moderate quality and 5% were rated low quality.

Device-measured sedentary time

Meta-analysis indicated that sedentary time increased by (WMD (95% CI)) 27.9 (23.2, 32.7), 61 (50.7, 71.4), 63.7 (53.3, 74) and 140.7 (105.1, 176.4) minutes per day over 1, 2, 3 and 4+ years of follow-up respectively. In all cases, heterogeneity was high (≥96%) and statistically significant (Fig. 4). Meta-regression indicated no statistically significant effect modification by gender, baseline age or study's location, attrition rate or quality (p>0.05). Using Egger's test there was no evidence for publication bias in 1, 3 and 4+ years of follow-up but there was some evidence for publication bias for 2-year duration of follow-up (p=0.04).

Meta-analysis indicated an annual change in sedentary time (minutes per day) of (ES (95% CI)) 7.8 (6.4, 9.1) minutes per year (Appendix 6). The I^2 value was 80.9%, indicating high heterogeneity.

Table 1 Descriptive characteristics of the included studies, stratified by method of sedentary behaviour measurement

	Device-measured N=30	**Self- or proxy-reported N=55**
Sample size		
<100	2 (6.6)	5 (9)
100 - 499	14 (46.6)	10 (18.1)
500 - 999	7 (23.3)	14 (25.4)
>1000	7 (23.3)	26 (47.2)
Duration of follow-up		
1y	5 (16.6)	12 (21.8)
2y	12 (40)	18 (30.9)
3y	4 (13.3)	10 (16.3)
4+y	9 (30)	15 (27.2)
Region		
Europe	18 (60)	18 (32.7)
Australia & NZ	5 (16.6)	12 (21.8)
N. America	5 (16.6)	18 (32.7)
S. America	n/s	3 (5.4)
Asia	2 (6.6)	3 (5.4)
Africa	n/s	1 (1.8)
Age at baseline		
Children only	14 (46.6)	26 (47.2)
Adolescents only	12 (40)	28 (50.9)
Children and adolescents	4 (13.3)	1 (1.8)

Data are presented N (%). Abbreviations, NZ: New Zealand, n/s: no studies.

Self- or proxy-reported sedentary behaviour

Studies reporting data collected by questionnaire presented data for single behaviours (such as television viewing, video games, computer use, homework and travel by car or bus) and/or behaviours aggregated in various combinations to create composite measures. Findings are summarized narratively only for studies that reported change in academic related activities and travel by car/bus (Appendix 11).

Single sedentary behaviours

Meta-analysis indicated that changes in duration of television viewing were non-significant at 1 year (WMD (95% CI)) (-0.6 (-5.0, 3.7)), 2 years (7 (-0.1, 14.2)) and 3 years (0 (-4.8, 4.8)) of follow-up. Based on 16 independent samples, an increase in television viewing was reported in those studies that reported change over 4+y of follow-up (26.1 (0.9, 51.3)). In all cases, heterogeneity was high (≥93.7%) and statistically significant (Fig. 5). Time spent playing video games increased by (WMD (95% CI)) 12.4 (4.8, 19.9), 5.7 (0.3, 11) and 15.3 (4.8, 25.8) minutes per day over 1, 2, 3+ years of follow up respectively. In all cases, heterogeneity was high (≥92.2%) and statistically significant (Fig. 6). Computer use increased by (WMD (95% CI)) 16.4 (2.4, 30.5), 28.7 (16.8, 40.5) and 35.5 (19.4, 51.6) minutes per day over 1, 2, 3+ years of follow-up respectively. Heterogeneity was high (≥68%) and statistically significant (Fig. 7). Using Egger's test there was no evidence for publication bias for single sedentary behaviours over 1, 2, 3 or 4+ years of follow-up. Meta-regression indicated no statistically significant effect modification by gender, baseline age or study attrition rate or quality (p>0.05). Compared to Europe, studies conducted in South America reported larger increases in video game use over 1 year of follow-up (p=0.002) and those conducted in Asia reported larger increases in computer use over 2 years of follow-up (p=0.03).

Estimated annual changes (minutes per day) in television viewing, video game and computer use were (ES (95% CI)) 0.6 (-0.1, 1.4), 0.6 (0.2, 1.1), and 2 (1, 3) respectively (Appendix 7 – 9).

Composite measures

Meta-analysis indicated that combined television viewing, video game play and computer use increased by (WMD (95% CI)) 20.8 (9.9, 31.8), 19.9 (14.1, 25.6), 40 (16.3, 63.7) and 42.6 (21.1, 64.1) minutes per day over 1, 2, 3 and 4+ years of follow-up respectively. In all cases, heterogeneity was high (≥97.3%) and statistically significant (Fig. 8). Using Egger's test there was no evidence for publication bias over 1, 2, 3 and 4+ years of follow-up. Meta-regression indicated no statistically significant effect modification by gender, baseline age or study's location, attrition rate or quality (p>0.05).

Estimated annual change (minutes per day) in television viewing, video game play and computer use was (ES (95% CI)) 0.3 (0.2, 0.5) minutes per year (Appendix 10).

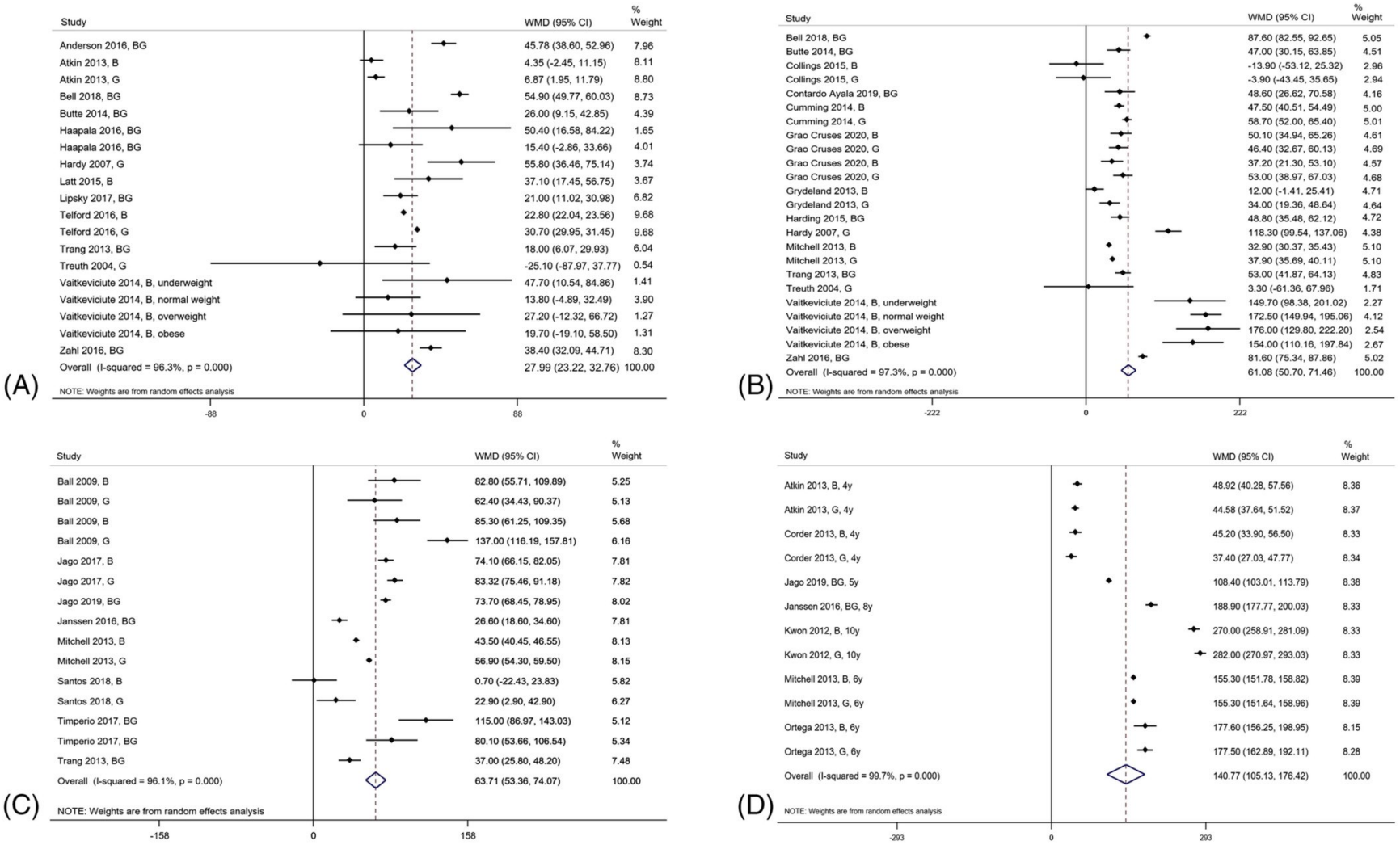


Figure 4 Change in device-measured sedentary time over (A) 1-, (B) 2-, (C) 3-, and (D) 4- to 10-year duration

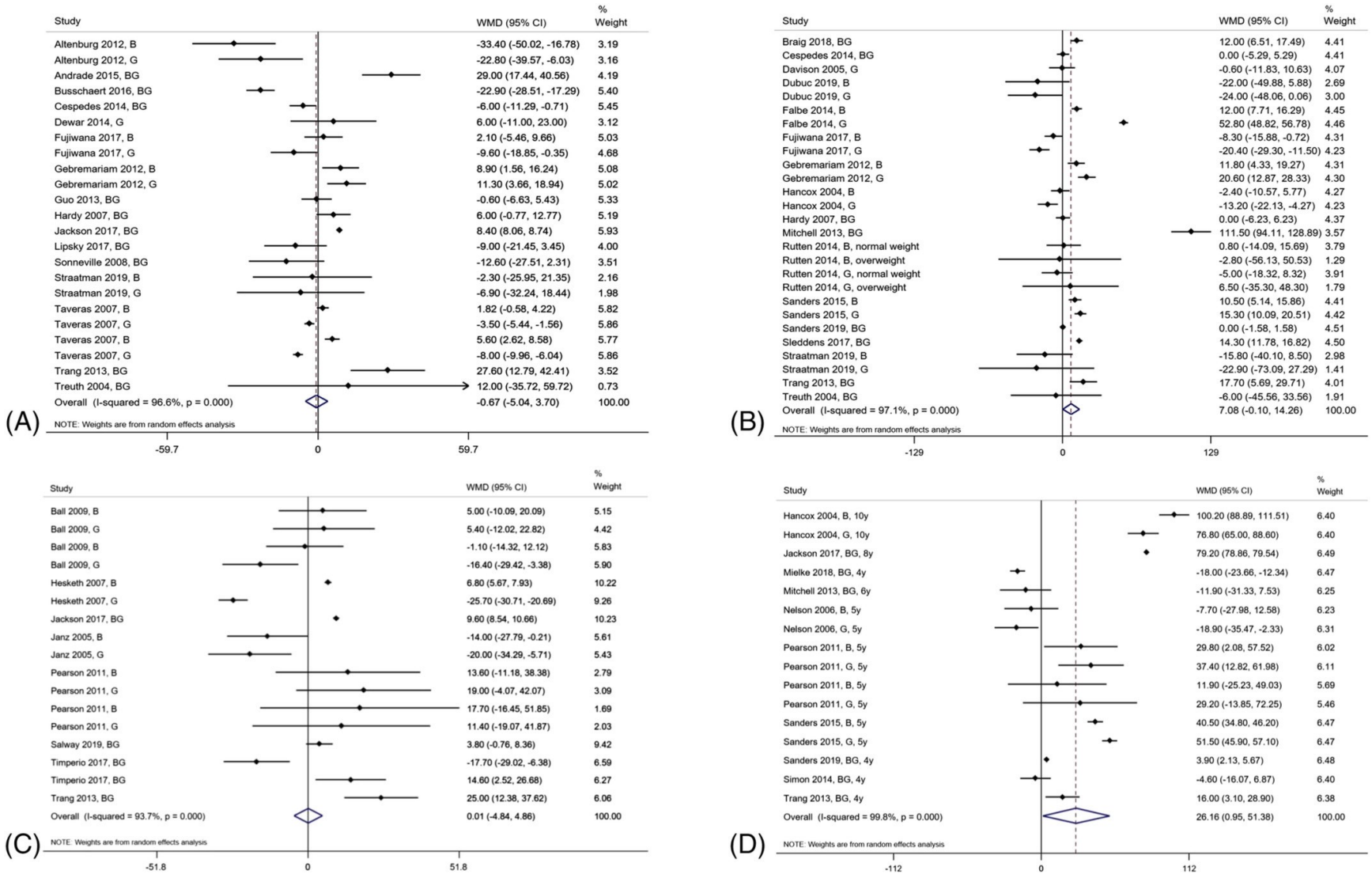


Figure 5 Change in self- or proxy-reported TV viewing over (A) 1-, (B) 2-, (C) 3-, and (D) 4- to 10-year duration

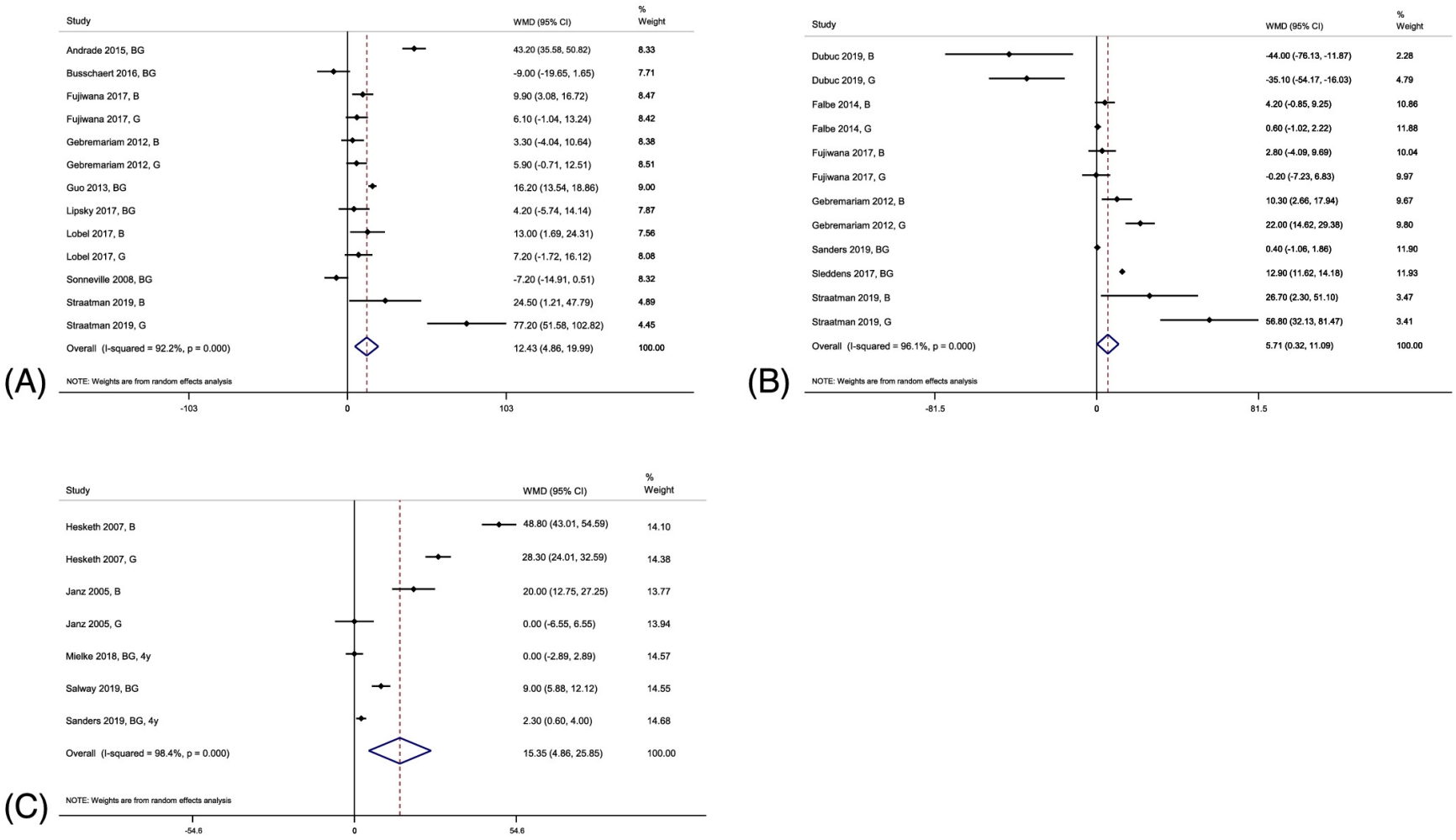


Figure 6 Change in self- or proxy-reported video games over (A) 1-, (B) 2-, and (C) 3- to 4-year duration

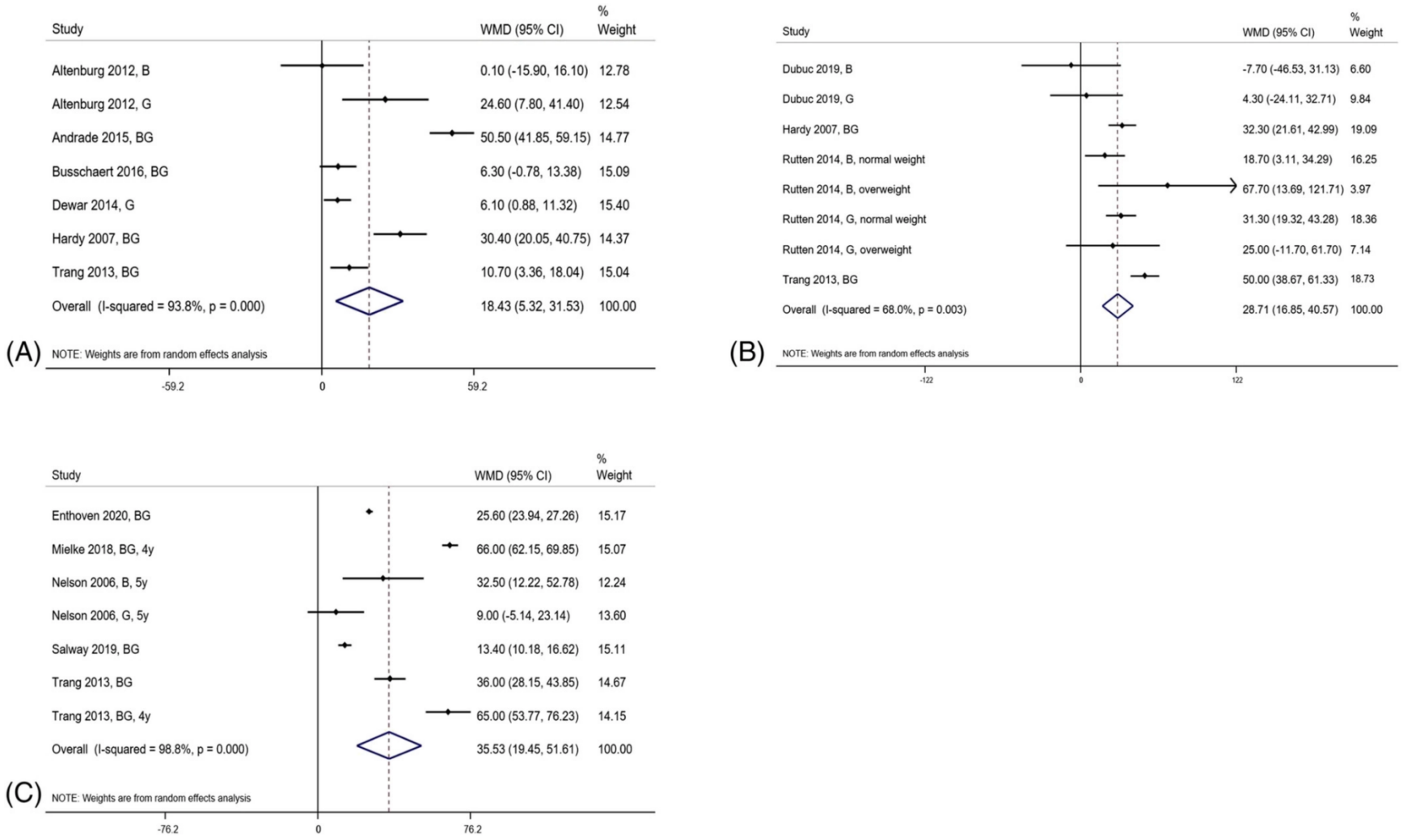


Figure 7 Change in self- or proxy-reported computer use over (A) 1-, (B) 2-, and (C) 3- to 5-year duration

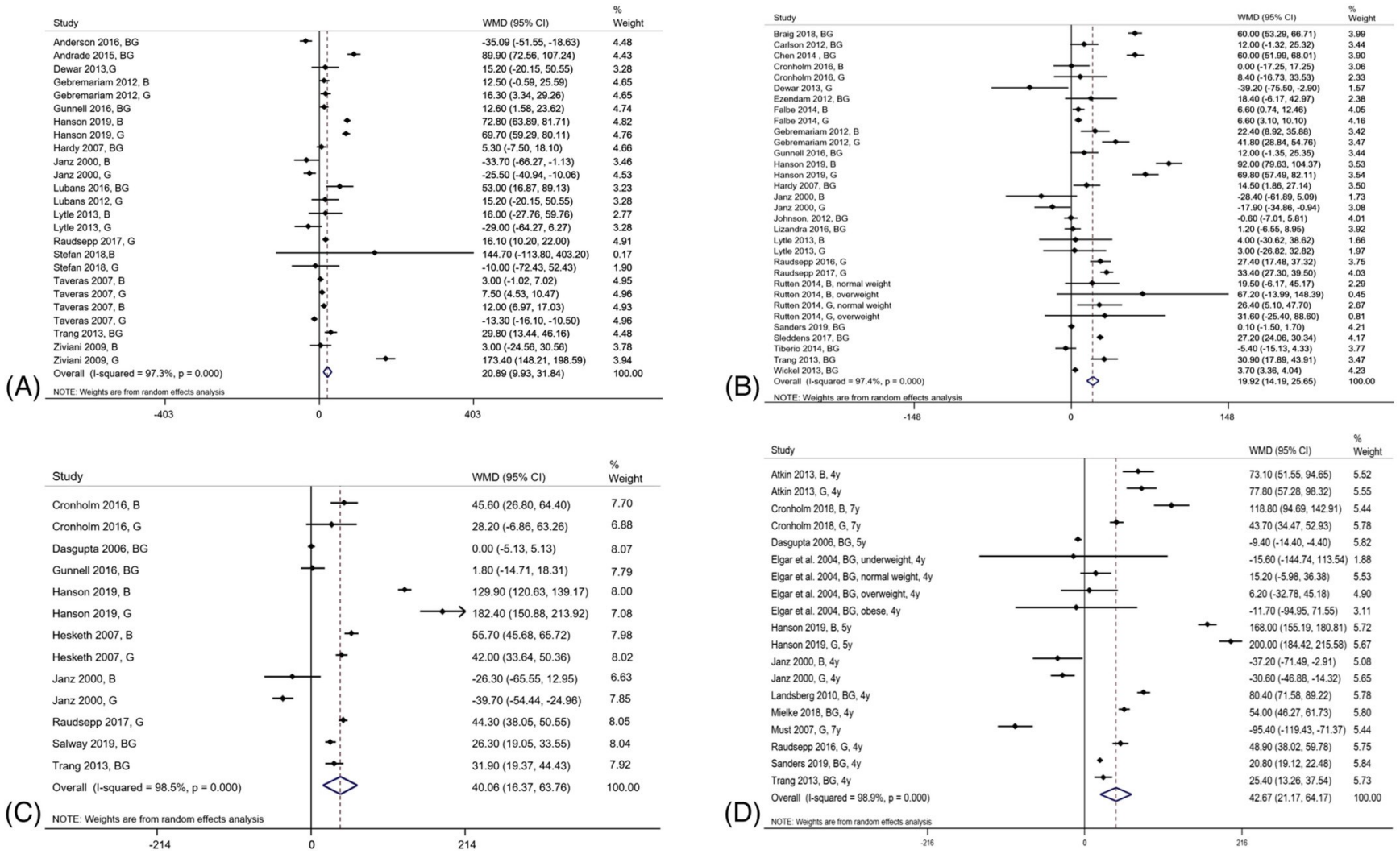


Figure 8 Change in self- or proxy-reported composite screen-based behaviours over (A) 1-, (B) 2-, (C) 3-, and (D) 4- to 7-year duration

Discussion

This is the first systematic literature review to summarize and meta-analyze longitudinal data on changes in sedentary behaviour during childhood and adolescence. For device-based measures of sedentary behaviour, meta-analysis indicated that sedentary time increases over time, with larger increases seen over longer durations of follow-up. The meta-regression indicated no statistically significant differences in sedentary time change according to age, gender, study location, quality or attrition. For self- or proxy-reported sedentary behavior, our synthesis indicated increases in time spent in video game play, computer use and a composite marker of screen-based behaviour, but television viewing appeared relatively stable and increased only over the longest durations of follow-up.

The meta-analysis indicated that device-measured daily sedentary time increased as children and adolescents age, by approximately 28 minutes over 1 year, 61 minutes over 2 years, 64 over 3 years and 141 minutes over 4 years of follow-up. Findings are consistent with cross-sectional data from the ICAD study, which showed that sedentary time increased in an approximately linear manner from the age of 5 years onwards, though the magnitude of change was not quantified in minutes (Cooper *et al.*, 2015). Similarly, a recent study using pan-European harmonized accelerometer data showed a linear increase in sedentary time with age; at age 4/5 years children accumulated approximately 250 minutes/day of sedentary time increasing to around 450 minutes/day at age 14/15 (Steene-Johannessen *et al.*, 2020). Changes in sedentary behavior mirror the well documented reduction in physical activity during childhood (Dumith *et al.*, 2011; Cooper *et al.*, 2015; Chong *et al.*, 2019; Farooq *et al.*, 2019). Given evidence that sedentary behavior tracks moderately from childhood to adulthood (Biddle, O'Connell and Braithwaite, 2011; Larouche *et al.*, 2012), age-related increases in overall sedentary time, as captured by device-based measurement, likely reflect changes in behaviour in a number of domains and settings over time. The need for behaviour change interventions to limit such changes will require clearer evidence on the specific nature of these changes, accompanied by stronger epidemiological evidence on how specific behaviours are linked with health and well-being.

A key finding of this review was that change in sedentary behaviour did not differ according to age at first assessment. Meta-regression showed that changes in this behaviour were similar in children (≥5 and <10 years old) and adolescents (≥10 and <18 years old) for either device-measured or self- or proxy-reported sedentary behaviour, supporting the view that, where appropriate, interventions to limit the age-related increase in sedentary behaviour may need to be implemented throughout the

childhood period. There is substantial evidence that adolescents engage in higher levels of sedentary behaviour than children (Pate *et al.*, 2011; Pearson *et al.*, 2017), but this is the first study that has examined whether changes in sedentary time within these periods differ. Findings are consistent with recent evidence that the age-related decline in physical activity may start during childhood, rather than being limited to the adolescent period (Reilly, 2016). Further information on how the accumulation of device-assessed sedentary time changes with age, including bout length and frequency of breaks, would be beneficial, as such factors may have important implications for health. Moreover, further evidence describing the social and environmental factors that influence sedentary behaviour and how these evolve over time is also required to inform intervention design.

There was no evidence that change in device-measured sedentary time and self- or proxy-reported sedentary behaviour differed between boys and girls over time. This is in line with the results from a recent study using pan-European accelerometer data which suggested that, whilst girls accumulated more sedentary time than boys, the pattern of change with increasing age was similar (Steene-Johannessen *et al.*, 2020). A recent systematic review that focused on sedentary behaviour change across the primary to secondary school transition also found no evidence for a gender difference, but this was not tested statistically (Pearson *et al.*, 2017). Additionally, a systematic review of tracking of sedentary behaviour from childhood to adolescence found little evidence of a gender difference (Biddle *et al.*, 2010). Results from an analysis in ICAD showed that boys were less sedentary and more active than girls at all ages, though the change in sedentary time appeared similar for both boys and girls over time (Cooper *et al.*, 2015). Despite the apparent consistency of existing evidence, changes in sedentary time between both genders over time have attracted little attention. Of the 85 studies that were included in the review, only 39 (42%) reported data separately for boys and girls. Whilst trajectories of overall sedentary time may be similar, it remains unclear whether changes in time spent in specific sedentary behaviours differ between boys and girls; further information on this topic would be informative for intervention design.

The meta-analyses indicated that time spent in video game play, computer use, and a composite measure of screen-based behaviour increased over all durations of follow-up examined; however, time spent in television viewing did not change for up to 3 years but it increased for more than 4 years duration of follow-up. Findings are similar to recent studies which showed that time spent in a composite marker of screen-based behaviour and also computer use and video game play increased over time (Iannotti and Wang, 2013; Kann *et al.*, 2018; Ryu *et al.*, 2019; Thomas *et al.*, 2019).

Interestingly, findings on television viewing partially contrasts with prior research reporting a decrease by a relatively small amount in traditional television viewing over time (Barnett *et al.*, 2018; Thomas *et al.*, 2019), but this was not tested statistically. In contradiction with earlier findings, a previous review of longitudinal studies looking at television viewing, found increases in boys and girls over time but the results were mixed in boys and girls according to weight status (Pearson *et al.*, 2017). Most studies in the current review focused on traditional sedentary behaviours, such as television viewing and video games, with very few describing changes in contemporary behaviours, such as tablet and phone use. The number of devices through which young people may access the internet and/or audio-visual media has expanded rapidly in recent years. Recent data showed that the proportion of children and adolescents aged 5 – 15 years old watching television programmes on tablets increased from 27% in 2015 to 43% in 2019 and on mobiles from 15% in 2015 to 26% in 2019 (OfCom, 2019). Further research is needed to examine how the duration of time spent in newer screen-based behaviours changes over time and whether this is displacing time previously spent watching broadcast television. Alongside this, there is a need for qualitative studies to explore how adolescents' attitudes and preferences for different screen- and non-screen based behaviours change over time.

The data for non-screen-based behaviours showed that academic-related activities and travel by car/bus increased over time, whilst time spent reading for school declined, but this was assessed in only three studies. Change in car/bus perhaps reflects greater engagement in social and recreational activities away from home as children age (Auhuber *et al.*, 2019; Evenson *et al.*, 2019). The concurrent increase in academic activities and the decline in school-related reading appears contradictory. These contradictions may reflect the transition from reading being an academic activity in its own right to a routine activity required to fulfil other school-related tasks. The lack of studies reporting age-related changes in these behaviours is a clear gap in the evidence and further research would provide a richer picture of changes in young people's sedentary behaviour patterns and preferences over time. In particular, only 2 studies were identified that assessed time spent in academic-related activities with and without a computer or tablet. As we seek to further disentangle the detrimental and beneficial associations of sedentary behaviour with physical and mental health, this topic in particular would be worthy of further study.

A key strength of this review is the inclusion of studies that used either device-based or questionnaire-based methods of measurement and use of meta-analysis to synthesize the data. In addition, broad

search criteria were used to identify relevant articles across 10 electronic databases and the manual searches without publication date restrictions. The protocol was registered with PROSPERO and the review is reported in accordance with PRISMA guidelines (Liberati *et al.*, 2009) and MOOSE (Stroup *et al.*, 2000). It included and summarized evidence from studies that measured a broad range of sedentary behaviours, both individually and in combination, providing a comprehensive overview of the published literature and highlighting gaps to be addressed in future research. Limitations of this work include the restriction to English language publications in peer-reviewed journals, which may have resulted in the exclusion of relevant articles. In addition, this review deviated from the published protocol by not searching the Global Health database (not available in our institution). Duplicate appraisal of study quality was conducted for 20% of studies. There was a high level of agreement when duplicate screening for inclusion was conducted, with no evidence of high levels of discrepancy for particular items. As a result, a duplicate screening of 20% of papers was deemed necessary, but an implication of this is that there may have been some discrepancies in those that were not duplicate screened. It is worth acknowledging that a limitation of the quality assessment/risk of bias assessment of the eligible studies is that some items (e.g., items A1 and B5) may not directly be considered relevant for the purpose of this review. Therefore, the high score of those items may have contributed to higher rating than it would potentially be. The I2 statistic implies the scope of wide range of change around the average change. Overall, the signal of direction appears same, but the magnitude varies across studies. Finally, selected accelerometer data collection and processing criteria were selected in summary tables but did not include/exclude papers from the meta-analysis on the basis of these factors. Variability in data processing methods and compliance with study protocols may have contributed to heterogeneity in the estimates of change that were synthesised.

The current study highlights several areas that would benefit from further research. Few of the included studies conducted stratified analyses to examine whether change in sedentary behavior varied according to social, demographic or anthropometric factors, such as socio-economic position, ethnicity or BMI. This information would aid in the identification of at-risk populations for intervention. Additionally, observational longitudinal studies are needed to collect data on the wide range of electronic media devices used by young people, moving beyond simplistic assessments of computer use or broadcast television. One in four young people (5 – 15 years old) do not watch live broadcast television at all and smartphone ownership increased by 10% from 2015 to 2019 (OfCom, 2019). Further research is also warranted to examine multi-tasking of portable devices and the context

in which such devices are used, which may moderate how these behaviours influence health. This may necessitate the development and validation of new tools to capture the diversity of electronic media devices being used, in combination with information on content and context.

Conclusion

This is the first systematic review to summarize published evidence on age-related change in sedentary behaviour in children and adolescents. Findings show that device-measured sedentary time increases with age; with no evidence that the magnitude of change varied by gender or age, though few studies provided the required data for these analyses. Synthesis of data on screen-based sedentary behavior assessed by questionnaire also indicated an increase with age. Whilst the evidence base linking sedentary behaviour with mental and physical health outcomes requires further development, findings suggest that the development and evaluation of interventions to limit age-related increases in specific sedentary behaviours may be appropriate. Further research into patterns of contemporary sedentary behavior use and to identify population sub-groups that may accumulate higher amounts of sedentary behaviour with age would be beneficial for the targeting of behavior change programs.

Chapter 3: Changes in adolescents' screen based behaviour over 2-years: Longitudinal results from the Study of Cognition, Adolescents and Mobile Phones

Introduction

The systematic review and meta-analysis presented in Chapter 2 showed that sedentary time and sedentary behaviour increase as children and adolescents age. However, the studies included in the review focused almost exclusively on television viewing and video game play with very few describing changes in the time spent using other screens, such as mobile phones. Further, less than half of the studies stratified data by sex, and none by ethnicity or socio-economic position. To address gaps in the literature identified in Chapter 2, this chapter addresses age-related changes in contemporary screen behaviours and whether change in screen behaviour varied in different sub-population groups. Using a large and ethnically diverse UK cohort of adolescents, this study examines changes in time spent in screen-based behaviours (including mobile phones, tablets, television and computers) and socio-demographic differences in these changes over approximately 2 years.

Background

Sedentary behaviours are highly prevalent in young people and are adversely associated with cardiometabolic and mental health, including antisocial behaviour and depression (Carson *et al.*, 2016; Hoare *et al.*, 2016). The most prevalent sedentary behaviours include screen-based activities, such as watching television and using a computer, video game console, smartphone or tablet (Arundell *et al.*, 2019). Global surveillance data show that more than half of young people exceed public health guidelines of 2 hours per day of recreational screen time (Saunders *et al.*, 2016; Thomas *et al.*, 2019). Given that screen behaviours account for a large part of adolescents' daily time and that these behaviours track into adulthood (Biddle *et al.*, 2010), it is important for behaviour change interventions to target potentially harmfully high levels of screen use early in life.

There is growing evidence that time spent in screen behaviours increases with age. For example, a recent systematic review of longitudinal studies found that time spent in television viewing, video game play and computer use increases by approximately 2 minutes per day per year during childhood and adolescence (Kontostoli *et al.*, 2021). However, much of the previous research on this topic has focused on traditional screen behaviours, such as television viewing, computer use and video games, with very few studies describing changes in more contemporary screen behaviours, such as tablet and

smartphone use. Given that the number of devices through which young people may access the internet and/or audio-visual media has expanded rapidly in recent years (OfCom, 2019). Television viewing may be being replaced by the use of newer screen devices, such as smartphones, tablets or E-books (Thomas *et al.*, 2019). In young people aged 5 – 15 years from the UK, for example, the prevalence of watching television programmes on a mobile device or tablet increased between 2015 and 2019 (15% vs. 26%, 27% vs. 43% respectively) (OfCom, 2019). Unsurprisingly, device use differs between children and adolescents; 2019 data from OfCom indicated that just 7% of children aged 8 – 11 had their own smartphone and 49% their own tablet whereas 83% of adolescents aged 12 – 15 had their own smartphone and 59% their own tablet (OfCom, 2019). Given the high prevalence of screen device ownership in this population, it is pertinent to assess how time spent in screen behaviours changes during adolescence. Such knowledge will help inform the targeting and timing of screen behaviour change interventions.

In addition to variability by age, there is also evidence that screen behaviours may differ by sex and socio-demographic factors. A longitudinal study in Australian adolescents found that, between the ages of 10 and 14, electronic game use increased more in boys than girls, whilst the reverse was true for time spent using social media (Thomas *et al.*, 2020). Cross-sectional evidence indicates that adolescents from families of low socioeconomic position may spend more time watching television or using a computer for leisure than their more affluent counterparts (Temmel and Rhodes, 2013), but little is known about how socioeconomic inequalities in contemporary screen activities evolve longitudinally. A recent review of longitudinal data reported that few studies conducted stratified analyses to examine whether change in screen time varied according to sex, socio-economic position and ethnicity (Kontostoli *et al.*, 2021). Strengthening the longitudinal evidence base on this topic is important to better understand behaviour changes in use of newer technologies over time and identify sub-groups that may warrant targeted intervention.

The aim of this study was to describe changes in time spent in screen-based behaviours (including mobile phones, tablets, television and computers) and examine socio-demographic differences in these changes over approximately 2 years in adolescents.

Methods

Sample and data collection

Data are from the Study of Cognition, Adolescents and Mobile Phones (SCAMP), led by Imperial College London (Toledano *et al.*, 2019). The SCAMP study examines the impact of mobile phones and other wireless devices on adolescents' cognitive, physical and mental health. Details of cohort characteristics, recruitment and participation rates are published elsewhere (Toledano *et al.*, 2019). Thirty-nine schools participated in the study, located in and around Greater London, United Kingdom. Head teachers at participating schools signed consent forms to confirm their participation. Parents of all Year 7 students (aged 11 to 12 years) received an information pack about the study and had the opportunity to opt their child out if they did not wish for them to participate. The adolescents could also withdraw on the day of assessment. The SCAMP study was conducted in accordance with the Declaration of Helsinki. Ethical approval was obtained from the Northwest Haydock Research Ethics Committee (ref 14/NW/0347).

Baseline data were collected between November 2014 and June 2016 when students were in Year 7. Of the 7,375 eligible participants, 6,616 (89.7%) completed the school-based computer assessment at baseline. Of this nonparticipation, 14.6% (n=111) was due to parental opt-out; the remaining 85.3% (n=648) was the result of absentees and withdrawals. Follow-up data were collected between November 2016 and July 2018 when students were in Years 9/10 (aged 13 to 15 years). As of July 2018, the attrition rate from the baseline computerized assessment was 24% (n=1593 adolescents) due to absentees, withdrawals, and school drop-out.

Self-reported screen behaviours

Assessments were conducted during school hours at baseline and follow-up. Separately for week and weekend days, participants self-reported duration of use for the following screen behaviours: phone calls on mobile phones, internet on mobile phones, social network sites on mobile phones, social network sites on other devices, tablet/eBook reader, laptop and desktop computer either at school or outside school hours, portable media player (i.e., iPods), portable video game console, television viewing, smart television and video game console use. An example question was: "How much time per day do you spend talking on your mobile phone? On weekdays'; Response options: '0 minutes', '1–5 min per day', '6 – 15 min per day', '16 – 30 min per day', '31 – 59 min per day', '1–2 h per day', '3 h or more per day". Questions can be found in Appendix 12. For television viewing only, participants were asked to report duration of use on a weekday before and after school hours.

Change in the duration of each behaviour was calculated by subtracting baseline from follow-up using response category mid-points (e.g., '1 – 5 min' =2.5 min), as used previously (Yang-Huang *et al.*, 2017).

