Physical activity, sedentary behaviour, and mental health in children: findings from the UK Millennium Cohort Study

Thesis submitted for the degree of Doctor of Philosophy

University College London

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July 2021

Declaration

I, Jane Ahn, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Abstract

Background: Research has shown that physical activity (PA) may improve mental health. This thesis explores the association between PA and mental health in UK Millennium Cohort Study children. The role of environmental characteristics, type and intensity of PA, and direction of causality will be investigated.

Methods: Accelerometer data were collected at age 7 and reported PA and sedentary behaviour data were collected at ages 5, 7, and 11. Mental health was measured using the Strengths and Difficulties Questionnaire (SDQ). Models were run separately by gender.

Associations between minutes of sedentary, light PA, moderate-to-vigorous (MVPA) and SDQ were estimated using multiple linear regression, adjusting for multiple confounders (n=6,153). Between-individual and -ward variances were estimated using multilevel models. Environmental effects were explored using green space, deprivation, and urbanicity variables.

Associations between reported PA and sedentary behaviours, and SDQ were estimated using three-wave, cross-lagged panel models.

Results: In fully adjusted models, increased light PA and MVPA for boys, and light PA only for girls and less sedentary time, was associated with fewer peer problems. MVPA was positively associated with conduct problems in boys. Increased PA and less sedentary time were associated with more hyperactive symptoms. These effects were observed in both single- and multilevel models.

No evidence of green space effects as confounder or moderator were observed in multilevel models. Intraclass correlation coefficients ranged from 4.5% (hyperactivity in girls) to 9.2% (peer problems in girls) in fully adjusted models.

In cross-lagged models, sports participation improved emotional and peer problems, and total difficulties. Less television was associated with fewer peer and conduct problems, hyperactive symptoms, and total difficulties in boys. Active commuting and electronic gaming were not found to predict mental health outcomes.

Conclusions: Whether PA improves mental health depends on the intensity and type of PA or sedentary behaviour, SDQ outcome, gender, and timing of exposure.

Impact statement

In this thesis, the relationship between physical activity (PA), sedentary behaviour, and mental health in children is explored. The results of the analyses conducted here benefit further academic study in this field by clarifying how the intensity, type, and timing of PA or sedentary behaviour are important when considering mental health effects and highlighting the areas of where additional investigation is required, particularly with respect to environmental context and how effects differ by gender.

This study was carried out on a longitudinal, population-based cohort of children born in the United Kingdom in 2000-2001. Data from three sweeps at ages 5, 7, and 11 were used but additional sweeps have been conducted or are ongoing (ages 14 and 17), thus, there is potential for continued investigation in this cohort to determine whether the relationships observed here persist or change in future.

Understanding the relationship between activity and mental health is valuable at a time when the Children and Adolescent Mental Health Services (CAMHS) in the NHS is increasingly under strain and access to services by young people in need is hampered by long waiting times. If some of the symptoms of mental health distress can be alleviated through behavioural changes such as increased PA, this would be valuable to health care providers and policy makers.

The importance of an active lifestyle and limiting sedentary behaviour in improving peer problems in children is increasingly relevant as issues with bullying in young people, both in person and online, can have grave mental health consequences. Further insights into the mechanisms behind the improvement of peer relations in children through active play and sports could help inform interventions. Government and health policy makers could benefit from the findings that excessive television exposure is harmful to children's mental health to inform their screen time guidance.

By demonstrating the benefits of PA to mental health outcomes, this research is useful to organisations promoting PA and sport in young people. Impact could extend to local initiatives to promote more PA programmes for children, and cleaner and safer spaces for walking and cycling. Some of the results presented in this thesis have contributed to the academic literature through a peer-reviewed publication. By additionally disseminating other results in scientific journals, for example, the results from the cross-lagged panel models, the impact of this thesis could be widened. The relationship between multiple reported PA and sedentary screen behaviour measures and mental health outcomes has not previously been described using longitudinal data from multiple sweeps in a nationally-representative cohort of children.

Acknowledgments

I would like to thank my supervisors, Professors Steve Cummins and Eirini Flouri. I would also like to thank Francesco Sera for statistical support and advice. I am indebted to Steven Papachristou at UCL IOE, who made time for everything from statistical advice and software assistance to general reassurance.

I gratefully acknowledge the families of the Millennium Cohort Study for their co-operation and time.

I would also like to thank HC, DS, RH, AP, ZG, RD, HB, SG for proofreading and preventing despair, CT & EW for when it really hit the fan, DS for 11th hour pizza, and WN for the endless cups of PWC. Finally, I am grateful to my family for their ongoing support, and especially my mother – her strength and perseverance are inspiring, and without her love and support, none of this would have been possible.

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1 Background: the mental health, physical activity and sedentary behaviour of children in the UK

1.1 Introduction

There is an established body of literature that demonstrates the positive benefits of physical activity to a broad range of health outcomes, including coronary heart disease, hypertension, some cancers, obesity, diabetes, and some musculo-skeletal problems (S. Biddle, Fox, & Boutcher, 2000; S. Biddle & Mutrie, 2008), and these benefits extend to mental health (Penedo & Dahn, 2005). Indeed, the importance of physical activity to an individual's mental health and overall well-being has been acknowledged by the earliest writers in the Western medical tradition: even in the 2nd century CE, Galen did not accept the pervading mind-body dichotomy of his time and advocated a more holistic approach to health. The study of the specific mental health benefits to children from physical activity (PA), however, has only relatively recently become the subject of scientific investigation.

According to a report by the Office of National Statistics, in 2017 approximately 13% of children aged 5-19 years in Great Britain had a clinically diagnosed mental disorder and rates have increased from 2004 in 5-15-year olds from 1 in 10 to 1 in 9. As the early years represent a critical period in child development, poor mental health in childhood may impact an individual's ability to establish positive relationships and affect their educational attainment and later mental health (Marmot, 2010). With the reduction in access to mental health services and increases in wait times, preventing or improving the effects of mental health disorders through lifestyle and behavioural changes is becoming increasingly important. Increasing PA is one of the ways through which improving mental health in children has been proposed (S. Biddle et al., 2000; S. Biddle & Mutrie, 2008).

As with mental health, the formation of an active lifestyle in childhood is important as it may be predictive of PA in adulthood (Bélanger et al., 2015; Smith, Gardner, Aggio, & Hamer, 2015; Telama, 2009), and the relationship between active lifestyles and mental health in adults has been established (S. Biddle, 2016; Conn, 2010; Mammen & Faulkner, 2013; Tenenbaum & Eklund, 2007). Physical activity in children is associated with reductions in depression, anxiety, and low self-esteem, and increased cognitive functioning (Ahn & Fedewa, 2011; S. J. Biddle & Asare, 2011; S. J. Biddle, Gorely, & Stensel, 2004). However, the mechanisms through which physical activity operates on mental health and well-being have predominantly been considered in the context of older populations (Hallal, Victora, Azevedo, & Wells, 2006; Paluska & Schwenk, 2000). Similarly, the importance of socioeconomic, demographic, relationship, and health-related characteristics in the patterning of mental health disorders (Kiernan & Mensah, 2009; Sadler et al.) and PA is acknowledged (S. J. Biddle et al., 2004; K. R. Hesketh et al., 2014; Chris J Riddoch et al., 2007) but their inclusion in studies examining the relationship between PA and mental health in children is inconsistent across the literature.

Given the potential for PA to alleviate the burden of poor mental health in children, the aim of this chapter is to explore the literature on the relationship between PA and mental health in children. Specifically, I propose to:

- provide a rationale for this thesis by describing the current status of mental health and physical activity in children in the UK;
- attempt to define physical activity within a framework of multidimensional behaviours, as well as to provide an overview of physical activity measurement;
- outline the existing evidence on the relationship between PA and mental health in children; and
- identify the factors associated with PA and mental health in the literature.

1.2 Mental health in children

In the UK, there is a growing concern over mental health disorders in children. A 2014 report from the House of Commons Health Committee (Health Committee, 2014) reported 'serious and deeply ingrained problems with the commissioning and provision of children's and adolescents' mental health services [which] run through the whole system from prevention and early intervention through to inpatient services for the most vulnerable young people'. In the UK, new and ongoing commitments from cross-government strategies have pledged to promote mental health, to help recovery from mental health problems, promote physical health via mental health, improve care and support, decrease avoidable harm, and decrease mental health stigma and discrimination (Department of Health, 2011).

Increasingly, the consequences of ignoring mental health disorders in early years is being recognised, with studies showing that conduct problems in childhood are associated with lower educational qualifications, unemployment or underemployment, divorce, teenage parenthood, criminal convictions and psychiatric disorders in adulthood (Richards & Huppert, 2011; Stevens, 2018). In a birth cohort in New Zealand, more than half of adults with mental health disorders were diagnosed in childhood with most adult forms of psychiatric disorders preceded by their juvenile counterparts (Kim-Cohen et al., 2003). Consequently, the priority is in preventing and treating mental disorders in childhood.

According to the 2017 report on Mental Health of Children and Young People in England, 12.8% of 5-19 year olds had a mental health disorder (Sadler et al., 2018). Comparing the 2017 rates of disorder in 5-15 year olds with previous surveys, there was an increase in emotional disorders (3.9% in 2004 and 5.8% in 2017) and disorders overall (9.7% in 1999, 10.1% in 2004, and 11.2% in 2017) while behavioural disorders remained stable (Sadler et al., 2018). The 2004 report of children in Great Britain showed that 10% of children suffered from mental health disorder, which did not increase from the previous survey in 1999 (Green, McGinnity, Meltzer, Ford, & Goodman, 2005). As in the previous surveys, in 2017 girls were more likely to have emotional disorders (10.0% vs 6.2%) and boys were more likely to have disorders characterised by behavioural problems (5.8% vs 3.4% and 2.6% vs 0.6%, respectively) (Sadler et al., 2018).

The report confirms that prevalence rates are increasing overall and has shown, that mental health disorder in girls increases substantially from 14.4% at 11-16 years to 23.9% at 17-19 years, whereas for boys rates decrease from 14.3% to 10.3% (Sadler et al., 2018). Given the increase in child mental health disorders, understanding how behaviours can help prevent or alleviate the symptoms of psychological distress is a priority for research and policy.

Measuring mental health in child populations is a challenge: in-depth clinical assessment at population level is neither feasible nor appropriate (Hunter, Higginson, & Garralda, 1996); and children's self-assessment may be hindered by language or cognitive development in young children, or influenced by what a child perceives as the 'correct' answer (G. Bryant, Heard, & Watson, 2015). Information from multiple informants (e.g. parent-, teacher-, and self-reported) better predicts mental health disorders in children, although how to integrate these, particularly when in disagreement, is a further challenge (Green et al., 2005) and acceptance of a diagnosis regardless of who has responded has been proposed (Bird, Gould, & Staghezza, 1992). In recent national surveys, the Strengths and Difficulties Questionnaire has been used as a proxy of mental (ill-)health of children (Green et al., 2005; Meltzer, Gatward, Goodman, & Ford, 2000; Vizard et al., 2018) due to its acceptability, reliability, and low respondent burden, which makes it appropriate for larger samples (Deighton et al., 2014; R. Goodman, 1997; Robert Goodman & Scott, 1999).