Socio-demographic factors

Participants self-reported their age, sex, and ethnicity. Ethnicity was categorised as White, Black, Asian, Mixed and Other/not interpretable. Parent-reported occupation was used as an indicator of socio-economic position by means of National Statistics Socioeconomic Classification (NS-SEC) levels (five-group version: managerial/professional, intermediate occupational, small employers/own, lower supervisory, semi-routine/routine). For this analysis, the five-group classification was collapsed into two groups ('high' = 'managerial/professional', 'middle-to-low' = the remaining four groups) as the high socio-economic group comprised for half of the sample.

Statistical analysis

Analyses were conducted in STATA 16.0 (Stata Corporation, Texas, USA). Baseline sample characteristics were summarised using descriptive statistics. Differences in baseline characteristics between adolescents with and without follow-up screen data were tested using Student's *t* tests or Chi-square tests for continuous and categorical variables respectively.

Change in screen activities was reported using mean and 95% confidence interval for weekdays and weekend day, stratified by sex. Sex differences in change were examined using independent t-tests. Multilevel multivariable linear regression was used to assess associations between socio-demographic factors (i.e., sex, age, ethnicity, and socio-economic position) and change in screen behaviours, with

participants nested within schools. Analyses were conducted separately for each screen behaviour and stratified by week and weekend day. Models were mutually adjusted for socio-demographic factors.

Results

Table 2 describes baseline characteristics of adolescents who provided data for one or more of the screen behaviours at baseline and follow-up. Adolescents were an average of 11.5 (0.4) years of age, mainly of high socio-economic position (67.3%) and White ethnicity (45.2%). Those included in the analyses did not differ in their demographic or social characteristics compared to those who were lost to follow-up (data not shown).

Changes in screen behaviours

Table 3 shows 2-year change in screen-based behaviours for weekdays and weekend days. On weekdays, time spent in all screen-based behaviours increased from baseline to follow-up, apart from use of portable video games and smart television viewing which remained stable and use of a portable media player which declined (full sample only). For those behaviours that increased, the magnitude of change ranged from an approximate 6 min/day increase in time spent visiting social network sites (on devices other than mobile phones) to a 60 min/day increase in internet use. On weekend days, time spent in all screen-based behaviours increased over 2 years, apart from smart television viewing which remained stable.

Change in the use of a desktop computer, tablet and laptop computer during school and non-school hours are shown in Table 4. Throughout the school hours, time spent using a desktop computer increased in boys but remained stable in girls. Tablet use increased in girls but remained stable in boys whilst laptop use remained stable in both boys and girls. During non-school hours, time spent using a desktop computer increased in boys but remained stable in girls, the use of laptop computer increased in girls but did not change in boys.

Table 2 Baseline characteristics of adolescents who provided data for one or more of the screen behaviours analysed

	All	Boys	Girls
Sex, n (%)	3,807	1,629 (42.7)	2,178 (57.2)
Age, mean (SD)	11.5 (0.4)	11.5 (0.4)	11.5 (0.4)
Socio-economic position, n (%)			
High	2,057 (67.3)	865 (67.4)	1,192 (67.2)
Middle-to-low	998 (32.6)	418 (32.5)	580 (32.7)
Ethnicity, n (%)			
White	1,705 (45.2)	757 (46.8)	948 (43.9)
Black	568 (15.0)	248 (15.3)	320 (14.8)
Asian	1,030 (27.3)	413 (25.5)	617 (28.6)
Mixed	432 (11.4)	182 (11.2)	250 (11.6)
Other/not interpretable	37 (0.9)	16 (0.9)	21 (0.9)

SD, standard deviation.

Table 3 Change (min/day) in screen behaviours on weekdays and weekend days over two years, stratified by sex. Data are mean (95% Confidence Interval)

			Weekday		
	Phone calls on mobile phones	**Internet on mobile phones**	**Social network sites on mobile phones**	**Social network sites on other devices**	**Video games console**
All	8 (6.4, 9.6)	60.8 (55.9, 65.7)	45.2 (42.1, 48.3)	6.8 (3.5, 10.2)	17.3 (12.9, 21.6)
Boys	6.6 (4.2, 8.9)	53 (45.4, 60.7)	38.5 (33.9, 43.2)	9.9 (4.6, 15.1)	24.9 (19.1, 30.6)
Girls	9.1 (6.9, 11.3)	66.7 (60.3, 73.0)*	50 (45.8, 54.3)*	4.6 (0.3, 8.9)	1.6 (-4.0, 7.3)*
	Portable media player	**Portable video games**	**Smart TV**	**TV viewing**	
All	-12.0 (-22.6, -1.4)	-2.3 (-8.6, 3.9)	-1.7 (-6.1, 2.6)	4.5 (0.5, 8.4)	
Boys	-12.8 (-30.2, 4.6)	-5.6 (-15.2, 3.9)	-5.0 (-11.9, 1.8)	-3.6 (-9.5, 2.3)	
Girls	-11.4 (-24.8, 1.9)	1.0 (-6.9, 9.0)	0.6 (-5.1, 6.3)	10.3 (5.1, 15.6)*	
			Weekend day		
	Phone calls on mobile phones	**Internet on mobile phones**	**Social network sites on mobile phones**	**Social network sites on other devices**	**Video games console**
All	10.8 (8.8, 12.7)	84.7 (78.9, 90.5)	57.3 (53.5, 61.1)	7.7 (3.6, 11.9)	25.7 (20.4, 31.1)
Boys	8.6 (5.8, 11.3)	73.1 (64.0, 82.2)	46 (40.5, 51.6)	11 (4.3, 17.6)	34.0 (27.1, 40.9)
Girls	12.5 (9.8, 15.2)*	93.5 (86.1, 100.9)*	65.4 (60.4, 70.5)*	5.4 (0.1, 10.7)	8.7 (0.5, 16.8)*
	Portable media player	**Portable video games**	**Smart TV**	**TV viewing**	
All	-23.0 (-35.3, -10.7)	-5.0 (-13.0, 2.8)	0.6 (-4.7, 6.0)	n/a	
Boys	-25.2 (-46.4, -5.1)	-12.6 (-24.5, -0.6)	-4.9 (-13.3, 3.3)		
Girls	-21.4 (-36.9, -5.9)*	2.7 (-7.7, 13.1)	4.7 (-2.3, 11.9)		

n/a, not applicable.* significant sex differences in change ($p < 0.05$).

Table 4 Change in time spent in desktop, tablet and laptop on weekdays and weekend days over two years, stratified by sex. Data are mean (95% Confidence Interval)

	School hours		
	Desktop computer (min/week)	**Tablet (min/week)**	**Laptop (min/week)**
Weekday			
All	6.9 (3.9, 10.0)	-1.2 (-4.8, 2.2)	0.7 (-2.1, 3.6)
Boys	14.5 (9.1, 20.0)	-11.9 (-17.7, -6.4)	-1.6 (-6.6, 3.3)
Girls	1.3 (-2.1, 4.8)*	6.5 (2.0, 11.0)*	2.5 (-0.8, 5.8)
	Non-school hours		
	Desktop computer (min/day)	**Tablet (min/day)**	**Laptop (min/day)**
Weekday			
All	11.4 (5.8, 17.0)	-2.5 (-7.1, 2.0)	11.3 (6.8, 15.7)
Boys	27 (17.7, 36.4)	-1.9 (-9.4, 5.6)	7.0 (-0.2, 14.4)
Girls	-1.4 (-8.1, 5.1)*	-2.9 (-8.8, 2.8)	14.3 (8.8, 19.8)
Weekend			
All	7.7 (0.7, 14.8)	-5.7 (-11.6, 0.2)	9.9 (4.7, 15.1)
Boys	26 (14.5, 37.5)	-9.4 (-18.8, -0.0)	0.4 (-7.7, 8.6)
Girls	-7.8 (-16.4, 0.7)*	-3.1 (-10.7, 4.5)	16.7 (9.9, 23.4)*

n/a, not applicable.

* significant sex differences in change ($p < 0.05$).

Association of socio-demographic factors with change in screen behaviours

Table 5 shows associations between socio-demographic factors and changes in screen behaviours on weekdays. Compared to boys, girls reported greater increases in the duration of phone calls, internet use, use of social network sites and television viewing and smaller increases in time spent playing video game consoles. Compared to those of White ethnicity, adolescents of Black ethnicity reported smaller increases in the duration of internet use, playing video game consoles, watching smart television and television viewing from baseline to follow-up. In addition, compared to White ethnicity, adolescents of Asian and mixed ethnicity reported smaller increases in time spent playing video games.

Table 6 shows associations between socio-demographic factors and changes in screen behaviours on weekend days. Compared to boys, girls reported greater increases in the duration of phone calls, internet use and use of social network sites but smaller increases in playing video game consoles. Compared to White ethnicity participants, adolescents of Black ethnicity reported smaller increases in the duration of internet use, playing video game consoles and using portable media players.

Table 5 Associations of selected sociodemographic factors with two-year change in screen behaviours on weekdays

	Phone calls on mobile phones (n = 2,444)		**Internet use on mobile phones** (n = 2,237)		**Social network sites on mobile phones** (n = 2,651)	
	b (95% CI)	P value	b (95% CI)	P value	b (95% CI)	P value
Sex						
Boys	Ref		Ref		Ref	
Girls	4.1 (0.4, 7.8)	**0.02**	16.7 (5.42, 28.2)	**0.004**	14.3 (6.6, 22)	**0.001**
Socio-economic position						
High	Ref		Ref		Ref	
Middle-to-low	0.1 (-3.8, 4.1)	0.94	11.3 (-0.7, 23.4)	0.06	5.4 (-2.2, 13.1)	0.16
Ethnicity						
White	Ref		Ref		Ref	
Black	1.2 (-4.2, 6.7)	0.66	-26.3 (-42.7, -9.8)	**0.002**	5.0 (-5.9, 16.1)	0.36
Asian	-3.8 (-8.5, 0.9)	0.11	-5.5 (-20.3, 9.2)	0.46	-5.6 (-15.5, 3.4)	0.21
Mixed	0.1 (-5.3, 5.7)	0.95	-0.6 (-17.7, 16.4)	0.93	-0.6 (-11.8, 10.5)	0.90

	Social network sites on other devices (n=2,640)		**Video games console** (n=1,342)		**Portable media player** (n=325)	
	b (95% CI)	P value	b (95% CI)	P value	b (95% CI)	P value
Sex						
Boys	Ref		Ref		Ref	
Girls	-3.4 (-11.1, 4)	0.36	-23 (-33.4, -12.5)	**0.001**	-1.6 (-24.6, 21.4)	0.89
Socio-economic position						
High	Ref		Ref		Ref	
Middle-to-low	3.8 (-3.9, 11.7)	0.33	-1.3 (-8.8, 11.4)	0.80	-21.4 (-47.6, 4.7)	0.10
Ethnicity						
White	Ref		Ref		Ref	
Black	2.6 (-8.5, 13.8)	0.64	-21.6 (-35.9, -7.4)	**0.003**	-32.8 (-68.0, 2.4)	0.06
Asian	1.8 (-7.9, 10.9)	0.75	-18.7 (-30.9, -6.5)	**0.003**	19.7 (-8.4, 47.9)	0.17

Mixed	1.6 (-9.8, 12.9)	0.80	-16.4 (-31.4, -1.4)	**0.03**	-0.9 (-39.2, 37.3)	0.96

	Portable video games (n= 443)		**Smart TV** (n= 1,370)		**TV viewing** (n= 2,924)	
	b (95% CI)	P value	b (95% CI)	P value	b (95% CI)	P value
Sex						
Boys	Ref		Ref		Ref	
Girls	5.2 (-9.4, 19.9)	0.48	8.3 (-1.5, 18.1)	0.09	15.3 (6.8, 23.8)	**0.001**
Socio-economic position						
High	Ref		Ref		Ref	
Middle-to-low	-1.3 (-16.0, 13.3)	0.85	9.2 (-1.7, 20.1)	0.09	-8.8 (-21.6, 3.9)	0.17
Ethnicity						
White	Ref		Ref		Ref	
Black	4.1 (-17.5, 25.8)	0.70	-15.1 (-30.0, -0.3)	**0.04**	-20.0 (-33.6, -6.4)	**0.004**
Asian	15.4 (-2.5, 33.4)	0.09	0.9 (-11.5, 13.3)	0.88	4.3 (-6.6, 15.4)	0.43
Mixed	0.2 (-20.0, 20.5)	0.98	1.6 (-14.2, 17.5)	0.83	5.1 (-8.8, 19.1)	0.47

b, beta coefficient; 95 CI, 95% Confidence Interval; Ref, Reference.

Table 6 Associations of selected sociodemographic factors with two-year change in screen behaviours on weekend days

	Phone calls on mobile phones (n = 2,444)		**Internet use on mobile phones** (n = 2,237)		**Social network sites on mobile phones** (n=2,651)	
	b (95% CI)	P value	b (95% CI)	P value	b (95% CI)	P value
Sex						
Boys	Ref		Ref		Ref	
Girls	6.1 (1.6, 10.6)	**0.008**	24.1 (10.4, 37.7)	**0.001**	23.5 (14.3, 32.7)	**0.001**
Socio-economic position						
High	Ref		Ref		Ref	
Middle-to-low	1.0 (-3.8, 5.8)	0.68	13.5 (-0.8, 27.9)	0.06	1.1 (-8.1, 10.4)	0.80
Ethnicity						
White	Ref		Ref		Ref	
Black	-2.0 (-8.7, 4.7)	0.55	-35.1 (-55.7, -16.5)	**0.001**	5.5 (-7.7, 18.8)	0.41
Asian	-4.5 (-10.3, 1.3)	0.12	-7.4 (-25.0, 10.2)	0.41	-6.4 (-17.9, 4.9)	0.26
Mixed	-0.4 (-7.2, 6.2)	0.89	6.5 (-13.8, 26.8)	0.53	-1.5 (-14.9, 11.8)	0.82
	Social network sites on other devices (n=2,648)		**Video games console** (n =1,342)		**Portable media player** (n=322)	
	b (95% CI)	P value	b (95% CI)	P value	b (95% CI)	P value
Sex						
Boys	Ref		Ref		Ref	
Girls	-5.1 (-14.3, 4.1)	0.27	-24.4 (-37.4, -11.3)	**0.001**	-0.1 (-27.1, 26.8)	0.99
Socio-economic position						
High	Ref		Ref		Ref	
Middle-to-low	3.5 (-6.2, 13.3)	0.47	5.2 (-7.3, 17.9)	0.42	-12.7 (-43.1, 17.5)	0.40
Ethnicity						
White	Ref		Ref		Ref	
Black	8.7 (-5.2, 22.6)	0.21	-23.5 (-41.4, -5.6)	**0.01**	-42.5 (-83.5, -1.6)	**0.04**
Asian	2.5 (-8.7, 13.3)	0.73	-12.8 (-28.0, 2.4)	0.09	17.9 (-14.4, 50.4)	0.27

Mixed	3.0 (-11.3, 17.4)	0.67	-5.9 (-24.7, 12.9)	0.72	9.1 (-36.8, 55.1)	0.69
	Portable video games (n= 443)		**Smart TV** (n= 1,370)			
	b (95% CI)	P value	b (95% CI)	P value		
Sex						
Boys	Ref		Ref			
Girls	13.1 (-5.1, 31.3)	0.15	11.4 (-0.5, 23.4)	0.06		
Socio-economic position						
High	Ref		Ref			
Middle-to-low	-2.7 (-21.3, 15.8)	0.77	12.7 (-0.5, 26.0)	0.06		
Ethnicity						
White	Ref		Ref			
Black	-17.8 (-45.2, 9.4)	0.20	-17.2 (-35.3, 0.8)	0.06		
Asian	15.1 (-7.4, 37.6)	0.18	4.4 (-10.6, 19.6)	0.56		
Mixed	-10.9 (-36.6, 14.8)	0.40	-0.3 (-19.6, 19.0)	0.97		

b, beta coefficient; 95 CI, 95% Confidence Interval; Ref, Reference; n/a, not applicable

Association of socio-demographic factors with change in screen behaviours during school and non-school hours

Table 7 shows associations between socio-demographic factors and change in the use of desktop computers, tablets, and laptop computers during school hours. Compared to boys, girls reported smaller increases in the duration of desktop use. Compared to participants of high socio-economic position, those of middle-to-low socio-economic position reported greater increases in the duration of desktop computer use. Compared to participants of White ethnicity, those of Black ethnicity reported smaller increases in the duration of laptop use.

Table 8 shows associations between socio-demographic factors and change in the use of desktop computers, tablets, and laptops during non-school hours. Compared to boys, girls reported smaller increases in the duration of desktop computer use on weekdays and weekend days but greater increases in laptop use on weekend days. Compared to participants of high socio-economic position, adolescents of middle-to-low socio-economic position reported smaller increases in the duration in laptop use on weekend days. Compared to those of White ethnicity, participants of Asian ethnicity reported greater increases in the duration of laptop use on weekdays and participants of Black ethnicity smaller increases on weekend days.

Table 7 Associations of selected sociodemographic determinants with two-year change in desktop, laptop, and tablet during school hours

	Desktop computer (n= 2,720)		**Tablet** (n=2,720)		**Laptop** (n=2,720)	
	b (95% CI)	P value	b (95% CI)	P value	b (95% CI)	P value
Sex						
Boys	Ref		Ref		Ref	
Girls	-17.4 (-25.2, -9.4)	**0.001**	6.6 (-2.3, 15.5)	0.14	3.8 (-3.1, 10.8)	0.24
Socio-economic position						
High	Ref		Ref		Ref	
Middle-to-low	9.9 (2.2, 17.6)	**0.01**	-4.1 (-12.8, 4.4)	0.34	-2.0 (-9.1, 5.0)	0.57
Ethnicity						
White	Ref		Ref		Ref	
Black	-2.2 (-13.2, 8.7)	0.57	-10.2 (-22.6, 2.2)	0.10	-10.8 (-20.9, -0.7)	**0.03**
Asian	-3.5 (-13.1, 6.0)	0.47	5.7 (-5.3, 16.7)	0.31	3.0 (-5.6, 11.7)	0.49
Mixed	-6.3 (-17.2, 4.6)	0.25	-4.3 (-16.7, 8.0)	0.49	-6.6 (-16.8, 3.5)	0.20

b, beta coefficient; 95 CI, 95% Confidence Interval; Ref, Reference.

Table 8 Associations of selected sociodemographic factors with two-year change in desktop, laptop, and tablet during non-school hours, stratified by day of the week

	Weekday					
	Desktop computer (n=1,039)		**Tablet** (n=1,468)		**Laptop** (n=1,811)	
	b (95% CI)	P value	b (95% CI)	P value	b (95% CI)	P value
Sex						
Boys	Ref		Ref		Ref	
Girls	-25.3 (-38.2, -12.4)	**0.001**	-2.8 (-13.7, 7.9)	0.60	8.1 (-2.3, 18.7)	0.12
Socio-economic position						
High	Ref		Ref		Ref	
Middle-to-low	2.9 (-10.6, 16.4)	0.67	1.7 (-9.6, 13.2)	0.75	-9.1 (-20.3, 2.0)	0.11
Ethnicity						
White	Ref		Ref		Ref	
Black	-4.5 (-23.3, 14.1)	0.63	1.7 (-14.0, 17.5)	0.82	0.7 (-14.8, 16.3)	0.92
Asian	-4.0 (-19.5, 11.5)	0.61	10.1 (-3.2, 23.5)	0.13	14.1 (1.2, 26.9)	**0.03**
Mixed	-2.2 (-22.9, 18.3)	0.82	7.2 (-9.2, 23.7)	0.39	-5.7 (-21.9, 10.4)	0.49
	Weekend					
	Desktop computer (n=1,027)		**Tablet** (n=1,454)		**Laptop** (n=1,803)	
	b (95% CI)	P value	b (95% CI)	P value	b (95% CI)	P value
Sex						
Boys	Ref		Ref		Ref	
Girls	-42.1 (-58.1, -26.1)	**0.001**	8.0 (-5.6, 21.8)	0.25	17.7 (5.4, 30.3)	**0.005**
Socio-economic position						
High			Ref		Ref	
Middle-to-low	4.6 (-12.4, 21.6)	0.59	5.2 (-9.2, 19.7)	0.47	-16.2 (-29.4, -3.0)	**0.01**
Ethnicity						
White	Ref		Ref		Ref	

Black	-15.9 (-39.7, 7.7)	0.18	-5.9 (-25.9, 14.0)	0.56	-18.3 (-36.7, -0.0)	**0.05**
Asian	-12.4 (-31.7, 6.9)	0.20	12.2 (-4.5, 29.0)	0.09	10.6 (-4.3, 25.5)	0.17
Mixed	-27.6 (-54.0, -1.18)	**0.04**	9.3 (-11.5, 30.3)	0.38	-1.7 (-20.9, 17.2)	0.85

b, beta coefficient; 95 CI, 95% Confidence Interval; Ref, Reference.

Discussion

This study described changes in adolescents' screen activities over a 2-year period and examined variation between socio-demographic subgroups. Time spent in most screen behaviours increased from baseline to follow-up apart from tablet and portable video game use which remained relatively stable. This study found evidence that age-related changes in screen behaviour may vary by sex and ethnicity but not by socio-economic position. Given that screen use tracks modestly into adulthood (Biddle *et al.*, 2010), approaches to balance time spent in screen behaviours may be important for this age group.

Most of the screen behaviours considered increased over the 2-year period of follow-up, ranging from a 5-minute/day increase in television viewing to a 60-minute/day increase in internet use on mobile phones on weekdays. On weekend days, the change in screen behaviours ranged from an 11-minute/day increase making phone calls to an 85-minute/day increase using the internet on mobile phones. These findings are consistent with a recent systematic review, which also showed an age-related increase in television viewing, video game play and computer use (Kontostoli *et al.*, 2021). In addition, two longitudinal studies reported increases in time spent in gaming, communicating and socializing online as well as in internet use over the 2-year (12 – 13 years old) and 4-year (14 – 15 years old) periods of follow up respectively (Kemp, Parrish and Cliff, 2020; Thomas *et al.*, 2020). The results suggest that there is a change in device use as adolescents age, most notably a reduction in television viewing and an increase in mobile phone use. The shift in screen use preference from television to mobile phone may be accompanied by a change in the social and environmental context in which the behaviour is undertaken. Compared to television viewing, mobile phone use and video game play are more likely to be done alone, providing fewer opportunities for co-viewing with parents and other family members. As a result, there might be implications not just for the impact of screen use in adolescents, but also for family time and social interaction. Further, adolescents' personal traits and the social and environmental context in which they undertake screen behaviours are known to influence young people's wellbeing (Olson, 2010). Therefore, future research should examine how the social context of screen time changes during adolescence and how this impacts upon markers of health and wellbeing.

Time spent using a tablet or portable video game console remained stable from baseline to follow-up. This is consistent with recent data from the UK that showing that tablet ownership peaks around the age of 10 and begins to plateau around the age of 10 to 12, around the same age that mobile phone

ownership and use begins to rise. In 2019, the prevalence of tablet ownership was 57% in children aged 5 – 7 years old, 66% in children aged 8 – 11 years old and 60% in adolescents aged 12 – 15 years old (Ofcom, 2021). Portable video game use also remained stable in American adolescents aged 13 – 18 years in 2015 (Rideout and Robb, 2019). The plateau in use of tablets and portable games consoles occurs in parallel to the increased use of mobile phones during this period, which may be better suited to adolescents changing needs and interests. Changes in device use accompany other social and behavioural developments that characterise adolescence, including increasing autonomy and independence from parents and greater emphasis on peer relationships. Interventions aimed at supporting young people in developing healthy screen behaviour patterns will need to accommodate changes in device ownership and preference with age.

The analysis showed that age-related changes in screen behaviours differed between boys and girls. The increase in time spent making phone calls, or using the internet, social network sites and television viewing was greater in girls than boys. Conversely, the increase in time spent in playing video games on a console and using desktop computers was greater in boys than girls. These findings are consistent with longitudinal data in Australian adolescents that showed electronic game use increased in boys whereas television viewing and social network use increased in girls over a 2-year period (Thomas *et al.*, 2020). The evidence is consistent that video game play is greater in boys whilst social network use is greater in girls, but both sexes use these tools to socialise virtually with their peers (Leonhardt and Overå, 2021; Thomas *et al.*, 2021). There is evidence that girls may experience social pressure to keep up to date with their peers' social media activity (fear of missing out), prompting greater usage of these platforms (Muscanell and Guadagno, 2012; Moore and Craciun, 2020). Additionally, some girls report negative experiences of playing video games, such as stress when playing against male counterparts, harassment and bullying (Lopez-Fernandez *et al.*, 2019). Boys, on the other hand, may be more likely to face difficulties in stopping playing video games as they enjoy the social relationships they have developed in the virtual world (Ryan, Rigby and Przybylski, 2006; Cahill, 2014). In exploring the role of social media and video games in enabling interaction between peers, the literature distinguishes the active and passive forms of communication. Passive use refers to browsing, scrolling and looking at content of others, and has been associated with negative impacts on well-being, such as depressed mood (Thorisdottir *et al.*, 2019). In contrast, active use refers to being engaged with media content (chatting, sharing photos, or status updates with a specific audience) and is related to more positive effects (Thorisdottir *et al.*, 2019). Further research to better understand the extent to which young people engage in passive and

active forms of communication across different devices, and associations with health and well-being, will help to inform intervention design. This will require the development of measurement methods, such as flexible questionnaires that capture new screen devices and time-use diaries, that allow screen time to be examined in more nuanced ways, distinguishing different activities and timings of use (Orben, 2020). Given that adolescents are more vulnerable to negative wellbeing than adults (Dienlin and Johannes, 2020), research to disentangle the type of communication by sex is of high importance to inform public health recommendations and interventions. Until the field of screen behaviour research develops further, the development of interventions to support a balanced duration of screen use as adolescents age may be appropriate.

Adolescents of Black ethnicity reported smaller increases for most of the studied screen behaviours than those of White ethnicity over the 2-year period. This is counter to previous longitudinal research, which showed that those of non-White ethnicity exhibited larger increases of screen time compared to people of White ethnicity (Brodersen *et al.*, 2007; De Craemer *et al.*, 2018). For example, data from the European Youth Heart Study showed that children of White ethnicity had lower odds of being in a higher category of computer time than children of non-White ethnicity. The reason for these contrasting findings is unclear but may be related to the differing approaches to classification of participant ethnicity; a key strength of the SCAMP cohort is the ethnic diversity of the sample, which enabled us to look at specific ethnic minority groups rather than collapsing amongst all non-White ethnicities. Further research to understand ethnic differences in adolescent screen-time is warranted (Kontostoli *et al.*, 2021), accompanied by research to explore the attitudes and norms related to screen behaviours across cultures (Ventura, Loken and Birch, 2009). It may be most revealing to examine parental and socio-cultural factors as mediators in any differences in screen behaviour associated with ethnicity, supporting the development of culturally sensitive and specific interventions.

There was no evidence for a difference in screen-time change between participants of different socio-economic position. Few previous studies have examined socio-economic variation in age-related screen-time change, but in children aged 6-9 years, those with less educated parents reported a higher increase in total screen time (a sum of time spent in television viewing, console game and computer) compared to those with more educated parents (Salway *et al.*, 2019). As noted previously, adolescence is a developmentally important period during which attitudes and behaviours are increasingly shaped by peers. Therefore, socioeconomic indicators based on parental characteristics

may become less valuable in explaining variations in behaviour. As research on physical activity has shown, the pathways through which different markers of socio-economic position may be associated with young people's health and behaviour are complex (Love *et al.*, 2019). Further research in diverse populations and using a range of socio-economic markers will help to disentangle the social patterning of screen-behaviours, which is likely to be equally complex.

Findings should be interpreted with reference to the following strengths and weaknesses. A key strength of this study is the ethnically diverse sample (45% White and 27% Asian) which is representative of the population of London (UK capital city; 45% White and 30% Asian). In addition, the longitudinal design enabled us to examine changes in screen behaviours and types of devices used over the developmentally important period of adolescence, a topic that has been understudied to date. Moreover, changes in screen behaviours were examined during school and non-school hours and separately for weekdays and weekend days, providing context-specific evidence to inform intervention design. The following limitations should be acknowledged. Firstly, the findings are derived from a British population and, as such, conclusions may not be fully generalizable to other nations, especially those from low-to-middle income countries with differing patterns of screen ownership. Secondly, self-reported data are susceptible to social desirability and recall biases which may lead to overestimation or underestimation of duration of time spent on screen behaviours. Thirdly, the screen-time questionnaire used in this study has not been empirically tested for reliability or validity for all the examined screen behaviours although a validation study for the SCAMP cohort suggests that self-reported usage of phone calls adequately distinguishes between true high and low use in SCAMP participants (Mireku *et al.*, 2018). The study examined self-reported mobile cumulative call time duration spent among adolescents from SCAMP and matched these data with records provided by mobile network operators (n = 350). The extent of agreement between self-reported mobile phone use and mobile operator traffic data use was evaluated using Cohen's weighted Kappa (κ) statistics. There was slight agreement between self-reported and mobile operator traffic data for call frequency and call duration during weekdays (κ = 0.08, 95% CI: 0.03–0.15). Fourthly, there was substantial missing data for time spent in portable media and portable video game analyses. Finally, analysis and interpretation focussed on age-related (within-person) changes in behaviour, but it should be acknowledged that they may, in part at least, reflect wider secular changes in device ownership and use over the 2-year study period. For example, the popularity of portable media players such as iPods and mp3 players declined over the period of study as their functionality became

incorporated into mobile phones; changes in their use may reflect such trends rather than an age-related change in device preference per se.

Conclusion

This study examines how 2-year change in screen behaviours on portable and non-portable devices is associated with socio-demographic factors in adolescents. Findings show that time spent in most of the studied behaviours increased with age, with evidence that the increase operates differently across sex and ethnicity. Although further research is needed to better understand how screen behaviours are associated, both positively and negatively, with physical and mental health and wellbeing, findings point to an increase in risk across early adolescence. Therefore, these findings provide useful insight for the development of interventions to support healthier approaches to screen use in this population.

Chapter 4: The diurnal pattern and social context of screen behaviours in adolescents: a cross-sectional analysis of the Millennium Cohort Study

Introduction

Chapter 2 showed an age-related increase in various forms of sedentary behaviour and identified gaps in current evidence pertaining to socio-demographic subgroups and contemporary sedentary behaviours. Chapter 3 aimed to build evidence on age-related change in contemporary screen behaviours and found a change in device use as adolescents age, most notably a reduction in television viewing and an increase in mobile phone use. It also found that the increase operates differently across sex. Sedentary behaviour is likely influenced by factors across all levels of the ecological model. The social environment is one of the many levels that can influence sedentary behaviour. Gaining knowledge which behaviours increase, when and with who can provide insight to intervention designs. Therefore, this chapter seeks to understand the distribution of screen behaviours across a 24-hour period and who young people spend time in screen behaviours with using UK data collected when adolescents aged 14 years old.

Background

Screen behaviours are highly prevalent in young people and excessive screen use may contribute to an increased risk of cardio-metabolic syndrome, mental health disorders, and poor academic attainment (Chastin *et al.*, 2015). The most prevalent screen activities include television viewing, tablet and smart-phone use (Arundell *et al.*, 2019), with data showing that more than half of young people exceed current screen-time recommendations of 2 hours a day (Thomas *et al.*, 2019). Considering that these behaviours track into adulthood (Biddle *et al.*, 2010), it is important for interventions to target them early in life.

Changing health behaviours requires an understanding of the factors that influence behaviour and the context in which they occur. The socio-ecological framework serves as a useful model for outlining the factors that might impact engagement in screen behaviours. This is because socio-demographic, environmental, and social factors play a key role in determining the accumulation of individuals' screen time (Coombs *et al.*, 2013; Temmel and Rhodes, 2013; Stierlin *et al.*, 2015). It is likely that humans behave differently in different contexts due to their innate ability to transform and connect in different ways at different times with a changing environment (Duncan, Jones and Moon, 1996).

Several recent studies have examined the social context in which young people's screen behaviour occurs, highlighting possible locations for the delivery of behavior change interventions (Arundell *et al.*, 2016a; Haycraft *et al.*, 2020). For example, previous research has shown that adolescents who spent more time alone after school reported higher screen-time than those who were with family or friends (Haycraft *et al.*, 2020). Much of this previous work, however, has focused on composite measures of screen time, aggregating data on different types of behaviour, such as television viewing and computer use. The Royal College of Paediatrics and Child Health advise against the use of composite screen-time markers in light of emerging evidence that the different behaviours may be differentially associated with health and wellbeing (Commons, 2018). To mitigate health risks, the development of interventions therefore should be informed by understanding of the context in which specific screen-based activities take place.

In addition to understanding the social and environmental context of screen-based activity, understanding its distribution across the day may also be informative for intervention design, highlighting periods of the day when specific behaviours are likely to occur. Previous research has shown that accelerometer measured time spent sedentary was greater after-school than before or during school (McLellan *et al.*, 2019), with around half of this time spent using screens (Arundell *et al.*, 2016a). Evidence also suggests that the afternoon and evening period during weekends represents the largest accumulation of sedentary time (McLellan *et al.*, 2019). However, the understanding is limited by the paucity of evidence regarding the timing of different types of screen activities throughout the day. There is evidence that sedentary behaviour patterns differ between boys and girls and that the determinants of these behaviours may also differ by sex (Stierlin *et al.*, 2015), yet we have limited information about how contextual factors may vary by sex. A recent study reported no difference by sex in where adolescents spent their after-school and weekday evening periods, or who they spent time with, but screen time was derived as a composite measure rather than by specific activity in that work, potentially masking true variation (Haycraft *et al.*, 2020).

There is a need to better understand the timing and contexts in which screen behaviours take place if interventions to address them are to be targeted precisely. This evidence will help to identify which agents of change to target (i.e. parents, peers), where interventions should be implemented (e.g. home, school) and/or the time of day (e.g. preschool, evening) that intervention strategies should be activated (Stanley, Ridley and Dollman, 2012). The aim of this study, therefore, is to describe diurnal

patterns in adolescents' screen-based behaviours and examine the association of social context with these behaviours at weekdays and weekend days.

Methods

Sample and data collection

Data are from the Millennium Cohort Study (MCS), a national longitudinal birth cohort study run by the Centre for Longitudinal Studies at the University College London. The MCS examines the social, economic, and health related circumstances of young people born in 2000-2002, recruited from all four countries of the UK (England, Scotland, Wales and Northern Ireland) (Connelly and Platt, 2014; Ipsos Mori, 2017). The MCS was nationally representative at inception and 18,552 families (18 818 children) were recruited at baseline. Data collection has taken place when participants were 9 months, and 3, 5, 6, 7, 14, 17 years of age. This cross-sectional analysis uses data from the sixth wave of assessment (MCS6; data collection: January 2015-April 2016), when participants were aged 14 years. In MCS6, 15,415 families were contacted for participation; 11,884 participants from 11,726 families provided partial or complete data. Parents and cohort members provided written and verbal consent prior to completing the survey (Ipsos MORI, 2016). The MCS6 was approved by the National Research Ethics Service, Research Ethics Committee London – Central (REC ref: 13/LO/1786). Data were anonymised and obtained from the UK Data Service (http://doi.org/10.5255/UKDA-SN-8156-7).

Time-use diary

Participants were invited to complete a time-use diary, available in 3 formats: online via the web, App via tablet or phone, and paper. Sixty-four percent of participants selected the App diary format, 29% used the online version and 7% the paper diary. Participants completed the diary for two randomly chosen days (one weekday and one weekend day) with behaviour recorded in 10-minute slots from 4am to 4am the next day. For each slot, participants indicated their main activity, selecting from a pre-specified list of 44 activities, nested within 12 categories (the full list of activity codes is presented in Appendix 13). In addition to reporting their main activity, cohort members also reported who they were with at that time, selecting from one or more of the following five options: alone, parents, siblings, friends, other adults.

Six screen-based activities were chosen for this analysis: electronic games and Apps, television viewing, phone calls, emails/texts, visiting social networking sites and internet browsing. Data were

aggregated to mean minutes per hour spent in each activity, separately for weekdays and weekend days.

Reports of adolescents' social context (i.e., 'who they were with') were coded into six categories: alone only, parents only, friends only, siblings only, parents and siblings only and other grouping (i.e., a combination of parents and friends and/or parents, friends and other adults).

Covariates

Participants sex, family income, ethnicity, body mass index (BMI) and home location (rural or urban classification) were included as potential covariates in the analysis (Fitzsimons, 2017). Indicators for home location were derived by geographically linked data across the four countries that specified whether participants were located in rural/urban areas based on population density (Department for Environmental Food & Rural Affairs in collaboration with the Office for National Statistics, 2016). Family income was measured using the Organisation for Economic Co-operation and Development (OECD) equivalised income quintiles, based on parent-reported household income. Ethnicity was parent-reported and categorised as White, Mixed, Indian, Pakistani and Bangladeshi, Black or Black British, and Other Ethnic group (including Chinese). Weight and height were measured by trained research assistants. Body mass index (BMI) was calculated as weight divided by height squared (kg/m^2) and International Obesity Task Force (IOTF) thresholds were used to categorise participants as underweight/normal weight, overweight and obese (Cole *et al.*, 2000).

Statistical analysis

Analyses were conducted using STATA 16.0 (Stata Corporation, Texas, USA), with survey commands used to account for the stratified clustered design of MCS. Due to differences in the social and environmental contexts in which participants were immersed, analyses were conducted separately for week and weekend days. To describe diurnal patterns in each of the selected behaviours, data were aggregated to summarise duration (minutes) in each behaviour for each hour of the 24h period of assessment. Social context information is presented as the proportion of time reported in each of the 6 contexts, separately for each behaviour of interest. Screen behaviour duration data were highly skewed; therefore, behavioural outcomes were dichotomised (no screen activity vs. screen activity) in the analysis of associations with social context. In addition, due to infrequent reports in phone calls, text/emails, using social network sites and internet browsing it was created two composite outcomes for use in this analysis: (1) phones, texts, and emails, (2) using social network sites and internet browsing. Reports of television viewing and electronic games/apps were analysed individually.

Multilevel multivariable logistic regression was used to assess associations between social contexts (i.e., who the adolescents were with) and screen activities. All models were adjusted for weight status, ethnicity, family income and home location. In preliminary analyses, we examined whether associations between social context and screen behaviours were moderated by sex, sibling status, ethnicity, socioeconomic position and family structure. Interaction terms were non-significant in all instances except for sex. Accordingly, all analyses were conducted separately for boys and girls. To account for the limited occurrence of screen-activities before and during school hours, weekday analysis was restricted to the after-school period (15.00-23.00). Analyses of weekend data focussed on the full 24h period.

Results

Data were available for 9,251 diaries, of which 1,431 were excluded due to missing data on social context and 940 were excluded due to missing data on diurnal pattern. Figure 9 shows diary and data inclusion. The analytical samples for diurnal and social context analyses were n=8,311 and n=7,829 respectively. Drop-out analysis indicated that participants included in the analyses were more likely to be of white ethnicity (P <0.001), have normal weight (P <0.05) and come from families with higher income (P <0.05) compared to those who were excluded.

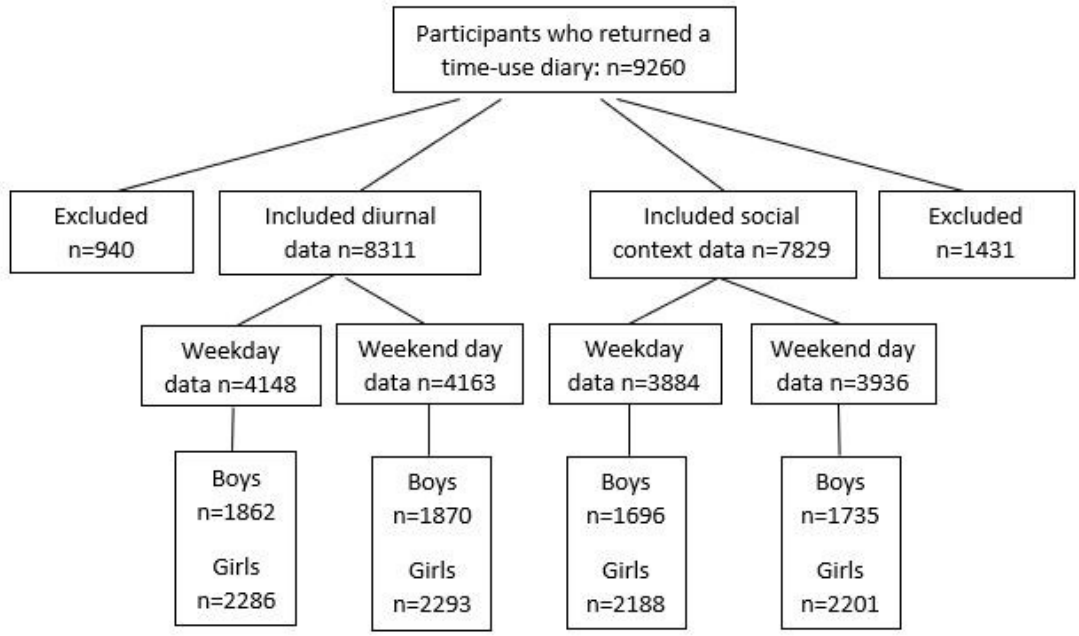
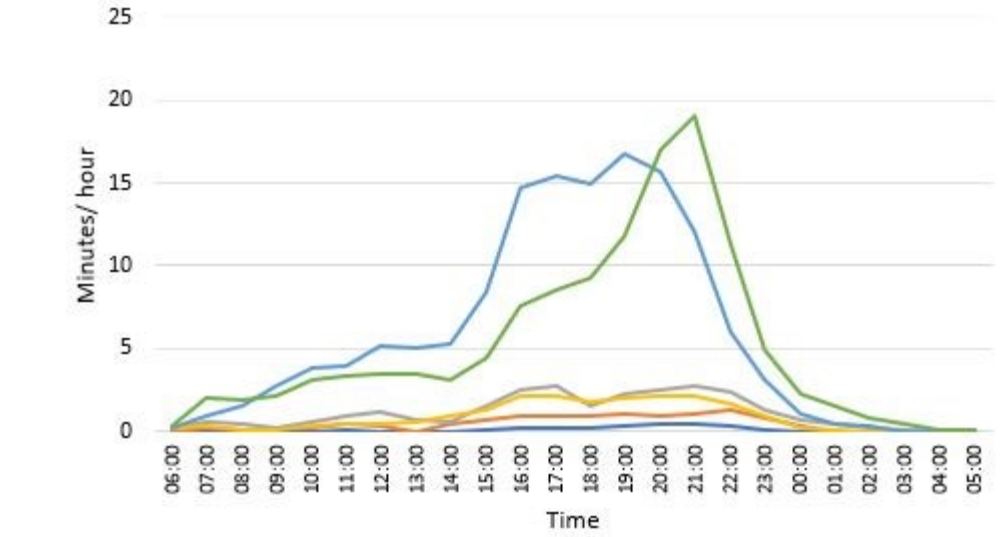


Figure 9 Participants who provided diurnal and social context data

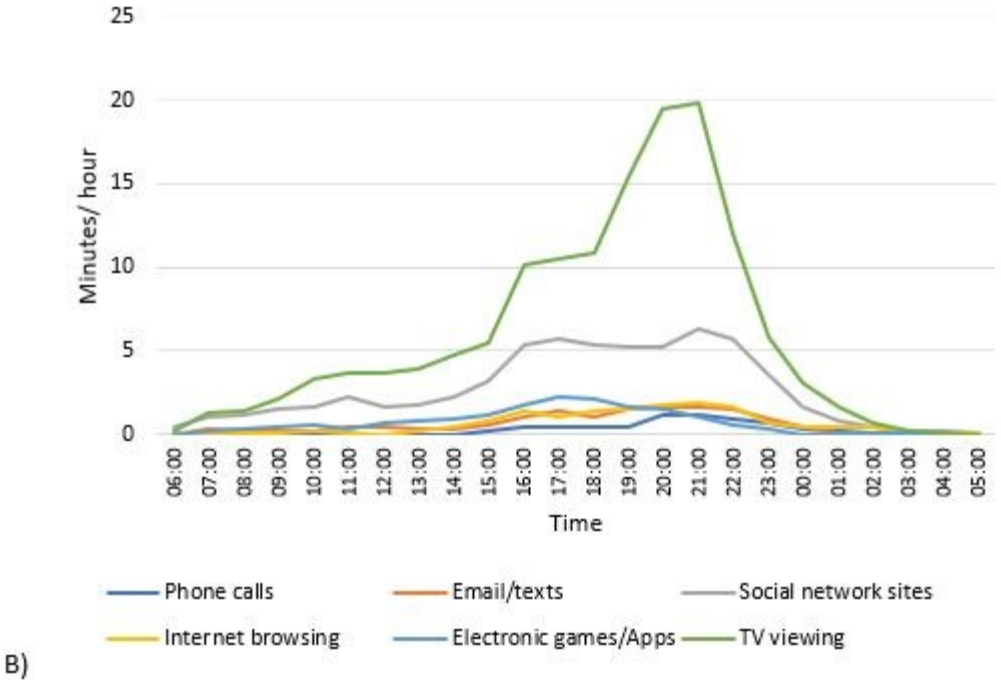
Diurnal patterns in screen activities

Figure 10 shows time spent in screen activities on a weekday, separately for boys and girls. Between midnight and 06:00, all screen behaviours accounted for less than 5 minutes in every hour. The most prevalent screen behaviour was television viewing in both sexes, followed by electronic games/apps in boys and using social networking sites in girls. The time spent viewing television was greatest in the evening, rising gradually from approximately 15:00 onwards to a peak of just under 20 minutes between 21:00 and 22:00 for both sexes. In boys, the time spent using electronic games/Apps was greatest in the late afternoon and evening hours, rising from approximately 14:00 onwards to a peak of 15-17 minutes per hour between 16:00 and 19:00. The time spent using social network sites ranged of 5-7 minutes for girls. Time spent on the phone, sending emails / texts and browsing the internet peaked between the hours of 16:00 and 22:00, but remained low at approximately 2 minutes per hour for both sexes.

Figure 11 shows time spent in screen activities on a weekend day, separately for boys and girls. Between midnight and 06:00 all screen behaviours accounted for less than 1 minute in every hour. The most prevalent screen behaviour was television viewing in both sexes, followed by electronic games/apps in boys and using social networking sites in girls. The time spent viewing television was greatest in the evening, but rose gradually from approximately 08:00 onwards, peaking at approximately 23 minutes between 20:00 and 21:00 for both sexes. In boys, use of electronic games/Apps was common thorough most of the waking day, averaging 10-15 minutes per hour between 11:00 and 21:00. In girls, use of social network sites was spread throughout the day accounting for 4-5 minutes per hour from 09:00-23:00. In both sexes, time spent on the phone, sending email/texts and browsing the internet remained low at approximately 2 minutes per hour throughout the day.

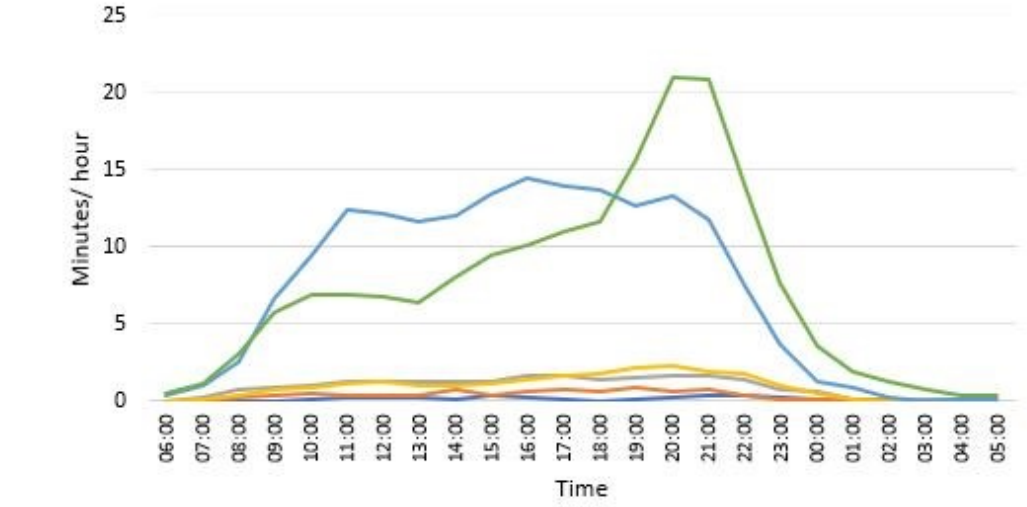


A)

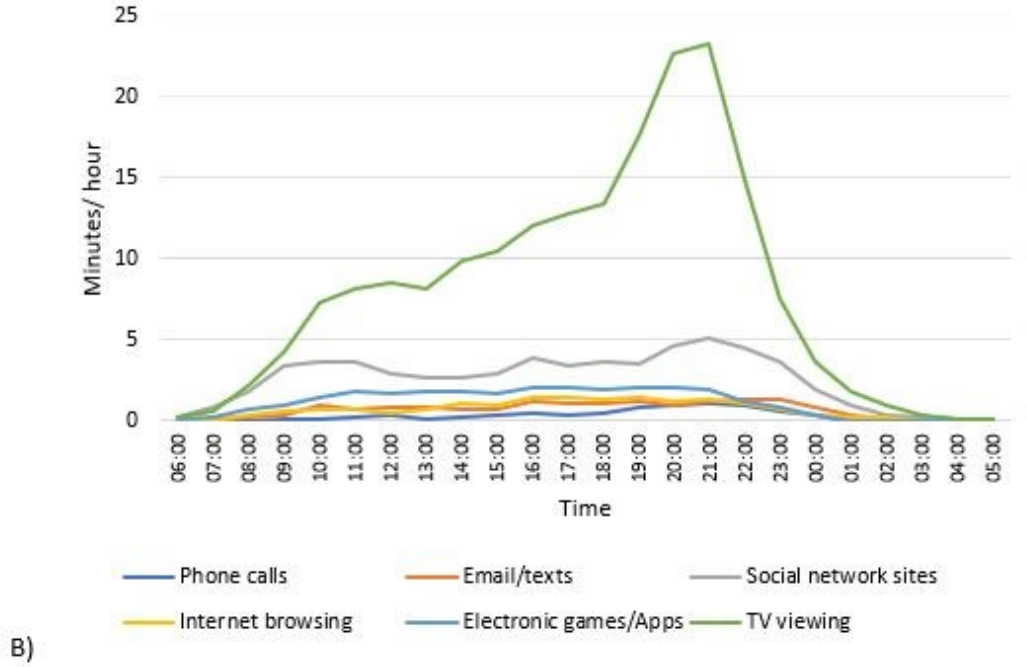


B)

Figure 10 Minutes per hour spent in screen behaviours on weekdays: A) boys, B) girls



A)



B)

Figure 11 Minutes per hour spent in screen behaviours on weekend days: A) boys, B) girls

Social contexts in screen behaviours

Figures 12 and 13 show social context of screen behaviours stratified by sex on a weekday and weekend day respectively. All the behaviours considered were undertaken alone for more than 50% of the time, except for television viewing and phone calls at the weekend (boys only). Secondary to being alone, the most frequently reported contexts were 'friends' and 'parents', but these accounted for less than 20% of time spent in each behaviour. Approximately 40% of the time spent in television viewing, was undertaken alone, 20% of the time with parents only and 20% parents & siblings only. The only categories of behaviour frequently undertaken with friends were playing electronic games or making phone calls either on a weekday or a weekend day.

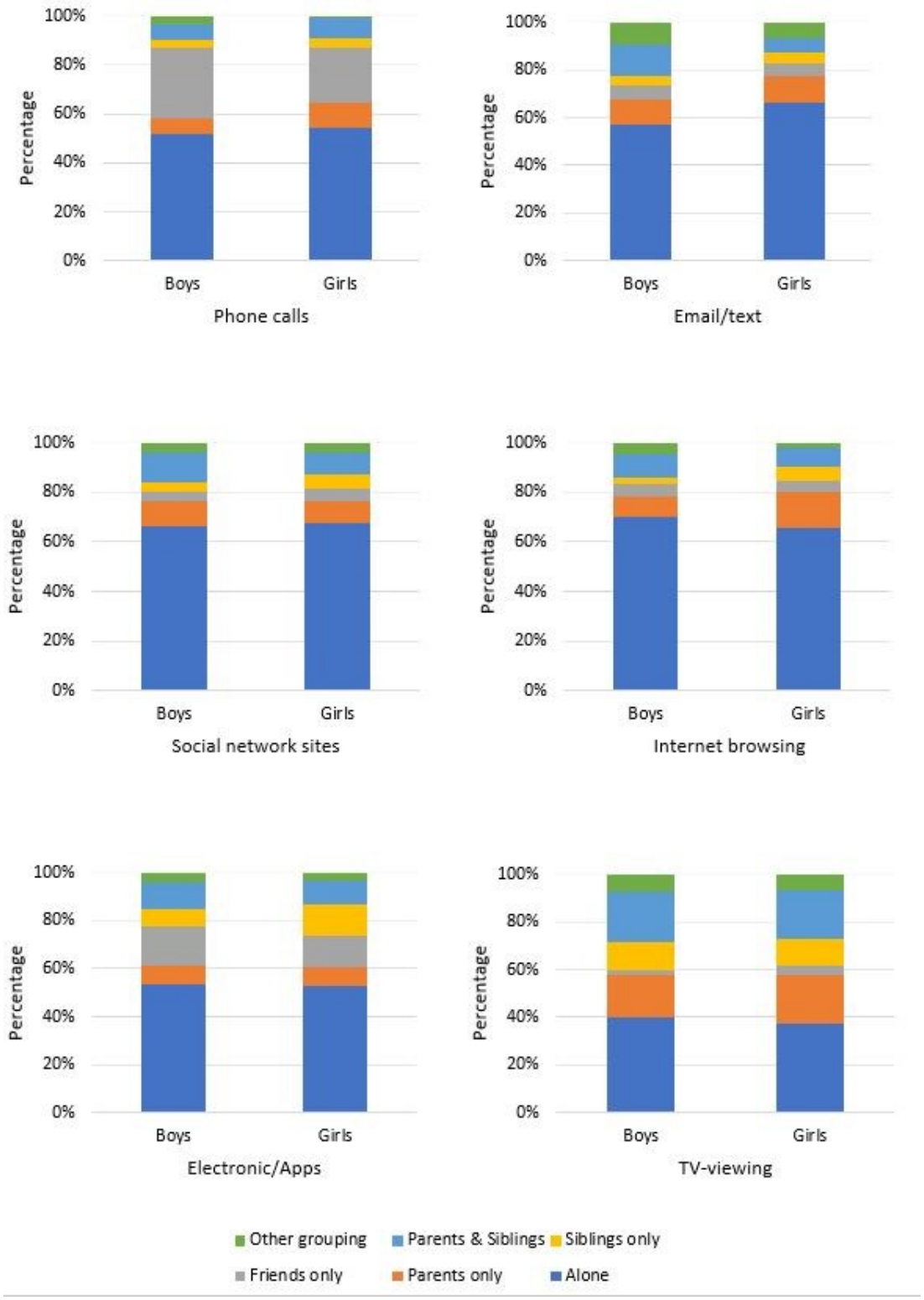


Figure 12 Social context of screen behaviours on a weekday, stratified by sex

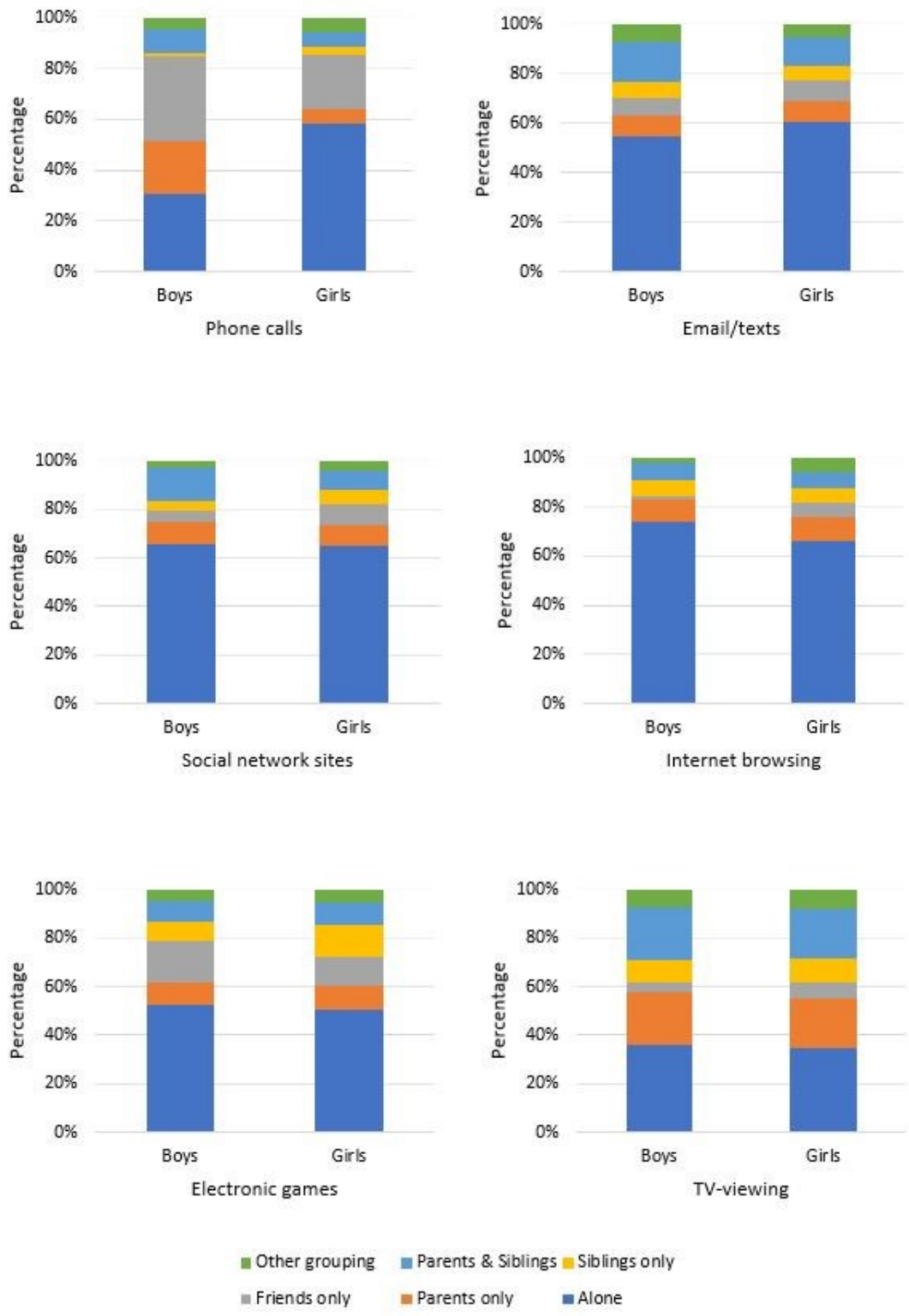


Figure 13 Social context of screen behaviours on a weekend day, stratified by sex

Associations between social contexts and screen behaviours on weekdays and weekend days

Associations between social contexts and screen-based activities on weekdays and weekend days stratified by sex are presented in Tables 9 and 10. Compared to the reference category of being alone, all social contexts were associated with lower odds of undertaking any of the behaviours studied on weekdays, with differences being highly statistically significant. In girls only, being with siblings was associated with higher odds of playing electronic games compared to being alone. Being with parents or siblings only and parents & siblings was associated with higher odds of time spent in television viewing on a weekday in boys and girls.

On weekend days, compared to the reference category of being alone, all social contexts were associated with lower odds of undertaking any of the behaviours studied in boys and girls, with most of the differences being highly statistically significant. In boys only, being with friends only was associated with higher odds of time spent in phone calls/emails compared to being alone. Being with friends only or siblings only was associated with higher odds of time spent in electronic games in both boys and girls, whilst being with parents or siblings only, parents & siblings and other grouping was associated with higher odds of time spent in television viewing in boys and girls.

Sensitivity analyses were conducted excluding data collected during August, corresponding to the main school summer holiday in the UK. The overall pattern of findings did not differ meaningfully to our main analysis either for weekdays or weekend days.

Table 9 Cross-sectional association between social contexts and screen behaviours on a weekday in boys (n=1805) and girls (n= 2180)

Phone calls and Email/texts				
	Boys		Girls	
	OR (95% CI)	P value	OR (95% CI)	P value
Alone	Reference group		Reference group	
Parents only	0.43 (0.21, 0.84)	0.01	0.28 (0.16, 0.47)	<0.001
Friends only	0.34 (0.15, 0.78)	0.01	0.30 (0.17, 0.51)	<0.001
Siblings only	0.52 (0.36, 0.74)	<0.001	0.59 (0.22, 1.06)	0.08
Parents & siblings	0.25 (0.14, 0.34)	<0.001	0.30 (0.25, 0.37)	<0.001
Other grouping	0.23 (0.08, 0.65)	0.005	0.08 (0.03, 0.21)	<0.001
Social network and Internet browsing				
	Boys		Girls	
	OR (95% CI)	P value	OR (95% CI)	P value
Alone	Reference group		Reference group	
Parents only	0.22 (0.13, 0.37)	<0.001	0.22 (0.16, 0.32)	<0.001
Friends only	0.04 (0.02, 0.09)	<0.001	0.05 (0.03, 0.09)	<0.001
Siblings only	0.28 (0.13, 0.58)	0.001	0.40 (0.26, 0.61)	<0.001
Parents & siblings	0.22 (0.14, 0.35)	<0.001	0.19 (0.14, 0.27)	<0.001
Other grouping	0.08 (0.06, 0.10)	<0.001	0.09 (0.05, 0.16)	<0.001
Electronic games				
	Boys		Girls	
	OR (95% CI)	P value	OR (95% CI)	P value
Alone	Reference group		Reference group	
Parents only	0.21 (0.15, 0.32)	<0.001	0.30 (0.13, 0.70)	0.006
Friends only	0.67 (0.46, 0.96)	0.03	0.56 (0.43, 0.74)	<0.001
Siblings only	0.80 (0.70, 0.91)	<0.001	2.03 (1.58, 2.60)	<0.001
Parents & siblings	0.23 (0.16, 0.33)	<0.001	0.46 (0.36, 0.59)	<0.001
Other grouping	0.15 (0.13, 0.18)	<0.001	0.14 (0.09, 0.21)	<0.001
TV viewing				
	Boys		Girls	
	OR (95% CI)	P value	OR (95% CI)	P value
Alone	Reference group		Reference group	
Parents only	2.28 (1.66, 3.13)	<0.001	2.57 (2.11, 3.14)	<0.001
Friends only	0.06 (0.03, 0.12)	<0.001	0.12 (0.09, 0.17)	<0.001
Siblings only	3.62 (2.47, 5.32)	<0.001	3.00 (2.34, 3.86)	<0.001
Parents & siblings	2.85 (2.15, 3.80)	<0.001	2.48 (2.06, 2.98)	<0.001
Other grouping	0.78 (0.69, 0.89)	<0.001	0.64 (0.50, 0.83)	0.001

OR, Odd Ratio; 95% CI, 95% Confidence Interval.

Table 10 Cross-sectional association between social contexts and screen behaviours on a weekend day in boys (n=1805) and girls (n= 2180)

Phone calls and Email/texts				
	Boys		Girls	
	OR (95% CI)	P value	OR (95% CI)	P value
Alone	Reference group		Reference group	
Parents only	0.80 (0.65, 0.97)	0.02	0.53 (0.36, 0.77)	<0.001
Friends only	1.85 (1.59, 2.15)	<0.001	0.93 (0.60, 1.42)	0.74
Siblings only	1.02 (0.48, 2.16)	0.94	0.60 (0.37, 0.98)	0.04
Parents & siblings	0.88 (0.46, 1.67)	0.70	0.52 (0.33, 0.81)	0.004
Other grouping	0.72 (0.55, 0.95)	0.02	0.37 (0.22, 0.64)	<0.001
Social network and Internet browsing				
	Boys		Girls	
	OR (95% CI)	P value	OR (95% CI)	P value
Alone	Reference group		Reference group	
Parents only	0.64 (0.57, 0.72)	<0.001	0.47 (0.43, 0.63)	<0.001
Friends only	0.17 (0.10, 0.35)	<0.001	0.42 (0.31, 0.57)	<0.001
Siblings only	0.94 (0.56, 1.59)	0.84	0.64 (0.43, 0.94)	0.02
Parents & siblings	0.48 (0.42, 0.54)	<0.001	0.26 (0.19, 0.36)	<0.001
Other grouping	0.23 (0.13, 0.40)	<0.001	0.22 (0.14, 0.33)	<0.001
Electronic games				
	Boys		Girls	
	OR (95% CI)	P value	OR (95% CI)	P value
Alone	Reference group		Reference group	
Parents only	0.59 (0.45, 0.79)	<0.001	1.17 (0.99, 1.37)	0.05
Friends only	3.23 (2.36, 4.44)	<0.001	3.12 (1.59, 6.09)	0.001
Siblings only	2.13 (1.43, 3.19)	<0.001	4.67 (2.78, 7.86)	<0.001
Parents & siblings	0.41 (0.30, 0.55)	<0.001	0.95 (0.61, 1.49)	0.84
Other grouping	0.46 (0.30, 0.72)	0.001	0.70 (0.57, 0.86)	<0.001
TV viewing				
	Boys		Girls	
	OR (95% CI)	P value	OR (95% CI)	P value
Alone	Reference group		Reference group	
Parents only	4.79 (3.82, 6.01)	<0.001	4.61 (3.82, 5.57)	<0.001
Friends only	0.51 (0.33, 0.77)	0.002	0.96 (0.73, 1.27)	0.80
Siblings only	5.43 (3.98, 7.41)	<0.001	4.59 (3.53, 5.97)	<0.001
Parents & siblings	4.40 (3.49, 5.57)	<0.001	5.01 (4.11, 6.10)	<0.001
Other grouping	1.79 (1.66, 1.93)	<0.001	1.51 (1.18, 1.94)	0.001

OR, Odd Ratio; 95% CI, 95% Confidence Interval.

Discussion

This study describes diurnal patterns in adolescents screen behaviours and examines the role of social context in these behaviours separately for week and weekend days. Screen behaviours peaked in the late afternoon and evening, with television viewing being most prevalent in both sexes, followed the use of electronic games/apps in boys and social networking sites in girls. Screen activities were mainly reported as being undertaken alone, except for television viewing. Being with family members was associated with more time television viewing in both sexes on weekdays and weekend days. These strong diurnal and social contextual patterns indicate that behaviour change interventions may be most efficacious if they are targeted at particular times of the day and particular agents, depending on the behaviour of interest.

Television viewing was found to be the main screen activity, rising from the afternoon onwards and peaking in the evening hours for both sexes on weekdays and weekend days. Findings are in line with a systematic review showing that television viewing was the most prevalent behaviour in the hours immediately after school (from 15:00 to dinner time) (Arundell *et al.*, 2016a). This is also consistent with evidence in the field of physical activity which shows that participation in active pursuits declines in the late afternoon and evening (Van Cauwenberghe *et al.*, 2012; Wiersma *et al.*, 2019). Findings therefore suggest that adolescents may be substituting active behaviours, for example sports and other non-screen activities with television viewing in the evenings, and this occurs more frequently as they reach young adulthood. Further, qualitative evidence shows that television viewing is a popular family-based activity, mostly used to watch movies in the evenings (Thomas *et al.*, 2021). Considering that evening screen time may adversely impact sleep (Mireku *et al.*, 2019; Xu *et al.*, 2019), findings suggest that the development of interventions aimed at reducing television viewing should be targeted at the evening, although, as discussed below, the impact on family function would require careful consideration.

During the late afternoon and evening on weekdays and the entire waking days on weekend, the observed increase in time spent television viewing was accompanied by higher levels of electronic game play in boys and social media use in girls. The differences I observed in electronic gaming and social networking use by sex are consistent with previous studies (Kenney and Gortmaker, 2017; Thomas *et al.*, 2020). Data suggest that electronic game play and social media use occurs throughout the day, though at a relatively low level. This is consistent with survey data showing that 45% of US adolescents are online and open an app on their telephone at least 50 times a day(Pew Research

Center, 2016). Further, a systematic review showed that young people spend around 6% of the after-school time in screen behaviours other than television viewing (Arundell *et al.*, 2016a). Whilst these behaviours might substitute for more physically active pursuits, they are pervasive and become the means for modern youth to connect and communicate with friends online (Thomas *et al.*, 2021), and develop new skills. Interventions to reduce screen time should therefore acknowledge the importance and the role of these screen behaviours in adolescents' social life, with a goal of the elimination of screen behaviours not therefore being feasible or desirable. Rather there is a need to balance screen time with other activities and support adolescents in establishing a heathy approach to screen use. Sex-specific findings suggest a potential need for tailored interventions for boys and girls by addressing constraints that are unique to, or most pronounced for boys and girls. Indeed, the importance of all these contexts highlights the complex network of considerations that interventions must account for.

Being with family members was associated with more time spent in television viewing in both sexes on weekdays and weekend days. The scarcity of evidence on the associations of social context with specific screen behaviours makes the direct comparison of the findings with prior research difficult. Nevertheless, other studies have noted that television viewing is often a family-based activity, supported by parents as an opportunity for quality family time and communication amongst family members (Fulkerson *et al.*, 2007; Thomas *et al.*, 2021). However, qualitative evidence suggests that television viewing is often a secondary or background activity alongside mobile phone or tablet use, which may undermine potential benefits associated with family interaction (Thomas *et al.*, 2021). Considered alongside evidence that having a television in the bedroom, which facilitates viewing alone, is associated with an increased likelihood of being exposed to violent or age-inappropriate content (Garrison, Liekweg and Christakis, 2011), family-based television viewing may be preferable to that undertaken in other contexts. In a prospective observational study, parental monitoring of children's media use, encompassing limit-setting and discussion of use/content, was positively associated with a number of social and behavioural outcomes (Gentile *et al.*, 2014). These findings illustrate the need to work alongside families in the development of interventions to modify children's screen use, ensuring efforts to limit screen time do not result in unintended adverse consequences on family dynamics or health.

The predominant social context for social network use or internet browsing was alone, whilst making phone calls/sending texts and playing electronic games was more likely to be done in the company of

friends and/or siblings, though this varied by sex and day of the week. Numerous studies have reported that social networking and playing video games provide valued opportunities for young people to socialise with friends (Leonhardt and Overå, 2021), but it is interesting to observe that this sometimes takes place alone and sometimes in the company of others. Any attempt to modify screen use in this population will need to account for the social function these activities hold in young peoples' lives. It is also likely that intervention programmes will need to be tailored to the sex- and time-specific (week / weekend) contexts in which these behaviours occur. Qualitative research has shown that young people recognise a range of benefits and problems associated with screen behaviours (Thomas *et al.*, 2021). Intervention developers should work alongside young people to identify key areas of concern and the most valued outcomes from behaviour change programmes targeting screen behaviours. These findings indicate that such programmes will need to accommodate the varied social contexts that accompany these behaviours, perhaps drawing upon siblings and friends to support behaviour change.

The study has several strengths and weaknesses. A key strength is the large geographically and demographically diverse sample. In addition, time-use diary data allowed me to study specific screen behaviours and the temporal and social context in which they were undertaken; something which has been little studied in this field to date. Lastly, the reporting of data in screen behaviours separately for weekday and weekend days allowed me to distinguish patterns to better inform the development of interventions. Results should be interpreted with the following limitations in mind. Firstly, data are derived from a British population and, as such, conclusions may not be generalizable to other nations, especially lower income countries with lower adoption of screen behaviours. Secondly, the analytical sample differed in a number of social and demographic characteristics to the wider cohort. Finally, this analysis was not able to account for concurrent screen use, such as using a mobile phone whilst also watching television.

Conclusion

This is the first study to use time-use diary data to describe diurnal patterns in adolescents screen behaviours and examine the association of social context with these behaviours. The development of interventions aimed at reducing television viewing should be targeted at the evening. Family members and friends may be particularly important targets in behaviour change interventions, but further research is needed to understand the potential impact of interventions to reduce screen time on family functioning. Nevertheless, all the evidence currently available suggests that adolescents should

be encouraged to moderate and maintain a balance throughout the day and throughout the week in time spent across all screen behaviours.

Chapter 5: The associations of contemporary screen-behaviours with physical activity, sedentary behaviour and sleep in adolescents: a cross-sectional analysis of the Millennium Cohort Study

Introduction

Chapter 2 showed an age-related increase in various forms of sedentary behaviour and Chapter 3 showed an age-related change in contemporary screen behaviours and particularly in device use, most notably a reduction in television viewing and an increase in mobile phone use. It also found that the increase operates differently across sex. Chapter 4 found that interventions to reduce television viewing may be best targeted at the evening whilst interventions to reduce video-game play in boys and social network use in girls may be targeted throughout the day. It also found that family members and friends may be particularly important targets in behaviour change interventions. Given that screen behaviours may compete time for more physically active alternatives, the fourth and final study of the thesis, presented in this chapter, examines the association between screen behaviours and physical activity, sedentary behaviour and sleep in adolescents and explore whether these associations vary by sex.

Background

Lack of physical activity, excessive screen-viewing and inadequate sleep may contribute to an increased risk of the metabolic syndrome, mental health disorders and poor academic attainment in young people (Chastin *et al.*, 2015; Tapia-Serrano, Sevil-Serrano and Sánchez-Miguel, 2021; Watson *et al.*, 2021). Reflecting a growing movement to consider these behaviours holistically, several countries have now issued 24-hour movement guidelines for children (5 – 13 years) and adolescents (14 – 17 years) (Australia, Department of Health, 2018; New Zealand, Ministry of Health 2020). In Canada, for example, young people are recommended to accumulate at least 60 minutes of moderate-to-vigorous intensity physical activity (MVPA) each day, limit sitting for extended periods with no more than 2 hours per day of recreational screen time and attain 8-11 hours of sleep each night (Tremblay *et al.*, 2016). Surveillance data indicate that in a 24-hour period, children and adolescents in Canada and New Zealand spend approximately half their time sedentary, one third sleeping and the remainder in light-intensity physical activity and MVPA (Carson *et al.*, 2017; Tye *et al.*, 2020).

The time available each day for physical activity, sedentary behaviour and sleep is finite, such that time spent on one activity has an impact on the availability of time for other activities. The

displacement hypothesis asserts that time spent in one behaviour (e.g. sitting) displaces that in another (e.g. physical activity) (Mutz, Roberts and Vuuren, 1993), although the evidence to support this hypothesis appears inconsistent. Review evidence indicates that some types of sedentary behaviour may be negatively associated with physical activity (Pearson *et al.*, 2014), but the size of the association is small, suggesting that these behaviours do not directly displace one another. However, much of the previous work on this topic has focussed on traditional forms of screen-use, such as playing video games or watching broadcast television on a television set, failing to account for new devices or modes of screen-based entertainment that have emerged in recent years. This is limiting given that in 2019 approximately 70% of youth aged 12 – 15 years had a social media account in the UK (OfCom, 2019), and spent approximately 3 hours per day on these services (Coyne *et al.*, 2020). Recent evidence indicates that smartphone and tablet use may be negatively associated with self-reported physical activity, though the strength of this association may vary with age and sex (Kenney and Gortmaker, 2017; Raustorp *et al.*, 2019). Similarly, previous studies have found that screen time (mainly television viewing and video games) (Espinoza and Juvonen, 2011; Foley *et al.*, 2013) and engagement in social media use (social networking or messaging sites or Apps on the internet) (Scott, Biello and Woods, 2019) are associated with late sleep onset. Nevertheless, there remains limited evidence of how contemporary screen behaviours (such as time spent in social networking sites and email/texts) may impact on overall sedentary time, or on time spent active or sleeping. A clearer understanding of how these behaviours interact may help to inform the content of behaviour change interventions.

Inconsistency of the evidence regarding displacement between health behaviours may, in part, be attributable to use of different methods to assess these behaviours, which may have varied by behaviour sub-type, recall period or temporal unit (Dall *et al.*, 2017). This is in addition to known limitations of self-report behaviour questionnaires, such as recall bias (Hidding *et al.*, 2017). An alternative to questionnaires for the assessment of specific behaviours is a time-use diary, which have been used to describe patterns of physical activity and sedentary behaviour in young people. Although numerous studies have deployed time-use diaries to assess sedentary and active behaviours in young people, much of this previous research has looked at a limited range of behaviours or used composite markers (Mullan, 2019; Haycraft *et al.*, 2020; Kemp, Parrish and Cliff, 2020), which might mask associations between individual behaviours.

The aim of this study is to examine the association of diary-assessed screen behaviours with overall physical activity, MVPA, sedentary behaviour and sleep in adolescents and explore whether these associations vary by sex.

Methods

Sample and data collection

Data are from the Millennium Cohort Study (MCS), a national longitudinal birth cohort study run by the Centre for Longitudinal Studies (CLS) at the University College London. The MCS examines the social, economic, and health-related circumstances of young people born between 2000-2002, recruited from all four countries of the UK (England, Scotland, Wales and Northern Ireland) (Connelly and Platt, 2014; Ipsos Mori, 2017). The MCS is nationally representative, and 18,552 families (18,818 children) were recruited at baseline. Seven sweeps of data collection have been undertaken up to 2020, conducted when participants were 9 months, 3, 5, 6, 7, 14, and 17 years of age.

This cross-sectional analysis uses data from the sixth sweep of assessment (MCS6; data collection: January 2015-April 2016), when participants were 14 years old. In MCS6, 15,415 families were contacted for participation; 11,884 participants from 11,726 families provided partial or complete data. A sub-sample (88%) of young people was invited to wear an activity monitor and complete a time-use diary. The subsample comprised all participants living in Wales, Scotland and Northern Ireland and 81% of participants in England. The English sample was restricted due to limitations on the number of the activity monitors available. The MCS6 was approved by the National Research Ethics Service (NRES) Research Ethics Committee (REC) London – Central (REC ref: 13/LO/1786). Data were anonymised and obtained free of charge from the UK Data Service (http://doi.org/10.5255/UKDA-SN-8156-7). Parents and cohort members provided written and verbal consent prior to completing the survey (Ipsos MORI, 2016).

Time-use diary

Participants were invited to complete a time-use diary for two randomly chosen days (one weekday and one weekend day) selected by the Computerised Assisted Personal Interviews (CAPI) programme during the interviewer visit. The diary was available in 3 formats: online via the web, App via tablet or phone, and paper. Sixty-four percent of participants selected the App diary format, 29% used the online version and 7% the paper diary (Ipsos Mori, 2017). Participants recorded their behaviour in 10-minute timeslots from 4am to 4am the next day. For each 10-minute timeslot, participants indicated

their main activity, selecting from a pre-specified list of 44 activities, nested within 12 categories (the full list of activity codes is presented in Appendix 13). Diaries (days) with missing data (one or more time-slots with no activity indicated) were excluded from the analysis, consistent with previous analyses using time-use diary data (Mireku, 2020).

Participants were categorized according to whether they did (user) or did not (non-user) report time in the following four activities: phone calls, email and texting, using social network sites and internet browsing. Preliminary analyses indicated that the duration of time spent in these individual behaviours was low and highly skewed, therefore I opted to dichotomise in all analyses focusing on individual behaviours. It was derived a summary duration variable, calculated as the sum of time spent in the 4 activities of interest.

It was derived an outcome variable to indicate time spent in other sedentary behaviours by summing time reported in the following activities: reading for school or pleasure, traveling by car/bus, playing electronic games and television viewing.

Accelerometer data

To provide an assessment of physical activity, participants wore a triaxial GENEActiv Original accelerometer (Heywood, 2018) (Activinsights Ltd, Kimbolton, UK) on the non-dominant wrist for the same days as time-use diaries were completed. Data were downloaded using GENEActiv software and raw data processed using the GGIR package in R, which includes autocalibration and non-wear detection functions (van Hees *et al.*, 2013). Data were collected in 5-second epochs and the analysis includes all days with 10 or more valid hours (i.e., a valid day was defined as one in which wear time exceeded 10 hours). Overall physical activity was estimated using the Euclidean norm minus one (ENMO), a measure of mean acceleration over a 24-hour period. Duration of MVPA was calculated as the time spent with ENMO ≥100mg (Da silva *et al.*, 2014).