1.3 Physical activity and sedentary behaviour in children

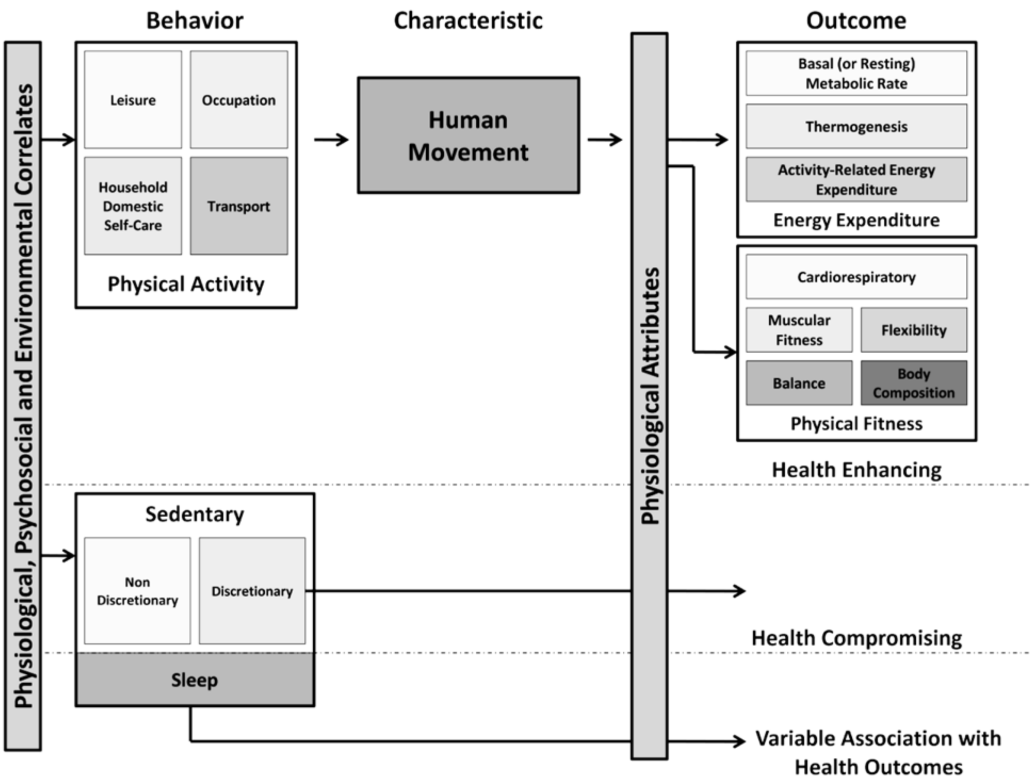
1.3.1 Defining physical activity and sedentary behaviour

According to guidelines published by the National Institute for Health and Care Excellence (NICE) (National Institute for Health and Care Excellence, 2009), physical activity is defined as any of the following:

- 'any force exerted by skeletal muscle that results in energy expenditure above resting level' (Caspersen, Powell, & Christenson, 1985).
- ‘Moderate-intensity activity increases breathing and heart rates to a level where the pulse can be felt and the person feels warmer.’
- ‘Vigorous activity results in being out of breath or sweating.’

Further to the NICE definition, Gabriel et al (Gabriel, Morrow, & Woolsey, 2012) have proposed a useful conceptual framework of physical activity as a complex and multidimensional behaviour, shown in the figure below.

Figure 1-1: Framework of physical activity as a multidimensional behaviour and outcomes (Gabriel et al., 2012)



Active and sedentary behaviours are considered, with active PA types categorised as leisure, occupation, household/domestic/self-care, and transport. Exercise is a subtype of leisure activity and is defined as ‘planned, structured, repetitive, and purposive in the sense that improvement or maintenance of one or more components of physical fitness is an objective.’ (Caspersen et al., 1985). Sport is another subtype of leisure PA which involves structure, competition, organisation, and strategy (Bélanger et al., 2015; Loy, 1968). PA is further defined by type, frequency, intensity and duration. Sedentary behaviours in Gabriel’s framework are either discretionary (e.g. reading, screen time not for school or work) or non-discretionary (e.g. sitting during school or work, sitting in a car). Sleep confers different physiological health effects than sedentary behaviour during waking hours and recent studies have considered its independent effects (Sarchiapone et al., 2014).

According to NICE guidance, sedentary behaviour is not simply the absence of physical activity but includes low energy expenditure activities such as reading, watching TV, sitting, lying down, and sleeping (Department of Health, Physical Activity, & Health Improvement and Protection, 2011; Townsend N et al., 2012). Individuals who meet recommendations for PA can still be at risk for chronic disease and poor health from too much sedentary behaviour, suggesting that these behaviours are independent and not functional opposites (S. J. Biddle et al., 2004; Hills, King, & Armstrong, 2007; Townsend N et al., 2012; M. Tremblay, Colley, Saunders, Healy, & Owen, 2010). A number of studies assessing the effects of sedentary screen time in particular found associations with health outcomes independent of PA (Goldfield et al., 2007; Mark Hamer, Stamatakis, & Mishra, 2009; A. S. Page, Cooper, Griew, & Jago, 2010).

A limitation of Gabriel's PA framework with respect to this thesis is that the model is not specific to children or young people and includes PA behaviours that are not relevant such as occupational and household/domestic PA. Whether PA is discretional or non-discretional for children should also be considered as this may be determined to some extent by their school or household circumstances, and impact whether this PA is 'health enhancing'. For example, a child might have compulsory physical education (PE) lessons in school and actively commute to school where there are no other options, and outcomes might vary according to these motivations.

There is the further assumption in Gabriel's model that all sedentary behaviours are 'health compromising'. Sedentary activities, such as reading and homework, could be beneficial and has been shown to improve cognition (D. Aggio, Smith, Fisher, & Hamer, 2016). Physiological responses to sedentary screen time may vary by medium: energy expenditure in sedentary video game play was found to be higher than TV viewing; and TV viewing, but not computer use, was found to be associated with higher blood pressure (Sweetser, Johnson, Ozdowska, & Wyeth, 2012). Finally, Gabriel's framework considers only physiological health outcomes of PA and sedentary behaviours, and the potential effects on mental health are absent.

1.3.2 Measuring physical activity and sedentary behaviour

One of the main challenges in understanding the relationship between PA and mental health in children is that there are a wide variety of measures available and these may affect the conclusions that can be drawn from the scientific investigation. The types of measures to assess PA and sedentary behaviour fall broadly into two categories: reported and objectively-measured. This section will briefly explore the main characteristics of these PA measures to better understand their strengths and limitations.

Self- or proxy-reported physical activity and sedentary behaviour

Subjectively reported PA and sedentary measures are some of the most frequently used due to their low staff and participant burden and cost. Types include but are not limited to self-administered recall (usually via questionnaire), interview-administered recall, diary, and proxy report. Studies have employed these methods to assess PA levels, and reviews have been conducted to demonstrate the reliability and validity of these measures (Stuart JH Biddle, Gorely, Pearson, & Bull, 2011; James F. Sallis, 1991); however, the most reliable and valid measures are not necessarily the most appropriate: detailed activity diaries, for example, are more likely to have poor adherence due to high subject burden (James F. Sallis, 1991). Compliance with complex or time-consuming procedures may be impossible to ensure in young children.

Depending on the constraints and objectives of the study, reported measures of PA and sedentary behaviour may be the most appropriate or the only means of attaining data, yet there is the danger of recall reporting and misclassification bias (Stuart JH Biddle et al., 2011). Light and moderate activities are more difficult to report than moderate-to-vigorous (MVPA) or vigorous activity. Perceptible changes, such as increased heart rate, sweating, and heavier breathing and the length of time an individual engages in higher intensity activities are easier to recall than less demanding activity. Light or moderate activities may also confer benefits, but few studies have assessed reported lower intensity activity due to the challenges in measurement and contextualisation (Janssen & Leblanc, 2010). Studies using reported sedentary measures have tended to focus on TV-viewing, and other forms of sedentary screen use, as a proxy for total sedentary time, but this is problematic as it may not be indicative of overall sedentary behaviour (S. J. Biddle, Gorely, & Marshall, 2009; Sugiyama, Healy, Dunstan, Salmon, & Owen, 2008). Notwithstanding the limitations of reported measures, understanding what activities children do—the type and context of activity—are essential to informing policy or designing effective interventions (Stuart JH Biddle et al., 2011). However, interpreting the impact of specific reported activities as proxies for overall PA and sedentary behaviour should be avoided.

Objectively measured physical activity and sedentary time

In recent years, objective PA and sedentary behaviour monitoring methods, such as pedometers, heart rate monitors and accelerometers, have become more easily accessible for large-scale population activity monitoring. Accelerometers avoid many of the inherent biases in subjective measures, and are reliable in measuring PA and sedentary time in children when compared with heart rate monitors, indirect and room calorimetry (measures oxygen consumption and carbon dioxide production), and doubly-labelled water (measures hydrogen and oxygen isotope elimination rates to calculate energy expenditure) (L. J. Griffiths et al., 2013).

A disadvantage is that some accelerometer models may erroneously interpret some types of movement as activity (e.g. sitting in car) (Treuth et al., 2004). Certain types of PA may be underestimated or not captured at all (e.g. cycling and swimming) (L. J. Griffiths et al., 2013). By employing calibration studies to determine how the accelerometer interprets a range of activities, and using an additional means of tracking activity such as a physical activity diary the effect of these biases can be mitigated (Evenson, Catellier, Gill, Ondrak, & McMurray, 2008; Pulsford et al., 2011).

With the increasing availability and affordability of objective PA measurement tools (e.g. pedometers and accelerometers), more studies may adopt these in place of reported measures to avoid some of the problems of bias inherent with reported PA and sedentary time. However, accelerometers cannot identify the types and quality of PA and sedentary activity undertaken and account for movement, duration, and intensity alone. Studies employing reported activity measures remain an important and informative body of literature, providing context to the type and quality of activity undertaken and allowing exploration of the pathways to mental health that perhaps cannot be accounted for through movement alone. The strengths and limitations of both objective and reported PA and sedentary measures must be borne in mind when considering the evidence.

1.3.3 Current recommendations and UK children's levels of PA and sedentary behaviour

The recommendations issued by the Chief Medical Officers (CMO) in the UK (2011) state that children should engage in moderate to vigorous physical activity (MVPA) for at least 60 minutes over the course of a day, with weight-bearing MVPA activities taking place at least twice a week (Department of Health et al., 2011).

In a study using Millennium Cohort Study PA data, only half of children aged 7 years met these guidelines, with 38% of girls meeting these levels of MVPA measured objectively using accelerometers (L. J. Griffiths et al., 2013). Significant variations were also seen by ethnic group and country. Children in Northern Ireland were the least active; Scottish children were the least sedentary. Girls were less active than boys in all ethnic minority groups, with overall activity levels lowest in Indian children who recorded the fewest steps and least minutes spent in MVPA, while Bangladeshi children had the lowest proportion meeting MVPA recommendations (33%).