Self-reported data

Participants self-reported their usual time of sleep onset and waking up, separately for week and weekend days, selecting from pre-defined response categories (Appendix 14). Sleep duration was estimated as the time elapsed between category mid-points for sleep onset and wake-time, consistent with previous research (Yang-Huang *et al.*, 2017). Sleep duration estimates were collapsed into four categories (≤7 hours, 7–8 hours, 8–9 hours, >9 hours) for weekday sleep duration and three categories (7–8 hours, 8–9 hours, >9 hours) for weekend sleep duration.

Covariates

Participants sex, family income, ethnicity, body mass index (BMI) and home location (rural or urban classification) were included as potential covariates in the analysis (Fitzsimons, 2017). Inclusion of covariates in the model was based on previous research that showed association of sex, family income, ethnicity, BMI, home location with screen behaviours and physical activity and sleep. Adjustment for these variables is also consistent with previous research that has examined associations between similar exposures and outcomes as the current study (Hoyos Cillero and Jago, 2011; Atkin *et al.*, 2013). Rural or urban home location, based on postal code, was derived on the basis of population density (Department for Environmental Food & Rural Affairs in collaboration with the Office for National Statistics, 2016). Family income was measured using the Organisation for Economic Co-operation and Development (OECD) equivalised income quintiles, based on parent-reported household income. Ethnicity was parent-reported and categorised as White, Mixed, Indian, Pakistani and Bangladeshi, Black or Black British, and Other Ethnic group (including Chinese). Weight and height were measured by trained research assistants. Body mass index (BMI) was calculated as weight divided by height squared (kg/m^2) and International Obesity Task Force (IOTF) thresholds were used to categorise participants as underweight/normal weight, overweight and obese (Cole *et al.*, 2000).

Statistical analysis

Analyses were conducted in STATA 16.0 (Stata Corporation, Texas, USA). Sample characteristics and daily duration of exposure and outcome variables were summarised using descriptive statistics. Sex differences in duration of exposure and outcome variables were examined using Mann-Whitney U tests, Student's t-tests and Chi-square tests for continuous and categorical variables. Baseline characteristics for those included and lost to follow-up were compared using Student's t-tests and Chi-square tests. Multiple linear regression models were used to examine the association between exposure variables and physical activity outcome variables, separately for weekdays and weekend days. Ordinal logistic regression models were used to examine the association between exposure variables and sleep duration categories. Proportional odds ratios from these models indicate the effect of a 1 unit increase in the exposure on the odds of having longer sleep duration relative to all combined shorter sleep durations, controlling for other variables in the model. The Brant test was used to test for violations of the proportional odds assumption. The association between exposure variables and sedentary behaviour was examined using hurdle models (Cameron and Trivedi, 2013), to account for the large number of zero values observed in the sedentary behaviour outcome. The

Hurdle model has two parts: (1) a probit component where the outcome is dichotomised (no sedentary time vs. any sedentary time, and (2) a linear regression component which models duration of time spent in sedentary behaviour for non-zero values. The linear component in this study has been reported, using the Delta-method (margins effect) to estimate the mean difference in the duration of sedentary behaviour in those who did / did not report the screen-behaviours of interest. For the composite screen-behaviour exposure variable, it is presented the estimated mean difference in sedentary behaviour for a 10-min increase in screen-time. All models were adjusted for sex, BMI category, ethnicity, family income and home location. Assumptions of the fitted models were explored with tests for normality, checking for homoscedasticity and collinearity. In all cases assumptions were not violated. Possible multicollinearity in regression analysis was explored with the variance inflation factor (VIF). In all cases, VIFs were ≤2, indicating minimal collinearity amongst variables in the model. Single screen behaviours were modelled simultaneously (mutually adjusted). The composite screen behaviour exposure was modelled separately. Interaction terms were added to regression models to examine effect modification by sex.

Results

Data from 8,625 diaries were available, of which 1,537 were excluded due to missing data. The analytical samples for weekday and weekend analyses were n=3595 and n=3580 respectively. Table 11 describes the characteristics of participants for the weekday sample. There were no differences in participant characteristics between the weekday and weekend samples. Participants were 14.2 (0.3) years of age, mainly of white ethnicity (85%), normal weight (76%) and mostly living in urban areas (74%). Participants included in the analyses were more likely to be of white ethnicity (P <0.001), have normal weight (P <0.05) and come from families with higher income (P <0.05) compared to those who were excluded.

Usage and duration of selected screen-based behaviours are presented in Table 12. The proportion of participants that reported usage of phone calls, email/text, and internet browsing was less than 20% during the week and at the weekend, with boys being less likely to report doing these activities than girls. Approximately 40% of participants reported time spent on social network sites. This was more likely on the weekend than during the week, and in girls than boys. Time spent on the 4 screen behaviours combined was greater at the weekend than during the week (median (IQR) 30 min (0, 90) vs. 20 min (0, 80)). Time estimates for MVPA, sedentary behaviour and sleep are presented in Table 13.

Table 11 Participant characteristics (weekday sample)

	All (n=3,595)	**Boys** (n=1,612)	**Girls** (n=1,983)
Age, mean ± SD, y	14.2 (0.3)	14.2 (0.3)	14.2 (0.3)
Ethnicity, n (%)			
White	3,043 (85)	1,351 (84)	1,692 (85)
Mixed	142 (4)	79 (4)	63 (3)
Indian	94 (3)	47 (2)	47 (2)
Pakistani & Bangladeshi	170 (4)	69 (4)	101 (5)
Black or Black British	61 (1)	31 (1)	30 (1)
Other ethnic group	67 (1)	24 (1)	43 (2)
Family income (quintile, n (%))			
First (lowest)	338 (9)	124 (7)	214 (10)
Second	450 (12)	194 (12)	256 (12)
Third	710 (19)	319 (19)	391 (19)
Forth	994 (27)	458 (28)	536 (27)
Fifth (highest)	1,100 (30)	515 (31)	585 (29)
BMI (IOTF classification), n (%)			
Normal weight (incl. underweight)	2,685 (76)	1,250 (78)	1,435 (75)
Overweight	606 (17)	257 (16)	349 (18)
Obese	216 (6)	92 (5)	124 (6)
Home location, n (%)			
Rural	908 (25)	391 (24)	517 (26)
Urban	2,681 (74)	1,217 (75)	1,464 (73)

SD: Standard Deviation; y: year;

Sample sizes vary due to missing data, Ethnicity: All= 3,577 B= 1,601 G= 1,976; Family Income: All= 3,592 B= 1,610 G= 1,982; BMI (International Obesity Task Force (IOTF)): All= 3,507 B= 1,599 G= 1,908; Home location: All= 3,589 B= 1,608 G= 1,981.

Table 12 Number and proportion of participants reporting use of selected screen-based behaviours and duration of summed screen behaviours (values are N (%) unless stated otherwise)

	Weekday				**Weekend**			
	Users		**Non-users**		**Users**		**Non-users**	
Exposure Variables	**Boys**	**Girls**	**Boys**	**Girls**	**Boys**	**Girls**	**Boys**	**Girls**
Phone calls	75 (4.6)	159 (8)	1,537 (95.3)	1,824 (91.9)*	95 (5.9)	199 (10)	1,504 (94.0)	1,782 (89.9)*
Email/text	180 (11.1)	370 (18.6)	1,432 (88.8)	1,613 (81.3)*	204 (12.7)	380 (19.1)	1,395 (87.2)	1,601 (80.8)*
Social network sites	421 (26.1)	974 (49.1)	1,191 (73.8)	1,009 (50.8)*	406 (25.3)	1,042 (52.6)	1,193 (74.6)	939 (47.4)*
Internet browsing	251 (15.5)	269 (13.5)	1,361 (84.4)	1,714 (86.4)	260 (16.2)	302 (15.2)	1,339 (83.7)	1,679 (84.7)
Screen behaviour (min), median (IQR)	**All**	**Boys**	**Girls**		**All**	**Boys**	**Girls**	
	20 (0, 80)	0 (0, 60)	30 (0, 90)*		30 (0, 90)	0 (0, 60)	40 (0, 120) *	

IQR: inter-quartile range.
Screen behaviour weekday sample All= 3,595 B= 1,612 G= 1,983; Screen behaviour weekend sample All= 3,580 B= 1,599 G= 1,981.
* Differences between sex (*P* value <0.001).

Table 13 Duration of overall and moderate-to-vigorous physical activity, sedentary behaviour and sleep

	Weekday			Weekend		
Outcome Variables	**All**	**Boys**	**Girls**	**All**	**Boys**	**Girls**
MVPA (min), mean ±SD	135.6 (62.7)	143.1 (67.4)	128.7 (57.1)*	114.3 (64.9)	117.8 (70.6)	111.2 (59)*
Overall physical activity (mean acceleration; ENMO), mean ±SD	35.2 (15.4)	38.4 (17.6)	32.2 (12.2)*	31.2 (15.5)	33.6 (18)	29.1 (12.4)*
Composite of sedentary behaviour (min), median (IQR)	200 (110, 310)	240 (120, 360)	180 (100, 270)*	270 (150, 410)	330 (180, 470)	240 (120, 350)*
Self-reported sleep duration, n (%)						
≤7 hrs	1,359 (11.8)	599 (10.4)	760 (13.1)*	0	0	0
7-8 hrs	3,375 (29.3)	1,600 (28.0)	1,775 (30.7)	233 (20)	121 (2.1)	112 (2.9)*
8-9 hrs	4,870 (42.4)	2,438 (42.6)	2,432 (42.1)	1,545 (13.4)	874 (15.3)	671 (11.6)
>9 hrs	1,882 (16.3)	1,076 (18.8)	806 (13.9)	9,708 (84.5)	4,718 (82.5)	4,990 (86.4)

IQR: inter-quartile range; SD: standard deviation; ENMO: Euclidean Norm Minus One; min: minutes; hrs: hours.

Accelerometer variables for MVPA and overall physical activity: weekday sample All= 4,546 B= 2,196 G= 2,350, weekend sample All= 4,457 B = 2,127 G= 2,330; Composite of sedentary behaviour variable: weekday sample All= 3,551 B= 1,596 G= 1,955, weekend sample All= 3,537 B= 1,582 G= 1,955. * Differences between sex (*P* value <0.001).

Associations between screen-based behaviours and physical activity

Cross-sectional associations between screen-based behaviours and physical activity are presented in Table 14. We found no association between making phone calls or sending emails/texts and either of the physical activity outcomes. Use of social network sites was associated with lower overall physical activity on weekend days and fewer minutes of MVPA on weekdays and weekend days. Internet browsing was associated with lower physical activity and MVPA on both weekdays and weekend days. A ten-minute increase in duration of screen behaviours was associated with lower physical activity and MVPA on both weekdays and weekend days. Tests for interaction by sex revealed that associations between the use of social network sites, email/text and physical activity and MVPA on weekends were stronger in girls than boys (Appendix 16 and 17). For example, compared to non-users, use of social networking sites was not associated with MVPA in boys (-3.4 (-12.3, 5.4)) but negatively associated in girls (-15.3 (-22.3, -8.40); p for interaction <0.05).

Table 14 Cross-sectional association between screen-based behaviours and accelerometer-assessed overall and moderate-to-vigorous physical activity

	Overall physical activity			
	Weekday		**Weekend**	
	β (95% CI)	***P* value**	**β (95% CI)**	***P* value**
Phone calls	-1.5 (-3.8, .82)	0.20	-0.18 (-2.40, 2.04)	0.87
Email/text	0.42 (-1.2, 2.07)	0.61	-0.95 (-2.64, 0.73)	0.26
Social network sites	-1.0 (-2.30, 0.20)	0.10	-1.9 (-3.25, -0.60)	0.004
Internet browsing	-2.6 (-4.28, -0.92)	0.002	-2.48 (-4.15, -0.80)	0.004
Screen behaviour≠	-0.21 (-0.27, -0.14)	<0.001	-0.20 (-0.26, -0.14)	<0.001
	Moderate-to-Vigorous Physical Activity			
	Weekday		**Weekend**	
	β (95% CI)	***P* value**	**β (95% CI)**	***P* value**
Phone calls	-5.31 (-14.9, 4.31)	0.27	-1.67 (-10.9,7.57)	0.72
Email/text	1.73 (-5.03, 8.51)	0.65	-3.54 (-10.5, 3.4)	0.32
Social network sites	-5.21 (-10.3, -0.04)	0.04	-10.0 (-15.5, -4.5)	<0.001
Internet browsing	-10.6 (-17.5, -3.69)	0.003	-10.8 (-17.8, -3.8)	0.002
Screen behaviour≠	-0.88 (-1.16, -0.60)	<0.001	-0.90 (-1.16, -0.65)	<0.001

≠ a change in outcome variable (min/day) for 10 minutes increase in screen behaviour. Phone calls, Email/text, Social network sites, Internet browsing: reference group is non-users. MVPA,

moderate to vigorous intensity physical activity; β: beta coefficient; 95% CI: 95% Confidence Interval.

Associations between screen-based behaviours and sedentary behaviour

Transformed hurdle model outputs indicating the association of screen-based behaviours with sedentary behaviours are presented in Table 15. Untransformed coefficients from the hurdle model are provided in Appendix 15. The use of social network sites was associated with approximately 19 and 17 fewer minutes of sedentary behaviour on both weekdays and weekends respectively. A ten-minute increase in the duration of screen-based behaviours was associated with 3 and 4 fewer minutes in sedentary behaviour on both weekdays and weekends respectively. Tests for interaction by sex revealed that the use of internet browsing on weekends was negatively associated with sedentary behaviour in boys (-57.7 (-89.0, -26.4)) but was not associated in girls (18.8 (-12.7, 50.4); p for interaction <0.05) (Appendix 18).

Table 15 Cross-sectional association between screen-based behaviours and composite sedentary behaviours

	Composite sedentary behaviour			
	Weekday		**Weekend**	
	Dy/dx (95% CI)	***P* value**	**Dy/dx (95% CI)**	***P* value**
Phone calls	-13.6 (-34.8, 7.6)	0.21	-1.5 (-25.2, 22.1)	0.89
Email/text	-9.3 (-24.2, 5.6)	0.22	-17.5 (-35, -0.0)	0.04
Social network sites	-19.8 (-31, -8.6)	<0.001	-17.5 (-30.9, -4.1)	0.01
Internet browsing	-0.7 (-16.3, 14.7)	0.92	6.1 (-11.6, 24)	0.49
Screen behaviour≠	-3.6 (-4.3, -2.9)	<0.001	-4.3 (-5, -3.6)	<0.001

≠ a change in outcome variable (min/day) for 10 minutes increase in screen behaviour.
Phone calls, Email/text, Social network sites, Internet browsing: reference group is non-users.
Dy/dx: Average marginal effect of dx (screen behaviours) on dy (sedentary behaviour); 95% CI: 95% Confidence Interval.

Associations between screen-based behaviours and sleep

Associations between screen-based behaviours and sleep duration are presented in Table 16. Participants who reported making phone calls or browsing the internet were less likely to attain ≥9 hours of sleep on weekdays. Adolescents using email/text and social network sites were less likely to attain ≥9 hours of sleep on both weekdays and weekend days. A ten-minute increase in the duration of screen-based behaviours was associated with lower odds of attaining ≥9 hours of sleep on both weekdays and weekend days. Test for interactions by sex showed that making phone calls was associated with lower odds of ≥9 hours of sleep on weekends in girls (0.62 (0.41, 0.93)) but was not associated with sleep duration in boys (1.41 (0.77, 2.59); p for interaction <0.05) (Appendix 19).

Table 16 Cross-sectional association between screen-based behaviour and sleep duration

	Sleep duration			
	Weekday		**Weekend day**	
	POR (95% CI)	***P* value**	**POR (95% CI)**	***P* value**
Phone calls	0.78 (0.61, 1.0)	0.05	0.86 (0.61, 1.22)	0.41
Email/text	0.80 (0.67, 0.95)	0.01	0.76 (0.59, 0.99)	0.04
Social network sites	0.78 (0.68, 0.89)	<0.001	0.78 (0.61, 1.00)	0.05
Internet browsing	0.75 (0.62, 0.89)	0.002	1.07 (0.87, 1.32)	0.47
Screen behaviour≠	0.96 (0.95, 0.96)	<0.001	0.98 (0.97, 0.99)	<0.001

≠ a change in outcome variable (Odd Ratio/day) for 10 minutes increase in screen behaviour.
Phone calls, Email/text, Social network sites, Internet browsing: reference group is non-users.
POR: Proportional odd ratio, 95% CI: 95% Confidence Interval.

Discussion

This study examined the association of selected screen-based behaviours with physical activity, sedentary behaviour and sleep in adolescents and explored whether the association varied by sex. The results show that participation in some screen-based behaviours and the duration of all screen-based behaviours are associated with less overall physical activity and MVPA, less sedentary behaviour, and shorter sleep duration on both weekdays and weekend days. A small number of differences in the direction or magnitude of these associations was observed between boys and girls, which may have implications for intervention design.

The use of social network sites and internet browsing was associated with lower overall PA and 5 to 10 fewer minutes of MVPA on both weekdays and weekend days. Findings are consistent with previous evidence (Busch, Manders and De Leeuw, 2013; Kenney and Gortmaker, 2017), which showed that time spent in contemporary screen-based behaviours (i.e. tablet, smartphone and social media) was associated with insufficient levels of PA (PA <60 minutes), measured by self-report questionnaire. However, findings contrast with those from a previous study in Norwegian adolescents, which reported that socialising and surfing online was not associated with physical activity (Chortatos *et al.*, 2020). These contrasting results may be due to geographic variability in how these behaviours interact. In a cross-national investigation (Melkevik *et al.*, 2010), strong negative associations between physical activity and screen-based sedentary behaviours were found in North America and the Nordic countries, but associations were generally weaker in the British Isles, Central Europe and the Baltic countries. Few studies to date have examined the association between screen-behaviours and vigorous intensity physical activity; this would be a valuable avenue for future research given the known health benefits of vigorous intensity physical activity. Findings indicate a complex suite of associations between screen-based activities and adolescents' physical activity, which may vary by behaviour and location amongst other things. Negative associations of visiting social networking sites and internet browsing with physical activity provide partial support for the displacement hypothesis, but the associations were generally small in magnitude, consistent with review evidence (Pearson *et al.*, 2014; Dalene *et al.*, 2018), particularly when considering the duration of use rather than doing / not doing these behaviours. Nonetheless, strategies to reduce time spent in specific screen-behaviours may be valuable as part of a package of measures in programmes aiming to promote physical activity in adolescents.

Surprisingly, the use of social network sites and the duration of screen-based behaviours were associated with less composite sedentary behaviour on both weekdays and weekend days. The scarcity of evidence on the associations of contemporary screen time with sedentary behaviour

makes the comparison of findings with prior research difficult. However, a previous study showed that the presence of television in the bedroom and combined presence of computer and television set were negatively associated with accelerometer-assessed sedentary time (Atkin, Corder and van Sluijs, 2013). There are several possible explanations for these findings. Firstly, adolescents may spend time using social media via portable devices, such as mobile phones, while engaging in light activity and are not necessarily sedentary. A study using data from two UK time-use surveys (2000–2015), found an increase in the time children spent using mobile devices and tablets when engaging in other activities throughout the day (i.e., time at school, during travel, and when eating) (Mullan, 2018). Research to establish body posture or the presence/absence of activity whilst using screen-based devices will advance our understanding on how screen behaviours may displace time in sedentary behaviour. Another potential explanation is that the negative associations of screen behaviours with sedentary behaviour may be due to the changes in media use and the shift from traditional (e.g., television viewing, video games) to contemporary screen use behaviours in the current generation. The composite measure of sedentary behaviour consists of the sum of screen and non- screen-based sedentary activities; therefore, it may be hypothesised that more time in social networking sites was associated with less television viewing, video-game play or reading for school or leisure, all of which are predominantly sedentary activities.

All four of the screen-based behaviours examined were associated with shorter sleep duration on weekdays, and the use of email/texts and social network sites was associated with shorter sleep on weekend days. Findings add to a growing body of evidence indicating that the use of screen devices (both traditional and contemporary) is associated with shorter sleep duration (i.e. less than 8 hours) in this population (Kenney and Gortmaker, 2017; Tambalis *et al.*, 2018; Kobel *et al.*, 2019; Li *et al.*, 2019). However, much of the previous research has examined whole week patterns in sleep behaviour, without distinguishing week and weekend days. This knowledge can help with the targeting and content of behaviour change interventions. Differences in the association observed across week and weekend days may reflect the differing daily routines of young people during the week/weekend, and the differing times of day when adolescents can engage in these activities. However, it would be valuable to see if these differences were replicated in further analyses before drawing firm conclusions. Given that short and interrupted sleep may have implications for adolescents' mental health and well-being (Thomée, Härenstam and Hagberg, 2011; Falbe *et al.*, 2015; Li *et al.*, 2019), these findings support the development of strategies to monitor screen time in programmes aimed at promoting healthy sleep habits in adolescents. Further research to corroborate these findings, however, should be undertaken prior to application of these strategies in practice.

This is one of the few existing studies that has examined whether associations of screen behaviours with physical activity, sedentary behaviour and sleep vary by sex. A number of significant interactions were observed, sometimes in opposing directions. For example, use of social networking sites was associated with 15 fewer minutes of MVPA in girls, but was not associated with MVPA in boys. This is consistent with prior evidence showing that the use of social media and chat apps for four or more hours per day was negatively associated with MVPA in girls, but no such association was observed in boys (da Costa *et al.*, 2021). It was also found that the association between internet browsing and sedentary behaviour was stronger in boys but not in girls. However, this finding is not consistent with evidence on bedroom media which showed that the negative association of television and computer ownership with sedentary time was stronger in girls than boys (Atkin, Corder and van Sluijs, 2013). Evidence on variations in the associations between screen behaviours and movement behaviours by sex is inconsistent at this point. In addition, few studies have formally tested for effect modification by sex. Further studies are required to examine whether the associations between screen behaviours, physical activity, sedentary behaviour and sleep vary by sex. This will help to inform the content and targeting of behaviour change interventions addressing this suit of health-related behaviours.

These findings cannot be used to determine causality, due to the cross-sectional design, but they do nonetheless add to the evidence base concerning inter-relations between health behaviours, particularly given the focus on contemporary screen behaviours, which have been little studied in this context to date. Previous research suggested that there is time for both screen activities (traditional devices) and physical activity and therefore provided limited support for the displacement hypothesis (Biddle *et al.*, 2004). Additionally, these findings indicate differential associations between specific screen activities and other health behaviours; use of social network sites was consistently associated with adolescents' physical activity, sedentary behaviour and sleep duration for example, whilst making phone calls or using email/texting was associated with sleep only. These nuances further our understanding of the complex pathways that link behaviour with health and can guide the development of behaviour change interventions. Where appropriate, advanced analytical techniques, such as compositional analysis, can further our understanding of how particular behaviours, or groups of behaviours, interact within our daily time budget (Foley *et al.*, 2019).

Strengths and limitations

A strength of this study is the large geographically and demographically diverse sample. In addition, it utilised device-based measures of overall PA and MVPA, reducing the bias associated with self-report. Regression models included adjustments for known confounders, and it explored

effect modification by sex. Lastly, the use of time-use diary derived data, allowed to study contemporary screen behaviours, such as use of social networking sites, which have been relatively understudied in this field to date. Nevertheless, these results should be interpreted with the following limitations in mind. Firstly, the results are derived from a British population and, as such, conclusions may not be fully generalizable to other nations. Secondly, due to the cross-sectional nature of the analysis, it cannot be determined the direction of the associations observed. Thirdly, the time-use diaries did not provide information on the type of device (e.g., tablet or smartphone, portable or non-portable) used whilst reporting time in screen behaviour which may have introduced variability into the associations of interest and limits direct applicability to the development of intervention strategies. Fourthly, it is acknowledged that a substantial number of participants were excluded from the analysis due to missing diary data, consistent with previous research using this methodology. The analytical sample differed in a number of social and demographic characteristics to the wider cohort, potentially limiting the generalisability of findings. Fifth, it is acknowledged that the activity levels were higher than the activity levels that are typically observed physical activity research. One explanation is that the use of ENMO ≥100mg as cut-off point is lower than what is typically used for adolescents (which is 200mg) in physical activity research. Lastly, the validity of the specific time use diary used in this study is unknown, though it was rigorously pilot-tested prior to use and diaries of a similar nature have demonstrated acceptable validity and reliability (Bauman, Bittman and Gershuny, 2019).

Conclusion

In this study, the use of social network sites and internet browsing were consistently associated with less MVPA and sedentary behaviour on both weekdays and weekend days, and the use of all screen behaviours was strongly associated with shorter sleep duration on weekdays. In light of continued growth in ownership and usage of screen-based devices in young people, further work to understand how these activities interact with other behaviours, including physical activity and sleep is warranted. These findings indicate that intervention strategies to limit screen-behaviours may be valuable components in programmes aimed at promoting MVPA and adequate sleep in this age group, along with appropriate tailoring by sex in some instances.

Chapter 6: Discussions and conclusions

This thesis has presented four interlinked studies which examined sedentary and screen behaviour in children and adolescents. Using the behavioural epidemiology framework and the ecological model, the thesis developed an understanding of the factors that influence sedentary and screen behaviour and the social contexts in which behaviour occurs. Further, the thesis examined whether there is an association between screen behaviours and other health behaviours (physical activity, sedentary behaviour, and sleep). The evidence presented here contributes to a wider body of knowledge of understanding patterns and influences of behaviour which it is hoped may inform future public health intervention development. This chapter summarises the main findings of each study reported within the thesis and contextualises the importance of these findings. It also reflects on the methodology adopted for each study. Finally, general conclusions and implications for future research are also discussed.

6.1. Summary of main findings

The systematic review and meta-analysis (**Chapter 2**) aimed to quantify the age-related change in sedentary behaviour during childhood and adolescence and examine whether change varied across socio-demographic population groups. A key finding was that device-measured sedentary time and self- or proxy-reported screen-based sedentary behaviour increases by approximately 8 and 0.3 minutes per day annually, respectively. Analysis also revealed that there was no evidence that the magnitude of change (i.e., differences in sedentary time change) varies by sex or age. These findings are important because they did not suggest the presence of specific groups that exhibit large increases in sedentary and screen behaviour (i.e., 'at-risk' groups).

This review identified several gaps in the understanding of this apparent age-related increase in sedentary behaviour. Most studies focused on television viewing and video-game play with very few describing changes in the time spent using other screens, such as mobile phones, over the same time frame. Also given that television viewing appeared relatively stable and increased only over the longest durations of follow-up in this review, it may be that contemporary screen behaviours displace time previously spent in television viewing. Time spent in contemporary screen behaviours therefore warrants investigation. Additionally, only just over 40% of the studies provided stratified data by sex. Evidence would be informative for intervention design to provide screen-based sedentary time for boys and girls over time. Further, only a limited number of studies conducted stratified analyses to examine change in sedentary behaviour according to ethnicity or BMI, and none stratified by socio-economic position. Information on population groups that may be most 'at risk' will assist with targeted intervention strategies. Nevertheless, this study

established a strong rationale to conduct further research into age-related changes in contemporary screen behaviours and factors associated with screen behaviour in adolescents.

As raised in the introduction to this thesis, if interventions aim to facilitate health-enhancing shifts in activity, sedentary behaviour and sleep, it is important to provide evidence of how screen behaviour changes, its association with other movement behaviours, and the potential influence of the immediate social environment. Chapters three, four and five examined factors associated with screen behaviours, including contemporary screen behaviours, and their associations with health behaviours.

Screen device ownership differs between children and adolescents; the proportion of children with a mobile phone is smaller than the proportion of adolescents with a mobile phone (OfCom, 2019). There is also a concern that adolescents spend a considerable amount of their awake time interacting with screens. **Chapter 3** described the changes in time spent in screen-based behaviours (including mobile phones, tablets, television and computers) and the socio-demographic differences in these changes over approximately 2 years in a cohort of British adolescents aged 11 – 15 years.

A key finding of the study described in **Chapter 3** is that time spent in most screen behaviours increased from baseline to follow-up, apart from tablet and portable video-game use which remained relatively stable. Additionally, evidence indicated that age-related changes in screen behaviour may vary by sex and ethnicity. The increase in time spent making phone calls, or using the internet, social network sites and television viewing was greater in girls than boys. Conversely, the increase in time spent in playing video game on consoles and using desktop computers was greater in boys than girls. A substantial increase was observed in time spent using mobile phones compared to other screen behaviours. This suggests that interventions aimed at changing adolescents' screen behaviour patterns will need to accommodate changes in device ownership, and sex differences in device use. It is hoped that this study improves understanding of the association between changes in a broad array of screen behaviours and socio-demographic factors. Alongside studying change over time, understanding the distribution of screen behaviours across the day would be informative for targeting timings in intervention designs. Further, the shift in screen device may reflect a change in interests as adolescents age, and these interests may be influenced by specific people adolescents choose to spend time with. Understanding the social context in which the behaviour is undertaken is therefore important. This knowledge will provide insights to intervention designs targeting adolescents' social environment.

Chapter 4 described the diurnal pattern in British adolescents' screen-based behaviours and examined the association of individual and social level factors, making full use of the breadth of information a time-use diary can provide. This study furthers the understanding of timing of screen behaviours across a 24-hour period and whether the presence of friends and family members is associated with a variety of screen behaviours. Findings showed that screen use peaked in the late afternoon and evening, with television viewing being most prevalent in both sexes, followed the use of electronic games/apps in boys and social networking sites in girls. Findings suggest that the development of interventions aimed at reducing television viewing should be targeted at the evening whereas all the other screen behaviours may be targeted throughout the day. Critically, this thesis highlighted that family members and friends may be particularly important targets in behaviour change interventions as being with family members was associated with time spent in television viewing whilst being with friends was associated with time spent in video game play. Findings from **Chapter 4** indicate that behaviour change interventions may be most efficacious if they are targeted at particular times of the day and at family members and friends, depending on the behaviour of interest.

The time available each day for physical activity, sedentary behaviour and sleep is finite, such that time spent on one activity has an impact on the availability of time for others. **Chapter 5** examined the association of time-use diary-assessed screen behaviours with overall physical activity, moderate-to-vigorous physical activity (MVPA), sedentary behaviour and sleep in British adolescents and explored whether these associations vary by sex. This study provides an understanding of the interaction of specific contemporary screen behaviours with health behaviours.

Findings provide partial support for the displacement hypothesis, such that participation in some screen-based behaviours was associated with less overall physical activity and MVPA, less sedentary behaviour, and shorter sleep duration on both weekdays and weekend days. There was evidence of sex differences with some screen behaviours. For example, use of social networking sites was associated with fewer minutes of MVPA in girls, but not in boys. Further, the association between internet browsing and sedentary behaviour was stronger in boys but not in girls. Findings indicate that strategies to limit screen-behaviours may be valuable components in programmes aimed at promoting MVPA and adequate sleep in this age group, along with appropriate tailoring by sex in some instances.

6.2. Contextualisation of findings

There is substantial evidence showing that certain sedentary and screen behaviours may be adversely associated with specific health markers (Carson *et al.* 2016). In light of this evidence, public health guidelines aim to communicate the amount of these behaviours that people should aim to undertake (UK Department of Health and Social Care, 2019). Yet British young people are insufficiently active and highly sedentary (Pearson, Sherar and Hamer, 2019) exacerbating the risk for morbidity and mortality in adulthood (Tremblay *et al.*, 2011).

Establishing reduced sedentary behaviour early in childhood is fundamental because there is evidence that physical activity declines through childhood into adolescence while sedentary behaviours increase (Pearson *et al.*, 2017; Farooq *et al.*, 2018). In addition, although limited in volume and inconsistent, evidence suggests that sedentary behaviour may also vary according to ethnicity, body mass index, and socio-economic position (O'Brien *et al.*, 2021). For example, children coming from low-income families had higher engagement in all forms of screen time compared to those coming from high-income families (Nagata *et al.*, 2021). Evidence shows that children growing up in lower income households do less well than their peers on a range of health outcomes, such as cognitive development, physical health, and social and behavioural development (Cooper and Stewart, 2017). As a result, strategies to reduce health inequalities at regional and national level are of public health importance.

To facilitate this, as noted in the introduction, the Behavioural Epidemiology Framework and ecological model assist guiding future research and identifying intervention targets. Identifying the influences on sedentary and screen behaviour will be important for assisting with planning for effective interventions that can be used to reduce screen time and disparities in health outcomes. The evidence presented in this thesis seeks to identify subgroups who are most 'at risk' due to their behaviour, timings of screen behaviour, the social context that influence screen behaviour, and the inter-relations of screen behaviours with health behaviours. In the three sections of this chapter that follow, age-related change and context that influence sedentary and screen behaviour, and inter-relations among health behaviours are discussed in detail.

6.2.1. Age-related change in sedentary and screen behaviour

Several studies have shown that participation in sedentary and screen behaviour increase from childhood to adolescence (Pate *et al.*, 2011; Pearson *et al.*, 2017). However, the existing review-level evidence has focussed on either reporting time estimates from repeated cross-sectional studies or summarising the evidence on changes in sedentary behaviour across the primary–secondary school transition. This evidence has undoubtedly contributed to the field of sedentary

behaviour, but it does not establish the timing of changes in sedentary behaviour during childhood and adolescence. Gaining knowledge of how behaviours change over time, strengthens the knowledge base for researchers designing effective public health interventions. Until recently, no reviews investigated sedentary behaviour over childhood and adolescence, but the synthesis of the available evidence via a systematic review is important to better describe change in sedentary behaviour throughout this developmental age periods.

The concurrent use of device-assessed and self- or proxy-report measures is desirable in sedentary behaviour research, particularly because the latter captures separate sedentary behaviour related constructs (Zhu and Owen, 2017). It is of interest, therefore, to examine both methods of measurement when exploring changes in sedentary behaviour over time. This thesis has shown an age-related increase in both sedentary time and specific screen behaviours (i.e., television viewing, video-game play and computer use) over time, with similar changes in children and adolescents, and boys and girls. Findings were consistent with previous studies using device-based or self-reported international and pan-European data (Cooper *et al.*, 2015; Ryu *et al.*, 2019; Steene-Johannessen *et al.*, 2020). Further there is evidence showing that adolescents engage in higher levels of sedentary behaviour than children (Pate *et al.*, 2011); however, **Chapter 2** has not just synthesized narratively time estimates but examined whether changes in sedentary and screen time differ throughout these periods, using meta-analysis and meta-regression. Findings from this review highlight the value of meta-regression, which derives sub-group estimates that could be of direct use to intervention designs and policymakers. Further, within the field of physical activity, increases in sedentary behaviour are consistent with recent evidence that the age-related decline in physical activity may start during childhood, rather than being limited to the adolescent period (Dumith *et al.*, 2011; Farooq *et al.*, 2019). Given that sedentary behaviour tracks moderately from childhood to adulthood; this thesis suggests that interventions may benefit from targeting reductions in all sedentary and screen behaviours in children and adolescents.

The systematic review in this thesis has highlighted the lack of evidence in contemporary screen behaviour change and stratified analysis to examine change across population sub-groups. Further, the majority of sedentary behaviour interventions have focused on children and more research on reducing adolescents' sitting is needed (Jones *et al.*, 2021). Therefore, the study in **Chapter 3** has provided longitudinal evidence of change in contemporary screen behaviour, and socio-demographic differences in adolescents

This thesis has shown that there is a change in device use as adolescents age, which is consistent with previous research that also showed increases in time spent in gaming, communicating and

socializing online as well as in internet use at 12 – 13 years old and 14 – 15 years old (Kemp, Parrish and Cliff, 2020; Thomas *et al.*, 2020). The apparent change in device use may be due to either normative changes in adolescents' interests, secular changes in device ownership or a combination of the two. Longitudinal research looking at how interests change over time showed that vocational interests intensity (i.e., interests that involve working with hands, research activities, creativity, people) decreased during early adolescence (11 – 13 years old) but then increased during late adolescence (i.e., 14 – 18 years old) (Hoff *et al.*, 2018). Moreover, the review showed that interests involving people tended to increase (i.e., self-expression, helping and managing people, social influence), whereas interests involving hands and scientific activities remained constant, independently of age. Therefore, people become more interested in activities involving communication with people over time. It could be hypothesized that the secular changes may facilitate the use of electronic devices as a means for interest development. For example, adolescents catch up with the latest trends in device or App use (i.e., Facebook, Tik-Tok, Instagram etc) to network with peers so to fulfil their social interest. Therefore, acknowledging on one hand the change in device use and on the other hand the development of social interest for this age group, these findings suggest that interventions aimed at supporting adolescents in developing healthy screen behaviour patterns will need to accommodate changes in device ownership.

The evidence presented in this thesis is consistent with previous research showing that video game play is greater in boys whilst social network use is greater in girls (Thomas et al. 2020; Leonhardt and Overå, 2021). Qualitative and quantitative evidence shows that both sexes use these tools to socialise virtually with their peers (Thomas et al. 2020; Leonhardt and Overå, 2021). In exploring the role of social media and video-games in enabling interaction between peers, the literature distinguishes the active and passive forms of communication with the latter being associated with adverse wellbeing, particularly in girls (Thorisdottir *et al.*, 2019). However, review-level data suggest that the association between digital technology use and psychological wellbeing is negative but very small in magnitude (Orben, 2020) and dominated by cross-sectional work that is generally of a low quality. Further, early adolescence (11 – 13 years old) appears to be the lifetime peak of gender differences in vocational interests. However, the interests of males and females gradually become more similar throughout late adolescence (14 – 18 years old) and young adulthood (Hoff *et al.*, 2018). Therefore, there remains little knowledge of how these screen behaviours change over late adolescence/early adulthood. Given the lack of information on the form of communication, these findings call for further longitudinal data to assess time spent in different types of screen behaviours in boys ang girls and whether types of screen behaviour are linked with health differently in boys and girls. This understanding will also be facilitated by the

development of new ways to measure screen behaviours. Until the epidemiological evidence is stronger regarding the link between screen behaviour and health, findings suggest that there might be the greatest advantage in targeting time spent on social networking sites and video games in adolescent girls and boys respectively.

Some of the findings presented in this thesis contradicts those of previous longitudinal research, which showed that young people of non-White ethnicity or lower socioeconomic position exhibited larger increases in screen time compared to peers of White ethnicity or higher socioeconomic position (Brodersen *et al.*, 2007; De Craemer *et al.*, 2018; O'Brien *et al.*, 2021). One possible explanation is that each individual culture has their own specific value system that impacts parenting style. For example, there is evidence that American mothers are more likely to promote autonomy, assertiveness, and self-actualization in their children, whereas Japanese mothers are more likely to promote emotional maturity, self-control, and social courtesy (Bornstein, 2012). These differences in attitudes and norms may explain ethnicity differences in screen time. Indeed, there may be attitudes and norms related to screen behaviours across cultures that would be of interest for future research to explore in detail. Analyses relying on Black, White and Asian classifications may not be sufficient and do not provide good understanding of current social trends. It is however necessary to recognise the effects of race, ethnicity, socioeconomic position, and gender, and to see them as operating simultaneously rather than in isolation. This would allow for the development of culturally sensitive interventions in the future. Further, this thesis shows no evidence for a difference in screen-time change between participants of different socio-economic position. Recently, video streaming services such as Netflix, and Amazon Prime have been growing at an exponential pace because of their affordability, wide availability, and accessibility through any internet-connected device (Stroll, 2022). As such, socio-economic indicators based on income may also become less valuable. As research on physical activity has shown, the pathways through which different markers of socio-economic position may be associated with young people's health and behaviour are complex (Love *et al.*, 2019). Therefore, further research is needed to disentangle associations between ethnicity and socio-economic position before we are able to draw clear conclusions on the social patterning of screen behaviour.

In summary, review level evidence shows that sedentary time and screen behaviours increase as young people age. Longitudinal data shows that there is an age-related increase for almost all screen behaviours, but this is most pronounced for internet use, video game play and social networking and appears to differ by sex. Together, findings suggest that the age-related increase might also be highlighted by a shift in device use from childhood to adolescence; thus,

interventions may accommodate device preference with age. Behaviour change interventions targeting reductions in sedentary and screen behaviour have been shown to be successful, although effects are small (Jones *et al.*, 2021). The bulk of the evidence on screen time interventions addresses the use of television, computers and video games. Additional experimental evidence is needed to address the use of mobile phones. As the technological landscape continues to rapidly evolve, the way children and adolescents interact with technology will continue to change. Whether interventions targeting the use of mobile phones would work is unknown. Nonetheless, findings suggest that it would be appropriate that interventions target contemporary screen behaviours and support young people in developing healthy screen behaviour patterns throughout childhood and adolescence.

6.2.2. Social context and diurnal pattern of screen behaviours

Across the 24 hours that make up a day, participation in screen time may not be distributed evenly, but rather certain periods are characterised by little or no screen time whilst at other times screen time is much more likely to occur. Most evidence reports time spent in screen behaviour in daily patterns and some studies have provided estimates of prevalence relative to the afterschool and weekday evening periods (Haycraft *et al.*, 2020). Clearly this approach is essential in providing surveillance data on screen time levels in young people, but it provides no insight as to when young people actually spend time in screen use. Understanding distribution across the whole day is particularly valuable. Further, little is known about whether adolescents use screens individually or with others (e.g., family/friends). Changing health behaviours requires an understanding of the factors that influence behaviour and the context in which they occur.

This thesis has shown that television viewing peaked at approximately 20 minutes per hour in the evening hours for both sexes on weekdays and weekend days. Findings are consistent with review-level evidence showing that television viewing was the most prevalent behaviour in the hours immediately after school for both sexes (Arundell *et al.*, 2016a). Further, the observed increase in time spent viewing television was accompanied by higher levels of electronic game play in boys and social media use in girls. Findings also reflect previous research in the field of physical activity which shows that participation in active pursuits declines in the late afternoon and evening (Van Cauwenberghe *et al.*, 2012; Wiersma *et al.*, 2019). This highlights that time for screen use competes with time for physical activity particularly for after school time and throughout a weekend day. This indicates that screen time accumulated within a short period either in the afternoon or throughout the weekend, depending on the behaviour, contributes significantly to leisure-related screen time.

Various interventions have been shown to be effective in reducing sitting and screen time either at school or in the home setting (Biddle, O'Connell and Braithwaite, 2011; Arundell *et al.*, 2019). Most interventions have focussed on sitting activities within a school setting through active breaks. The home setting, where young people spend large amounts of time, has been targeted through screen limits or allowances to a lesser extent than the school setting. Findings suggest that interventions to target television viewing in the afternoon and evening time may be promising. Further, findings highlight the temporal nature of adolescents' social media use in girls and video-game use in boys. Therefore, it may be appropriate that intervention strategies focus upon establishing a heathy approach throughout the day.

Additionally, this thesis has shown the importance of family members and friends as being involved in supporting the adolescent to limit their screen time because they are often present when the behaviours take place. Being with family members was associated with more time spent in television viewing and being with siblings and friends was associated with more time spent playing electronic games in both sexes. Although television viewing is a family-based activity, which provides an opportunity for communication amongst family members (Fulkerson *et al.*, 2007; Thomas *et al.*, 2021), qualitative evidence suggests that television viewing is often a secondary or background activity alongside mobile phone or tablet use, which may undermine potential benefits associated with family interaction (Thomas *et al.*, 2021). Considered alongside evidence that having a television in the bedroom, which facilitates viewing alone, is associated with an increased likelihood of being exposed to violent or age-inappropriate content (Garrison, Liekweg and Christakis, 2011), family-based television viewing may be preferable to that undertaken in other contexts. Furthermore, as noted earlier, studies have reported that social networking and playing video games provide valued opportunities for young people to socialise with friends (Leonhardt and Overå, 2021) but it is interesting to observe that this sometimes takes place alone and sometimes in the company of others.

Cross-sectional evidence suggests that video game play places children at increased risk of psychological issues such as loneliness due to screen addiction (Raza *et al.*, 2021). A recent meta-analysis of sedentary behaviour interventions targeting school children indicates that social environment interventions (parent-children dyads) are effective in reducing sedentary behaviour (Lam *et al.*, 2022) but the targeting of peers in order to reduce sedentary and screen behaviour is yet to be investigated. In the field of physical activity interventions, targeting peers, although focused in girls, has shown promise (Sebire *et al.*, 2018). Similar approaches in future sedentary behaviour research may hold potential for reducing sedentary behaviour whilst strengthening social relationships among adolescents. This thesis contributes to the evidence base suggesting

that behaviour change interventions may be most efficacious if they target the immediate social environment (i.e., family members, friends), depending on the behaviour of interest.

6.2.3. Inter-relations of screen behaviours with physical activity, sedentary behaviour and sleep

Although not included within conceptualisations of the ecological model, the time available each day for physical activity, sedentary behaviour and sleep is finite, such that time spent on one activity has an impact on the availability of time for other activities. Much of the existing literature has examined the association between traditional forms of screen-use, primarily television viewing or a composite measure of television viewing and video game play, and physical activity. Yet this overlooks the variety of contemporary screen behaviours in which young people engage in recent years and the interaction not only with physical activity but also with sleep duration. Identifying which behaviours exactly displace time in health behaviours will provide new understanding on their impact for health.

Findings in this thesis show that the use of social network sites and internet browsing were consistently associated with less MVPA and sedentary behaviour on both weekdays and weekend days, and the use of all screen behaviours was strongly associated with shorter sleep duration on weekdays. Review-level evidence has shown that some types of sedentary behaviour may be negatively associated with physical activity (Pearson *et al.*, 2014), but the size of the association is small, suggesting that these behaviours do not directly displace one another. However, the available evidence has aggregated time-use, with the result that any screen specific variations in the association are masked. Further evidence shows that screen-based sedentary behaviour is associated with sleep duration, while sedentary behaviour for doing homework is not associated with sleep duration in preschool children (Chang and Lei, 2021). The impact of screen based sedentary behaviour and non-screen based sedentary behaviour on physical activity and sedentary behaviour warrants further investigation. This evidence will identify which sedentary behaviours are associated with other health behaviours. It is likely that humans behave differently in different contexts due to their innate ability to transform and connect in different ways at different times with a changing environment (Duncan, Jones and Moon, 1996). This highlights the complexity of factors that may be at play switching from one activity to another. As noted previously, time for screen use may compete with time for physical activity with this 'competition' being visible in the afternoon time. In order to optimise intervention effectiveness, research to identify the factors that influence active, sedentary and sleep behaviours unique to the morning and afternoon is required. These findings indicate the complexity among types of behaviours and health behaviours. In view of this evidence, findings indicate that intervention strategies to limit

time spent on social network sites and internet browsing may be valuable components in programmes aimed at promoting MVPA and adequate sleep in this age group.

In summary, the findings presented here add to the evidence base concerning inter-relations between health behaviours, particularly given the focus on contemporary screen behaviours, which have been little studied in this context to date. Findings indicate differential associations between specific screen activities and other health behaviours. These nuances further our understanding of the complex pathways that link behaviour with health and can guide the development of behaviour change interventions in aiming a balance among health behaviours.

6.3. Reflections on the methods used

Secondary data analysis and evidence synthesis were conducted for all the four studies that this thesis addressed. As a starting point, a systematic review of observational longitudinal data delivered an overview of available evidence on age-related change in sedentary behaviour in children and adolescents. This method made feasible the quantitative synthesis of change in several different time periods using a rigorous and transparent approach. Further, a great advantage of this method is that it identified research gaps in the available evidence base. Namely, gaps in the current evidence base of sedentary and screen behaviour, some of which the three other studies in this thesis have addressed. The importance and choice of a systematic review for the synthesis of the available evidence goes without question, nonetheless the screen behaviours studied in this review appeared out of date. We know that the electronic media landscape may have changed. This highlights the importance of future research to update these findings so that it provides researchers with the latest trends.

Age-related change in contemporary screen behaviours was examined using data from a large cohort study (i.e., SCAMP) of British adolescents. This method allowed the estimation of change of time spent in screen behaviour collected from the same population over two time periods. This study included an ethnically diverse sample representative of London, UK; this is a great advantage as it allowed the reporting of time spent in screen behaviours for sub-population groups.

The third and the fourth studies were of a cross-sectional design using data from the same longitudinal study, the UK Millennium Cohort Study. The use of time use diary data enables a comprehensive description of contemporary screen behaviours, the diurnal pattern across a 24-hour period and the social influences in specific screen behaviours. It also utilised device-based measures of overall physical activity and moderate-to-vigorous physical activity, reducing the bias associated with self-report.

Although these two different studies (i.e., SCAMP and MCS) in Chapter 3, 4, and 5 run by different UK institutions and used different tools to measure screen behaviour, both provided an understanding about screen behavioural patterns in British adolescents. However, analyses were cross-sectional, and therefore causality cannot be established because data on each participant were recorded only once and hence it is difficult to infer the temporal association between a risk factor and an outcome. Thus, only association, not causation, can be inferred from this study design. These four interlinked studies adopted study designs that have frequently been used in the field of sedentary behaviour and physical activity epidemiology to describe the distribution and correlates of sedentary behaviour in children and adolescents.

Finally, Chapter 3, 4 and 5 included a large number of analyses of associations which are partly exploratory. It should be acknowledged that although exploratory testing is valuable as it can improve understanding of variables that have not been previously examined, it holds the risk of false positives. One way to overcome the risk of false positive would be to adjust the level of statistical significance. However, previous evidence in epidemiology research suggests that it should be avoided (Rothman, 1990).

6.3.1 Personal reflection

As for my personal reflection upon completion of this thesis, this journey has developed not only my skills in research and data analysis but has also shaped my thinking. The review was the starting point to build knowledge in sedentary behaviour and to guide my research focus. I had the privilege to deviate from the research proposal that my first supervisor wrote, follow my own research interests and receive support from the team. Therefore, research ideas in Chapter 3, 4 and 5 were developed from the review and its associated reading. The progressive narrowing of the focus of interest allowed a more detailed consideration of screen behaviours. The use of software in this thesis, including STATA and Microsoft Office Excel to manage the volume of data and conduct analysis, Covidence and PRISMA statement to support the systematic review were important to address the research questions and provided an opportunity to develop my skills and experience that will be transferrable in future research. I had the pleasure to experience the peer-review process, to present my work internally and externally, to network with other researchers and get involved in their research projects. Further, during these past four years, I have also reflected on aspects of academic research that excite me. Equally, I have also reflected on the parts that do not develop any enthusiasm. Having spent considerable amount of time analysing data and writing the findings for these studies have made me realise where and how I see myself in the future. Collectively, this experience has been a great lesson.

6.4. Suggestions for future research

Whilst the review aimed to describe changes in sedentary behaviour with age for sub-population groups, this was not feasible due to the lack of available data regarding socio-demographic and anthropometric factors. As such, research to conduct stratified analysis, for example by socio-economic status, ethnicity, or body mass index, to show whether change in sedentary behaviour varies across sub-groups will enable intervention programmes to be targeted at the most appropriate population groups.

Further, contextualising the findings of specific screen behaviours with the social context that influence screen-based behaviours was challenging due to the use of a range of different methodologies in previous studies which precludes comparison with findings of this thesis. There is not a great benefit in providing a composite measure of screen behaviour and presenting the social context alongside composite estimates as this practice can mask important behavioural differences. Therefore, the relationship between social context and measured contemporary single screen behaviours should be examined further. Qualitative studies may also be useful because they could potentially further our understanding on how interactions between family members are formed whilst members spend time in specific screen behaviours. This evidence will facilitate the development of interventions to work alongside family members and friends to modify children's screen use, ensuring that there are no avoidable adverse consequences on social dynamics.

Future research is needed to keep up with the ever-expanding range of screen behaviours. Since screen behaviours and their type of use are differently associated with health outcomes this is an important future avenue of study. One way of expanding our knowledge would be to develop assessment tools or use current tools in combination that can capture the breadth of device use, and the type of use (e.g., active vs. passive). For example, if researchers are to use questionnaires, then these questionnaires should be flexible to include questions about device use and the screen behaviour undertaken through that device. Innovative research using cameras may be valuable in capturing the form of communication whilst using social media platforms and different devices. Evidence has shown that wearable cameras represent the best objective method currently available to categorise the social and environmental context of accelerometer-defined episodes of activity in free-living conditions (Doherty *et al.*, 2013).

In addition, as noted within **Chapter 5**, along with the use of questionnaires, body worn devices would contribute to the body of knowledge to distinguish screen behaviours performed whilst in seated position or in light activity. This would enhance the exploration of the relationship between

screen based sedentary behaviour and health. The use of Euclidean Norm Minus One (ENMO) and Mean Amplitude Deviation (MAD) thresholds in raw accelerometer data have accurately distinguished between sedentary activity and light physical activity (Bakrania *et al.*, 2016). Further, large cohort studies, such as MCS, may consider providing the raw accelerometer data alongside processed data. Having access to the raw data would allow for researchers to make their own data processing decisions.

6.5. Conclusion

The development of behaviour change interventions is necessary for changing the population shift in sedentary and screen behaviour in children and adolescents. For the development of effective interventions, evidence on factors and potential targets that influence sedentary and screen behaviour is deemed necessary. This thesis suggests that interventions may benefit from balancing, if not limiting, sedentary and screen behaviour in children and adolescents. The temporal nature of these screen behaviours also suggests a time targeted approach may be appropriate and provides evidence for the field to target health behaviours simultaneously. Social networking, video-game play and television viewing are highly prevalent and hold the potential to be targeted in future research and work with the immediate social environment may be promising in contributing to population level shifts in screen behaviour.

References

Altenburg, T. M. *et al.* (2012) 'Direction of the association between body fatness and self-reported screen time in Dutch adolescents', *The International Journal of Behavioral Nutrition and Physical Activity*, 9. doi: 10.1186/1479-5868-9-4.

Anderson, E. L. *et al.* (2016) 'Long-term effects of the Active for Life Year 5 (AFLY5) school-based cluster-randomised controlled trial', *BMJ Open*, 6(11), pp. 1–11. doi: 10.1136/bmjopen-2015-010957.

Andrade, S. *et al.* (2015) 'School-based intervention on healthy behaviour among Ecuadorian adolescents: Effect of a cluster-randomized controlled trial on screen-time Health behavior, health promotion and society', *BMC Public Health*, 15(1). doi: 10.1186/s12889-015-2274-4.

Arundell, L. *et al.* (2016a) 'A systematic review of the prevalence of sedentary behavior during the after-school period among children aged 5-18 years', *International Journal of Behavioral Nutrition and Physical Activity*, 13(1), pp. 1–9. doi: 10.1186/s12966-016-0419-1.

Arundell, L. *et al.* (2016b) 'The correlates of after-school sedentary behavior among children aged 5-18 years: A systematic review Energy balance-related behaviors', *BMC Public Health*, 16(1). doi: 10.1186/s12889-015-2659-4.

Arundell, L. *et al.* (2019) 'Informing Behaviour Change: What Sedentary Behaviours Do Families Perform at Home and How Can They Be Targeted?', *International Journal of Environmental Research and Public Health*, 16(22), p. 4565. doi: 10.3390/ijerph16224565.

Atkin, A. J. *et al.* (2013) 'Determinants of Change in Children's Sedentary Time', *PLoS ONE*, 8(6), pp. 1–9. doi: 10.1371/journal.pone.0067627.

Atkin, A. J., Corder, K. and van Sluijs, E. M. F. (2013) 'Bedroom media, sedentary time and screen-time in children: A longitudinal analysis', *International Journal of Behavioral Nutrition and Physical Activity*, 10, pp. 1–10. doi: 10.1186/1479-5868-10-137.

Auhuber, L. *et al.* (2019) 'Leisure Activities of Healthy Children and Adolescents', *International journal of environmental research and public health*. doi: 10.3390/ijerph16122078.

Australian 24-HourMovement Guidelines for Children and Young People (5–17) (2018) 'An Integration of Physical Activity, Sedentary Behaviour and Sleep', *Australian Government Department of Health: Canberra, Australia*.

Ayala, A. M. C. *et al.* (2019) 'Longitudinal Changes in Sitting Patterns, Physical Activity, and Health Outcomes in Adolescents', *CHILDREN-BASEL*, 6(1). doi: 10.3390/children6010002.

Babey, S. H., Hastert, T. A. and Wolstein, J. (2013) 'Adolescent sedentary behaviors: Correlates differ for television viewing and computer use', *Journal of Adolescent Health*, 52(1), pp. 70–76. doi: 10.1016/j.jadohealth.2012.05.001.

Bakrania, K. *et al.* (2016) 'Intensity Thresholds on Raw Acceleration Data: Euclidean Norm Minus One (ENMO) and Mean Amplitude Deviation (MAD) Approaches', *PLOS ONE*, 11(10), p. e0164045. Available at: https://doi.org/10.1371/journal.pone.0164045.

Ball, K. *et al.* (2009) 'Socioeconomic Position and Children's Physical Activity and Sedentary Behaviors: Longitudinal Findings from the CLAN Study', *Journal of Physical Activity and Health*, 6(3), pp. 289–298. doi: 10.1123/jpah.6.3.289.

Barnett, T. A. *et al.* (2018) 'Sedentary behaviors in today's youth: Approaches to the prevention and management of childhood obesity a scientific statement from the American Heart Association', *Circulation*. doi: 10.1161/CIR.0000000000000591.

Basterfield, L. *et al.* (2012) 'Physical activity, sedentary behavior, and adiposity in English children.', *American journal of preventive medicine*, 42(5), pp. 445–451. doi: 10.1016/j.amepre.2012.01.007.

Bauman, A., Bittman, M. and Gershuny, J. (2019) 'A short history of time use research; Implications for public health', *BMC Public Health*. doi: 10.1186/s12889-019-6760-y.

Bell, J. A. *et al.* (2018) 'Associations of device-measured physical activity across adolescence with metabolic traits: Prospective cohort study.', *PLoS medicine*, 15(9), p. e1002649. doi: https://dx.doi.org/10.1371/journal.pmed.1002649.

Biddle, S. J. H. *et al.* (2004) 'Physical activity and sedentary behaviours in youth: Issues and controversies', *Journal of The Royal Society for the Promotion of Health*. doi: 10.1177/146642400312400110.

Biddle, S. J. H. *et al.* (2009) 'Temporal and environmental patterns of sedentary and active behaviors during adolescents' leisure time.', *International journal of behavioral medicine*, 16(3), pp. 278–286. doi: 10.1007/s12529-008-9028-y.

Biddle, S. J. H. *et al.* (2010) 'Tracking of sedentary behaviours of young people: A systematic review', *Preventive Medicine*, 51(5), pp. 345–351. doi: 10.1016/j.ypmed.2010.07.018.

Biddle, S. J. H., García Bengoechea, E. and Wiesner, G. (2017) 'Sedentary behaviour and adiposity in youth: A systematic review of reviews and analysis of causality', *International Journal of Behavioral Nutrition and Physical Activity*, 14(1), pp. 1–21. doi: 10.1186/s12966-017-0497-8.

Biddle, S. J. H., O'Connell, S. and Braithwaite, R. E. (2011) 'Sedentary behaviour interventions in Young People: A Meta-Analysis', *British Journal of Sports Medicine*, 45(11), pp. 937–942. doi: 10.1136/bjsports-2011-090205.

Biswas, A. *et al.* (2015) 'Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults: a systematic review and meta-analysis.', *Annals of internal medicine*, 162(2), pp. 123–132. doi: 10.7326/M14-1651.

Bornstein, M. H. (2012) 'Cultural Approaches to Parenting', *Parenting, science and practice*. 2012/06/14, 12(2–3), pp. 212–221. doi: 10.1080/15295192.2012.683359.

Braig, S. *et al.* (2018) 'Screen time, physical activity and self-esteem in children: The Ulm birth cohort study', *International Journal of Environmental Research and Public Health*, 15(6), pp. 1–12. doi: 10.3390/ijerph15061275.

Brodersen, N. H. *et al.* (2007) 'Trends in physical activity and sedentary behaviour in adolescence: Ethnic and socioeconomic differences', *British Journal of Sports Medicine*, 41(3), pp. 140–144. doi: 10.1136/bjsm.2006.031138.

Bull, F. C. *et al.* (2020) 'World Health Organization 2020 guidelines on physical activity and sedentary behaviour', *British Journal of Sports Medicine*, 54(24), pp. 1451 LP – 1462. doi: 10.1136/bjsports-2020-102955.

Busch, V., Manders, L. A. and De Leeuw, J. R. J. (2013) 'Screen time associated with health behaviors and outcomes in adolescents', *American Journal of Health Behavior*, 37(6), pp. 819–830. doi: 10.5993/AJHB.37.6.11.

Busschaert, C. *et al.* (2016) 'Socio-Demographic, Social-Cognitive, Health-Related and Physical Environmental Variables Associated with Context-Specific Sitting Time in Belgian Adolescents: A One-Year Follow-Up Study', *Plos One*, 11(12), pp. 1–23. doi: 10.1371/journal.pone.0167553.

Butte, N. F. *et al.* (2014) 'Longitudinal effects of parental, child and neighborhood factors on moderate-vigorous physical activity and sedentary time in Latino children', *International Journal*

of Behavioral Nutrition and Physical Activity, 11(1), pp. 1–12. doi: 10.1186/s12966-014-0108-x.

Cahill, L. (2014) 'Equal ≠ the same: sex differences in the human brain', *Cerebrum : the Dana forum on brain science*, 2014, p. 5. Available at: https://pubmed.ncbi.nlm.nih.gov/25009695.

Cameron, A. and Trivedi, P. (2013) *Regression Analysis of Count Data*. Cambridge: Cambridge University Press.

Carlson, J. A. *et al.* (2012) 'Dietary-Related and Physical Activity-Related Predictors of Obesity in Children: A 2-Year Prospective Study', *Childhood Obesity*, 8(2), pp. 110–115. doi: 10.1089/chi.2011.0071.

Carson, V., Tremblay, M. S., *et al.* (2016) 'Associations between sleep duration, sedentary time, physical activity, and health indicators among Canadian children and youth using compositional analyses [1]', *Applied Physiology, Nutrition, and Metabolism*, 41(6 (Suppl. 3)), pp. S294–S302. doi: 10.1139/apnm-2016-0026.

Carson, V., Hunter, S., *et al.* (2016) 'Systematic review of sedentary behaviour and health indicators in school-aged children and youth: an update', *Applied Physiology, Nutrition, and Metabolism*, 41(6 (Suppl. 3)), pp. S240–S265. doi: 10.1139/apnm-2015-0630.

Carson, V. *et al.* (2017) 'Health associations with meeting new 24-hour movement guidelines for Canadian children and youth', *Preventive Medicine*. doi: 10.1016/j.ypmed.2016.12.005.

Van Cauwenberghe, E. *et al.* (2012) 'Patterns of physical activity and sedentary behaviour in preschool children', *International Journal of Behavioral Nutrition and Physical Activity*, 9, pp. 1–11. doi: 10.1186/1479-5868-9-138.

Cespedes, E. M. *et al.* (2014) 'Television Viewing, Bedroom Television, and Sleep Duration From Infancy to Mid-Childhood', *Pediatrics*, 133(5), pp. e1163–e1171. doi: 10.1542/peds.2013-3998.

Chang, Z. and Lei, W. (2021) 'A Study on the Relationship Between Physical Activity, Sedentary Behavior, and Sleep Duration in Preschool Children.', *Frontiers in public health*, 9, p. 618962. doi: 10.3389/fpubh.2021.618962.

Chaput, J. *et al.* (2016) 'Sleep and Health Indicators in School-Aged Children and Youth 1', 282(June). doi: 10.1139/apnm-2015-0627.

Chastin, Sebastien F M *et al.* (2015) 'Combined Effects of Time Spent in Physical Activity, Sedentary Behaviors and Sleep on Obesity and Cardio-Metabolic Health Markers: A Novel Compositional Data Analysis Approach.', *PloS one*, 10(10), p. e0139984. doi: 10.1371/journal.pone.0139984.

Chen, Y. C. *et al.* (2014) 'Pathway from central obesity to childhood asthma: Physical fitness and sedentary time are leading factors', *American Journal of Respiratory and Critical Care Medicine*, 189(10), pp. 1194–1203. doi: 10.1164/rccm.201401-0097OC.

Chong, K. H. *et al.* (2019) 'Changes in physical activity, sedentary behaviour and sleep across the transition from primary to secondary school: A systematic review', *Journal of Science and Medicine in Sport*. doi: 10.1016/j.jsams.2019.12.002.

Chortatos, A. *et al.* (2020) 'Comparing three screen-based sedentary behaviours ' effect upon adolescents ' participation in physical activity : The ESSENS study', pp. 1–15.

Cliff, D. P. *et al.* (2016) 'Objectively measured sedentary behaviour and health and development in children and adolescents: systematic review and meta-analysis.', *Obesity reviews : an official journal of the International Association for the Study of Obesity*, 17(4), pp. 330–344. doi: 10.1111/obr.12371.

Cole, T. J. *et al.* (2000) 'Establishing a standard definition for child overweight and obesity worldwide: International survey', *British Medical Journal*. doi: 10.1136/bmj.320.7244.1240.

Colley, R. C. *et al.* (2011) 'Physical activity of Canadian children and youth: accelerometer results from the 2007 to 2009 Canadian Health Measures Survey.', *Health reports*, 22(1), pp. 15–23.

Collings, Paul J. *et al.* (2015) 'Magnitude and determinants of change in objectively-measured physical activity, sedentary time and sleep duration from ages 15 to 17.5y in UK adolescents: The ROOTS study', *International Journal of Behavioral Nutrition and Physical Activity*, 12(1), pp. 1–10. doi: 10.1186/s12966-015-0222-4.

UK House of Commons. Written evidence submitted by the Royal College of paediatrics and child health (SMH0156). UK: Science and technology Committee, 2018.

Connelly, R. and Platt, L. (2014) 'Cohort profile: UK Millennium Cohort Study (mcs)', *International Journal of Epidemiology*, 43(6), pp. 1719–1725. doi: 10.1093/ije/dyu001.

Coombs, N. *et al.* (2013) 'Children's and adolescents' sedentary behaviour in relation to socioeconomic position', *Journal of Epidemiology and Community Health*, 67(10), pp. 868–874. doi: 10.1136/jech-2013-202609.

Cooper, A. R. *et al.* (2015) 'Objectively measured physical activity and sedentary time in youth: The International children's accelerometry database (ICAD)', *International Journal of Behavioral Nutrition and Physical Activity*, 12(1 PG-). doi: 10.1186/s12966-015-0274-5.

Cooper, Kerris and Stewart, Kitty (2017) *Does Money Affect Children's Outcomes? An update.* CASEpapers (203). Centre for Analysis of Social Exclusion, The London School of Economics and Political Science, London, UK.

Corder, K. *et al.* (2015) 'Change in objectively measured physical activity during the transition to adolescence', *British Journal of Sports Medicine*, 49(11), pp. 730–736. doi: 10.1136/bjsports-2013-093190.

da Costa, B. G. G. *et al.* (2021) 'Association between screen time and accelerometer-measured 24-h movement behaviors in a sample of Brazilian adolescents.', *Public health*, 195, pp. 32–38. doi: 10.1016/j.puhe.2021.03.029.

Coyne, S. M. *et al.* (2020) 'Does time spent using social media impact mental health?: An eight year longitudinal study', *Computers in Human Behavior*. doi: 10.1016/j.chb.2019.106160.

De Craemer, M. *et al.* (2018) 'Changes in children's television and computer time according to parental education, parental income and ethnicity: A 6-year longitudinal EYHS study', *PLoS ONE*. doi: 10.1371/journal.pone.0203592.

Cronholm, F. *et al.* (2016) 'A Physical Activity Intervention Program in School is Also Accompanied by Higher Leisure-Time Physical Activity: A Prospective Controlled 3-Year Study in 194 Prepubertal Children', *Journal of Physical Activity and Health*, 14(4), pp. 301–307. doi: 10.1123/jpah.2016-0213.

Cronholm, F. *et al.* (2018) 'A comparative study found that a seven-year school-based exercise programme increased physical activity levels in both sexes', *Acta Paediatrica, International Journal of Paediatrics*, 107(4), pp. 701–707. doi: 10.1111/apa.14172.

Cumming, S. P. *et al.* (2014) 'Concurrent and prospective associations among biological maturation, and physical activity at 11 and 13 years of age', *Scandinavian Journal of Medicine and Science in Sports*, 24(1), pp. 20–28. doi: 10.1111/sms.12103.

Dalene, K. E. *et al.* (2018) 'Cross-sectional and prospective associations between sleep, screen

time, active school travel, sports/exercise participation and physical activity in children and adolescents', *BMC Public Health*. doi: 10.1186/s12889-018-5610-7.

Dall, P. M. *et al.* (2017) 'TAxonomy of Self-reported Sedentary behaviour Tools (TASST) framework for development, comparison and evaluation of self-report tools: content analysis and systematic review.', *BMJ open*, 7(4), p. e013844. doi: 10.1136/bmjopen-2016-013844.

Dasgupta, K. *et al.* (no date) 'Emergence of sex differences in prevalence of high systolic blood pressure: analysis of a longitudinal adolescent cohort.', *Circulation*, 114(24 PG-2663–2670), pp. 2663–2670. Available at: https://search.ebscohost.com/login.aspx?direct=true&db=ccm&AN=106145553&site=ehost-live NS -.

Davison, K. K., Francis, L. A. and Birch, L. L. (2005) 'Links between parents' and girls' television viewing behaviors: a longitudinal examination', *The Journal of pediatrics*, 147(4), pp. 436–442. doi: 10.1016/j.jpeds.2005.05.002.

Department for Environmental Food & Rural Affairs in collaboration with the Office for National Statistics (2016) 'Guide to applying the Rural Urban Classification to data', (July), p. 11. Available at: www.gov.uk/defra.

Dewar, D. L. *et al.* (2013) 'The nutrition and enjoyable activity for teen girls study: a cluster randomized controlled trial.', *American journal of preventive medicine*, 45(3 PG-313–7), pp. 313–317. doi: https://dx.doi.org/10.1016/j.amepre.2013.04.014.

Dewar, D. L. *et al.* (2014) 'Exploring changes in physical activity, sedentary behaviors and hypothesized mediators in the NEAT girls group randomized controlled trial', *Journal of Science and Medicine in Sport*, 17(1), pp. 39–46. doi: 10.1016/j.jsams.2013.02.003.

Dienlin, T. and Johannes, N. (2020) 'The impact of digital technology use on adolescent well-being', *Dialogues in Clinical Neuroscience*, 22(2), pp. 135–142. doi: 10.31887/DCNS.2020.22.2/tdienlin.

Doherty, A. R. *et al.* (2013) 'Using wearable cameras to categorise type and context of accelerometer-identified episodes of physical activity.', *The international journal of behavioral nutrition and physical activity*, 10, p. 22. doi: 10.1186/1479-5868-10-22.

Dominick, J. R. (1984) 'Videogames, Television Violence, and Aggression in Teenagers', *Journal of Communication*, 34(2), pp. 136–147. doi: https://doi.org/10.1111/j.1460-2466.1984.tb02165.x.

Dowd, K. P. *et al.* (2018) *A systematic literature review of reviews on techniques for physical activity measurement in adults: A DEDIPAC study*, *International Journal of Behavioral Nutrition and Physical Activity*. International Journal of Behavioral Nutrition and Physical Activity. doi: 10.1186/s12966-017-0636-2.

Downing, K. L., Hnatiuk, J. and Hesketh, K. D. (2015) 'Prevalence of sedentary behavior in children under 2years: A systematic review.', *Preventive medicine*, 78, pp. 105–114. doi: 10.1016/j.ypmed.2015.07.019.

Dubuc, M.-M., Aubertin-Leheudre, M. and Karelis, A. D. (2019) 'Lifestyle Habits Predict Academic Performance in High School Students: The Adolescent Student Academic Performance Longitudinal Study (ASAP).', *International journal of environmental research and public health*, 17(1). doi: https://dx.doi.org/10.3390/ijerph17010243.

Dumith, S. C. *et al.* (2011) 'Physical activity change during adolescence: a systematic review and a pooled analysis.', *International journal of epidemiology*, 40(3), pp. 685–698. doi: 10.1093/ije/dyq272.

Duncan, C., Jones, K. and Moon, G. (1996) 'Health-related behaviour in context: a multilevel modelling approach.', *Social science & medicine (1982)*, 42(6), pp. 817–830. doi: 10.1016/0277-9536(95)00181-6.

Egger, M. *et al.* (1997) 'Bias in meta-analysis detected by a simple, graphical test', *BMJ*, 315(7109), pp. 629 LP – 634. doi: 10.1136/bmj.315.7109.629.

Ekelund, U. *et al.* (2006) 'TV viewing and physical activity are independently associated with metabolic risk in children: the European Youth Heart Study.', *PLoS medicine*, 3(12), p. e488. doi: 10.1371/journal.pmed.0030488.

Ekelund, U. *et al.* (2012) 'Moderate to vigorous physical activity and sedentary time and cardiometabolic risk factors in children and adolescents.', *JAMA*, 307(7), pp. 704–712. doi: 10.1001/jama.2012.156.

van Ekris, E. *et al.* (2017) 'Erratum to: An evidence-update on the prospective relationship between childhood sedentary behaviour and biomedical health indicators: a systematic review and meta-analysis: Childhood sedentary behaviour and future health (Obesity Reviews, (2016), 17, 9, ', *Obesity Reviews*. doi: 10.1111/obr.12526.

Elgar, F. J. *et al.* (2004) 'Sedentary behaviour, physical activity and weight problems among adolescents in wales', *Psychology and Health*, 19(SUPPL. 1), pp. 48–49. doi: 10.1016/j.puhe.2004.10.011.

Enthoven, C. A. *et al.* (2020) 'The impact of computer use on myopia development in childhood: The Generation R study', *PREVENTIVE MEDICINE*, 132. doi: 10.1016/j.ypmed.2020.105988.

Espinoza, G. and Juvonen, J. (2011) 'The pervasiveness, connectedness, and intrusiveness of social network site use among young adolescents.', *Cyberpsychology, behavior and social networking*, 14(12), pp. 705–709. doi: 10.1089/cyber.2010.0492.

Evenson, K. R. *et al.* (2019) 'Physical Activity and Sedentary Behavior among US Hispanic/Latino Youth: The SOL Youth Study', *Medicine and Science in Sports and Exercise*. doi: 10.1249/MSS.0000000000001871.

Ezendam, N. P. M., Brug, J. and Oenema, A. (2012) 'Evaluation of the web-based computer-tailored FATaintPHAT intervention to promote energy balance among adolescents: Results from a school cluster randomized trial', *Archives of Pediatrics and Adolescent Medicine*, 166(3), pp. 248–255. doi: 10.1001/archpediatrics.2011.204.

Fairclough, S. J. *et al.* (2009) 'Associations between children's socioeconomic status, weight status, and sex, with screen-based sedentary behaviours and sport participation', *International Journal of Pediatric Obesity*, 4(4), pp. 299–305. doi: 10.3109/17477160902811215.

Falbe, J. *et al.* (2014) 'Longitudinal relations of television, electronic games, and digital versatile discs with changes in diet in adolescents', *The American Journal of Clinical Nutrition*, 100(6), pp. 1173–81. doi: 10.3945/ajcn.114.088500.1.

Falbe, J. *et al.* (2015) 'Sleep duration, restfulness, and screens in the sleep environment', *Pediatrics*. doi: 10.1542/peds.2014-2306.

Farooq, A. *et al.* (2019) 'Longitudinal changes in moderate-to-vigorous-intensity physical activity in children and adolescents: A systematic review and meta-analysis', *Obesity Reviews*, (September), pp. 1–15. doi: 10.1111/obr.12953.

Farooq, M. A. *et al.* (2018) 'Timing of the decline in physical activity in childhood and adolescence: Gateshead Millennium Cohort Study', *British Journal of Sports Medicine*, 52(15), pp. 1002–1006.

doi: 10.1136/bjsports-2016-096933.

Fitzsimons, E. (2017) 'Millennium Cohort Study. Sixth Survey 2015-2016. User Guide (First Edition).', (February). Available at: http://doc.ukdataservice.ac.uk/doc/8156/mrdoc/pdf/mcs6_user_guide_28march2017.pdf.

Foley, L. *et al.* (2019) 'Cross-sectional and longitudinal associations between active commuting and patterns of movement behaviour during discretionary time: A compositional data analysis.', *PloS one*, 14(8), p. e0216650. doi: 10.1371/journal.pone.0216650.

Foley, L. S. *et al.* (2013) 'Presleep activities and time of sleep onset in children.', *Pediatrics*, 131(2), pp. 276–282. doi: 10.1542/peds.2012-1651.

Fujiwara, H. *et al.* (2018) 'Arterial stiffness in junior high school students: Longitudinal observations', *Pediatrics International*, 60(2), pp. 127–135. doi: 10.1111/ped.13475.

Fulkerson, J. A. *et al.* (2007) 'Correlates of psychosocial well-being among overweight adolescents: The role of the family.', *Journal of Consulting and Clinical Psychology*. Fulkerson, Jayne A.: School of Nursing, University of Minnesota, 5-160 Weaver Densford Hall, Minneapolis, MN, US, 55455, fulke001@umn.edu: American Psychological Association, pp. 181–186. doi: 10.1037/0022-006X.75.1.181.

Garrison, M. M., Liekweg, K. and Christakis, D. A. (2011) 'Media use and child sleep: the impact of content, timing, and environment', *Pediatrics*. 2011/06/27, 128(1), pp. 29–35. doi: 10.1542/peds.2010-3304.

Gebremariam, M. K. *et al.* (2012) 'Stability and change in screen-based sedentary behaviours and associated factors among Norwegian children in the transition between childhood and adolescence', *BMC Public Health*, 12(1), p. 104. doi: 10.1186/1471-2458-12-104.

Gentile, D. A. *et al.* (2014) 'Protective effects of parental monitoring of children's media use a prospective study', *JAMA Pediatrics*, 168(5), pp. 479–484. doi: 10.1001/jamapediatrics.2014.146.

Grao-Cruces, A. *et al.* (2020) 'Changes in the school and non-school sedentary time in youth: The UP&DOWN longitudinal study', *JOURNAL OF SPORTS SCIENCES*, 38(7), pp. 780–786. doi: 10.1080/02640414.2020.1734310.

Grydeland, M. *et al.* (2013) 'Intervention effects on physical activity: The HEIA study - a cluster randomized controlled trial', *International Journal of Behavioral Nutrition and Physical Activity*, 10(1), p. 1. doi: 10.1186/1479-5868-10-17.

Gunnell, K. E. *et al.* (2016) 'Examining the bidirectional relationship between physical activity, screen time, and symptoms of anxiety and depression over time during adolescence', *Preventive Medicine*, 88, pp. 147–152. doi: 10.1016/j.ypmed.2016.04.002.

Guo, W., Key, T. J. and Reeves, G. K. (2019) 'Accelerometer compared with questionnaire measures of physical activity in relation to body size and composition: a large cross-sectional analysis of UK Biobank', *BMJ Open*, 9(1), p. e024206. doi: 10.1136/bmjopen-2018-024206.

Guo, Y. *et al.* (2013) 'Myopic Shift and Outdoor Activity among Primary School Children: One-Year Follow-Up Study in Beijing', *PLoS ONE*, 8(9). doi: 10.1371/journal.pone.0075260.

Haapala, H. L. *et al.* (2017) 'Changes in physical activity and sedentary time in the Finnish Schools on the Move program: a quasi-experimental study', *Scandinavian Journal of Medicine and Science in Sports*, 27(11), pp. 1442–1453. doi: 10.1111/sms.12790.

Hanson, S. K. *et al.* (2019) 'Longitudinal patterns of physical activity, sedentary behavior and sleep in urban South African adolescents, Birth-To-Twenty Plus cohort', *BMC PEDIATRICS*, 19. doi:

10.1186/s12887-019-1619-z.

Harding, S. K. *et al.* (2015) 'Longitudinal changes in sedentary time and physical activity during adolescence', *International Journal of Behavioral Nutrition and Physical Activity*, 12(1), pp. 1–7. doi: 10.1186/s12966-015-0204-6.

Hardy, L. L. *et al.* (2014) 'Temporal trends in weight and current weight-related behaviour of australian aboriginal school-aged children', *Medical Journal of Australia*, 200(11), pp. 667–671. doi: 10.5694/mja13.10614.