Other studies with UK populations have reported similar results: a large proportion of children are not meeting the recommended amounts of PA. With lower intensity thresholds in counts-per-minute (CPM) for MVPA, larger proportions of children were meeting guidelines, but still under 60% of girls met recommended cut-offs (Owen et al; Steele et al). Boys performed better with 76-81.5% meeting >=60 minutes of MVPA per day. Where higher intensity thresholds were employed (2802-3600 CPM), the prevalence of sufficiently active children across studies ranged from 5.1% to 33% in boys and from 0.4% to 21% in girls (Chris J Riddoch et al., 2007).

Hesketh et al (2014) reported in a study of younger children (aged 4) that all children were meeting recommendations of 180 minutes of MVPA, although cut-offs for intensity were much lower at 400 CPM (K. R. Hesketh et al., 2014). Girls were less active, spending 18% less time in MVPA than boys, and activity levels also varied by time of day, and other factors such as maternal education levels and type of child care (K. R. Hesketh et al., 2014).

With objectively-measured PA, determining appropriate levels of PA is complicated and there is ongoing work in how these cut-offs should be constructed (Crouter, Horton, & Bassett, 2013). Furthermore, understanding how these counts of cut-offs translate into activities for children and how these can be embedded in policy recommendations is a challenge. The motivations for activity behaviours also merit consideration: a study investigating transportation choices for school commuting found that distance, traffic, and other safety concerns were barriers to children actively commuting to school by walking or cycling (Jenna R. Panter, Andrew P. Jones, Esther M. F. Van Sluijs, & Simon J. Griffin, 2010).

Currently, the UK does not have published guidelines for sedentary time in children. Health authorities in Canada and Australia have recommended less than two hours of screen time, and to limiting sitting for extended periods; however, similar guidance does not exist in the UK (Canadian Paediatric Society, 2017; Department of Health, 2017; Viner, Davie, & Firth, 2019). A report on the Health Behaviour in School-Aged Children in the UK found that 62% of children aged 11-15 reported screen time use of more than two hours per day, with 11% reporting more than 5 hours or more per day (Brooks et al., 2015). According to accelerometer data in the Avon Longitudinal Study of Parents and Children, the mean minutes spent in sedentary activity was 430 for boys and 442 for girls at age 12, increasing to 476 and 504 at age 14, and 513 and 529 at age 16 for boys and girls, respectively (J. A. Mitchell et al., 2012). These studies have shown that the majority UK children exceed the screen time guideline proposed by other national health agencies, and that sedentary time increases as children grow older. There are no established thresholds for absolute sedentary time, however, and further studies are required to interpret its significance in terms of health outcomes.

1.4 The relationship between physical activity, sedentary behaviour, and mental health outcomes in children

The benefits of PA on mental health in adults is well-established (S. Biddle, 2016; Conn, 2010; Mammen & Faulkner, 2013; Tenenbaum & Eklund, 2007), however, there are fewer studies that investigate this relationship in young children. A growing body of evidence shows that PA in children is associated with reductions in depression, anxiety, and low self-esteem, and increased cognitive functioning (Ahn & Fedewa, 2011; S. J. Biddle & Asare, 2011; S. J. Biddle et al., 2004). There are fewer studies that focus specifically on sedentary activities, but the emerging literature suggests that sedentary behaviours present increased risks of depressive symptoms, poorer cognitive function, and psychological distress (Asare, 2015; M. Hamer, Coombs, & Stamatakis, 2014; M. Hamer & Stamatakis, 2014; Zhai, Zhang, & Zhang, 2015). The evidence of the impact of sedentary behaviours on mental health is more equivocal, and its consideration as an independent risk factor for mental health outcomes is still developing. Physical activity is broadly considered to have a positive effect on mental health and well-being, although the direction and underlying mechanisms in this relationship are not fully understood. The possibility that the relationship operates in the other direction (i.e. that mental health has an impact on active and sedentary behaviours) has been studied less but some studies have found evidence to support this (A. S. Page et al., 2010; Stavrakakis, de Jonge, Ormel, & Oldehinkel, 2012; Wiles et al., 2008).

1.4.1 The effect of physical activity and sedentary behaviour on mental health outcomes

A body of cross-sectional evidence, using a range of PA measures, has shown that PA levels are associated with mental health. In a sample of UK children (mean age 8.5 years), Hamer et al (2009) reported that those who were in the lowest self-reported PA group had the highest odds of psychological distress compared with the other groups (Mark Hamer et al., 2009). Low levels of self-reported PA were associated with depression and diminished psychological wellbeing (Brodersen, Steptoe, Williamson, & Wardle, 2005; Kremer et al., 2014; Ussher, Owen, Cook, & Whincup, 2007). Using pedometers, Parfitt and Eston reported a strong negative correlation of total daily steps with depression and anxiety (Parfitt & Eston, 2005). Across a number of studies, greater accelerometer measured MVPA was significantly related to a range of mental health outcomes including improved social functioning and behavioural conduct, reduced anxiety, and fewer symptoms of psychological distress (Allison et al., 2005; Martikainen et al., 2012; A. S. Page et al., 2010; Parfitt, Pavey, & Rowlands, 2009).

The cross-sectional evidence on sedentary behaviour showed similar patterns in the opposite direction. A study by Brodersen et al (2005) found that the association between emotional symptoms and sedentary behaviour was more pronounced in 11-12 year old girls than boys; although, both genders reported a positive relationship between increased sedentary time and emotional and conduct problems, and hyperactivity (Brodersen et al., 2005). Frequently, studies used reported measures of screen time as proxy for sedentary behaviour. Ussher et al (2007), reported lower psychological wellbeing in both boys and girls with greater use of screen based technology (Ussher et al., 2007). In a study of Australian children aged 10-16 years, less leisure screen time use was associated with lower odds for depressive symptoms (Kremer et al., 2014). A study by Page et al, however, highlighted the problem with using screen time as proxy for sedentary time: self-reported screen-based activities were positively associated with SDQ scores, while objectively-measured sedentary time was found to be negatively associated with SDQ scores (A. S. Page et al., 2010).

While these studies present evidence for associations between PA, sedentary behaviour, and mental health, the cross-sectional study design does not allow casual inferences to be made. The possibility exists that children who have poorer mental health may have less motivation to be active or choose to engage in more sedentary behaviours. Stronger evidence on the direction of this relationship is available in a number of longitudinal and intervention studies.

Longitudinal cohort studies have largely shown that higher levels of PA have a beneficial effect on psychological outcomes (Jerstad, Boutelle, Ness, & Stice, 2010; Rothon et al., 2010; Sagatun, Søgaard, Bjertness, Selmer, & Heyerdahl, 2007; Stavrakakis et al., 2012; Wiles et al., 2008). In a study of children in the North West of England (n=1,446), Wiles et al found that children who met PA guidelines (>1 hour/day) had fewer emotional symptoms at follow-up (-0.10 points per additional 20 min/day) compared with those who did not meet recommendations, adjusting for a range of confounders including age, gender, socio-economic deprivation, weight, and height (Wiles et al., 2008). The study used the Strengths and Difficulties Questionnaire to assess psychological distress. The number of sporting participation sessions >20 minutes was used as a proxy for PA, however, and this may not capture important elements such as the intensity and duration of activity. Furthermore, the effect size was small (representing a 9% reduction in average symptoms compared to baseline) and it is unclear whether this important from a population perspective. There were no additional associations observed for the other SDQ subscales, but the relationship with emotional problems supports the hypothesis that PA may induce physiological responses preventative of depression (Wiles et al., 2008).

How the physiological responses might affect mental health, however, is less clear, as highlighted in a study by Stavrakakis et al. Data from three time points in a cohort of children aged 10-17 (n=2,230), were analysed to determine whether prior greater PA was related to lower depressive symptoms. PA was operationalised by combining questions on weekly frequency of exercise, weekly participation in PA, and summer- and winter-specific questions on weekly PA. Depression was measured using the mean scores of the Affective Problems scale of the Youth Self-Report (YSR) and Child Behavior Checklist (CBCL). Gender and SES were included in the models as confounders, and multiple imputation was conducted to account for attrition between the waves (Stavrakakis et al., 2012). Attempts to identify different effects on subgroups of depression were made by creating affective subscales (loss of pleasure, crying, self-harm, suicidal ideation, feelings of worthlessness, feelings of guilt) and somatic subscales (lack of appetite, overtiredness, reduced sleep, trouble sleeping, and lack of energy). Although prior PA was found to be significantly associated with affective disorders at both later time points, somatic symptoms were not. This result runs contrary to the hypothesis that PA produces the physiological responses producing better sleep and more energy, resulting in fewer depressive symptoms (Saunders et al., 2016; Stavrakakis et al., 2012).

Further evidence from cohort studies demonstrates that the evidence of the benefits of PA on mental health is not firmly established. A study of children (n=2,789) 11-14 years old in East London found no association between changes in PA levels and odds of depressive symptoms at follow-up (Rothon et al., 2010). The study used a reported ordinal measure of PA that assessed the number of hours per week of PA that resulted in breathlessness and sweating, and the validated Short Moods and Feelings Questionnaire (SMFQ) for mental health. While the measure attempted to capture multiple dimensions of PA (duration and intensity), the authors acknowledge that the reported measure may not have captured intensity accurately nor actual energy expenditure which may be important for achieving mental health benefits (Rothon et al., 2010).

Specific PA type may also be a dimension that affects the mechanisms through which it operates on mental health. A systematic review examining the psychological and social benefits of sports participation examined 30 publications (of which 9 were longitudinal) and found that increased sport participation was associated with lower social isolation, social anxiety, better social self-concept, and improved self-esteem (Eime, Young, Harvey, Charity,

& Payne, 2013); in another study team sport involvement in particular was found to have protective effects against depression for girls (Gore, Farrell, & Gordon, 2001).

The longitudinal evidence on sedentary behaviour and mental health is limited to the effects of screen time on mental health outcomes (Allen & Vella, 2015; Asare, 2015; Babic et al., 2017; Bélair, Kohen, Kingsbury, & Colman, 2018; Hinkley et al., 2014). The use of screen time measures as a proxy for overall sedentary time can be problematic as associations with mental health might be driven more by the content and context of the screen time activity rather than the sedentary behaviour itself (Koolhaas et al., 2019). Furthermore, the reported use of screen time may be subject to social desirability and recall bias. Nonetheless, the studies available broadly demonstrated that increased screen time was predictive of poorer mental health. One study that examined the relationship between screen time and psychosocial well-being in children in Australia found negative associations with SDQ emotional, peer, and conduct problems subscales (Allen & Vella, 2015). The screen time measure was a composite score based on the number of minutes spent watching television and playing electronic games. The effect of a combined screen time measure (TV/DVD and video games) on mental health was also found to be significantly associated with depression in a large study of 9,702 Canadian children (Bélair et al., 2018).