Hardy, L. L., Bass, S. L. and Booth, M. L. (2007) 'Changes in Sedentary Behavior among Adolescent Girls: A 2.5-Year Prospective Cohort Study', *Journal of Adolescent Health*, 40(2), pp. 158–165. doi: 10.1016/j.jadohealth.2006.09.009.

Hashem, R. *et al.* (2019) 'Associations between objectively assessed and questionnaire - based sedentary behaviour with body mass index and systolic blood pressure in Kuwaiti adolescents', *BMC Research Notes*, pp. 8–13. doi: 10.1186/s13104-019-4626-0.

Haycraft, E. *et al.* (2020) 'Screen-time during the after-school period: A contextual perspective', *Preventive Medicine Reports*, 19(November 2019). doi: 10.1016/j.pmedr.2020.101116.

Healy, G. N. *et al.* (2008) 'Objectively measured sedentary time, physical activity, and metabolic risk: the Australian Diabetes, Obesity and Lifestyle Study (AusDiab).', *Diabetes care*, 31(2), pp. 369–371. doi: 10.2337/dc07-1795.

van Hees, V. T. *et al.* (2013) 'Separating Movement and Gravity Components in an Acceleration Signal and Implications for the Assessment of Human Daily Physical Activity', *PLoS ONE*. doi: 10.1371/journal.pone.0061691.

Hesketh, K. *et al.* (2007) 'Stability of television viewing and electronic game/computer use in a prospective cohort study of Australian children: relationship with body mass index', *The international journal of behavioral nutrition and physical activity*, 4, p. 60. doi: 10.1186/1479-5868-4-60.

Heywood, J. (2018) 'Millennium Cohort Study Physical Activity: Accelerometer dataset MCS6(2015) USER GUIDE', 6(March), pp. 1–8.

Hidding, L. M. *et al.* (2017) 'Systematic Review of Childhood Sedentary Behavior Questionnaires: What do We Know and What is Next?', *Sports Medicine*, 47(4), pp. 677–699. doi: 10.1007/s40279-016-0610-1.

Higgins, J. (editors). (2011) 'Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0 [updated March 2011].', *The Cochrane Collaboration, 2011. Available from www.handbook.cochrane.org.*

Hoare, E. *et al.* (2016) 'The associations between sedentary behaviour and mental health among adolescents: A systematic review', *The International Journal of Behavioral Nutrition and Physical Activity*, 13. doi: 10.1186/s12966-016-0432-4.

Hoff, K. A. *et al.* (2018) 'Normative changes in interests from adolescence to adulthood: A meta-analysis of longitudinal studies.', *Psychological bulletin*, 144(4), pp. 426–451. doi: 10.1037/bul0000140.

Hoyos Cillero, I. and Jago, R. (2010) 'Systematic review of correlates of screen-viewing among young children.', *Preventive medicine*, 51(1), pp. 3–10. doi: 10.1016/j.ypmed.2010.04.012.

Hoyos Cillero, I. and Jago, R. (2011) 'Sociodemographic and home environment predictors of screen viewing among Spanish school children', *Journal of Public Health*, 33(3), pp. 392–402. doi:

10.1093/pubmed/fdq087.

Hozo, S. P., Djulbegovic, B. and Hozo, I. (2005) 'Estimating the mean and variance from the median, range, and the size of a sample', *BMC Medical Research Methodology*, 5(1), p. 13. doi: 10.1186/1471-2288-5-13.

Iannotti, R. J. and Wang, J. (2013) 'Trends in physical activity, sedentary behavior, diet, and BMI among US adolescents, 2001-2009.', *Pediatrics*, 132(4 PG-606–14), pp. 606–614. doi: https://dx.doi.org/10.1542/peds.2013-1488.

Ipsos Mori (2017) 'Millennium Cohort Study Sixth Sweep (MCS6) Technical Report. Prepared for the Centre for Longitudinal Studies, UCL Institute of Education.', 2017(February). Available at: http://www.ipsos-mori.com/terms.http://www.ipsos-mori.com/terms.

Ipsos MORI (2016) 'Millennium Cohort Study Sixth Sweep (MCS6) Appendix B : English Language Survey Materials –', (September).

Jackson, S. L., Cunningham, S. A. and Author, P. M. (2017) 'The Stability of Children's Weight Status Over Time, and the Role of Television, Physical Activity, and Diet in Elementary School HHS Public Access Author manuscript', *Prev Med*, 100, pp. 229–234. doi: 10.1016/j.ypmed.2017.04.026.

Jago, R. *et al.* (2017) 'Change in children's physical activity and sedentary time between Year 1 and Year 4 of primary school in the B-PROACT1V cohort', *International Journal of Behavioral Nutrition and Physical Activity*, 14(1), pp. 1–13. doi: 10.1186/s12966-017-0492-0.

Jago, R. *et al.* (2019) 'Association of BMI category with change in children's physical activity between ages 6 and 11 years: a longitudinal study', *International Journal of Obesity*. doi: 10.1038/s41366-019-0459-0.

Janssen, X., Mann, Kay D., *et al.* (2016) 'Development of sedentary behavior across childhood and adolescence: Longitudinal analysis of the Gateshead Millennium Study', *International Journal of Behavioral Nutrition and Physical Activity*, 13(1), pp. 1–10. doi: 10.1186/s12966-016-0413-7.

Janz, K. F., Burns, T. L. and Levy, S. M. (2005) 'Tracking of activity and sedentary behaviors in childhood: The Iowa bone development study', *American Journal of Preventive Medicine*, 29(3), pp. 171–178. doi: 10.1016/j.amepre.2005.06.001.

Johnson, B. A. *et al.* (2012) 'Multilevel analysis of the Be Active Eat Well intervention: environmental and behavioural influences on reductions in child obesity risk.', *International journal of obesity (2005)*, 36(7 PG-901–7), pp. 901–907. doi: https://dx.doi.org/10.1038/ijo.2012.23.

Jones, A. *et al.* (2021) 'Identifying effective intervention strategies to reduce children's screen time: a systematic review and meta-analysis', *International Journal of Behavioral Nutrition and Physical Activity*, 18(1), pp. 1–20. doi: 10.1186/s12966-021-01189-6.

Jones, R. A. *et al.* (2013) 'Tracking physical activity and sedentary behavior in childhood: A systematic review', *American Journal of Preventive Medicine*, 44(6), pp. 651–658. doi: 10.1016/j.amepre.2013.03.001.

Kann, L. *et al.* (2018) 'Youth risk behavior surveillance - United States, 2017', *MMWR Surveillance Summaries*. doi: 10.15585/mmwr.ss670.

Katzmarzyk, P. T. and Mason, C. (2009) 'The physical activity transition.', *Journal of physical activity & health*, 6(3), pp. 269–280. doi: 10.1123/jpah.6.3.269.

Kemp, B. J., Parrish, A.-M. and Cliff, D. P. (2020) '`Social screens' and `the mainstream': longitudinal competitors of non-organized physical activity in the transition from childhood to adolescence',

INTERNATIONAL JOURNAL OF BEHAVIORAL NUTRITION AND PHYSICAL ACTIVITY, 17(1). doi: 10.1186/s12966-019-0908-0.

Kenney, E. L. and Gortmaker, S. L. (2017) 'United States Adolescents' Television, Computer, Videogame, Smartphone, and Tablet Use: Associations with Sugary Drinks, Sleep, Physical Activity, and Obesity.', *The Journal of pediatrics*, 182, pp. 144–149. doi: 10.1016/j.jpeds.2016.11.015.

Janz, KF et al. (2000) 'Tracking physical fitness and physical activity from childhood to adolescence: the Muscatine study.', *Medicine & Science in Sports & Exercise*, 32(7 PG-1250–1257), pp. 1250–1257.

Klitsie, T. *et al.* (2013) 'Children's sedentary behaviour: descriptive epidemiology and associations with objectively-measured sedentary time', *BMC Public Health*, 13(1), p. 1092. doi: 10.1186/1471-2458-13-1092.

Knell, G. *et al.* (2019) 'Prevalence and Likelihood of Meeting Sleep, Physical Activity, and Screen-Time Guidelines Among US Youth', *JAMA Pediatrics*, 173(4), pp. 387–389. doi: 10.1001/jamapediatrics.2018.4847.

Kobel, S. *et al.* (2019) 'Cross-sectional associations of objectively assessed sleep duration with physical activity, BMI and television viewing in German primary school children', *BMC Pediatrics*. doi: 10.1186/s12887-019-1429-3.

Kontostoli, E. *et al.* (2021) 'Age-related change in sedentary behavior during childhood and adolescence: A systematic review and meta-analysis.', *Obesity reviews : an official journal of the International Association for the Study of Obesity*, 22(9), p. e13263. doi: 10.1111/obr.13263.

Kwon, S. *et al.* (2012) 'Breaks in sedentary time during childhood and adolescence: Iowa bone development study', *Medicine and science in sports and exercise*, 44(6), pp. 1075–1080. doi: 10.1249/MSS.0b013e318245ca20.

Lipsky, LM *et al.* (2017) 'Diet quality of US adolescents during the transition to adulthood: Changes and predictors', *American Journal of Clinical Nutrition*, 105(6), pp. 1424–1432. doi: http://dx.doi.org/10.3945/ajcn.116.150029.

Lam, K. *et al.* (2022) 'How effective and how expensive are interventions to reduce sedentary behavior? An umbrella review and meta-analysis.', *Obesity reviews : an official journal of the International Association for the Study of Obesity*, p. e13422. doi: 10.1111/obr.13422.

Landsberg, B. *et al.* (2010) 'Clustering of lifestyle factors and association with overweight in adolescents of the Kiel Obesity Prevention Study.', *Public health nutrition*, 13(10 A), pp. 1708–1715. doi: 10.1017/S1368980010002260.

Larouche, R. *et al.* (2012) 'Life transitions in the waning of physical activity from childhood to adult life in the Trois-Rivières study', *Journal of Physical Activity and Health*. doi: 10.1123/jpah.9.4.516.

Lätt, E. *et al.* (2015) 'Vigorous physical activity rather than sedentary behaviour predicts overweight and obesity in pubertal boys: A 2-year follow-up study', *Scandinavian Journal of Public Health*, 43(3), pp. 276–282. doi: 10.1177/1403494815569867.

Leatherdale, S. T. and Wong, S. L. (2008) 'Modifiable characteristics associated with sedentary behaviours among youth.', *International journal of pediatric obesity : IJPO : an official journal of the International Association for the Study of Obesity*, 3(2), pp. 93–101. doi: 10.1080/17477160701830879.

Leonhardt, M. and Overå, S. (2021) 'Are There Differences in Video Gaming and Use of Social Media among Boys and Girls?-A Mixed Methods Approach.', *International journal of*

environmental research and public health, 18(11). doi: 10.3390/ijerph18116085.

Li, X. *et al.* (2019) 'Sleep mediates the association between adolescent screen time and depressive symptoms.', *Sleep Medicine*, 57, pp. 51–60. doi: 10.1016/j.sleep.2019.01.029.

Liberati, A. *et al.* (2009) 'The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration', *Journal of Clinical Epidemiology*, 62(10), pp. e1–e34. doi: 10.1016/j.jclinepi.2009.06.006.

Lieberman, P. (2007) 'The Evolution of Human Speech: Its Anatomical and Neural Bases', *Current Anthropology*, 48(1), pp. 39–66. doi: 10.1086/509092.

Lizandra, J. *et al.* (2016) 'Does sedentary behavior predict academic performance in adolescents or the other way round? A longitudinal path analysis', *PLoS ONE*, 11(4), pp. 1–13. doi: 10.1371/journal.pone.0153272.

Lobel, A. *et al.* (2017) 'Video Gaming and Children's Psychosocial Wellbeing: A Longitudinal Study', *Journal of Youth and Adolescence*, 46(4), pp. 884–897. doi: 10.1007/s10964-017-0646-z.

Lopez-Fernandez, O. *et al.* (2019) 'Female gaming, gaming addiction, and the role of women within gaming culture: A narrative literature review', *Frontiers in Psychiatry*, 10(JULY), pp. 1–14. doi: 10.3389/fpsyt.2019.00454.

Love, R. *et al.* (2019) 'Socioeconomic and ethnic differences in children's vigorous intensity physical activity: A cross-sectional analysis of the UK Millennium Cohort Study', *BMJ Open*, 9(5), pp. 1–8. doi: 10.1136/bmjopen-2018-027627.

Lowry, R. *et al.* (2012) 'Association of sleep duration with obesity among US high school students', *Journal of Obesity*, 2012. doi: 10.1155/2012/476914.

Lubans, D. R. *et al.* (2012) 'Preventing obesity among adolescent girls: One-year outcomes of the nutrition and enjoyable activity for teen girls (NEAT Girls) cluster randomized controlled trial', *Archives of Pediatrics and Adolescent Medicine*, 166(9), pp. 821–827. doi: 10.1001/archpediatrics.2012.41.

Lubans, D. R. *et al.* (2016) 'Assessing the sustained impact of a school-based obesity prevention program for adolescent boys: the ATLAS cluster randomized controlled trial', *International Journal of Behavioral Nutrition and Physical Activity*, 13(1), p. 92. doi: 10.1186/s12966-016-0420-8.

Lytle, L. A. *et al.* (2013) 'Examining the longitudinal relationship between change in sleep and obesity risk in adolescents', *Health education & behavior : the official publication of the Society for Public Health Education*. 2012/09/14, 40(3), pp. 362–370. doi: 10.1177/1090198112451446.

Maitland, C. *et al.* (2013) 'A place for play? The influence of the home physical environment on children's physical activity and sedentary behaviour.', *The international journal of behavioral nutrition and physical activity*, 10, p. 99. doi: 10.1186/1479-5868-10-99.

Malina, R. M. (2001) 'Adherence to physical activity from childhood to adulthood: A perspective from tracking studies', *Quest*. doi: 10.1080/00336297.2001.10491751.

Martinez-Gomez, D. *et al.* (2012) 'Sedentary behaviors and emerging cardiometabolic biomarkers in adolescents.', *The Journal of pediatrics*, 160(1), pp. 104–10.e2. doi: 10.1016/j.jpeds.2011.06.037.

Matthews, C. E. *et al.* (2008) 'Amount of time spent in sedentary behaviors in the United States, 2003-2004.', *American journal of epidemiology*, 167(7), pp. 875–881. doi: 10.1093/aje/kwm390.

McLellan, G. *et al.* (2019) 'Segmented sedentary time and physical activity patterns throughout

the week from wrist-worn ActiGraph GT3X+ accelerometers among children 7–12 years old', *Journal of Sport and Health Science*, 00, pp. 1–10. doi: 10.1016/j.jshs.2019.02.005.

Melkevik, O. *et al.* (2010) 'Is spending time in screen-based sedentary behaviors associated with less physical activity: A cross national investigation', *International Journal of Behavioral Nutrition and Physical Activity*. doi: 10.1186/1479-5868-7-46.

Mielke, G. I. *et al.* (2018) 'Socioeconomic position and sedentary behavior in Brazilian adolescents: A life-course approach', *Preventive Medicine*, 107(August 2017), pp. 29–35. doi: 10.1016/j.ypmed.2017.12.008.

Minges, K. E. *et al.* (2015) 'Reducing youth screen time: Qualitative metasynthesis of findings on barriers and facilitators', *Health Psychology*, 34(4), pp. 381–397. doi: 10.1037/hea0000172.

Mireku, M. O. *et al.* (2018) 'Total recall in the SCAMP cohort: Validation of self-reported mobile phone use in the smartphone era', *Environmental Research*, 161(December 2016), pp. 1–8. doi: 10.1016/j.envres.2017.10.034.

Mireku, M. O. *et al.* (2019) 'Night-time screen-based media device use and adolescents' sleep and health-related quality of life', *Environment International*. doi: 10.1016/j.envint.2018.11.069.

Mireku, M. O. (2020) 'Waking Activities and Sleep: Analysis of UK Adolescents' Daily Time-Use Diaries', *Journal of Adolescent Health*. doi: 10.1016/j.jadohealth.2020.05.050.

Mitchell, J. A. *et al.* (2012) 'Time spent in sedentary behavior and changes in childhood BMI: a longitudinal study from ages 9 to 15 years', *International Journal Of Obesity*, 37, p. 54. Available at: https://doi.org/10.1038/ijo.2012.41.

Mitchell, J. A. and Byun, W. (2013) 'Sedentary Behavior and Health Outcomes in Children and Adolescents', *American Journal of Lifestyle Medicine*, 8(3), pp. 173–199. doi: 10.1177/1559827613498700.

Mitchell, J. A., Pate, R. R. and Liese, A. D. (2013) 'Changes in cardiovascular disease risk factors from age 9 to 19 and the influence of television viewing', *Obesity*, 21(2), pp. 386–393. doi: 10.1002/oby.20014.

Moore, K. and Craciun, G. (2020) 'Fear of Missing Out and Personality as Predictors of Social Networking Sites Usage: The Instagram Case', *Psychological Reports*. doi: 10.1177/0033294120936184.

Morris, J. N. *et al.* (1953) 'Coronary heart-disease and physical activity of work.', *Lancet (London, England)*, 262(6795), pp. 1053–1057. doi: 10.1016/s0140-6736(53)90665-5.

Mullan, K. (2018) 'Technology and Children's Screen-Based Activities in the UK: The Story of the Millennium So Far', *Child Indicators Research*, 11(6), pp. 1781–1800. doi: 10.1007/s12187-017-9509-0.

Mullan, K. (2019) 'A child's day: trends in time use in the UK from 1975 to 2015', *British Journal of Sociology*. doi: 10.1111/1468-4446.12369.

Muscanell, N. L. and Guadagno, R. E. (2012) 'Make new friends or keep the old: Gender and personality differences in social networking use', *Computers in Human Behavior*, 28(1), pp. 107–112. doi: https://doi.org/10.1016/j.chb.2011.08.016.

Must, A. *et al.* (2007) 'Activity, inactivity, and screen time in relation to weight and fatness over adolescence in girls', *Obesity*, 15(7), pp. 1774–1781. doi: 10.1038/oby.2007.211.

Mutz, D. C., Roberts, D. F. and Vuuren, D. P. van (1993) 'Reconsidering the Displacement

Hypothesis: Television's Influence on Children's Time Use', *Communication Research*, 20(1), pp. 51–75. doi: 10.1177/009365093020001003.

Nagata, J. M. *et al.* (2021) 'Sociodemographic Correlates of Contemporary Screen Time Use among 9-10-Year-Old Children', *The Journal of Pediatrics*. doi: 10.1016/j.jpeds.2021.08.077.

Nelson, M. C. *et al.* (2006) 'Longitudinal and Secular Trends in Physical Activity and Sedentary Behavior During Adolescence', *Pediatrics*, 118(6), pp. e1627–e1634. doi: 10.1542/peds.2006-0926.

O'Brien, W. *et al.* (2021) 'Relationship between Gender, Physical Activity, Screen Time, Body Mass Index and Wellbeing in Irish Children from Social-Disadvantage', *Child Care in Practice*, pp. 1–15. doi: 10.1080/13575279.2021.1887815.

Office of Communications (OfCom) (2021) 'Children and parents: media use and attitudes report Content consumption and online activities', *Ofcom*, (April), pp. 1–8.

Office of Communications (2019) 'Children and Parents: Media Use and Attitudes', *Ofcom*, (October), p. 220. Available at: http://stakeholders.ofcom.org.uk/binaries/research/media-literacy/october-2013/research07Oct2013.pdf.

Olds, T., Ridley, K. and Dollman, J. (2006) 'Screenieboppers and extreme screenies: the place of screen time in the time budgets of 10-13 year-old Australian children.', *Australian and New Zealand journal of public health*, 30(2), pp. 137–142. doi: 10.1111/j.1467-842x.2006.tb00106.x.

Olds, T. S. *et al.* (2010) 'Descriptive epidemiology of screen and nonscreen sedentary time in adolescents: A cross sectional study', *The International Journal of Behavioral Nutrition and Physical Activity*, 7. doi: 10.1186/1479-5868-7-92.

Olson, C. K. (2010) 'Children's Motivations for Video Game Play in the Context of Normal Development', *Review of General Psychology*, 14(2), pp. 180–187. doi: 10.1037/a0018984.

Orben, A. (2020) 'Teenagers, screens and social media: a narrative review of reviews and key studies', *Social Psychiatry and Psychiatric Epidemiology*, 55(4), pp. 407–414. doi: 10.1007/s00127-019-01825-4.

Ortega, F. B. *et al.* (2013) 'Objectively Measured Physical Activity and Sedentary Time during Childhood, Adolescence and Young Adulthood: A Cohort Study', *PLoS ONE*, 8(4). doi: 10.1371/journal.pone.0060871.

Owen, N. *et al.* (2010) 'Too much sitting: the population health science of sedentary behavior.', *Exercise and sport sciences reviews*, 38(3), pp. 105–113. doi: 10.1097/JES.0b013e3181e373a2.

Paffenbarger, R. S. J. *et al.* (1986) 'Physical activity, all-cause mortality, and longevity of college alumni.', *The New England journal of medicine*, 314(10), pp. 605–613. doi: 10.1056/NEJM198603063141003.

Panahi, S. and Tremblay, A. (2018) 'Sedentariness and Health: Is Sedentary Behavior More Than Just Physical Inactivity? ', *Frontiers in Public Health* , p. 258.

Pate, R. R. *et al.* (2011) 'Sedentary behaviour in youth', *British Journal of Sports Medicine*, 45(11), pp. 906–913. doi: 10.1136/bjsports-2011-090192.

Pate, R. R. *et al.* (2013) 'Factors associated with development of excessive fatness in children and adolescents: a review of prospective studies.', *Obesity reviews : an official journal of the International Association for the Study of Obesity*, 14(8), pp. 645–658. doi: 10.1111/obr.12035.

Pearson, N. *et al.* (2011) 'Tracking of children's body-mass index, television viewing and dietary

intake over five-years.', *Preventive medicine*, 53(4-5 PG-268–70), pp. 268–270. doi: https://dx.doi.org/10.1016/j.ypmed.2011.07.014.

Pearson, N., Braithwaite, R. E., Biddle, S. J H, *et al.* (2014) 'Associations between sedentary behaviour and physical activity in children and adolescents: A meta-analysis', *Obesity Reviews*, 15(8), pp. 666–675. doi: 10.1111/obr.12188.

Pearson, N. *et al.* (2017) 'Sedentary behaviour across the primary-secondary school transition: A systematic review', *Preventive Medicine*, 94, pp. 40–47. doi: 10.1016/j.ypmed.2016.11.010.

Pearson, N., Sherar, L. B. and Hamer, M. (2019) 'Prevalence and Correlates of Meeting Sleep, Screen-Time, and Physical Activity Guidelines Among Adolescents in the United Kingdom', *JAMA Pediatrics*, 173(10), pp. 993–994. doi: 10.1001/jamapediatrics.2019.2822.

'Pew Research Center' (2016), pp. 81–81. doi: 10.1007/978-1-349-68398-7_161.

Prentice-Dunn, H. and Prentice-Dunn, S. (2012) 'Physical activity, sedentary behavior, and childhood obesity: a review of cross-sectional studies.', *Psychology, health & medicine*, 17(3), pp. 255–273. doi: 10.1080/13548506.2011.608806.

Raudsepp, L. (2016) 'Bidirectional association between sedentary behaviour and depressive symptoms in adolescent girls', *European Journal of Sport Science*, 16(8), pp. 1153–1158. doi: 10.1080/17461391.2016.1174312.

Raudsepp, L. and Riso, E.-M. (2017) 'Longitudinal Associations Between Sedentary Behavior of Adolescent Girls, Their Mothers, and Best Friends', *Pediatric Exercise Science*, 29(3), pp. 419–426. doi: 10.1123/pes.2016-0255.

Raustorp, A. *et al.* (2019) 'School-based study showed a correlation between physical activity and smartphone and tablet use by students aged eight, 11 and 14', *Acta Paediatrica, International Journal of Paediatrics*, pp. 0–2. doi: 10.1111/apa.15041.

Raza, S. H. *et al.* (2021) 'Investigating Binge-Watching Adverse Mental Health Outcomes During Covid-19 Pandemic: Moderating Role of Screen Time for Web Series Using Online Streaming', *Psychology research and behavior management*, 14, pp. 1615–1629. doi: 10.2147/PRBM.S328416.

Reilly, J. J. (2016) 'When does it all go wrong? Longitudinal studies of changes in moderate-to-vigorous-intensity physical activity across childhood and adolescence', *Journal of Exercise Science and Fitness*, 14(1), pp. 1–6. doi: 10.1016/j.jesf.2016.05.002.

Rideout, V. and Robb, M. (2019) 'The Common Sense Census: Media Use By Tweens and Teens', *Common Sense Media*, pp. 1–104. doi: 10.1017/CBO9781107415324.004.

Robert J Hancox, Barry J Milne, R. P. (2004) 'Association between child and adolescent television viewing and adult ...', *The Lancet*, 364(9430), pp. 257–262.

Rodriguez-Ayllon, M. *et al.* (2019) 'Role of Physical Activity and Sedentary Behavior in the Mental Health of Preschoolers, Children and Adolescents: A Systematic Review and Meta-Analysis', *Sports Medicine*, pp. 1383–1410. doi: 10.1007/s40279-019-01099-5.

Rutten, C., Boen, F. and Seghers, J. (2014) 'Changes in Physical Activity and Sedentary Behavior during the Transition from Elementary to Secondary School', *Journal of Physical Activity and Health*, 11(8), pp. 1607–1613. doi: 10.1123/jpah.2012-0465.

Ryan, R. M., Rigby, C. S. and Przybylski, A. (2006) 'The Motivational Pull of Video Games: A Self-Determination Theory Approach', *Motivation and Emotion*, 30(4), pp. 344–360. doi: 10.1007/s11031-006-9051-8.

Ryu, S. *et al.* (2019) 'Secular Trends in Sedentary Behavior Among High School Students in the United States, 2003 to 2015.', *American Journal of Health Promotion*, 33(8), pp. 1174–1181. doi: 10.1177/0890117119854043.

Sakamoto, A. (1994) 'Video Game Use and The Development of Sociocognitive Abilities in Children: Three Surveys of Elementary School Students1', *Journal of Applied Social Psychology*, 24, pp. 21–42.

Sallis, J. F., Owen, N. and Fisher, E. B. (2008) 'Ecological models of health behavior', *Health behavior and health education: Theory, research, and practice*.

Sallis, J. F., Owen, N. and Fotheringham, M. J. (2000) 'Behavioral epidemiology: a systematic framework to classify phases of research on health promotion and disease prevention.', *Annals of behavioral medicine : a publication of the Society of Behavioral Medicine*, 22(4), pp. 294–298. doi: 10.1007/BF02895665.

Salway, R. E. *et al.* (2019) 'Associations between socioeconomic position and changes in children's screen-viewing between ages 6 and 9: a longitudinal study', *BMJ OPEN*, 9(12). doi: 10.1136/bmjopen-2018-027481.

Sanders, T. *et al.* (2015) 'The influence of neighbourhood green space on children's physical activity and screen time: Findings from the longitudinal study of Australian children', *International Journal of Behavioral Nutrition and Physical Activity*, 12(1). doi: 10.1186/s12966-015-0288-z.

Sanders, T. *et al.* (2019) 'Type of screen time moderates effects on outcomes in 4013 children: evidence from the Longitudinal Study of Australian Children', *The international journal of behavioral nutrition and physical activity*, 16(1), p. 117. doi: 10.1186/s12966-019-0881-7.

Santos, A. *et al.* (2018) 'Relationship Among Changes in Sedentary Time, Physical Activity, and Body Mass Index in Young Schoolchildren: A 3-Year Longitudinal Study', *Pediatric Exercise Science*, 30(3), pp. 426–432. doi: 10.1123/pes.2017-0163.

Saunders, T. J. *et al.* (2016) 'Combinations of physical activity, sedentary behaviour and sleep: relationships with health indicators in school-aged children and youth [1]', *Applied Physiology, Nutrition, and Metabolism*, 41(6 (Suppl. 3)), pp. S283–S293. doi: 10.1139/apnm-2015-0626.

Sawka, K. J. *et al.* (2013) 'Friendship networks and physical activity and sedentary behavior among youth: a systematized review', *International Journal of Behavioral Nutrition and Physical Activity*, 10(1), p. 130. doi: 10.1186/1479-5868-10-130.

Scott, H., Biello, S. M. and Woods, H. C. (2019) 'Social media use and adolescent sleep patterns: cross-sectional findings from the UK millennium cohort study', *BMJ open*, 9(9), p. e031161. doi: 10.1136/bmjopen-2019-031161.

Scully, M. *et al.* (2022) 'Prevalence and trends in Australian adolescents' adherence to 24-hour movement guidelines: findings from a repeated national cross-sectional survey.', *BMC public health*, 22(1), p. 105. doi: 10.1186/s12889-021-12387-z.

Sebire, S. J. *et al.* (2018) 'Results of a feasibility cluster randomised controlled trial of a peer-led school-based intervention to increase the physical activity of adolescent girls (PLAN-A)', *International Journal of Behavioral Nutrition and Physical Activity*, 15(1), p. 50. doi: 10.1186/s12966-018-0682-4.

Da silva, I. C. M. *et al.* (2014) 'Physical activity levels in three Brazilian birth cohorts as assessed with raw triaxial wrist accelerometry', *International Journal of Epidemiology*. doi: 10.1093/ije/dyu203.

Simon, C. *et al.* (2014) 'A socio-ecological approach promoting physical activity and limiting sedentary behavior in adolescence showed weight benefits maintained 2.5 years after intervention cessation', *International Journal of Obesity*, 38(7), pp. 936–943. doi: 10.1038/ijo.2014.23.

Skrede, T. *et al.* (2019) 'The prospective association between objectively measured sedentary time, moderate-to-vigorous physical activity and cardiometabolic risk factors in youth: a systematic review and meta-analysis', *Obesity Reviews*, 20(1), pp. 55–74. doi: 10.1111/obr.12758.

Sleddens, E. F. C. *et al.* (2017) 'Bidirectional associations between activity-related parenting practices, and child physical activity, sedentary screen-based behavior and body mass index: A longitudinal analysis', *International Journal of Behavioral Nutrition and Physical Activity*, 14(1), pp. 1–9. doi: 10.1186/s12966-017-0544-5.

Sonneville, K. R. and Gortmaker, S. L. (2008) 'Total energy intake, adolescent discretionary behaviors and the energy gap', *International Journal of Obesity*, 32(SUPPL. 6), pp. 19–27. doi: 10.1038/ijo.2008.178.

Stamatakis, E. *et al.* (2015) 'Sedentary time in late childhood and cardiometabolic risk in adolescence.', *Pediatrics*, 135(6), pp. e1432-41. doi: 10.1542/peds.2014-3750.

Stanley, R. M., Ridley, K. and Dollman, J. (2012) 'Correlates of children's time-specific physical activity: A review of the literature', *International Journal of Behavioral Nutrition and Physical Activity*, 9, pp. 1–13. doi: 10.1186/1479-5868-9-50.

Steene-Johannessen, J. *et al.* (2020) 'Variations in accelerometry measured physical activity and sedentary time across Europe – harmonized analyses of 47,497 children and adolescents', *International Journal of Behavioral Nutrition and Physical Activity*, 17(1), p. 38. doi: 10.1186/s12966-020-00930-x.

Stefan, L. *et al.* (2018) 'One-year changes in physical activity and sedentary behavior among adolescents: the Croatian Physical Activity in Adolescence Longitudinal Study (CRO-PALS).', *International journal of adolescent medicine and health*, (8506960 PG-). doi: https://dx.doi.org/10.1515/ijamh-2017-0223.

Stierlin, A. S. *et al.* (2015) 'A systematic review of determinants of sedentary behaviour in youth: A DEDIPAC-study', *International Journal of Behavioral Nutrition and Physical Activity*, 12(1). doi: 10.1186/s12966-015-0291-4.

Straatmann, V. S. *et al.* (2019) 'Stability and bidirectional relationship between physical activity and sedentary behaviours in Brazilian adolescents: Longitudinal findings from a school cohort study', *PLOS ONE*, 14(1). doi: 10.1371/journal.pone.0211470.

Stroup, D. F. *et al.* (2000) 'Meta-analysis of Observational Studies in EpidemiologyA Proposal for Reporting', *JAMA*, 283(15), pp. 2008–2012. doi: 10.1001/jama.283.15.2008.

Tambalis, K. D. *et al.* (2018) 'Insufficient sleep duration is associated with dietary habits, screen time, and obesity in children', *Journal of Clinical Sleep Medicine*. doi: 10.5664/jcsm.7374.

Tanaka, C., Reilly, J. J. and Huang, W. Y. (2014) 'Longitudinal changes in objectively measured sedentary behaviour and their relationship with adiposity in children and adolescents: Systematic review and evidence appraisal', *Obesity Reviews*, 15(10), pp. 791–803. doi: 10.1111/obr.12195.

Tapia-Serrano, M. A., Sevil-Serrano, J. and Sánchez-Miguel, P. A. (2021) 'Adherence to 24-Hour Movement Guidelines among Spanish Adolescents: Differences between Boys and Girls', *Children* . doi: 10.3390/children8020095.

Taveras, E. M. *et al.* (2007) 'Longitudinal Relationship Between Television Viewing and Leisure-Time Physical Activity During Adolescence', *PEDIATRICS*, 119(2), pp. e314–e319. doi: 10.1542/peds.2005-2974.

Telford, R. M. *et al.* (2016) 'Outcomes of a four-year specialist-taught physical education program on physical activity: A cluster randomized controlled trial, the LOOK study', *International Journal of Behavioral Nutrition and Physical Activity*, 13(1 PG-). doi: 10.1186/s12966-016-0388-4.

Temmel, C. S. D. and Rhodes, R. (2013) 'Correlates of Sedentary Behaviour in Children and Adolescents Aged 7-18: A Systematic Review', *The Health & Fitness Journal of Canada*.

Thomas, G. *et al.* (2019) 'A Descriptive Epidemiology of Screen-Based Devices by Children and Adolescents: a Scoping Review of 130 Surveillance Studies Since 2000', *Child Indicators Research*. doi: 10.1007/s12187-019-09663-1.

Thomas, G., Bennie, Jason A., De Cocker, K., Ireland, M. J., *et al.* (2020) 'Screen-based behaviors in Australian adolescents: Longitudinal trends from a 4-year follow-up study', *Preventive Medicine*. doi: 10.1016/j.ypmed.2020.106258.

Thomas, G. *et al.* (2021) 'Exploring contemporary screen time in Australian adolescents: A qualitative study', *Health Promotion Journal of Australia*, 32(S2), pp. 238–247. doi: https://doi.org/10.1002/hpja.440.

Thomée, S., Härenstam, A. and Hagberg, M. (2011) 'Mobile phone use and stress, sleep disturbances, and symptoms of depression among young adults - A prospective cohort study', *BMC Public Health*. doi: 10.1186/1471-2458-11-66.

Thorisdottir, I. E. *et al.* (2019) 'Active and Passive Social Media Use and Symptoms of Anxiety and Depressed Mood Among Icelandic Adolescents', *Cyberpsychology, Behavior, and Social Networking*, 22(8), pp. 535–542. doi: 10.1089/cyber.2019.0079.

Tiberio, S. S. *et al.* (2014) 'Parental monitoring of children's media consumption: the long-term influences on body mass index in children.', *JAMA pediatrics*, 168(5), pp. 414–21. doi: 10.1001/jamapediatrics.2013.5483.

Timperio, A. *et al.* (2017) 'Typologies of neighbourhood environments and children's physical activity, sedentary time and television viewing', *Health and Place*, 43(June 2016), pp. 121–127. doi: 10.1016/j.healthplace.2016.10.004.

Toledano, M. B. *et al.* (2019) 'Cohort Profile: The Study of Cognition, Adolescents and Mobile Phones (SCAMP)', *International Journal of Epidemiology*, 48(1), pp. 25-26I. doi: 10.1093/ije/dyy192.

Tooth, L. *et al.* (2005) 'Quality of reporting of observational longitudinal research', *American Journal of Epidemiology*, 161(3), pp. 280–288. doi: 10.1093/aje/kwi042.

Trang, N. H. H. D. *et al.* (2013) 'Longitudinal sedentary behavior changes in adolescents in Ho Chi Minh City', *American Journal of Preventive Medicine*, 44(3), pp. 223–230. doi: 10.1016/j.amepre.2012.10.021.

Tremblay, M. S. *et al.* (2011) 'Systematic review of sedentary behaviour and health indicators in school-aged children and youth', *International Journal of Behavioral Nutrition and Physical Activity*, 8(1), p. 98. doi: 10.1186/1479-5868-8-98.

Tremblay, M. S. *et al.* (2016) 'Canadian 24-Hour Movement Guidelines for Children and Youth: An Integration of Physical Activity, Sedentary Behaviour, and Sleep', *Applied Physiology, Nutrition, and Metabolism*, 41(6 (Suppl. 3)), pp. S311–S327. doi: 10.1139/apnm-2016-0151.

Tremblay, M. S. *et al.* (2017) 'Sedentary Behavior Research Network (SBRN) – Terminology Consensus Project process and outcome', *International Journal of Behavioral Nutrition and Physical Activity*, 14(1), p. 75. doi: 10.1186/s12966-017-0525-8.

Treuth, M. S. *et al.* (2009) 'A longitudinal study of sedentary behavior and overweight in adolescent girls', *Obesity*, 17(5), pp. 1003–1008. doi: 10.1038/oby.2008.598.

Tye, L. S. *et al.* (2020) 'Physical Activity, Sedentary Behaviour and Sleep, and Their Association with BMI in a Sample of Adolescent Females in New Zealand', *International Journal of Environmental Research and Public Health* . doi: 10.3390/ijerph17176346.

UK Department of Health (2019) 'UK Chief Medical Officers ' Physical Activity Guidelines', (September), pp. 1–65. Available at: https://www.gov.uk/government/publications/physical-activity-guidelines-uk-chief-medical-officers-report.

Vaitkeviciute, D. *et al.* (2014) 'Physical activity and bone mineral accrual in boys with different body mass parameters during puberty: A longitudinal study', *PLoS ONE*, 9(10). doi: 10.1371/journal.pone.0107759.

Vancampfort, D. *et al.* (2018) 'Sedentary behavior and depressive symptoms among 67,077 adolescents aged 12-15years from 30 low- and middle-income countries', *International Journal of Behavioral Nutrition and Physical Activity*, 15(1), pp. 1–9. doi: 10.1186/s12966-018-0708-y.

Ventura, A. K., Loken, E. and Birch, L. L. (2009) 'Developmental trajectories of girls' BMI across childhood and adolescence', *Obesity*, 17(11), pp. 2067–2074. doi: 10.1038/oby.2009.123.

Verloigne, M. *et al.* (2012) 'Family- and school-based correlates of energy balance-related behaviours in 10-12-year-old children: a systematic review within the ENERGY (EuropeaN Energy balance Research to prevent excessive weight Gain among Youth) project.', *Public health nutrition*, 15(8), pp. 1380–1395. doi: 10.1017/S1368980011003168.

Watson, A. *et al.* (2021) 'Associations between meeting 24-hour movement guidelines and academic achievement in Australian primary school-aged children.', *Journal of sport and health science*. doi: 10.1016/j.jshs.2020.12.004.

Whitt-Glover, M. C. *et al.* (2009) 'Disparities in physical activity and sedentary behaviors among US children and adolescents: Prevalence, correlates, and intervention implications', *Journal of Public Health Policy*, 30(SUPPL. 1), pp. 309–334. doi: 10.1057/jphp.2008.46.

Wickel, E. E., Issartel, J. and Belton, S. (2013) 'Longitudinal Change in Active and Sedentary Behavior during the After-School Hours', *Journal of Physical Activity and Health*, 10(3), pp. 416–422. doi: 10.1123/jpah.10.3.416.

Wiersma, R. *et al.* (2019) 'Physical activity around the clock: Objectively measured activity patterns in young children of the GECKO Drenthe cohort', *BMC Public Health*, 19(1), pp. 1–11. doi: 10.1186/s12889-019-7926-3.

Wong, S. H. S., Huang, W. Y. and He, G. (2015) 'Longitudinal changes in objectively measured physical activity differ for weekdays and weekends among Chinese children in Hong Kong Energy balance-related behaviours', *BMC Public Health*, 15(1), pp. 1–8. doi: 10.1186/s12889-015-2618-0.