There is evidence, however, that the effect on mental health might depend on the type of screen-based activity and a composite measure might not observe these differences. For example, a study that reported separate estimates for total screen time and TV viewing found significant associations with increased daily TV use, but not for computer games (Primack, Swanier, Georgiopoulos, Land, & Fine, 2009). Similarly, TV/DVD viewing was associated with total psychological difficulties (SDQ) but other types of screen time (computer use, mobile/table) were not (Babic et al., 2017). The context and content of TV viewing has been suggested as a possible mechanism for the differences observed—TV viewing is a less interactive activity and this may contribute to feelings of loneliness or psychological and emotional stress via exposure to violent content (Babic et al., 2017; Gentile et al., 2011; Primack et al., 2009).

Differences in observed associations may also be the result of the mental health measures used. In a study on the effects of electronic media screen use (measured by the emotional and peer problems subscales of the SDQ and four subscales of the KINDL Questionnaire for Measuring Health-Related Quality of Life in Children and Adolescents), additional hours of e-game/computer use was associated with a two-fold increase in odds of emotional problems for girls (SDQ) and increased TV viewing a 1.2 and 1.3 increase in odds of family functioning for boys and girls, respectively (Hinkley et al., 2014). SDQ peer problems were not negatively impacted by screen time. Notably, associations were not observed for the KINDL subscale for emotional wellbeing, highlighting that the differences in mental health outcomes may depend not only on the domain of the subscale, but in the precise measure used.

While a number of cross-sectional studies have explored the relationship between PA, sedentary behaviour, and mental health using objective measures such as accelerometry, to my knowledge, no longitudinal studies have examined whether objectively measured PA or sedentary time might impact mental health.

Intervention studies have been conducted to determine whether a defined amount of PA improved mental health in children. In theory, a well-designed intervention would allow the researcher to conclude whether a particular PA intervention could be said to produce the change in mental health; however, the studies available provide varying conclusions depending on the type of PA prescribed and the mental health domain measured. In a systematic review conducted by Larun et al. (2006) on 16 studies with a total of 1,191 participants the authors assessed the effectiveness of exercise-based interventions in preventing or treating anxiety and depression in young people aged 0-20 years. Only one study in the general population found that a weight training exercise intervention resulted in improvements to anxiety. Of the five studies examining the intervention effects on depression (145 participants), there were significant effects overall for intervention; however, when broken down by participant characteristics (at-risk children vs not), and intervention type, only weight training as intervention was found to be significant (Larun, Nordheim, Ekeland, Hagen, & Heian, 2006). The remaining studies were conducted on children in treatment. The ages of the children in the studies ultimately selected for review was not described by the authors and so its applicability to this thesis is unknown so evidence in support of the benefits of PA on mental health is limited in this review.

Conversely, a comprehensive meta-analysis of intervention studies by Ahn and Fedewa analysed 73 randomised control trial (RCT) and non-RCT studies, totalling 246 effect sizes, and found small, significant effects on mental health in children aged 3.67-17.66 years. Differences in study design and outcome measures accounted for differences in results: in RCT studies, PA interventions were found to be effective in reducing depression, anxiety, psychological distress, and emotional disturbance. Characteristics of the PA programmes also impacted effects of interventions: RCT studies focused on circuit training showed the greatest improvements to mental health, followed by combined physical activity; in non-RCT studies, only sports participation interventions resulted in a reduction in children’s mental disturbance (Ahn & Fedewa, 2011). Highly intense PA in RCT studies and moderate PA in non-RCT studies were also significant in reducing mental health problems. The duration of the intervention was also important with the greatest number of hours (>33 hours) reducing mental health disturbance most in RCT studies, while for non-RCT studies, the shortest duration (<20 hours) showed the strongest effect (Ahn & Fedewa, 2011).

Overall, intervention study review authors report a small effect in support of exercise reducing mental health symptoms or improving self-esteem. Crucially, as there were no negative effects reported, in spite of limited evidence, the authors support PA interventions to improve mental health. Comparing intervention studies is challenging as the methods and samples differ between studies, and conclusions are not readily generalisable. These studies demonstrate the importance of reconsidering PA and mental health as multidimensional constructs, where the type, intensity, and setting can affect different aspects of psychological functioning. Intervention studies are important, however, as they provide some indication of the direction of causality and the PA measurements are often well-defined and controlled. Prescribed activity, however, is not the same as free-living activity so the conditions may not be replicable, and results may not be directly applicable to policy recommendations or population-level PA guidelines.

1.4.2 Evidence for a bidirectional association? The effect of mental health on physical activity and sedentary behaviour

The focus of this thesis is on the effect of PA and sedentary behaviour on mental health but the possibility of reverse causality or a bidirectional relationship must be considered, given the volume of cross-sectional evidence and the implications for future studies and policy. In the adult population, there is evidence to suggest that depression was associated with subsequent low levels of PA (Roshanaei-Moghaddam, Katon, & Russo, 2009). For much of the cross-sectional evidence reviewed in the previous section, there exists a tacit assumption that PA or sedentary behaviours are predictive of mental health, however, these conclusions cannot be reached without longitudinal evidence. In the cross-sectional studies reviewed in the previous section, it is equally possible that the association between activity and mental health were driven by the mental health symptoms. In studies that looked at internalising and externalising domains of mental health functioning separately, It was not uncommon for externalising mental health symptoms (such as hyperactivity, behavioural, and conduct problems) to be positively associated with PA and negatively associated with both reported and objectively-measured sedentary behaviour (A. S. Page et al., 2010; van Egmond-Frohlich, Weghuber, & de Zwaan, 2012; Wiles et al., 2008). The authors suggest potential reverse causality: hyperactive children may be more likely to fidget, exhibit restless behaviour or may be more naturally inclined to play games or sports, which might account for the positive association. Children who spend too little time in very light activity may be exhibiting symptoms of hyperactivity or the activity may simply be a proxy for other factors such as less regulation of their activity (e.g. bedtimes and naptimes) or greater access to screen entertainment (Parfitt et al., 2009).

Fewer studies are available that directly examine the effect of mental health status on PA or sedentary levels, as the relationship is not readily amenable to interventions or trials. The longitudinal studies investigating the effect of mental health on physical activity and sedentary behaviours are limited in number and the evidence that the relationship may operate in this direction is equivocal. In a cohort study of Australian children aged 7-9 (n=791) data were collected at three time periods (4- and 8-year follow-up periods). Depression was measured using the Children's Depression Inventory, which has demonstrated validity and reliability in assessing clinical and sub-clinical depression (Kovacs, 2015). Physical activity levels were measured using pedometers (first wave) and accelerometers (second and third wave), and cardio-respiratory fitness (CRF) measured by a 20-m multistage shuttle test (Tomkinson, Léger, Olds, & Cazorla, 2003). Depression was found to have a significantly negative effect on CRF at both follow-up points for girls but not boys; however, significant associations were not observed for depression and MVPA nor light PA (Olive, Telford, Byrne, Abhayaratna, & Telford, 2016). In their discussion, the authors focus on the cross-sectional evidence which showed a strong relationship between depression and both intensities of PA, but further exploration as to whether this is due to an inverse relationship (PA affecting depression) or because of potential limitations of the PA (quantify duration and intensity only) and depression measures would be helpful in justifying their conclusions that mental health affects PA.

In another study, associations of behavioural and emotional development measured by the SDQ (at ages 3 and 7), and sedentary time and MVPA were investigated by Griffiths et al using Millennium Cohort Study data. In this study, the authors found that higher total difficulties scores and externalising problems were associated with a reduction in median minutes of sedentary times (L. Griffiths et al., 2016). Although significant, the effect sizes were small: -1.1 minutes/unit total difficulties score for boys and -1.2 minutes/unit for girls between ages 3 and 5, and -1.2 minutes/unit for boys between ages 5 and 7; -2.5 minutes/unit emotional problems score in boys and -3.3 minutes/unit in girls. Mental health was not found to be predictive of MVPA minutes, which is concordant with the results in the study by Olive et al.

Support for bidirectional relationships have been observed in other longitudinal cohorts. Stavrakakis et al used cross-lagged structural equation models to investigate whether PA and depressive symptoms were reciprocally related, accounting for the stability of the autoregressive paths over three points in time (Stavrakakis et al., 2012). The results indicated a bidirectional relationship where, notably, depressive symptoms preceded a decrease in PA as reported by a 5-point scale (Stavrakakis et al., 2012). Symptoms included depressed mood, loss of pleasure, and low self-worth. Use of multiple follow-up points and control for previous mental health and PA levels add support to the evidence of a bidirectional relationship; however, the use of reported PA based on a single question may not be reliable. Further investigation using validated questionnaires or objective measures of PA would strengthen the case for bidirectionality. Similar results supported bidirectional associations between depression and exercise in a longitudinal study of girls followed over a 6-year period, where major and minor depression resulted in diminished likelihood of PA participation (35% and 18%, respectively) (Jerstad et al., 2010). The study only examined girls, however, so these conclusions cannot be extended to boys. These studies broadly support the hypothesis that depressive symptoms may lead to diminished enjoyment, sense of self-efficacy, and social connectedness, resulting in less engagement in PA (Jerstad et al., 2010; Stavrakakis et al., 2012).

1.4.3 Summary

There is a growing body of literature that explores the relationship between PA, sedentary time, and mental health in children. The majority of the evidence available, however, is cross-sectional and not helpful in determining the direction of this association; although, most cross-sectional studies did observe significant relationships for both PA/sedentary behaviour and mental health. There were some longitudinal and intervention studies that found evidence of causation in both directions; however, the number of studies were limited and inconsistency across studies in measures, sample size, ages, and follow-up times meant that more general conclusions about the relationship from the evidence base as a whole could not be reached.

In the longitudinal evidence available examining the effects of PA/sedentary behaviour on mental health, only reported measures of activity were used. There are advantages to the use of reported measures (see section 1.3.2), as they demonstrate that specific types of activity can impact mental health differently and may highlight potential pathways. The benefits of reported measures notwithstanding, the absence of objective measures of PA and sedentary is a limitation of the evidence, as there are elements of PA/sedentary behaviour that are better captured by objective measure that may be important to our understanding of their impact on mental health. For example, more intense activity could yield mental health advantages not observed at lower intensities—intensity is difficult to capture by questionnaire due to the sporadic nature of children's activities, as well as the possibility of bias in reporting. Moreover, it would be useful to understand how overall objective sedentary time and PA affect mental health—for example, high amounts of overall sedentary time might result in the displacement of active/healthier behaviour, and its association with poor mental health would highlight the potential harm of sedentary behaviour irrespective of type.

The use of objective PA and sedentary time measures might help to avoid bias due to recall and social desirability but does not preclude inaccuracy or misclassification of activity. For example, in accelerometry, the epoch length, or the interval of time between PA measurement count recordings, is set by the investigators and determines the quantity of data available – shorter epochs mean that the data will provide a more comprehensive picture of the PA. In a number of the cross-sectional accelerometer studies, long epochs of 1 minute were reported (Goldfield et al., 2007; Martikainen et al., 2012; Parfitt et al., 2009). Longer epochs are usually selected where battery life is an issue; however, the short bursts of PA characteristic of younger children might be underestimated in these studies, and shorter epochs are recommended (Edwardson & Gorely, 2010).

The systematic reviews and meta-analyses confirm the difficulty in consolidating conclusions from the studies because of major differences in PA measures; attempts to aggregate results have shown extensive heterogeneity in the studies. For example, the meta-analysis by Larun et al observed only a borderline positive relationship between PA and decreased anxiety, but after disaggregating the results based on significant study differences, children who underwent weight training, and children at risk were shown to have significant reductions in anxiety (Larun et al., 2006).

There were a range of measures used to measure mental health outcomes in the literature (SDQ, CBCL, YSR, SMFQ, and KINDL), which is indicative of the different aspects of mental health functioning as well as differences in study methodology. However, these differences mean that results cannot be directly compared: in studies where multiple mental health measures were used, results were not consistent in the same study sample between measures purporting to measure similar health domains (i.e. emotional problems in the SDQ vs. KINDL (Hinkley et al., 2014)).

How the study operationalised the mental health measure may have also affected results. For example, where SDQ total difficulties scores were reported, a number of studies reported no associations (Clark et al., 2007; A. S. Page et al., 2010), whereas others reported changes when SDQ was divided into the internalising/externalising domains or into individual subscales (Brodersen et al., 2005; L. Griffiths et al., 2016; Hinkley et al., 2014; Sagatun et al., 2007; van Egmond-Frohlich et al., 2012; Wiles et al., 2008).

Because of the diversity of measures and methods, the studies reviewed here do not amount to a concordant and cohesive body of evidence, and definitive conclusions about the significance and the direction of this relationship cannot be drawn. Due to this heterogeneity, the utility and accuracy of conducting meta-analyses of the literature have been questioned even by authors themselves (S. J. Biddle & Asare, 2011; Janssen & Leblanc, 2010; Larun et al., 2006). Nonetheless, the literature has highlighted the following key points, which will be considered going forward:

1. PA, sedentary behaviour, and mental health are conceptually complex and diverse behaviours and how they are measured is important and likely to impact outcomes;
2. The relationship between PA/sedentary behaviour and mental health may be bidirectional;
3. Different PA and sedentary behaviours are likely to be related to different aspects or domains of mental health functioning;
4. Characteristics of the child (i.e. gender and age) are important to consider in the relationship between PA/sedentary behaviour and mental health outcomes

In considering the above, I will attempt to address the following gaps in the literature:

1. The absence of longitudinal studies using objective PA and sedentary measures to assess their relationship to mental health;
2. The relative lack of evidence supporting a bidirectional association between PA/sedentary behaviour and mental health;
3. The consideration and/or capture of the multiple dimensions of physical activity and sedentary behaviour;

In order to further clarify the nature of the association between PA, sedentary behaviour, and mental health, an understanding of the measurable factors that might have an impact on this relationship is essential. The next section will provide an overview of the correlates of PA/sedentary behaviour and mental health, and will investigate their relationship to both independent and dependent variables.

1.5 Correlates of physical activity, sedentary behaviour, and mental health

There is an extensive body of literature that identifies correlates of PA or mental health in children, and this section will explore these factors. While the aim of this thesis and the studies in the previous section was to assess the independent relationship of sedentary behaviour and PA on mental health in children, failure to consider these factors may result in erroneous or unrepresentative results, and the availability or absence of important correlates in studies must be borne in mind when interpreting the conclusions (Gabriel et al., 2012).

In their systematic review on the correlates of PA, Sallis and colleagues examined 108 studies published before 1999 on children ages 3-18 to identify variables associated with PA, which were grouped into the following categories: demographic/biological; psychological/cognitive/emotional; behavioural attributes/skills; social/cultural (J. F. Sallis, Prochaska, & Taylor, 2000). In a follow-up, Van Der Horst and colleagues examined 60 studies published between 1999 and 2005 to identify the biological, demographic, behavioural, social, physical, and psychological correlates of physical activity and sedentary behaviour (Van Der Horst, Paw, Twisk, & Van Mechelen, 2007). A study conducted by Patalay and Fitzsimons identified a range of correlates of mental illness and wellbeing in children in the MCS and identified categories of individual, family, and social, and wider environment into which factors were grouped (Praveetha Patalay & Emla Fitzsimons, 2016). Within these studies, I identified several significant correlates common to PA, sedentary behaviour, and mental health: gender, ethnicity, self-esteem, socioeconomic status of parents, parental education, single parenthood, and urban/rural designation. Additional evidence will be presented below on the potential importance of age, body composition, disability, cognition, parental mental health, area deprivation, and green space. Based on the categories defined in the studies above, I have grouped these variables into the following categories of characteristics: biological and demographic, psychological and cognitive, household structure and demographic, and environmental and wider context. In the following section, I will summarise the literature on each of the potential correlates of PA, sedentary behaviour, and, where available, I will examine their role in the association between PA and mental health.

1.5.1 Biological and demographic children's characteristics

Gender

The literature overwhelmingly reports that boys are more active than girls, and girls engage in more sedentary behaviours (K. R. Hesketh et al., 2014; Praveetha Patalay & Emla Fitzsimons, 2016; J. F. Sallis et al., 2000). A study by Hesketh et al showed that at four years of age, boys engaged in up to 18% more MVPA than girls, suggesting that gender differences begin early in the life course (K. R. Hesketh et al., 2014). These gender differences continue through later childhood and adolescence, and persist throughout adulthood (Andersen, Crespo, Bartlett, Cheskin, & Pratt, 1998; C. B. Bradley, McMurray, Harrell, & Deng, 2000; A. S. Page et al., 2010). Not only are girls less active, but the decline in PA observed as children grow older is more pronounced in girls (S. J. Biddle et al., 2004).

The cause for these gender differences in PA in children is complex and likely influenced by cultural norms, but it has been suggested that participation in sports and games is a factor. Boys are more likely to be faced with social pressure to participate in organised sports or active games both in and outside of school (Ferron, Narring, Cauderay, & Michaud, 1999). In young girls, this absence of expectation to participate in PA can be detrimental—qualitative work has shown that girls feel less supported in PA pursuits, resulting in their feeling less benefit from PA participation than girls (Cardon et al., 2005). Gender differences in body acceptance may also be a contributing factor – even pre-pubertal girls feel judged by their appearance and may not engage in PA if they perceive themselves as unattractive (Lagerberg, 2005).

Measurement and type of PA or sedentary behaviour may also be an issue when considering gender differences. A study of children aged 10-11 years found no differences in the activity levels of boys and girls, but only step counts were used, thus the type and intensity of activity were not considered (Parfitt & Eston, 2005). Accelerometry in children has indicated that boys engage in more MVPA than girls and are less sedentary behaviour (L. J. Griffiths et al., 2013). However, activities not registered by accelerometers (for example, swimming and cycling) or activities that might be physically demanding but not meet the cut-offs for MVPA might be patterned by gender, which might lead to inaccurate conclusions. Conversely, other studies found that boys spent more hours using electronic media and had greater reported total sedentary hours. Boys may be more ‘active’ while engaged in behaviours such as electronic gaming, which might account for the differences between objective and reported measures. Seasonal factors may affect PA in boys and girls differently – Brodersen et al. found that rain was a deterrent for PA in girls while boys were more sedentary in cold weather (Brodersen et al., 2005).

As with PA, gender differences in mental health are also observable early in childhood—young boys have greater mental health problems, particularly in externalising symptoms (i.e. conduct problems and hyperactivity)(Green et al., 2005). By adolescence, however, girls have more emotional problems, anxiety, and depressive disorders than boys (Green et al., 2005).

One of the issues in disentangling the gender differences is that mental health is measured differently from study to study, and differences might be dependent on the specific domain or subscale examined: Sagatun and colleagues reported that girls have worse total difficulties, emotional, and hyperactivity SDQ scores than boys at age 15-16 with boys showing more conduct and peer problems than girls (Sagatun et al., 2007). Peer problems in girls only were reported for increased TV viewing and PC usage (Hinkley et al., 2014) and emotional problems were more pronounced for girls with increased sedentary time (Brodersen et al., 2005). The differences that can be drawn out when using particular domains or subscales may be important in considering the pathways through which gender affects mental health, and how these may further be influenced by PA or sedentary behaviour.

The role of gender on the relationship between PA and mental health is complex and results differ depending on how both PA and mental health are measured, and the study design. In meta-analysis of randomised controlled trial (RCT) and non-RCT intervention studies, gender was found to be a moderator but the findings were not consistent: in RCTs, male-only and mixed-gender samples improved most in mental health outcomes, while in non-RCT, females showed the most improvement (Ahn & Fedewa, 2011; Wiles et al., 2008).

Gender differences observed in the effects of PA on mental health also varied by mental health measure. One study reported a positive association between sedentary behaviour and peer and emotional problems in girls only (Hinkley et al., 2014); while another study found that PA was associated with lower total difficulties scores in both genders but sedentary behaviour was associated with higher scores in boys only (Ussher et al., 2007).

It is possible that parents and children may hold standards of what it means to be 'active' that are different for boys and girls, and that this may result in biased reporting or potentially influence how PA affects mental health. For example, boys who played sports outside of school and were perceived as physically active by their parents had fewer depressive symptoms than those who were less active or perceived as inactive, but this relationship was not observed in girls (Tomson, Pangrazi, Friedman, & Hutchison, 2003). This indicates the mechanisms through which PA operates on mental health may differ by gender. Physiological mechanisms may be at work in boys who, if more likely to engage in MVPA than girls, may benefit from increased endorphin secretion (Ahn & Fedewa, 2011; Paluska & Schwenk, 2000). Improvements to peer relationships in boys via social interaction in team sports and increased self-esteem and confidence in girls are potential gender-specific psychosocial pathways (Lagerburg, 2005).

In summary, the evidence has demonstrated that there are strong gender differences in PA and mental health, but that theoretical and methodological factors influence the effects observed. Treating gender conceptually as a moderator by analysing boys and girls separately could help clarify these differences. Further studies exploring gender patterns using multiple

PA measures to account for a range of PA types and intensities, and mental health measures that explore multiple aspects of mental health functioning, would enrich our understanding of gender differences.

Age

Age is another important factor to consider in the relationship between PA and mental health as activity levels and prevalence of mental disorders change throughout childhood. As children grow older, changes in schooling, social behaviours, and physiological changes with childhood development and puberty may have an effect on both PA levels and mental health outcomes.

Evidence shows that as children grow older they become more sedentary, and that there is a steep decline in PA across adolescence in Western countries (S. J. Biddle et al., 2004) which is more pronounced in girls (Brodersen et al., 2005; Kremer et al., 2014). Establishing physically active behaviours and habits in early childhood may increase the likelihood of higher PA levels in adolescence and adulthood (Smith et al., 2015; Telama, 2009). Encouraging young girls in particular, who have not yet outgrown an interest in games, running, and climbing, to maintain PA levels might prevent activity decline (Lagerberg, 2005).

The prevalence of mental health disorder also increases in older children: emotional, anxiety, conduct, and hyperkinetic disorders all increase in prevalence from 5-10 year olds to 11-16 year olds (Green et al., 2005). Although, it might be easier to identify clinical mental health disorder in older children so the extent of mental health problems in younger children may be under-represented (Hinkley et al., 2014).