Xu, F. *et al.* (2019) 'Relationship between physical activity, screen time, and sleep quantity and quality in US adolescents aged 16–19', *International Journal of Environmental Research and Public Health*. doi: 10.3390/ijerph16091524.

Yang-Huang, J. *et al.* (2017) 'Socioeconomic differences in children's television viewing trajectory: A population-based prospective cohort study', *PloS one*, 12(12), pp. e0188363–e0188363. doi:

10.1371/journal.pone.0188363.

Years), M. of H. C. and Y. P. (5–17 (2020) ‘Sit Less, Move More, SleepWell’. Available online: https://www.health.govt.nz/our-work/preventative-health-wellness/physical-activity#kids’.

Zahl, T., Steinsbekk, S. and Wichstrøm, L. (2017) ‘Physical Activity, Sedentary Behavior, and Symptoms of Major Depression in Middle Childhood’, *Pediatrics*, 139(2), p. e20161711. doi: 10.1542/peds.2016-1711.

Zhang, G. *et al.* (2016) ‘Television watching and risk of childhood obesity: a meta-analysis.’, *European journal of public health*, 26(1), pp. 13–18. doi: 10.1093/eurpub/ckv213.

Zhu, W. and Owen, N. (2017) *Sedentary Behavior and Health: Concepts, Assessments, and Interventions*. 1st edn. Human Kinetics, Inc.

Ziviani, J. *et al.* (2009) ‘Physical Activity of Young Children’, *Physical & Occupational Therapy in Pediatrics*, 28(1), pp. 25–39. doi: 10.1300/J006v28n01_03.

Appendices

Appendix 1 PRISMA 2009 checklist

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	Page 24
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	On the published article
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	Page 24-25
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	Page 24-25
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	Page 25
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	Page 26
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	Page 25-26
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	Appendix 2
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	Page 26-28
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	Page 27-28
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	Page 26
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data	Page 27-28

		synthesis.	
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	Page 28-29
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	Page 29
Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	Page 27-28
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	Page 29
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	Page 30-31
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	Appendix 4a, 4b
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	Appendix 5
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	Page 32-35
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	Page 36-38
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	Page 33
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	Page 33
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	Page 39-43
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	Page 42
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	Page 43
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	Page 44

Appendix 2 Example of the search strategy in MEDLINE database

1	**Study design**	**'Longitudinal study' OR' cohort study' OR panel study OR 'follow-up study' OR 'prospective study'**
2	Participants	child* OR adolescen* OR young OR youth OR teenage* OR 'young people' OR 'school-aged children' OR 'primary education' OR 'middle school aged children' OR 'secondary education OR student
3	Outcomes	'sedentar* behav*' OR 'sedentar* time' OR 'sitting behav*' OR 'physical inactivity' OR 'physical* inactiv*' OR 'sedentary OR inactiv* OR 'sedentary lifestyle'
		OR 'screen based entertainment' OR 'watch* television' OR 'watch* time' OR 'screen time' OR 'computer behav*' sedentary behavio* OR sedentar* OR sitting OR 'screen time' OR 'screen-time' OR 'small screen' OR 'screen based' OR 'screen-based' OR television OR video games OR screen time OR watch* OR view* OR dvd* OR video* OR screen media OR 'video gam*' OR video gam* OR computer gam* OR electronic gam* OR 'electronic media' OR television OR TV OR 'electronic game*' OR e-game* OR 'e game*' OR computer OR 'computer behave*' OR video OR DVD OR 'video games'
		OR 'social media' OR 'communications media' OR 'mobile application' OR 'mobile phone' OR texting or 'text messag*' OR app OR apps OR 'mobile applications' OR smartphone* OR 'smart phone*' OR 'cell phone*' OR 'mobile phone*' OR 'small screen*' OR iphone* OR ipad* OR ipod* OR tablet* OR laptop*
		OR 'non screen time' OR 'non screen-time' OR 'sedentar* pattern*' OR 'car seat' OR car OR automobile* OR auto OR 'motor vehicle*' OR bus OR indoor* OR in-door OR 'bed rest' OR

		homework OR reading OR studying OR 'school assignment' OR 'educational activit*' OR schoolwork OR 'reading material*' OR stand* OR pose OR relaxation
4	Additional filters	English language
5		1 AND 2 AND 3 AND 4

Appendix 3 Methodological quality assessment items (previously used by Tanaka et al. 2014; Jones *et al.* 2013; and Tooth *et al.* 2005)

Item	**Description**
A. Study population and participation (baseline): the study sample represents the population of interest on key characteristics.	
1. Adequate description of sampling frame, recruitment methods, period of recruitment and place of recruitment	Item was scored positively if three of the following points were mentioned: (i) description of how participants were sampled (e.g. sourced from the electoral roll, all schools in state or country, or from a larger study); (ii) description of specific methods used for recruitment (e.g. newsletters, phone call, advertising); (iii) period of recruitment provided (e.g. March 2010); or (iv) place of recruitment detailed (e.g. Wollongong, Australia, Glasgow)
2. Adequate description of baseline study sample (i.e. individuals entering the study) for key characteristics	Item was scored positively if all three of the following points were mentioned: (i) number of participants; (ii) age (mean age or % at each age); and (iii) gender
B. Study attrition: loss to follow-up not associated with key characteristics (i.e. the study data adequately represent the sample)	
3. Provision of the exact number of participants at each follow-up measurement(s)	Item was scored positively if the number or percentage of participants at each time point was detailed
4. Provision of exact information on follow-up duration	Item was scored positively if detail about the follow-up duration (e.g. 1 year, 6 years) was provided
5. Presentation of data showing non-selective non-response during follow-up measurement(s)	Item was scored positively if those who dropped out of the study were similar on key characteristics to those who were retained at follow-up.
C. Data collection	
6. Adequate description of methods of data collection of sedentary behaviour (i.e. tools and processes)	Objective measurement of sedentary behaviour: item was scored positively if at least three of the following points were mentioned: (i) type of instrument; (ii) length of epoch; (iii) number of days worn; (iv) number of hours day–1 worn; (v) number of minutes monitored; (vi) description of monitor placement; and (vii) data reduction methods described
	Subjective measures: Item was scored *positively* if the instrument was described including the number of items.
7. Adequate measurement of physical activity/sedentary behavior	Item was scored *positively* if physical activity was measured objectively and/or sedentary behavior was measured by proxy report, including provision of validity and/or reliability data and a reference
8. Where appropriate, clear description of accelerometer cut points to define sedentary behaviour	Item was scored *positively* if the cut points were referenced (subjective measures were given an N/A,

	which meant that those studies were scored using a total of 9 rather than 10)
D. Data analyses	
9. Adequate description of analyzed sample (inclusion and exclusion criteria)	Item was scored positively if details of the samples included in final analysis (e.g. included if at least 6 h of activity monitoring was achieved) were included
10. The analyzed sample was at least medium in size	Item was scored *positively* if analyzed sample was≥250 participants

Appendix 4a Overview of sample characteristics and sedentary behaviour measurement methods for device-based studies (N=30)

Authors Date Study name Country	Sample size (N)	Baseline age (years; mean unless stated otherwise)	Duration of follow-up (years)	Accelerometer settings			Data presented
				Epoch (s)	SB cut-point[1] (cpm)	Valid day definition (h or min/day)	
Anderson et al.(Anderson *et al.*, 2016) **2016 (AFLY5) UK**	1157	9.5	1	10	≤100	≥8 h	Weekday
Atkin et al.(Atkin, Corder and van Sluijs, 2013) **2013 (SPEEDY) UK**	1512	10.3	1, 4	5	≤100	≥500 min	Weekly
Ball et al.(Ball *et al.*, 2009) **2009 (CLAN) Australia**	542	5 – 6; 10 – 11	3	N/A	1.0 to 1.9 METs	≥12 h	Weekly
Bell et al.(Bell *et al.*, 2018) **2018 (ALSPAC) UK**	1826	12	1, 2	10	≤199	≥10 h	Weekly
Butte et al.(Butte *et al.*, 2014) **2014 San Francisco**	B 133 G 149	8 – 10	1, 2	60	AEE< 0.01 kcal kg-1 min−1 or PAR < 1.5	≥1000 min	Weekly
Collings et al.(Collings *et al.*, 2015) **2015 (ROOTS) UK**	B 72 G 72	B 15.1 G 15.1	2.4	30	≤1.5 METs	≥48 h	Weekly
Contardo Ayala et al.(Ayala *et al.*, 2019) **2019 (NEArbY Study) Australia**	280	14.9	2	15	≤100	≥8 h	Weekly
Corder et al.(Corder *et al.*, 2015) **2015 (SPEEDY) UK**	B 189 G 220	10.3	1, 4	5	≤100	≥500 min	Weekly
Cumming et al.(Cumming *et al.*, 2014) **2014 (ALSPAC) UK**	B 671 G 680	11.7	2	10	≤199	≥10 h	Weekly
Grao-Cruses et al.(Grao-Cruces *et al.*, 2020) **2020 (UP & DOWN Study) Spain**	826; 678	8; 13	2	10	≤100	≥10 h	Weekend
Grydeland et al.(Grydeland *et al.*, 2013) **2013 (HEIA) Norway**	485	11.2	2	10	≤100	≥8 h	Weekly
Haapala et al.(Haapala *et al.*, 2017) **2017 (MOVE program) Finland**	319	9.9; 14.1	1	10	≤100	≥500 min	Weekday

Harding et al.(Harding *et al.*, 2015) **2015 (PEACH) UK**	B 140 G 223	B 12.0 G 12.0	2	15	≤100	≥480 min;	Weekend
Hardy et al.(Hardy, Bass and Booth, 2007) **2007 (Girls Healthy Development) Australia**	196	12.8	1, 2.5	N/R	≤1.5 METS	≥12 h	Weekday, weekend, weekly
Jago et al.(Jago *et al.*, 2017) **2017 (B-PROACTIVE) UK**	B 899 G 938	5-6	3	15	≤100	≥500 min	Weekday, weekend
Jago et al.(Jago *et al.*, 2019) **2019 (B-PROACTIVE) UK**	1299	6	3, 5	10	≤100	≥500 min	Weekday, weekend
Janssen et al.(Janssen, Kay D. Mann, *et al.*, 2016) **2016 (Gateshead Millennium) UK**	B 255 G 252	7.5	3, 6, 8	15	≤25	≥6 h	Weekly
Kwon et al.(Kwon *et al.*, 2012) **2012 (Iowa) USA**	B 201 G 222	B 5.7 G 5.7	3, 6, 8, 10	60; 5	≤100	≥10 h	Weekly
Lätt et al.(Lätt *et al.*, 2015) **2015 Estonia**	B 313	B 11.9	1	15	≤100	≥8 h	Weekly
Lipsky et al.(L.M. *et al.*, 2017) **2017 (Next plus) USA**	566	16.5	1	30	≤100	≥500 min	Weekly
Mitchell et al.(Mitchell *et al.*, 2012) **2012 (NIHCD) USA**	B 461 G 477	9	2, 3, 6	N/R	≤100	≥10 h	Weekly
Ortega et al.(Ortega *et al.*, 2013) **2013 (EYHS) Sweden**	B 180 G 123	B 9.6 G 9.5	6	15	≤100	≥10 h	Weekday, weekend, weekly
Santos et al.(Santos *et al.*, 2018) **2018 Portugal**	64	6.3	3	5	≤100	≥10 h	Weekly
Telford et al.(Telford *et al.*, 2016) **2016 (LOOK) Australia**	B 125 G 127	11	1	60	≤100	≥10 h	Weekly
Timperio et al.(Timperio *et al.*, 2017) **2017 (HEAPS) Australia**	563	5 – 6; 10 – 12	3	15	≤100	≥8 h	Weekend
Trang et al.(Trang *et al.*, 2013) **2013 (Ho Chi Minh city) Vietnam**	B 364 G 395	11.8	1, 2, 3	15	≤100	≥8 h	Weekly
***Treuth et al.**(Treuth *et al.*, 2009) **2004 USA**	G 91	8	1, 2	N/R	N/R	≥1000 min	Weekday, weekend
Vaitkeviciute et al.(Vaitkeviciute *et al.*, 2014) **2014 Estonia**	B 206	12	1, 2	60	≤100	≥8 h	Weekly

Wong et al.(Wong, Huang and He, 2015) **2015 Hong Kong**	263	7.8	1, 2	60	≤100	≥10 h	Weekday, weekend
Zahl et al.(Zahl, Steinsbekk and Wichstrøm, 2017) **2017 Norway**	795	6	3, 6	10	≤100	≥480 min	Weekday

Abbreviations: s = second, cpm = counts per minute, min = minutes, h = hours, B = boys, G = girls, y = year, N/R = not reported, AEE = Activity energy expenditure, PAR = physical activity ratio, MET = metabolic equivalent. AFLY5 = Active for Life Year 5, SPEEDY = Sport, Physical activity and Eating behaviour: Environmental Determinants in Young people, CLAN = Children Living in Active Neighborhoods, The NEArbY Study = The Neighbourhood Activity in Youth Project, ALSPAC = Avon Longitudinal Study of Parents and Children, HEIA = Health in Adolescents, EYHS = European Youth Heart Study, LOOK = Lifestyle of our Kids, HEAPS = Health, Eating and Play Study, PEACH = Personal and Environmental Associations with Children's Health.

*sedentary time measured with a heart rate monitor.

[1] Cut-points are reported as counts per minute unless otherwise stated.

Appendix 4b Overview of sample characteristics and sedentary behaviour measurement methods for self- or proxy-report studies (N=63)

Authors Date Study Name Country	Sample size (N)	Baseline age (years; mean unless stated otherwise)	Duration of follow-up (years)	Respondent (self- or proxy-report), name of instrument	Data presented
Altenburg et al.(Altenburg *et al.*, 2012) **2012 (DOiT) Netherlands**	465	B 12.9 G 12.7	1	SR, N/R	Weekly
Anderson et al.[1] **2016 (AFLY 5) UK**	1157	9.5	1	SR, N/R	Weekday, weekend
Andrade et al.(Andrade *et al.*, 2015) **2015 (ACTIVITAL) Ecuador**	740	12.8	1.5, 2.5	SR, N/R	Weekday, weekend
Atkin et al.[2] **2013 (SPEEDY) UK**	1745	10.3	4	SR, ASAQ	Weekly
Ball et al.[3] **2009 (CLAN) Australia**	542	5 – 6 10 – 12	3	PR & SR, N/R	Weekly
Braig et al.(Braig *et al.*, 2018) **2018 (Ulm Birth Cohort) Germany**	B 246 G 273	11	2	SR, N/R	Weekly
Busschaert et al.(Busschaert *et al.*, 2016) **2016 Belgium**	513	15.0	1	SR, N/R	Weekly
Carlson et al.(Carlson *et al.*, 2012) **2012 (MOVE project) USA**	271	6.7	2	PR, N/R	Weekday
Cespedes et al.(Cespedes *et al.*, 2014) **2014 (Project Viva) USA**	1864	5	1, 2	PR, N/R	Weekly
Chen et al.(Chen *et al.*, 2014) **2014 (Taiwan Children Healthy study) Taiwan**	2758	9.7	2	SR, IPAQ	Weekly
Cronholm et al.(Cronholm *et al.*, 2016) **2016 (POP) Sweden**	B 50 G 38	B 7.9 G 7.9	2, 3	PR & SR, N/R	Weekly
Cronholm et al.(Cronholm *et*	B 38 G 38	B 8.0 G 7.9	4.6, 7	PR & SR, N/R	Weekly

al., 2018) **2018 (POP) Sweden**					
Dasgupta et al.(Dasgupta *et al.*, no date) **2006 (McGill NDIT) USA**	662	12.7	3, 5	SR, N/R	Weekly
Davison et al.(Davison, Francis and Birch, 2005) **2005 USA**	G 187	9	2	PR, N/R	Weekly
Dewar et al.(Dewar *et al.*, 2013) **2013 (NEAT) Australia**	G 179	13.2	1, 2	SR, ASAQ	Weekly
Dewar et al.(Dewar *et al.*, 2014) **2014 (NEAT) Australia**	G 179	13.2	1	SR, ASAQ	Weekly
Dubuc et al.(Dubuc, Aubertin-Leheudre and Karelis, 2019) **2019 (ASAP) Canada**	199	13.1	2	SR, N/R	Weekly
Elgar et al.(Elgar *et al.*, 2004) **2004 (HBSC) UK**	B 293 G 361	B 11.7 G 11.6	4	SR, N/R	Weekly
Enthoven et al.(Enthoven *et al.*, 2020) **2020 (Generation R) Netherlands**	5074	6	3	PR, N/R	Weekly
Ezendam et al.(Ezendam, Brug and Oenema, 2012) **2012 (FATaintPHAT) Netherlands**	B 198 G 200	12.6	2	SR, N/R	Weekly
Falbe et al.(Falbe *et al.*, 2014) **2014 (Growing Up Today) USA**	B 3668 G 4604	G 15.7 B 15.6	2	SR, N/R	Weekly
Fujiwana et al.(Fujiwara *et al.*, 2018) **2017 Japan**	1729	B 12.5 G 12.6	1, 2	SR, N/R	Weekly
Gebremariam et al.(Gebremariam *et al.*, 2012) **2012 (HEIA) Norway**	934	11.2	1, 2	N/R	Weekly
Gunnell et al.(Gunnell *et al.*, 2016) **2016 (REAL) USA**	B 458 G 702	13.5	1, 2, 3	SR, N/R	Weekly

Guo et al.(Guo *et al.*, 2013) **2013 China**	681	7.7; 8.1	1	PR, N/R	Weekly
Hancox et al.(Robert J Hancox, Barry J Milne, 2004) **2004 New Zealand**	991	5	2, 4, 6, 8, 10	PR & SR, N/R	Weekly
Hanson et al.(Hanson *et al.*, 2019) **2019 (Bt20+) South Africa**	1414	12	1, 2, 3, 4, 5	SR, N/R	Weekly
Hardy et al.(Hardy, Bass and Booth, 2007) **2007 (Girls Healthy Development) Australia**	G 163	12.8	1, 2	SR, N/R	Weekly, weekday, weekend
Hesketh et al.(Hesketh *et al.*, 2007) **2007 (HOYVS) Australia**	1278	7.6	3	N/R	Weekly
Jackson et al.(Jackson, Cunningham and Author, 2017) **2017 (ECLS-K) USA**	4983	5	1, 3, 5, 8	PR & SR, N/R	Weekly
Janz et al.(Janz, Burns and Levy, 2005) **2005 (Iowa) USA**	B 176 G 202	5.6	3	PR, N/R	Weekly
Janz et al.(KF, JD and LT, 2000) **2000 (Muscatine) USA**	B 61 G 62	B 10.8 G 10.3	1, 2, 3, 4	SR, N/R	Weekly
Johnson et al.(Johnson *et al.*, 2012) **2012 (Be active eat well) Australia**	977	8.1	2	PR, N/R	Weekly
Landsberg et al.(Landsberg *et al.*, 2010) **2010 (KOPS) Germany**	389	10.2	4	SR, N/R	Weekday
Lipsky et al.(L.M. *et al.*, 2017) **2017 (NEXT plus) USA**	566	16.5	1	SR, N/R	Weekly
Lizandra et al.(Lizandra *et al.*, 2016) **2016 Spain**	B 348 G 407	12.92	2	SR, ASAQ	Weekly
Lobel et al.(Lobel *et al.*, 2017) **2017**	B 98 G 96	7.2 – 11.4	1	PR & SR, N/R	Weekly

Netherlands					
Lubans et al.(Lubans *et al.*, 2016) **2016 (ATLAS) Australia**	B 180	12.7	1.5	SR, modified ASAQ	Weekly
Lubans et al.(Lubans *et al.*, 2012) **2012 (NEAT) Australia**	G 179	13.2	1	SR, ASAQ	Weekly, weekday, weekend
Lytle et al.(Lytle *et al.*, 2013) **2013 (IDEA and ECHO) USA**	IDEA: 349 ECHO: 374	B 14.7 G 14.7	IDEA: 1, 2 ECHO: 2	SR, N/R	Weekly
Mielke et al. (Mielke *et al.*, 2018) **2018 (Pelotas Birth Cohort) Brazil**	4441	11	4	SR, N/R	Weekday
Mitchell et al.(Mitchell, Pate and Liese, 2013) **2013 (NHLBI) USA**	G 2379	10.0	2, 4, 6	SR, N/R	Weekly
Must et al.(Must *et al.*, 2007) **2007 (MIT Growth) USA**	G 196	10	7.5	SR, N/R	Weekly
Nelson et al.(Nelson *et al.*, 2006) **2006 (EAT) USA**	B 366 G 440	12.8	5	SR, adapted from Godin Leisure-Time Exercise Questionnaire and Planet Health surveys.	Weekly
Pearson et al.(Pearson *et al.*, 2011) **2011 Australia**	296	B 5.9, G 5.9; B 11.1, G 11.2	3, 5	PR, N/R	Weekly
Raudsepp et al.(Raudsepp, 2016) **2016 Estonia**	G 312	11.3	2, 4	SR, ASAQ	Weekly
Raudsepp et al.(Raudsepp and Riso, 2017) **2017 Estonia**	G 149	11.4	1, 2, 3	SR, Ecological Momentary Assessment	Weekly
Rutten et al.(Rutten, Boen and Seghers, 2014) **2014 Belgium**	B 212 G 260	10.97	2	SR, N/R	Weekly
Salway et al.(Salway *et al.*, 2019) **2019 (B-PROACT1V) UK**	1299	6	3	PR, N/R	Weekday, weekend
Sanders et al.(Sanders *et al.*, 2015) **2015 (LSAC)**	B 2277 G 2187	6.3	2, 4, 5	PR & SR, N/R	Weekday, weekend

Australia					
Sanders et al.(Sanders *et al.*, 2019) **2019 (LSAC) Australia**	4103	10-11	2, 4	PR & SR, N/R	Weekly
Simon et al.(Simon *et al.*, 2014) **2014 (ICAPS) France**	358	11.6	2	SR, N/R	Weekly
Sleddens et al.(Sleddens *et al.*, 2017) **2017 (KOALA) Netherlands**	B 868 G 826	5.0	2	PR, N/R	Weekly
Sonneville et al.(Sonneville and Gortmaker, 2008) **2008 (Planet Health) USA**	780	11.7	1.5	SR, N/R	Weekly
Stefan et al.(Stefan *et al.*, 2018) **2018 (CRO-PALS) Croatia**	B 28 G 53	15.5	1	SR, SHAPES	Weekly
Straatman et al.(Straatmann *et al.*, 2019) **2019 (ELANA) Brazil**	526	B 11 G 10.9	1, 2	SR, N/R	Weekly
Taveras et al.(Taveras *et al.*, 2007) **2007 (Growing-Up Today) USA**	B 4487 G 6369	10 – 12; 13 – 15	1	SR, N/R	Weekly
Tiberio et al.(Tiberio *et al.*, 2014) **2014 (3GS) USA**	213	7.2	2	PR, N/R	Weekly
Timperio et al.(Timperio *et al.*, 2017) **2017 (HEAPS) Australia**	778	5 – 6; 10 – 12	3	PR, N/R	Weekday, weekend
Trang et al.(Trang *et al.*, 2013) **2013 (Ho Chi Minh City) Vietnam**	B 364 G 395	11.8	1, 2, 3, 4	SR, ASAQ	Weekly
Treuth et al.(Treuth *et al.*, 2009) **2004 USA**	G 91	8	1, 2	PR, Physical Activity Interview for Children	Weekly
Wickel et al.(Wickel, Issartel and Belton, 2013) **2013 (SECCYD) USA**	B 441 G 445	B 9.0 G 9.0	2	PR & SR, N/R	Weekday
Ziviani et al.(Ziviani *et al.*, 2009) **2009 Australia**	B 26 G 33	6 – 8	1	PR, N/R	Weekly

Abbreviations: B = boys, G = girls, Y = year, SR = self-reported, PR = proxy-reported, N/R = not reported, SHAPES = School Health Action, Planning and Evaluation System, IPAQ = International Physical Activity Questionnaire, 3DPAR = 3-Day Physical Activity Recall. DOit = Dutch Obesity Intervention in Teenagers, POP = Paediatric Osteoporosis Prevention, McGill NDIT = McGill University Study on the Natural History of Nicotine Dependence in Teens (NDIT), NEAT = Nutrition and Enjoyable Activity for Teen Girls, ASAP = Adolescent Student Academic Performance longitudinal project, HBSC = Health Behaviour of School-aged Children, REAL = Research on Eating and Adolescent Lifestyles, Bt20+ = Birth-to-Twenty Plus Cohort, HOYVS = Health of Young Victorians Study, COMPASS = cohort for obesity, marijuana use, physical activity, alcohol use, smoking, and sedentary behaviour, ECLS-K = Early Childhood Longitudinal Study Kindergarten Cohort, KOPS = Kiel Obesity Prevention Study, ATLAS = Active Teen Leaders Avoiding Screen-time, NHLBI = National Heart, Lung and Blood Institute, NICHD = National Institute of Child Health and Human Development, MIT = Massachusetts Institute of Technology Growth and Development Study, EAT = Eating Among Teens, LSAC = Longitudinal Study of Australian Children, ICAPS = Intervention Centered on Adolescents' Physical activity and Sedentary behaviour, CRO-PALS = Croatian Physical Activity in Adolescence Longitudinal Study, ELANA = Longitudinal Study of Adolescent Nutritional Assessment, 3GS = Three Generational Study, SECCYD = Study of Early Child Care and Youth Development.

Appendix 5 Methodological and reporting quality assessment for the included studies (N=85)

	Items										
Authors Date Study name Country	**A1. Recruitment**	**A2. Study sample**	**B3. Attrition**	**B3. Follow-up duration**	**B5. Non-response**	**C6. Data collection**	**C7. Validity, Reliability**	**C8. Cut-points[1]**	**D9. Analysed sample**	**D10. Sample size**	**TOTAL SCORE (%)**
Altenburg et al.(Altenburg *et al.*, 2012) **2012 (DOiT) Netherlands**	1	1	0	1	0	1	1	N/A	0	0	5/9 (55%)
Anderson et al.(Anderson *et al.*, 2016) **2016 (AFLY5) UK**	1	1	1	1	1	0	1	1	1	1	9/10 (90%)
Andrade et al.(Andrade *et al.*, 2015) **2015 (ACTIVITAL) Ecuador**	1	1	1	1	0	1	1	N/A	1	1	8/9 (88%)
Atkin et al.[2] 2013 (SPEEDY) UK	1	1	1	1	0	1	1	1	1	1	9/10 (90%)
Ball et al.[3] 2009 (CLAN) Australia	1	0	0	0	0	1	1	1	0	0	4/10 (40%)
Bell et al.(Bell *et al.*, 2018) **2018 (ALSPAC) UK**	1	1	1	1	1	1	1	1	1	1	10/10 (100%)
Braig et al.[34] 2018 (Ulm Birth Cohort) Germany	1	1	1	1	0	1	1	N/A	1	1	8/9 (88%)
Busschaert et al.[36] 2016 Belgium	1	1	1	1	0	1	1	N/A	1	1	8/9 (88%)
Butte et al.(Butte *et al.*, 2014) **2014 USA**	0	1	1	1	0	1	0	1	1	1	7/10 (70%)
Carlson et al.[37] 2012 (MOVE project) USA	0	1	0	1	0	1	1	N/A	0	1	5/9 (55%)
Cespedes et al.[38] 2014 (Project Viva) USA	1	1	0	1	0	1	1	N/A	1	1	7/9 (77%)

Chen et al.[39] 2014 (Taiwan Children Healthy study) Taiwan	1	1	1	1	0	0	1	N/A	1	1	7/9 (77%)
Collings et al.(Collings *et al.*, 2015) **2015 (ROOTS) UK**	1	1	1	1	0	1	1	1	1	0	8/10 (80%)
Contardo Ayala et al.(Ayala *et al.*, 2019) **2019 (NEArbY Study) Australia**	1	1	1	1	1	1	1	1	1	1	10/10 (100%)
Corder et al.(Corder *et al.*, 2015) **2015 (SPEEDY) UK**	1	1	1	1	0	1	1	1	1	1	9/10 (90%)
Cronholm et al.(Cronholm *et al.*, 2016) **2016 (POP) Sweden**	1	1	0	1	0	1	0	N/A	0	0	4/9 (44%)
Cronholm et al.(Cronholm *et al.*, 2018) **2018 (POP) Sweden**	1	1	1	1	0	1	0	N/A	1	0	6/9 (66%)
Cumming et al.(Cumming *et al.*, 2014) **2014 (ALSPAC) UK**	1	1	1	1	0	1	1	1	1	1	9/10 (90%)
Dasgupta et al.(Dasgupta *et al.*, no date) **2006 (McGill NDIT) USA**	0	1	1	1	0	1	0	N/A	1	1	6/9 (66%)
Davison et al.(Davison, Francis and Birch, 2005) **2005 USA**	0	1	1	1	1	1	0	N/A	1	0	6/9 (66%)
Dewar et al.(Dewar *et al.*, 2013) **2013 (NEAT) Australia**	1	0	1	1	1	1	1	N/A	1	0	7/9 (77%)
Dewar et al.(Dewar *et al.*, 2014) **2014 (NEAT) Australia**	1	0	1	1	0	1	1	N/A	1	0	6/9 (66%)
Dubuc et al.(Dubuc, Aubertin-Leheudre and Karelis, 2019) **2019 (ASAP) Canada**	0	1	1	1	0	0	0	N/A	1	0	4/9 (44%)
Elgar et al.(Elgar *et al.*, 2004) **2004 (HBSC) UK**	1	1	1	1	0	1	1	N/A	1	1	8/9 (88%)

Enthoven et al.(Enthoven *et al.*, 2020) **2020 (Generation R) Netherlands**	1	1	1	0	0	1	0	N/A	0	1	5/9 (55%)
Ezendam et al.(Ezendam, Brug and Oenema, 2012) **2012 (FATaintPHAT)Netherlands**	1	1	1	1	1	1	1	N/A	1	1	9/9 (100%)
Falbe et al.(Falbe *et al.*, 2014) **2014 (Growing Up Today) USA**	1	1	1	1	0	1	1	N/A	1	1	8/9 (88%)
Fujiwana et al.(Fujiwara *et al.*, 2018) **2017 Japan**	0	1	1	1	0	0	0	N/A	0	1	4/9 (44%)
Gebremariam et al.[54] 2012 (HEIA) Norway	1	1	1	1	1	1	1	N/A	1	1	9/9 (100%)
Grao-Cruses et al.(Grao-Cruces *et al.*, 2020) **2020 (UP&DOWN) Spain**	1	1	1	1	0	1	1	1	1	1	9/10 (90%)
Grydeland et al.(Grydeland *et al.*, 2013) **2013 (HEIA) Norway**	1	1	1	1	1	1	1	1	1	1	10/10 (100%)
Gunnell et al.(Gunnell *et al.*, 2016) **2016 (REAL) USA**	1	1	1	1	0	1	1	N/A	1	1	8/9 (88%)
Guo et al.(Guo *et al.*, 2013) **2013 China**	1	1	0	1	0	1	0	N/A	1	1	6/9 (66%)
Haapala et al.(Haapala *et al.*, 2017) **2017 (MOVE program) Finland**	1	1	1	1	0	1	1	1	1	1	9/10 (90%)
Hancox et al.(Robert J Hancox, Barry J Milne, 2004) **2004 New Zealand**	1	1	1	1	0	0	0	N/A	1	1	6/9 (66%)
Hanson et al.(Hanson *et al.*, 2019) **2019 (Bt20+) South Africa**	1	1	1	1	0	1	1	N/A	1	1	8/9 (88%)
Harding et al.(Harding *et al.*, 2015) **2015 (PEACH) UK**	1	1	1	1	0	1	1	1	1	1	9/10 (90%)

Hardy et al.(Hardy, Bass and Booth, 2007) **2007 (Girls Healthy Development) Australia**	0	0	1	1	0	0	1	1	1	0	5/10 (50%)
Hesketh et al. [60] 2007 (HOYVS) Australia	1	1	1	1	0	0	0	N/A	1	1	6/9 (66%)
Jackson et al.(Jackson, Cunningham and Author, 2017) **2017 (ECLS-K) USA**	1	1	0	0	0	1	0	N/A	0	1	4/9 (44%)
Jago et al.(Jago *et al.*, 2017) **2017 (B-PROACTIVE) UK**	1	1	1	1	1	1	1	1	1	1	10/10 (100%)
Jago et al.(Jago *et al.*, 2019) **2019 (B-PROACTIVE) UK**	1	1	1	1	1	1	1	1	1	1	10/10 (100%)
Janssen et al.(Janssen, Kay D. Mann, *et al.*, 2016) **2016 (Gateshead Millennium) UK**	1	1	1	1	1	1	1	1	1	1	10/10 (100%)
Janz et al.(Janz, Burns and Levy, 2005) **2005 (Iowa) USA**	1	1	1	1	0	1	0	1	1	1	8/10 (80%)
Janz et al.(KF, JD and LT, 2000) **2000 (Muscatine) USA**	0	1	1	1	0	0	1	N/A	0	0	4/9 (44%)
Johnson et al.(Johnson *et al.*, 2012) **2012 (Be active, eat well) Australia**	1	1	0	1	0	1	1	N/A	1	1	7/9 (77%)
Kwon et al.(Kwon *et al.*, 2012) **2012 (Iowa Bone Development) USA**	1	1	1	1	0	1	1	1	1	1	9/10 (90%)
Landsberg et al.(Landsberg *et al.*, 2010) **2010 (KOPS) Germany**	0	1	0	1	0	0	0	N/A	0	1	3/9 (33%)
Lätt et al.(Lätt *et al.*, 2015) **2015 Estonia**	0	1	0	0	0	1	1	1	1	1	6/10 (60%)
Lipsky et al.(L.M. *et al.*, 2017) **2007 (NEXT plus)**	1	1	1	0	0	1	1	1	1	1	8/10 (80%)

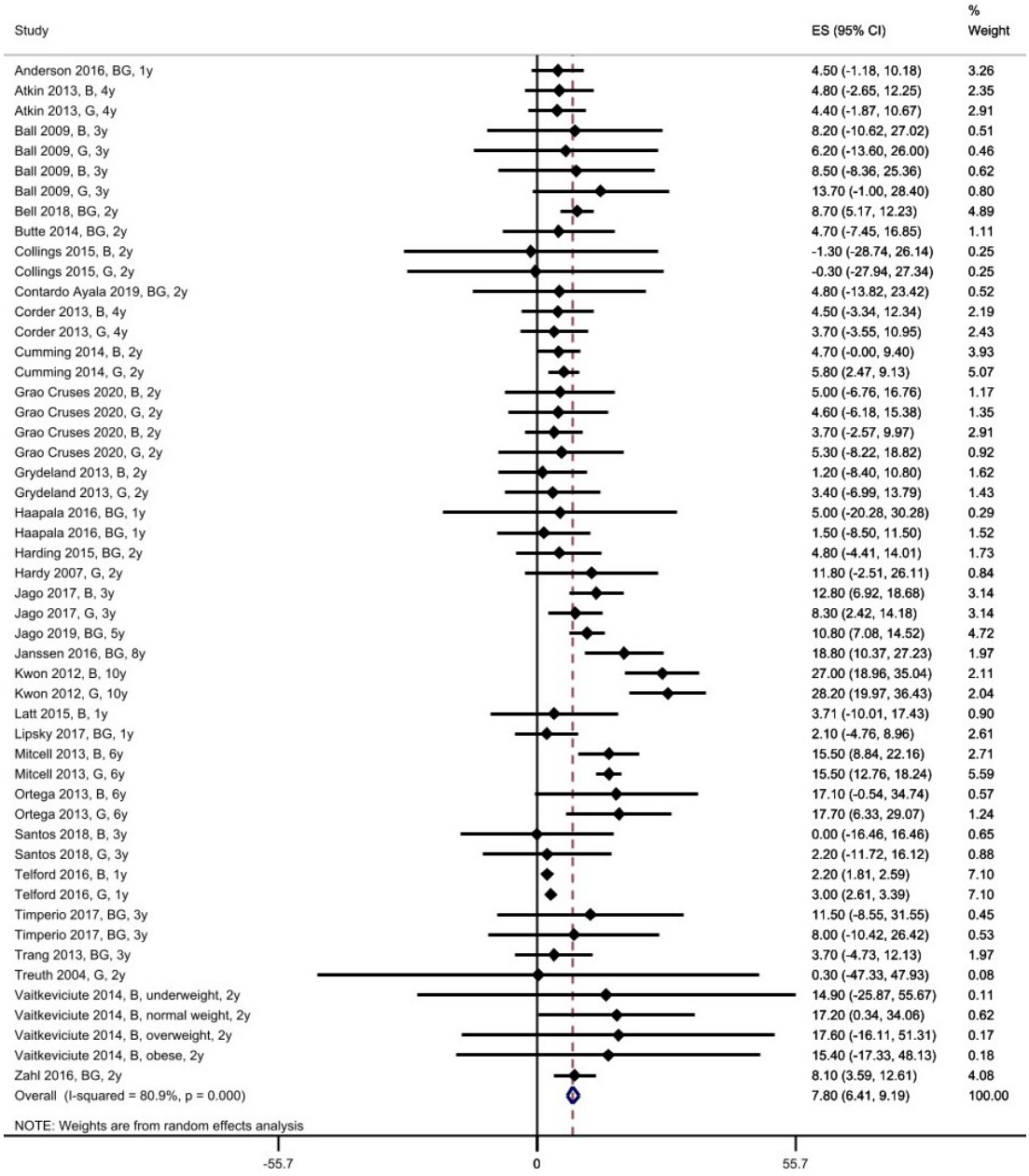
USA											
Lizandra et al.(Lizandra *et al.*, 2016) **2016 Spain**	0	1	1	1	0	1	1	N/A	1	1	7/9 (77%)
Lobel et al.(Lobel *et al.*, 2017) **2017 Netherlands**	1	1	1	1	0	0	0	N/A	0	0	4/9 (44%)
Lubans et al.[69] 2016 (ATLAS) Australia	1	1	1	1	0	1	1	N/A	1	0	7/9 (77%)
Lubans et al.(Lubans *et al.*, 2012) **2012 (NEAT) Australia**	1	0	1	1	1	1	1	N/A	1	0	7/9 (77%)
Lytle et al.(Lytle *et al.*, 2013)**2013 (IDEA and ECHO) USA**	1	1	1	1	0	1	0	N/A	1	1	7/9 (77%)
Mielke et al.[72] 2018 (Pelotas Birth Cohort) Brazil	1	1	1	1	0	1	1	N/A	0	1	7/9 (77%)
Mitchell et al.(Mitchell, Pate and Liese, 2013) **2013 (NHLBI) USA**	0	0	1	1	0	0	0	N/A	0	1	3/9 (33%)
Mitchell et al.(Mitchell *et al.*, 2012) **2012 (NIHCD) USA**	1	1	1	0	0	1	1	1	1	1	8/10 (80%)
Must et al.(Must *et al.*, 2007) **2007 (MIT Growth) USA**	1	1	1	1	0	1	0	N/A	1	0	6/9 (66%)
Nelson et al.(Nelson *et al.*, 2006) **2006 (EAT) USA**	1	1	1	0	0	1	1	N/A	1	1	7/9 (77%)
Ortega et al.(Ortega *et al.*, 2013) **2013 (EYHS) Sweden**	1	1	1	1	0	1	1	1	1	0	8/10 (80%)
Pearson et al.(Pearson *et al.*, 2011) **2011 Australia**	1	1	1	1	0	1	1	N/A	1	1	9/9 (88%)
Raudsepp et al.(Raudsepp, 2016) **2016 Estonia**	0	1	1	1	0	1	1	N/A	1	1	7/9 (77%)