Given these changes in PA and mental health through childhood, accounting for age in analyses is important, but also exploring whether the timing of the PA or sedentary exposure affects the outcome can highlight potential sensitive periods. For example, PA and sedentary behaviour in early childhood is associated with factors such as improved motor functioning, sleep, and self-esteem (Linda S. Pagani, Fitzpatrick, & Barnett, 2013; M. S. Tremblay et al., 2016) and these may have greater impact than if the exposure occurred at a later time (Mistry, Minkovitz, Strobino, & Borzekowski, 2007; L. S. Pagani, Fitzpatrick, Barnett, & Dubow, 2010).

If children are becoming increasingly inactive while independently having more mental health issues as they grow older, increasing PA could potentially alleviate some of the burden of mental illness. However, if the effect of PA varies at different periods in childhood, understanding any patterns or persistence of effects will be essential to targeting interventions and informing policy.

Ethnicity

The evidence on whether ethnic minorities have worse mental health outcomes is mixed. In studies of children living in the UK, higher levels of mental health issues have been noted in particular ethnic minority populations (Dearden & Sibieta, 2010; Praveetha Patalay & Emla Fitzsimons, 2016), while others have suggested that certain ethnic minority groups have a mental health advantage over their white counterparts (A. Goodman, Patel, & Leon, 2010; Maynard & Harding, 2010).

Overwhelming, the evidence reports that ethnic minority children are less active and more sedentary than White children (Andersen et al., 1998; C. B. Bradley et al., 2000; J. F. Sallis et al., 2000). A study of children in South London found that ethnic minority girls were less active and both genders of ethnic minority groups were more sedentary (Brodersen et al., 2005). In the UK Millennium Cohort Study, Indian children took the fewest steps, recorded the least MVPA and were among the most sedentary; the lowest proportion of children meeting MVPA recommendations was in the Bangladeshi group (L. J. Griffiths et al., 2013). Owen et al reported lower PA levels in South Asian children than European white and black African-Caribbean children in London (Owen et al., 2009), and children of migrant parents in Germany were found to have higher hours of television and screen time (van Egmond-Frohlich et al., 2012).

No studies to my knowledge have explored the role of ethnicity in the relationship between PA and mental health in children, however, given the evidence of lower PA and higher sedentary behaviour in ethnic minority groups and the mixed effects of ethnicity on mental health outcomes, ethnicity may play a confounding role.

Body composition

Children who are overweight and obese spend more time in sedentary behaviours and there is evidence to suggest that they engage in less PA (J. F. Sallis et al., 2000; Van Der Horst et al., 2007). They also have greater prevalence of mental health disorders and suffer from lower self-esteem and poor self-image (Allender, Cowburn, & Foster, 2006; Goldfield et al., 2007). There is evidence to suggest that some of the effects of body composition on mental health could be moderated by gender, where boys not meeting standards for BMI had higher rates of depression than their female counterparts, although normal weight girls were more likely to be depressed than normal weight boys (Tomson et al., 2003)

In the relationship between PA and mental health, the effect of body composition is mixed. Ahn et al (2011) found that the effects of PA on mental health were equal in a meta-analysis of RCT and non-RCT studies in both overweight/obese groups and normal weight children

(Ahn & Fedewa, 2011). In Parfitt et al (2005) after adjusting for body fatness, the association between light PA and mental health was non-significant; however, in the very light and vigorous activity groups the relationship remained significant (Parfitt & Eston, 2005). Thus, body fat might be an important factor in the association between PA and mental health depending on the intensity of activity undertaken.

Surprisingly, some of the evidence seems to indicate that overweight and obese children do not differ significantly in PA from their normal weight counterparts. Hesketh et al (2014) observed that overweight and normal weight children had non-significant differences in PA but this was in children aged 4 (K. R. Hesketh et al., 2014) and, as mentioned in the previous section, age can be an important factor – with activity levels naturally decreasing with ageing, the decline could be steeper in those children who may feel increasingly self-conscious or incapable due to overweight or obesity. Other authors have suggested that body weight may be less important than body image and self-perception in PA levels, which might account for differences appearing later in childhood (Allender et al., 2006).

A study conducted by Goldfield et al (2007) focused on the specific experience of overweight and obese children in assessing the impact of PA on mental health outcomes. Increases in PA were associated with improved perceived physical condition, body satisfaction and overall self-worth, which were not due to changes in body composition (Goldfield et al., 2007). Given the high rates of overweight and obesity in children in the UK—in 2017, 30% of children aged 2-15 in England were overweight or obese (Conolly & Davies, 2018)—these are important observations as improvement in body perception may help improve mental health. Overall, the evidence as to whether body composition plays a role in the PA/mental health relationship is equivocal; nonetheless, body fat and body mass index measures were included in a number of studies reviewed, indicating its importance for consideration in this field of research (Crews, Lochbaum, & Landers, 2004; Hinkley et al., 2014; Martikainen et al., 2012).

Disability

In the UK, 7.3% of children have some type of disability, which is defined as ‘a physical or mental impairment which has a substantial long-term adverse effect on his ability to carry out normal day-to-day activities’ (Her Majesty’s Stationery Office, 2010), including controlled chronic disease. Disability can be progressive or stable but they impair physical or mental functioning and can affect development in childhood (Mattsson, 1972). Additionally, three-quarters of children with a disability have special educational needs (SEN); twice the number of young people with SEN are not in education, training, or employment by 18 years of age, and have 20 times the risk of being excluded from school than children without SEN (BMA, 2013).

Examples of long-standing limiting illness (LSLI) affecting children include a wider range of conditions such as asthma, multiple sclerosis, and diabetes; mobility and structural impairments; and learning disabilities (BMA, 2013). Children with disability are more likely to be sedentary and have lower levels of fitness, which could lead to health complications in adulthood (Murphy & Carbone, 2008; Rimmer & Rowland, 2008). Bullying, lack of parental and instructor support, poor motivation, and lack of confidence were reported by disabled children as examples of barriers to PA (Bloemen et al., 2015).

A report found that 36% of children in Britain with learning disabilities had a mental health disorder, and were six times more likely to have a diagnosable psychiatric disorder than children without learning disabilities (Emerson & Hatton, 2007). Over half of children with physical disabilities were reported to have a mental disorder in a study of Canadian children (Butler et al., 2018). The alarmingly high rates of mental health problems in both physically and learning-disabled children, as well as the physical, psychological, and environmental barriers to PA that they might face, highlights the importance of including disability in studies examining the associations between PA and mental health.

1.5.2 Psychological and cognitive characteristics

Cognitive ability

The evidence for an association between cognitive development and mental health in childhood is extensive, suggesting that low cognition is predictive of poor mental health in adolescence and adulthood (Batty, Mortensen, & Osler, 2005; Colcombe & Kramer, 2003; Feinstein & Bynner, 2004; Hatch et al., 2007; Hinshaw, 1992; Praveetha Patalay & Emla Fitzsimons, 2016).

Physical activity is believed to influence children's neurological development via neurotrophin production, regulating the survival, growth, and differentiation of neurons as their brains develop (Vaynman & Gomez-Pinilla, 2006). These correspond to cognitive improvements in processing speed, response control, and working memory (Diamond, 2002; Tomporowski, Lambourne, & Okumura, 2011). An extensive review of the evidence on PA and cognitive ability was conducted by Tomporowski et al and found evidence that physically fit children display greater cognitive performance than less fit children, and that exercise improved performance in matching-to-sample tasks, perceptual-motor skill tests, and visual-motor coordination tests (Tomporowski, Davis, Miller, & Naglieri, 2008; Tomporowski et al., 2011). There is also evidence to suggest that children with cognitive disorders or delay participate in fewer sports and engage in less physical activity than typically developing children (Marquis & Baker, 2015; Neville, Guo, Boreham, & Lakes, 2021).

Studies have indicated that increased TV viewing in young children was associated with cognitive delay in young children (Chonchaiya & Pruksananonda, 2008; Lin, Cherng, Chen, Chen, & Yang, 2015). However, in a study using objectively measured sedentary time, the results showed that increased sedentary minutes at age 7 was associated with better cognitive performance at age 11 (D. Aggio et al., 2016). The authors suggest that this is likely driven by sedentary behaviours such as doing homework and reading; although it has been suggested that some forms of sedentary screen time, such as action video games can improve visual and attentional skills. (Boot, Kramer, Simons, Fabiani, & Gratton, 2008). Additionally, children with lower cognitive ability may engage in more passive activities such as television viewing because they are less challenging (D. Aggio et al., 2016).

Self-esteem

Self-esteem is broadly defined as a favourable or unfavourable attitude toward the self, informing an individual's sense of their worth, and the extent to which they value themselves (Blascovich & Tomaka, 1991; Rosenberg, 1965). Several studies have found that PA is significantly associated with self-esteem in children (Bowker, 2006; DeBate, Pettee Gabriel, Zwald, Huberty, & Zhang, 2009; Parfitt & Eston, 2005). The pathway through which PA operates on self-esteem may be different for boys and girls: a study by Bowker et al found that sports participation improved self-esteem for girls via physical appearance and physical competence; whereas for boys the path for physical appearance was non-significant and a direct path from sports participation to self-esteem was significant (Bowker, 2006). Two studies have additionally reported PA increases with self-esteem, demonstrating that this relationship is not necessarily unidirectional (K. K. Davison, Werder, Trost, Baker, & Birch, 2007; Neumark-Sztainer, Story, Hannan, Tharp, & Rex, 2003).

The evidence supporting an association between sedentary behaviour and self-esteem is less consistent. For example, there was no association between reported weekday or weekend television viewing or PC use (Hinkley et al., 2014), and objectively-measured bout durations of sedentary time nor frequency of the bouts were found to be associated with self-esteem (Faulkner, Carson, & Stone, 2014).

Self-esteem and mental health are strongly correlated in a number of cross-sectional studies, but there is some debate as to which direction this relationship operates. The 'vulnerability model' suggests that low self-esteem is a risk factor for mental health problems, through social avoidance, excessive reassurance seeking, or anti-social behaviour (Orth, Robins, &

Roberts, 2008). In contrast, the 'scar model' suggests that the low self-esteem is a consequence of the mental health disorder, where the disorder changes the way the individual processes information about their self-perception, or in damaging social networks and support (Orth et al., 2008).

Orth el al conducted cross-lagged regression analyses on two datasets and found that low self-esteem significantly predicted depression at three follow-up points in time; conversely, depression did not predict self-esteem (Orth et al., 2008). Although, the study participants were older (18 years at first contact and 21 years at final contact), these findings were confirmed in a study where self-esteem was measured at ages 11, 13, and 15 and was found to be associated with depression in both adolescence and later adulthood (Trzesniewski et al., 2006). Domain-specific associations were found where self-esteem at age 11 was prospectively related to externalising problems at age 13 (Donnellan, Trzesniewski, Robins, Moffitt, & Caspi, 2005).

Fewer studies support the scar hypothesis, although intervention studies on children with ADHD or externalising problems have indicated that hyperactivity is predictive of poor self-esteem at follow-up (Harpin, Mazzone, Raynaud, Kahle, & Hodgkins, 2016; Mazzone et al., 2013; Wehmeier, Schacht, & Barkley, 2010).

1.5.3 Household demographic and family characteristics

Especially with younger children, exploring the impact of household and family characteristics is essential: unlike adults or adolescents, children are not fully autonomous, and are subject to their caregivers' rules and schedules, and the constraints on their resources. This section will consider the importance of socioeconomic status (SES), family composition, and maternal depression in the relationship between PA and mental health.

Socioeconomic status (SES)

SES and mental health

There is strong documented evidence that household SES (defined as a quantification of education, income, employment status or occupational class, or any combination of these measures) is an important determinant of children's mental health and well-being (R. H. Bradley & Corwyn, 2002; Green et al., 2005; Kalff et al., 2001; Kiernan & Mensah, 2009).

Income is most consistently found to be associated with mental health, with more deprived individuals having worse mental health outcomes. Using MCS data, Kiernan et al found that any experience of poverty led to increased odds in behavioural problems in children. Children in persistently poor families were also more likely to have behavioural problems (SDQ) than those who had not experienced poverty (Kiernan & Mensah, 2009). Higher odds of mental health problems were observed at higher levels of poverty in children aged 7 (A. Pearce, Lewis, & Law, 2013). Other studies have reported that socioeconomically disadvantaged children have worse cognitive development, emotional health, and lower quality of life (McLoyd, 1998; Najman et al., 2004; von Rueden et al., 2006).

In spite of the consistent relationship with income and mental health, it is complicated to disentangle, as poverty is linked to many different factors including housing, access to health care, adequate nutrition, and access to materials and experiences that might benefit a child's development (R. H. Bradley & Corwyn, 2002). This is important when considering the mechanisms through which the elements of SES might operate on mental health, and how these might differ within certain conditions and contexts.

Parental levels of education are an important part of SES as it might capture traits that are beneficial to a child's mental health that might otherwise be missed by other SES measures. For example, immigrant families may have high levels of educational attainment from their country of origin, but lower income and occupational status in their country of residence – their characteristics and the mental health of their children may be similar to children of the non-immigrant higher income groups (A. Goodman et al., 2010).

This relationship between educational attainment and mental health may vary across different groups: a study on children aged 8-18 found that either parent's highest educational status, measured by the International Standard Classification of Education (ISCED), was positively associated with mental health but was more important in childhood rather than adolescence - income poverty was found to have a greater effect in adolescence on psychological well-being (von Rueden et al., 2006). McMunn et al found a strong gradient of higher maternal educational attainment and better SDQ scores in children aged 4-15, but this pattern was not observed for father's education (A. M. McMunn, Nazroo, Marmot, Boreham, & Goodman, 2001).

Similar patterns have been observed for occupational and employment status, where children of parents from lower occupational and workless backgrounds have a higher risk of behavioural problems (Kalff et al., 2001; Mensah & Kiernan, 2010) but variations on this theme have emerged. McMunn et al found that children in dual-earner households had better mental health outcomes, but identified some gender patterns as well: girls in male-only breadwinner families were more likely to have poor mental health than those where their mother was working, and boys in female-only breadwinner households equally had mental health problems (A. McMunn, Kelly, Cable, & Bartley, 2012).

SES, physical activity and sedentary behaviour

Children in high SES families may have higher levels of PA via greater access to sports and clubs, and the parents may be more aware of the importance of PA (S. J. Biddle et al., 2004); however, the evidence is inconsistent (James F. Sallis, 1991). For example, while one study found that boys who were from the lowest SES group spent the longest time engaging in screen-based, sedentary activities (Mark Hamer et al., 2009), another study found that children whose mothers were employed in lower level occupations spent more time engaging in moderate to vigorous PA (L. J. Griffiths et al., 2013).

Other studies have similarly reported that children from lower SES backgrounds are more active when using objective measures of PA (Chris J Riddoch et al., 2007; Ruiz et al., 2011), but whether this socioeconomic patterning of PA results in any corresponding mental health benefits requires further investigation. For example, Hesketh et al noted that children from lower SES backgrounds had higher levels of PA in the evenings but that this could be due to more regulated bedtimes in higher SES children (K. R. Hesketh et al., 2014). Higher levels of PA observed may be non-discretionary – children of lower SES families were found to engage in active commuting more than their wealthier counterparts, possibly as a result of decreased access to motorised transportation (Panter, Corder, Griffin, Jones, & van Sluijs, 2013).

Whether maternal SES characteristics are associated with active or sedentary behaviours is also inconsistent in the available evidence. One hypothesis suggests that children of employed mothers engage in more screen time at home due to less supervision, and they may be prevented from outdoor activities for safety reasons (Brown, Broom, Nicholson, & Bittman, 2010; Hawkins, Cole, & Law, 2009). In a study of children aged 5, children whose mothers were employed part- or full-time were more likely to be driven to school (compared to walking/cycling), potentially reflecting the increased demands on time or safety concerns (Hawkins et al., 2009). Conversely, another Australian study reported that children whose mothers worked full-time watched the least television compared to those whose mothers worked part-time or were not employed (K. Hesketh, Crawford, & Salmon, 2006). Maternal education levels are thought to impact children's PA levels via higher likelihood of health-related knowledge acquisition and of promoting healthy behaviours (Lauren B. Sherar et al., 2016; L. B. Sherar, Muhajarine, Esliger, & Baxter-Jones, 2009). Study results are mixed however, with some reporting that maternal higher education was associated with a higher number of sedentary minutes and fewer minutes of MVPA (Lauren B. Sherar et al., 2016), and others reporting less television viewing, greater MVPA, and more vigorous PA at weekends (K. Hesketh et al., 2006; L. B. Sherar et al., 2009).

Family composition

Family composition and mental health

Much of the effect of family composition on mental health is mediated by socioeconomic circumstances. Single-parent households in particular are more likely to have lower incomes, which contribute to observed mental health disadvantages and behavioural issues (R. H. Bradley & Corwyn, 2002; Kiernan & Mensah, 2009; Lipman, Boyle, Dooley, & Offord, 2002; Spencer, 2005). Families with multiple children may additionally strain household resources (Blake, 1981; Downey, 2001). Nonetheless, there is evidence that family composition can have an independent effect on children's mental health, which suggests that familial stability, parenting styles, and parental and sibling availability and support all have an important role in children's well-being that cannot be addressed through socioeconomic circumstances alone. Pearce et al found that higher SDQ scores in children living in reconstituted families could not be accounted for by adjusting for poverty, unlike children in lone parent households (A. Pearce et al., 2013). Incremental increases in risk were observed in the greater number of sweeps spent in lone parent or reconstituted households, when compared with natural couple families (Anna Pearce, Hope, Lewis, & Law, 2014).

Children with siblings may be at a mental health disadvantage via the effects of 'resource dilution', whereby children are in competition for their parents' time and energy, in addition to financial resources (Blake, 1981; Downey, 2001). In the absence of strong maternal and paternal bonds, children are at higher risk of emotional and behavioural problems (Jenkins & Smith, 1990); however, parents are not the only source of family support and the role of siblings is often overlooked. Positive sibling relationships have been shown to be associated with social competence, peer acceptance, and adjustment, providing mental health benefits into old age (Feinberg, Solmeyer, & McHale, 2012; Waldinger, Vaillant, & Orav, 2007). Furthermore, sibling relationships can also serve as buffer for negative experiences within the family, such as marital problems and breakdown, and low peer and parent support (Feinberg et al., 2012; Gass, Jenkins, & Dunn, 2007). Sibling conflict, however, can have the opposite effect and has been linked to depressive symptoms (Kim, McHale, Crouter, & Osgood, 2007).

Family composition, physical activity and sedentary behaviour

The effect of family composition on PA and sedentary behaviour varies widely. Children in two-parent household may have increased parental availability to engage in activities, for supervision in parks, or transportation to sports and clubs (J. F. Sallis et al., 1992). Single-parent households lacking the time for extended and active supervision may leave children to spend more time using screen-based entertainment (Hinkley et al., 2014; Lindquist, Reynolds, & Goran, 1999). On the other hand, children who have less supervision may spend more time out of doors or actively commuting to school or other places, and there is evidence that children in lone-parent households do engage in higher levels of PA than those in two-parent families (L. J. Griffiths et al., 2013; Lindquist et al., 1999). Other studies suggest that parental presence has no effect on either PA levels or sedentary behaviour (Brodersen et al., 2005). Having siblings was associated with more low intensity and MVPA in girls but not boys, and was not associated with television time for either gender (K. Hesketh et al., 2006).

While there is no consensus on the effect of family composition on PA and mental health, it is important factor to consider as only-child, lone-parent and reconstituted family types increase.

Parental psychological health

Parental psychological health and children's mental health

Parental mental health is an established factor associated with children's mental health outcomes. Environmental effects via exposure to parental depressive symptoms, genetic inheritance of factors causing depression, and shared exposure to adversity that increase risk for depression are proposed mechanisms behind the intergenerational transmission of depression from parents to children (Lewis, Rice, Harold, Collishaw, & Thapar, 2011). Studies have shown that maternal depressive symptoms, in particular, are associated with child mental health disorder (Fernandez Castelao & Kröner-Herwig, 2013; Kiernan & Mensah, 2009; Mensah & Kiernan, 2010).

Kiernan et al found that children whose mothers were persistently depressed also had higher odds of behavioural problems than those whose mothers were never depressed, and that maternal depression was more important a predictor than poverty in children aged 3 (Kiernan & Mensah, 2009). Children whose mothers were chronically or severely depressed from pregnancy to when the child was 11 years of age had three times the odds (OR 3.04, 95% CI 2.19, 4.21) of suicide ideation compared with children whose mothers had minimal depressive symptoms (Hammerton et al., 2015). For a child's cognitive and social development, maternal depression remained an important determinant even after adjusting for other factors, while the effect of paternal depression was mediated by socioeconomic adversity (Mensah & Kiernan, 2010).

Parental psychological health and children's physical activity and sedentary behaviour

The evidence that parental mental health is associated with children's PA or sedentary behaviour is limited. A number of studies have linked maternal depression with increased sedentary screen time (Conners, Tripathi, Clubb, & Bradley, 2007; Hoyos Cillero & Jago, 2010); however, no studies to my knowledge have examined parental or maternal depression and PA. Nonetheless, parental mental health is associated with parenting behaviours which have the potential to affect children's PA. For example, promotion of PA in children was lower for parents who suffered from depressive symptoms (Fernald, Jones-Smith, Ozer, Neufeld, & DiGirolamo, 2008; Lampard, Jurkowski, Lawson, & Davison, 2013), and parental PA levels were found to be positively associated with children's PA (J. F. Sallis et al., 2000).

1.5.4 Summary of correlates of physical activity, sedentary behaviour, and mental health

This section examined a range of biological, demographic, psychological, cognitive, household, and parental characteristics to explore their relationship to activity and mental health. While the evidence was grouped into distinct categories, there is likely substantial interplay between these factors, and their independent effects cannot be exhaustively considered in the present study. For example, the effects of maternal depression on children's mental health outcomes may differ by gender (Cortes, Fleming, Catalano, & Brown, 2006); and family composition may affect income poverty or vice versa (Amato, 2005; Blake, 1981). Studies investigating the relationship between PA and mental health simultaneously adjust for multiple factors within a single model to account for these characteristics (Mark Hamer et al., 2009; Hinkley et al., 2014; Kremer et al., 2014; Martikainen et al., 2012; Sagatun et al., 2007; Ussher et al., 2007); thus, observed effects are more readily attributable to an independent association between PA and mental health.