Raudsepp et al.(Raudsepp and Riso, 2017) **2017 Estonia**	0	1	1	1	0	1	1	N/A	1	1	7/9 (77%)
Rutten et al.(Rutten, Boen and Seghers, 2014) **2014 Belgium**	0	1	1	1	0	1	1	N/A	0	0	5/9 (55%)
Salway et al.(Salway *et al.*, 2019) **2019 (B-PROACT1V) UK**	1	1	1	1	0	1	1	N/A	1	1	9/9 (100%)
Sanders et al.(Sanders *et al.*, 2015) **2015 (LSAC) Australia**	1	1	1	1	0	0	0	N/A	0	1	5/9 (55%)
Sanders et al.(Sanders *et al.*, 2019) **2019 (LSAC) Australia**	1	1	1	1	0	1	0	N/A	1	1	7/9 (77%)
Santos et al.(Santos *et al.*, 2018) **2018 Portugal**	0	1	1	1	0	1	1	1	1	0	7/10 (70%)
Simon et al.(Simon *et al.*, 2014) **2014 (ICAPS) France**	1	1	0	1	0	0	0	N/A	0	1	4/9 (44%)
Sleddens et al.(Sleddens *et al.*, 2017) **2017 (KOALA) Netherlands**	0	1	0	1	0	0	0	N/A	0	1	3/9 (33%)
Sonneville et al.[86] 2008 (Planet Health) USA	1	1	1	1	0	1	1	N/A	1	1	8/9 (88%)
Stefan et al.(Stefan *et al.*, 2018) **2018 (CRO-PALS) Croatia**	1	1	1	1	1	1	1	N/A	1	0	8/9 (88%)
Straatman et al.(Straatmann *et al.*, 2019) **2016 (ELANA) Brazil**	1	1	1	1	0	1	0	N/A	1	1	7/9 (77%)
Taveras et al.(Taveras *et al.*, 2007) **2007 (Growing-Up Today) USA**	1	0	0	1	0	1	0	N/A	0	1	4/9 (44%)
Telford et al.(Telford *et al.*, 2016) **2016 LOOK) Australia**	1	1	1	1	0	1	1	1	1	1	9/9 (100%)

Tiberio et al.(Tiberio *et al.*, 2014) **2014 (3GS) USA**	1	0	0	0	0	1	1	N/A	1	0	4/9 (44%)
Timperio et al.(Timperio *et al.*, 2017) **2017 (HEAPS) Australia**	1	1	1	1	0	1	1	1	1	1	9/10 (90%)
Trang et al.(Trang *et al.*, 2013) **2013 (Ho Chi Minh) Vietnam**	1	1	1	1	0	1	1	1	1	1	9/10 (90%)
Treuth et al.(Treuth *et al.*, 2009) **2004 USA**	0	1	1	1	0	1	1	1	1	0	7/10 (70%)
Vaitkeviciute et al.(Vaitkeviciute *et al.*, 2014) **2014 Estonia**	0	1	1	1	0	1	1	1	1	0	7/10 (70%)
Wickel et al.(Wickel, Issartel and Belton, 2013) **2013 (SECCYD) USA**	1	1	1	1	0	1	0	N/A	1	1	7/9 (77%)
Wong et al.(Wong, Huang and He, 2015) **2015 Hong Kong**	1	1	1	1	0	1	1	1	1	1	9/10 (90%)
Zahl et al.(Zahl, Steinsbekk and Wichstrøm, 2017) **2017 Norway**	0	0	1	1	0	1	1	1	1	1	7/10 (70%)
Ziviani et al.(Ziviani *et al.*, 2009) **2009 Australia**	0	1	1	0	0	1	0	N/A	1	1	5/9 (55%)

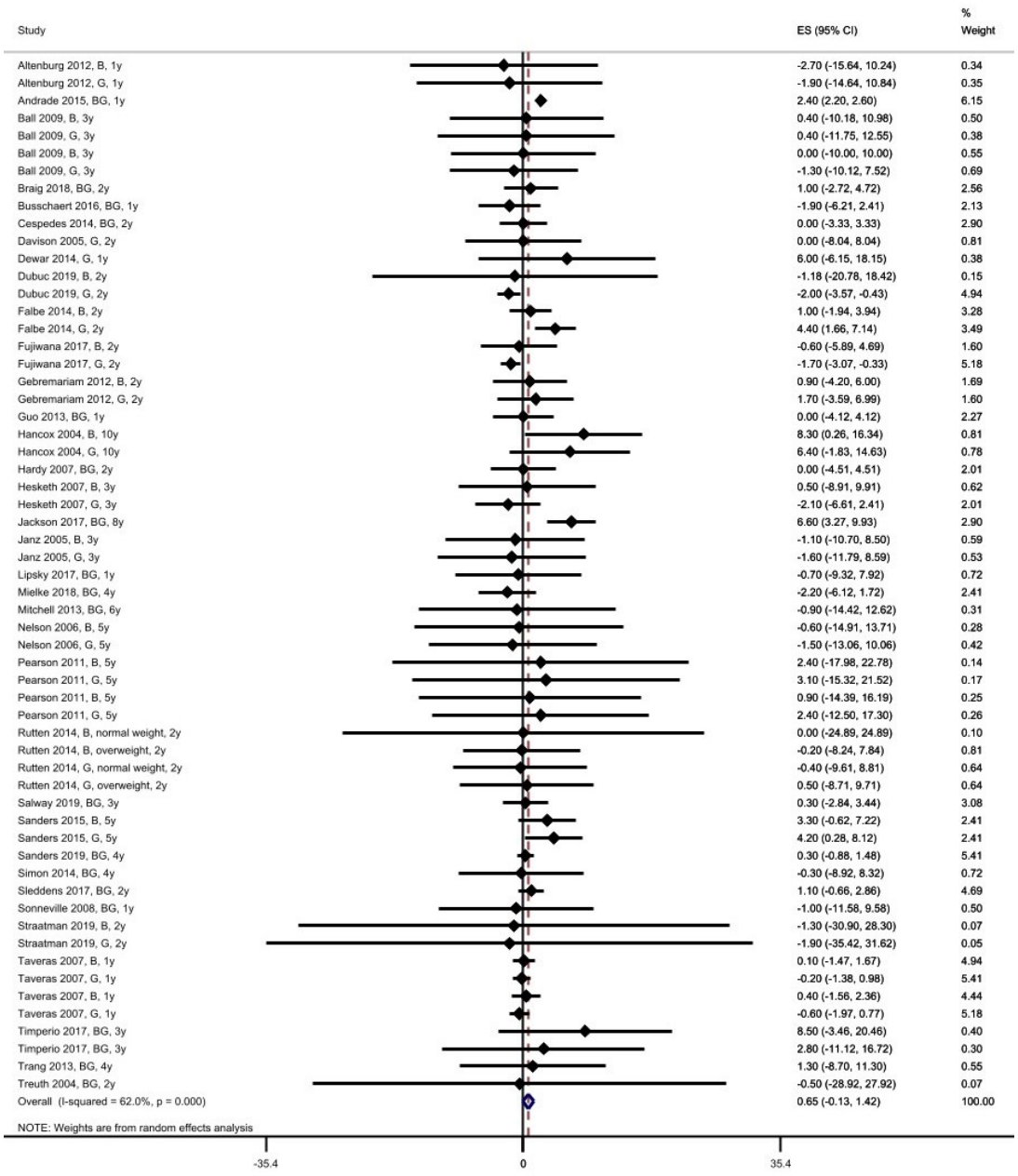
Abbreviations: N/A = not applicable. [1] Item was scored *positively* if the cut points to define sedentary behaviour were referenced (subjective measures were given an N/A, which meant that those studies were scored using a total of 9 rather than 10).

Appendix 6 Annual change (min per day per year) in device-based sedentary time



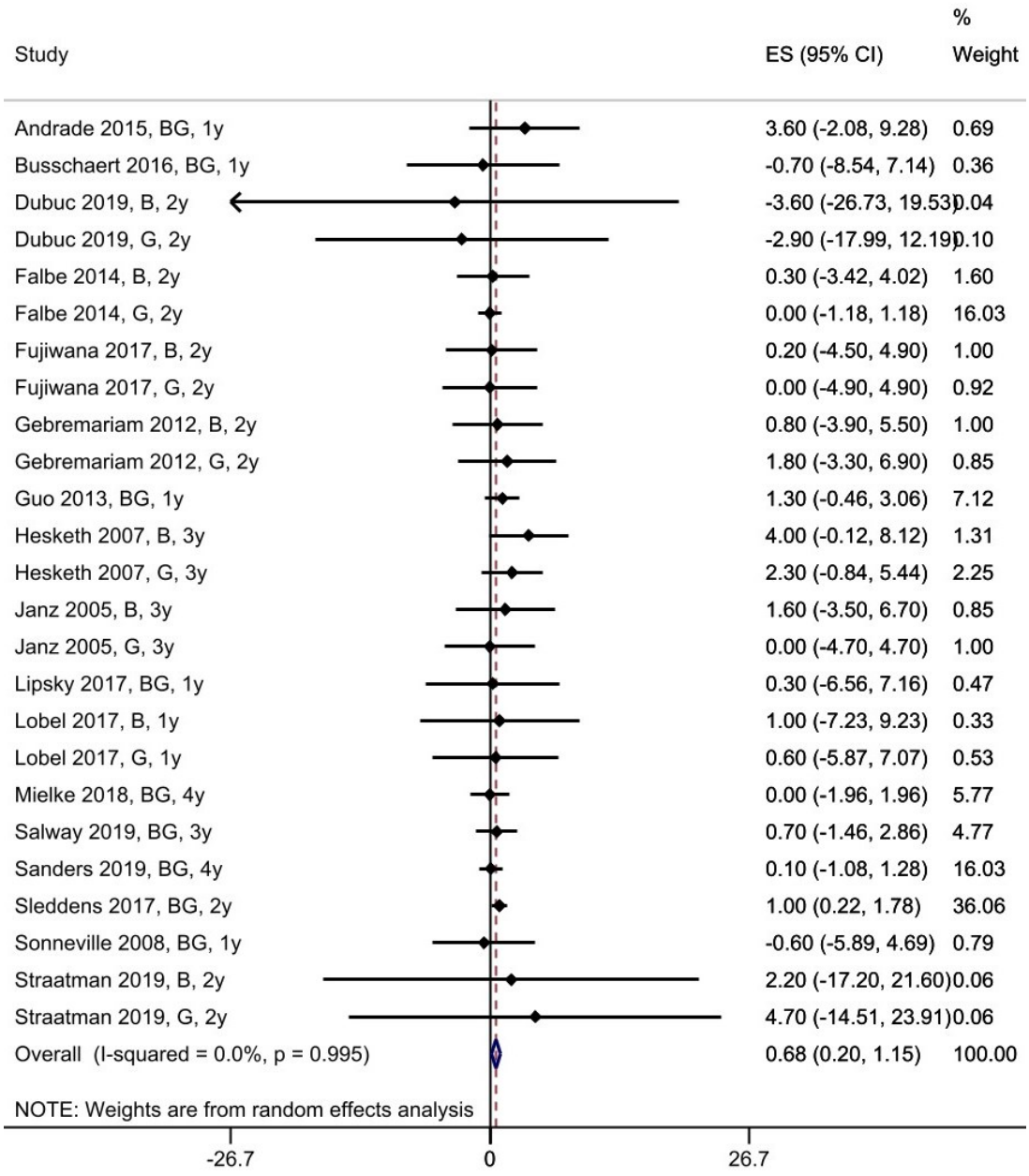
Abbreviations: B=boys, G=girls, BG=boys and girls, y=year.

Appendix 7 Annual change (min per day per year) in self- or proxy-reported TV-viewing



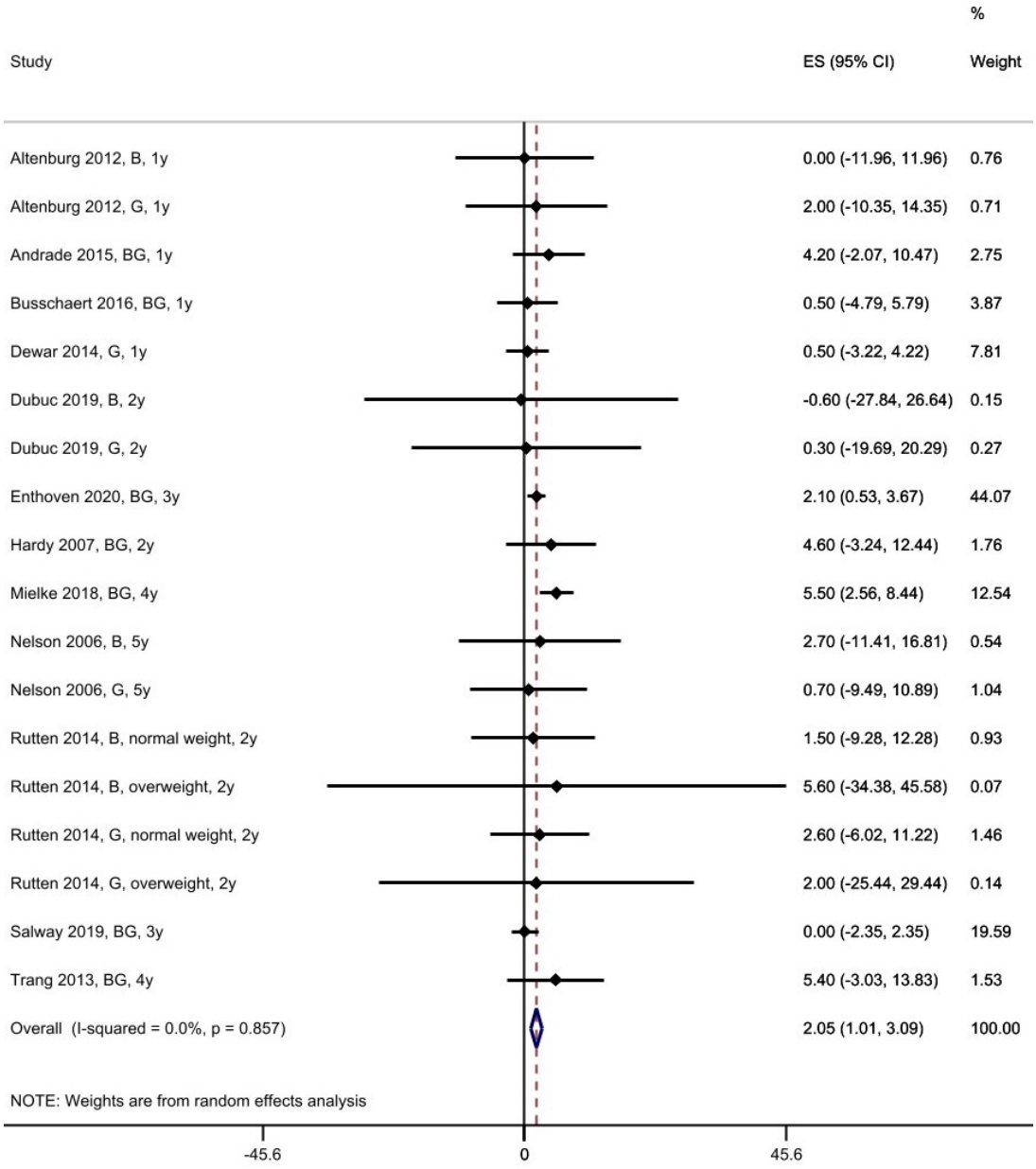
Abbreviations: B=boys, G=girls, BG=boys and girls, y=year.

Appendix 8 Annual change (min per day per year) in self- or proxy-reported video games



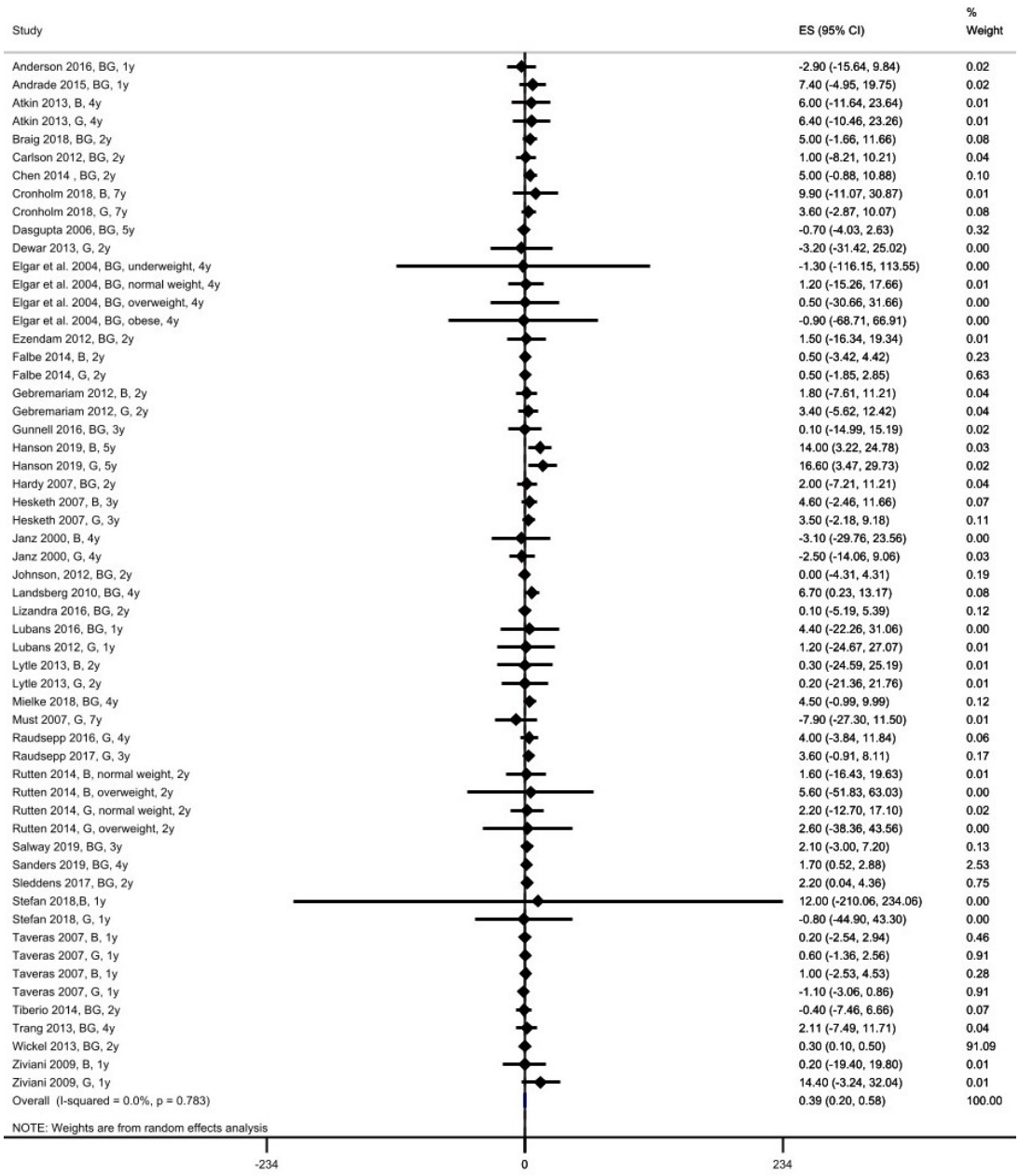
Abbreviations: B=boys, G=girls, BG=boys and girls, y=year.

Appendix 9 Annual change (min per day per year) in self- or proxy-reported computer use



Abbreviations: B=boys, G=girls, BG=boys and girls, y=year.

Appendix 10 Annual change (min per day per year) in self- or proxy-reported composite screen-based behaviours



Abbreviations: B=boys, G=girls, BG=boys and girls, y=year.

Appendix 11 Direction of change in self-/ proxy-reported sedentary behaviour over selected durations of follow-up

Duration of follow-up (years)	Y1	Y2	Y3	Y4-Y10
Academic-related activities				
Increase	5	11	1	2
Decrease	4	n/s	n/s	n/s
Travel by car/bus				
Increase	2	3	1	2
Decrease	1	n/s	n/s	n/s

Abbreviations: n/s= no studies

Data is presented as *k*=independent samples.

Appendix 12 Questions related to time spent in screen behaviours

1a) How much time per day do you spend talking on your mobile phone? On weekdays

1) 0 minutes per day
2) 1 – 5 minutes per day
3) 6 – 15 minutes per day
4) 16 – 30 minutes per day
5) 31 – 59 minutes per day
6) 1 – 2 hours per day
7) More than 3 hours per day

1b) How much time per day do you spend talking on your mobile phone? On a weekend day

1) 0 minutes per day
2) 1 – 5 minutes per day
3) 6 – 15 minutes per day
4) 16 – 30 minutes per day
5) 31 – 59 minutes per day
6) 1 – 2 hours per day
7) More than 3 hours per day

2a) How much time per day do you spend using the internet on your mobile phone? On weekdays

1) 0 minutes
2) 1 – 10 minutes per day
3) 11 – 30 minutes per day
4) 31 – 59 minutes per day
5) 1 – 2 hours per day
6) 3 – 4 hours per day
7) 5 – 6 hours per day
8) 7 or more hours per day

2b) How much time per day do you spend using the internet on your mobile phone? On weekend days

1) 0 minutes
2) 1 – 10 minutes per day
3) 11 – 30 minutes per day
4) 31 – 59 minutes per day
5) 1 – 2 hours per day
6) 3 – 4 hours per day
7) 5 – 6 hours per day
8) 7 or more hours per day

3) How much time PER WEEK do you spend using the following devices at school during lesson and break time? a desktop computer

1) None/Don't use this at school
2) Less than 30 minutes per week
3) 31 – 59 minutes per week
4) 1 – 2 hours per week
5) 3 – 4 hours per week
6) 5 – 6 hours per week
7) 7 hours or more per week

4) How much time PER WEEK do you spend using the following devices at school during lesson and break time? a laptop

1) None/Don't use this at school
2) Less than 30 minutes per week
3) 31 – 59 minutes per week
4) 1 – 2 hours per week
5) 3 – 4 hours per week
6) 5 – 6 hours per week
7) 7 hours or more per week

5) How much time PER WEEK do you spend using the following devices at school during lesson and break time? a tablet (e.g., iPad)

1) None/Don't use this at school
2) Less than 30 minutes per week
3) 31 – 59 minutes per week
4) 1 – 2 hours per week
5) 3 – 4 hours per week
6) 5 – 6 hours per week
7) 7 hours or more per week

6a) How much time per day do you use the following devices outside of school? Desktop Computer on weekdays

1) None
2) 1 – 10 minutes per day
3) 11 – 30 minutes per day

4) 31 – 59 minutes per day
5) 1 – 2 hours per day
6) 3 – 4 hours per day
7) 4 – 8 hours per day
8) 8 – 12 hours per day
9) More than 12 hours per day

6b) How much time per day do you use the following devices outside of school? Desktop Computer on a weekend day

1) None
2) 1 – 10 minutes per day
3) 11 – 30 minutes per day
4) 31 – 59 minutes per day
5) 1 – 2 hours per day
6) 3 – 4 hours per day
7) 4 – 8 hours per day
8) 8 – 12 hours per day
9) More than 12 hours per day

7a) How much time per day do you use the following devices outside of school? Laptop on weekdays

1) None
2) 1 – 10 minutes per day
3) 11 – 30 minutes per day
4) 31 – 59 minutes per day
5) 1 – 2 hours per day
6) 3 – 4 hours per day
7) 4 – 8 hours per day
8) 8 – 12 hours per day
9) More than 12 hours per day

7b) How much time per day do you use the following devices outside of school? Laptop on a weekend day

1) None
2) 1 – 10 minutes per day
3) 11 – 30 minutes per day
4) 31 – 59 minutes per day
5) 1 – 2 hours per day
6) 3 – 4 hours per day
7) 4 – 8 hours per day
8) 8 – 12 hours per day
9) More than 12 hours per day

8a) How much time per day do you use the following devices outside of school? Tablet/eBook Reader on weekdays

1) None
2) 1 – 10 minutes per day

3) 11 – 30 minutes per day
4) 31 – 59 minutes per day
5) 1 – 2 hours per day
6) 3 – 4 hours per day
7) 4 – 8 hours per day
8) 8 – 12 hours per day
9) More than 12 hours per day

8b) How much time per day do you use the following devices outside of school? Tablet/eBook Reader on a weekend day

1) None
2) 1 – 10 minutes per day
3) 11 – 30 minutes per day
4) 31 – 59 minutes per day
5) 1 – 2 hours per day
6) 3 – 4 hours per day
7) 4 – 8 hours per day
8) 8 – 12 hours per day
9) More than 12 hours per day

9a) How much time per day do you use the following devices outside of school? Portable media player on weekdays

1) None
2) 1 – 10 minutes per day
3) 11 – 30 minutes per day
4) 31 – 59 minutes per day
5) 1 – 2 hours per day
6) 3 – 4 hours per day
7) 4 – 8 hours per day
8) 8 – 12 hours per day
9) More than 12 hours per day

9b) How much time per day do you use the following devices outside of school? Portable media player on a weekend day

1) None
2) 1 – 10 minutes per day
3) 11 – 30 minutes per day
4) 31 – 59 minutes per day
5) 1 – 2 hours per day
6) 3 – 4 hours per day
7) 4 – 8 hours per day
8) 8 – 12 hours per day
9) More than 12 hours per day

10a) How much time per day do you use the following devices outside of school? Video Game Console on weekdays

1) None
2) 1 – 10 minutes per day
3) 11 – 30 minutes per day
4) 31 – 59 minutes per day
5) 1 – 2 hours per day
6) 3 – 5 hours per day
7) More than 5 hours per day

10b) How much time per day do you use the following devices outside of school? Video Game Console on a weekend day

1) None
2) 1 – 10 minutes per day
3) 11 – 30 minutes per day
4) 31 – 59 minutes per day
5) 1 – 2 hours per day
6) 3 – 5 hours per day
7) More than 5 hours per day

11a) How much time per day do you use the following devices outside of school? Portable Video Game Console on weekdays

1) None
2) 1 – 10 minutes per day
3) 11 – 30 minutes per day
4) 31 – 59 minutes per day
5) 1 – 2 hours per day
6) 3 – 5 hours per day
7) More than 5 hours per day

11b) How much time per day do you use the following devices outside of school? Portable Video Game Console on a weekend day

1) None
2) 1 – 10 minutes per day
3) 11 – 30 minutes per day
4) 31 – 59 minutes per day
5) 1 – 2 hours per day
6) 3 – 5 hours per day
7) More than 5 hours per day

12a) How much time per day do you use the following devices outside of school? Smart TV on weekdays

1) None
2) 1 – 10 minutes per day
3) 11 – 30 minutes per day
4) 31 – 59 minutes per day
5) 1 – 2 hours per day
6) 3 – 5 hours per day

7) More than 5 hours per day

12b) How much time per day do you use the following devices outside of school? Smart TV on a weekend day

1) None
2) 1 – 10 minutes per day
3) 11 – 30 minutes per day
4) 31 – 59 minutes per day
5) 1 – 2 hours per day
6) 3 – 5 hours per day
7) More than 5 hours per day

13) On a normal week day during term time, how many hours do you spend watching television programmes or films?¬ ¬Please remember to include time spent watching programmes or films on a computer or mobile device as well as on a TV, DVD etc. Please also include time spent before school as well as time after school.

1) None
2) 1 – 10 minutes per day
3) 11 – 30 minutes per day
4) 31- 59 minutes per day
5) 1 – 2 hours per day
6) 3 – 4 hours per day
7) 5 – 6 hours per day
8) 7 hours or more per day

14a) How much time overall, do you spend on social network sites (e.g., Facebook, Twitter) per day, using a mobile phone? On weekdays

1) 0 minutes
2) 1 – 10 minutes per day
3) 11 – 30 minutes per day
4) 31 – 59 minutes per day
5) 1 – 2 hours per day
6) 3 – 4 hours per day
7) More than 5 hours per day

14b) How much time overall, do you spend on social network sites (e.g., Facebook, Twitter) per day, using a mobile phone? On a weekend day

1) 0 minutes
2) 1 – 10 minutes per day
3) 11 – 30 minutes per day
4) 31 – 59 minutes per day
5) 1 – 2 hours per day
6) 3 – 4 hours per day
7) More than 5 hours per day

15a) How much time per day do you spend on social network sites (e.g., Facebook, Instagram, Twitter)? On a weekday using all OTHER devices

1) 0 minutes
2) 1 – 10 minutes per day
3) 11 – 30 minutes per day
4) 31 – 59 minutes per day
5) 1 – 2 hours per day
6) 3 – 4 hours per day
7) 5 – 6 hours per day
8) More than 7 or more hours per day

15b) How much time per day do you spend on social network sites (e.g., Facebook, Instagram, Twitter)? On a weekend day using all OTHER devices

1) 0 minutes
2) 1 – 10 minutes per day
3) 11 – 30 minutes per day
4) 31 – 59 minutes per day
5) 1 – 2 hours per day
6) 3 – 4 hours per day
7) 5 – 6 hours per day
8)More than 7 or more hours per day

Appendix 13 Full list of categories and codes (behaviours) for time-use diary.

Categories	Codes
Sleep and personal care	Sleeping and resting; Personal care
School, homework, and education	Homework; In class; School breaks; School clubs; Detention
Paid or unpaid work	Paid work; Unpaid work for family or other non-household members
Chores, housework, and looking after people or animals	Cooking, cleaning, and shopping for the household; Fixing things around the house, fixing bike, gardening; Looking after siblings in the household; Looking after parent or other adult in the household (medical or personal care); Looking after animals
Eating and drinking	Eating or drinking in a restaurant or café; Eating a meal; Eating a snack or having a drink
Physical exercise and sports	Cycling; Ball games and training; Jogging, running, walking, hiking; Team ball games and training; Swimming and other water sports; Other physical exercise and other sports
Travelling (including walking to school)	Travel by bus, taxi, tube, plane; Travel by car, van (including vehicles owned by friends and family); Travel by physically active means (walk, bike etc.)
Social time and family time	Attending live sporting events; Cinema, theatre, performance, gig; Exhibition, museum, library, other cultural events; Shopping; Speaking on the phone; Speaking, socialising face-to-face
Internet, TV, and digital media	Answering emails, instant messaging, texting; Browsing and updating social networking sites (e.g. Twitter, Facebook, BBM, Snapchat); General internet browsing, programming (not time on social networking sites); Listening to music, radio, iPod, other audio content; Playing electronic games and Apps; Watching TV, DVDs, downloaded videos
Volunteering and religious activities	Volunteering; Religious activities
Hobbies and other free time activities	Did nothing, just relaxing, bored, waiting; Hobbies, arts and crafts, musical activities, writing stories, poetry; Reading (not for school)
Any other activity	Other activities not listed

Appendix 14 Self-completed questions on sleep habits.

About what time do you usually go to sleep on a school night?

1. Before 9 pm
2. 9 - 9:59 pm
3. 10 – 10:59 pm
4. 11 - midnight
5. After midnight

About what time do you usually wake up in the morning on a school day?

1. Before 6 am
2. 6 - 6:59 am
3. 7 – 7:59 am
4. 8 - 8:59 am
5. After 9 am

About what time do you usually go to sleep on the nights when you do not have school the next day?

1. Before 9 pm
2. 9 - 9:59 pm
3. 10 - 10:59 pm
4. 11 - midnight
5. After midnight

About what time do you wake up in the morning on the days when you do not have school?

1. Before 8 am
2. 8 - 8:59 am
3. 9 – 9:59 am
4. 10 - 10:59 am
5. 11 - 11:59 am
6. After Midday

Appendix 15 Hurdle model: Linear regression for the association of screen-based behaviour with sedentary behaviour

	Composite sedentary behaviour			
	Weekday		**Weekend**	
	β (95% CI)	***P* value**	**β (95% CI)**	***P* value**
Phone calls	-.17 (-.41, .06)	0.14	0.29 (0.00, 0.57)	0.04
Email/text	0.12 (-.06, 0.31)	0.21	0.05 (-0.13, 0.24)	0.59
Social network sites	0.31 (0.16, 0.45)	<0.001	0.29 (0.14, 0.44)	<0.001
Internet browsing	0.42 (0.19, 0.66)	<0.001	0.40 (0.16, 0.63)	<0.001
Screen behaviour	-.01 (-0.01, -0.00)	<0.001	-.00 (-.01, -.00)	<0.001

B, beta coefficient; 95% CI, 95% Confidence Interval.

Appendix 16 Interaction by sex for the association between screen-based behaviour and overall physical activity

	Overall physical activity			
	Weekday		**Weekend**	
	β (95% CI)	***P* value**	**β (95% CI)**	***P* value**
Phone calls				
Boys	-0.74 (-5.07, 3.58)	0.73	0.22 (-3.51, 3.97)	0.59
Girls	-2.09 (-4.86, 0.67)	0.13	-1.03 (-3.78, 1.72)	0.46
Sex*phone calls	-1.35 (-6.48, 3.78)	0.60	-1.25 (-5.90, 3.38)	0.59
Email/text				
Boys	-0.16 (-2.91, 2.59)	0.90	0.47 (-2.29, 3.23)	0.73
Girls	0.26 (-1.77, 2.30)	0.79	-2.53 (-4.63, -0.43)	0.01
Sex*Email/text	0.42 (-3.00, 3.85)	0.80	-3.00 (-6.48, 0.46)	0.09
Social network sites				
Boys	-0.58 (-2.60, 1.42)	0.56	-0.29 (-2.42, 1.82)	0.78
Girls	-1.65 (-3.24, -0.06)	0.04	-3.23 (-4.90, -1.55)	0.001
Sex* Social network sites	-1.06 (-3.63, 1.49)	0.41	-2.93 (-5.63, -0.22)	**0.03**
Internet browsing				
Boys	-4.18 (-6.56, -1.80)	0.001	-1.68 (-4.16, 0.79)	0.18
Girls	-1.29 (-3.63, 1.05)	0.27	-3.52 (-5.77, -1.27)	0.002
Sex* Internet browsing	2.89 (-0.45, 6.23)	0.09	-1.83 (-5.18, 1.50)	0.28
Screen behaviour				
Boys	-0.23 (-0.33, -0.13)	0.001	-0.16 (-0.25, -0.07)	0.001
Girls	-0.19 (-0.26, -0.12)	0.001	-0.20 (-0.27, -0.14)	0.001
Sex* Screen behaviour	0.04 (-0.09, 0.18)	0.52	-0.06 (-0.18, 0.05)	0.30

B, beta coefficient; 95% CI, 95% Confidence Interval.

Appendix 17 Interaction by sex for the association between screen-based behaviour and MVPA

	Moderate-to-vigorous physical activity			
	Weekday		**Weekend**	
	β (95% CI)	***P* value**	**β (95% CI)**	***P* value**
Phone calls				
Boys	-1.65 (-19.50, 16.20)	0.85	-1.19 (-16.81, 14.42)	0.88
Girls	-8.11 (-19.5, 3.30)	0.16	-4.84 (-16.3, 6.64)	0.40
Sex*phone calls	-6.46 (-27.66, 14.72)	0.55	-3.65 (-23.03, 15.72)	0.71
Email/text				
Boys	-1.88 (-13.2, 9.47)	0.74	3.34 (-8.20, 14.8)	0.57
Girls	1.66 (-6.75, 10.0)	0.69	-11.2 (-20.0, -2.49)	0.01
Sex*Email/text	3.55 (-10.5, 17.7)	0.62	-14.6 (-29.1, -0.10)	**0.04**
Social network sites				
Boys	-2.91 (-11.2, 5.3)	0.49	-3.45 (-12.3, 5.41)	0.44
Girls	-7.90 (-14.4, -1.35)	0.01	-15.3 (-22.3, -8.40)	0.001
Sex* Social network sites	-4.98 (-15.5, 5.59)	0.35	-11.9 (-23.2, -0.65)	**0.03**
Internet browsing				
Boys	-13.7 (-23.6, -3.94)	0.006	-7.14 (-17.4, 3.19)	0.17
Girls	-8.62 (-18.3, 1.04)	0.08	-15.7 (-25.1, -6.37)	0.001
Sex* Internet browsing	5.16 (-8.63, 18.9)	0.46	-8.60 (-22.5, 5.34)	0.22
Screen behaviour				
Boys	-0.93 (-1.32, -0.51)	0.001	-0.69 (-1.07, -0.31)	0.001
Girls	-0.84 (-1.13, -0.55)	0.001	-0.94 (-1.20, -0.67)	0.001
Sex* Screen behaviour	0.04 (-0.46, 0.65)	0.74	-0.39 (-0.91, 0.12)	0.13

B, beta coefficient; 95% CI, 95% Confidence Interval.

Appendix 18 Interaction by sex for the association between screen-based behaviour and composite sedentary behaviour

	Composite sedentary behaviour			
	Weekday		**Weekend**	
	β (95% CI)	***P* value**	**β (95% CI)**	***P* value**
Phone calls				
Boys	-0.65 (-54.2, 52.9)	0.98	-57.4 (107.2, -7.61)	0.02
Girls	-36.62 (-80.0, 6.75)	0.09	-9.20 (-47.6, 29.2)	0.63
Sex*phone calls	-35.9 (-104.9, 32.9)	0.30	48.2 (-14.7, 111.1)	0.13
Email/text				
Boys	-36.0 (-72.5, 0.45)	0.05	-63.8 (-99.6, -27.9)	0.001
Girls	-27.6 (-57.2, 1.89)	0.06	-20.3 (-49.8, 9.19)	0.17
Sex*Email/text	8.37 (-38.5, 55.3)	0.72	43.4 (-2.91, 89.8)	0.06
Social network sites				
Boys	-69.8 (-95.5, -44.1)	0.001	-57.8 (-84.4, -31.3)	0.001
Girls	-42.5 (-65.0, -19.9)	0.001	-37.8 (-61.0, -14.5)	0.001
Sex* Social network sites	27.2 (-6.74, 61.3)	0.11	20.0 (-15.1, 55.2)	0.26
Internet browsing				
Boys	-50.7 (-81.9, -19.6)	0.001	-57.7 (-89.0, -26.4)	0.001
Girls	-13.5 (-46.7, 19.6)	0.43	18.8 (-12.7, 50.4)	0.24
Sex* Internet browsing	37.2 (-8.18, 82.6)	0.10	76.6 (32.1, 121.0)	**0.001**
Screen behaviour				
Boys	-6.78 (-8.43, -5.13)	0.001	-7.58 (-9.13, -6.03)	0.001
Girls	-5.5 (-6.47, -4.37)	0.001	-5.69 (-6.73, -4.65)	0.001
Sex* Screen behaviour	-2.80 (-34.4, 28.8)	0.86	1.37 (-30.6, 33.3)	0.93

B, beta coefficient; 95% CI, 95% Confidence Interval.

Appendix 19 Interaction by sex for the association between screen-based behaviour and sleep duration

	Sleep duration			
	Weekday		**Weekend**	
	β (95% CI)	***P* value**	**β (95% CI)**	***P* value**
Phone calls				
Boys	0.77 (0.50, 1.17)	0.23	1.41 (0.77, 2.59)	0.26
Girls	0.73 (0.54, 1.00)	0.05	0.62 (0.41, 0.93)	0.02
Sex*phone calls	0.95 (0.56, 1.61)	0.86	2.27 (1.09, 4.72)	**0.02**
Email/text				
Boys	0.66 (0.49, 0.88)	0.005	0.95 (0.64, 1.40)	0.80
Girls	0.82 (0.66, 1.01)	0.06	0.63 (0.45, 0.87)	0.005
Sex*Email/text	1.24 (0.86, 1.77)	0.23	1.50 (0.90, 2.50)	0.11
Social network sites				
Boys	0.73 (0.59, 0.90)	0.004	0.97 (0.72, 1.31)	0.89
Girls	0.75 (0.63, 0.89)	0.001	1.08 (0.81, 1.43)	0.57
Sex* Social network sites	1.02 (0.78, 1.33)	0.85	1.10 (0.73, 1.66)	0.62
Internet browsing				
Boys	0.63 (0.49, 0.82)	0.001	0.75 (0.53, 1.05)	0.09
Girls	0.78 (0.61, 1.00)	0.05	0.77 (0.53, 1.11)	0.16
Sex* Internet browsing	1.23 (0.86, 1.74)	0.24	1.02 (0.62, 1.68)	0.91
Screen behaviour				
Boys	0.96 (0.95, 0.97)	0.001	0.98 (0.97, 0.99)	0.04
Girls	0.96 (0.95, 0.97)	0.001	0.98 (0.97, 0.99)	0.002
Sex* Screen behaviour	1.00 (0.98, 1.01)	0.86	0.99 (0.97, 1.01)	0.51

B, beta coefficient; 95% CI, 95% Confidence Interval.