1.6 Environmental and wider contextual factors

The meaning and importance of place as a theme in child health research has become more prevalent, as its impact on aspects of children's lives is increasingly recognised. 'Place' in this sense refers to more than geographical location, but also the characteristics of the environment that influence and define children's social interaction, culture, and identity (J. Lee & Abbott, 2009). Where I refer to 'context', 'environment' or 'space', the meaning should be read as the sociocultural construct and characteristics of place bounded by geographical or geopolitical divisions. Children, arguably more so than adults, are shaped by place as their lack of autonomy and independence of movement mean they are confined to the environment in which they live. As children are undergoing development, their environment could have a profound impact on their behaviour and health outcomes.

The level of green space, area deprivation, and area rural-urban designation, are characteristics of place considered important throughout the literature to both PA/sedentary behaviours and mental health in children. The following sections will explore the evidence on the importance of these contextual characteristics and the role of environment in the relationship between PA, sedentary behaviour, and mental health.

1.6.1 Associations between environmental characteristics and mental health

Green space and mental health

There is extensive evidence that suggests that green space is beneficial to children's mental health status. Studies have shown that higher green space use is associated with improved self-esteem and peer relationships (McCracken, Allen, & Gow, 2016). Higher quality, greater quantity, and closer proximity to green space were broadly associated with better SDQ scores (Daniel Aggio, Smith, Fisher, & Hamer, 2015; Amoly et al., 2014; Feng & Astell-Burt, 2017). In a study in schoolchildren in Barcelona, more surrounding greenness at home and school was positively associated with attention span and cognition (Payam Dadvand et al., 2015). A review by McCormick et al (2017) concluded that green space improved mental health in children across the 12 studies reviewed (McCormick, 2017). There is limited evidence that green space is unimportant for child mental health: McCracken et al (2016) found that the presence alone of residential green space did not improve any mental health outcomes (McCracken et al., 2016), while other studies found effects differed by gender (Markevych et al., 2014).

The studies focus on different aspects of green space (proximity, ease of access, quality and type of green space, for example) which highlights the many potential pathways through which green space might affect mental health or fail to have an effect. Given the heterogeneity of the green space measures used, comparison across studies is difficult and no conclusions can be reached on the precise mechanisms through which green space improves mental health. Nonetheless, the evidence indicates that green space is positively associated with mental health in children, despite the diversity of measures.

Area level deprivation and mental health

A number of studies report that area deprivation is associated with children's mental health. Individuals, and particularly children, from more deprived areas spend more time in areas near their homes and are more likely to be affected by the environmental conditions (Maas, Verheij, Spreeuwenberg, & Groenewegen, 2008). A study by Schneiders et al (2003) found that neighbourhood disadvantage was associated with higher total difficulties, and internalising and externalising problems on the Child Behavioural Checklist, after controlling for parental SES. Increases in total problems between ages 10-12 years and follow up at 12-14 years were also associated with neighbourhood disadvantage (Schneiders et al., 2003). Flouri et al (2012) found that neighbourhood deprivation was significantly associated with peer problems in pre-school children, independent of individual and family characteristics (E. Flouri, Mavroveli, & Tzavidis, 2012). Reijneveld et al (2005) reported that children in deprived areas had much higher rates of psychosocial problems and these were not explained by individual and family characteristics (Reijneveld, Brugman, Verhulst, & Verloove-Vanhorick, 2005). Kalff et al (2001) similarly found that children living in deprived neighbourhoods were at higher risk of behavioural problems, and that this was not accounted for by parental SES (Kalff et al., 2001).

Rural-urban designation and mental health

According to a report by the Local Government Association (2017), there are potentially higher risks for poorer mental health and wellbeing in children in England, particularly via social isolation and reduced access to emotional and mental health support (Local Government Association, 2017). However, the literature does not systematically report worse mental health in rural children. According to a study on MCS children, there was no difference between urban and rural children in mental illness and wellbeing outcomes (P. Patalay & E. Fitzsimons, 2016), and a study on Canadian children also showed no urban/rural differences in behaviour and temperament (Thompson et al., 2018). Weich et al (2018) reported better mental health in rural inhabitants in the UK, however the study was conducted in an adolescent and adult population (Weich, Twigg, & Lewis, 2018).

Worse support for children with mental health difficulties in rural settings is reported, however, due to barriers such as travel distance to service locations, a lack of resources, greater wait times, and the inability of primary care providers to recognised mental health issues due to inadequate training and confidence (Care Quality Commission, 2018; O'Brien, Harvey, Howse, Reardon, & Creswell, 2016).

1.6.2 Associations between environmental characteristics and activity

Green space and activity

The literature suggests that the positive links between green space and health outcomes may be due to increased levels of PA in areas with more green space – Sallis et al (2008) have suggested that by offering an environment that is safe and attractive for exercise and activity, green spaces promote higher levels of PA (J. F. Sallis, Owen, & Fisher, 2008). There are a number of studies supporting the claim that green space affects activity levels in school-aged children. Lachowycz et al (2011) showed that in UK children 10-11 years of age, over a third of weekday evening and weekend MVPA occurred in green spaces, consistent across all seasons (Lachowycz & Jones, 2011). Residential green space and proximity to forested areas was associated with less sedentary time in children 9-12 years old in Spain (P. Dadvand et al., 2014).

Children in California aged 8-14 years with >20 minutes of exposure to greener spaces (90th centile or above) had nearly 5 times the daily rate of MVPA of those with no exposure to greener spaces (incident rate ratio 4.72; 95% CI 3.09, 7.20) (Almanza, Jerrett, Dunton, Seto, & Ann Pentz, 2012). In Bristol, UK, similar findings were reached in 1,300 schoolchildren where MVPA thresholds were more likely to be attained in green spaces rather than other types of urban environments, particularly in boys (Wheeler, Cooper, Page, & Jago, 2010).

Deprivation, physical activity and sedentary behaviour

The evidence on the association between PA and area deprivation is mixed. Some studies have reported low levels of PA in areas of high deprivation (K. Davison & Lawson, 2006; Ellis, Grimsley, Goyder, Blank, & Peters, 2007), while others report more PA in deprived neighbourhoods (Gómez, Johnson, Selva, & Sallis, 2004; Gordon-Larsen, McMurray, & Popkin, 2000; Pouliou et al., 2015). Differences may relate to the PA and deprivation measures used. Two studies used neighbourhood crime rates as measures of deprivation (Gómez et al., 2004; Gordon-Larsen et al., 2000) and only one study used objective measures of PA (Pouliou et al., 2015). Perceived neighbourhood safety was found to be associated with greater PA participation and less TV viewing (Datar, Nicosia, & Shier, 2013). The relationship between deprivation and PA may also differ by gender: Brodersen et al found that sedentary behaviour was not associated with area deprivation in boys, but girls in deprived areas were more likely to be sedentary (Brodersen et al., 2005). Furthermore, deprived areas may suffer from ‘deprivation amplification’, which is the idea that individual or household deprivation is amplified by area deprivation (Sally Macintyre, 2007). In the case of PA, deprivation amplification might take the form of fewer and lower quality of PA facilities than those available than in affluent areas, further exacerbating low PA levels. A study in Canadian children found that deprived areas were less likely to have PA promoting features or resources (Pabayo, Belsky, Gauvin, & Curtis, 2011), while evidence from Glasgow found that children in deprived areas were less likely to walk, cycle, and play outside (S. Macintyre, 2000). Not all studies supported the hypothesis of deprivation amplification: a study in Germany found no association between deprivation and access to PA facilities for children; however, the study reported only the presence of sites, and the comparative quality of free vs fee-based facilities was not assessed (Schneider, D'Agostino, Weyers, Diehl, & Gruber, 2015).

In a study of UK children, children in higher deprivation was associated with greater independent mobility; however, the neighbourhoods were also less crime safe, and had worse pedestrian and traffic safety scores (Noonan, Boddy, Knowles, & Fairclough, 2016). Thus, even if children from deprived neighbourhoods are more active in some respects, they are not necessarily active in safe, child-friendly environments and this might impact negatively on their mental health.

Rural-urban designation and PA

There is increasing concern being raised about the effect of urban settings and the built environment on PA levels. Area transportation infrastructure, land use, and travel patterns, in conjunction with broader social and specific individual attributes, could influence PA behaviours (Transportation Research Board, 2005). Evidence suggests that characteristics of the built environment related to rural-urban status can impact PA levels in children.

A systematic review conducted by Davison et al (2006) identified three main categories of rural-urban attributes that might affect children's PA: recreation infrastructure, transport infrastructure, and local conditions (K. Davison & Lawson, 2006). Regarding transport infrastructure, children were more active when road hazards (high speed/density traffic, roads to cross) were absent, and when there was access to sidewalks and controlled crossings (K. Davison & Lawson, 2006). The proximity of recreational infrastructure in the form of equipment and play structures at school had positive effects on children's PA, as did closer proximity to school for walking (K. Davison & Lawson, 2006). However, it was not clear whether road hazards and accessible recreational infrastructure were more prevalent in rural or urban settings.

Joens-Matre et al (2008) found that urban children in the Midwestern United States were the least active overall compared to children in small cities and rural areas (Joens-Matre et al., 2008). However, children in small cities were the most active, and rural children, while not the least active, had the highest prevalence of overweight (Joens-Matre et al., 2008). Patterns of activity within rural and urban children might also differ by time of year: a study on children in rural and urban schools in Cyprus reported that urban children were more active in winter, while rural children were more active in summer (Loucaides, Chedzoy, & Bennett, 2004). Access to indoor facilities or the type of activity undertaken may be why patterns can differ between rural and urban children.

Additional factors related to urban areas may also restrict PA: Molnar et al (2004) reported that between-neighbourhood variation in levels of PA in children living in Chicago could be partially accounted for neighbourhood social disorder and lack of safety (Molnar, Gortmaker, Bull, & Buka, 2004). Larsen et al (2009) found that active commuting to school was associated with lower residential density, with higher density areas being associated with increased motorised traffic which serves as a safety deterrent for children (Larsen et al., 2009).

One of the challenges in exploring how rural and urban setting affect PA levels in children is that their movements are regulated by parents, and their perceptions of the environment will have an impact on children's ability to use the spaces available to them.

1.6.3 Role of the environment in the relationship between physical activity and mental health

The previous subsections explored the relationship between environmental characteristics, PA and mental health, and found that the evidence broadly supports the premise that more green space improves both PA and mental health. The extension to these investigations is whether green space moderates the association between PA and mental health. The notion of 'green physical activity', which is PA undertaken in green spaces, is a relatively new area of study. That the interaction between PA and green space prompts richer psychological responses and mental health benefits, via the quantity and quality of PA in time spent in a more restorative environment, has been confirmed in a number of recent studies in older populations (Barton & Pretty, 2010; Marselle, Irvine, & Warber, 2013; R. Mitchell, 2013; E. A. Richardson, Pearce, Mitchell, & Kingham, 2013; Yeh et al., 2016).

The evidence in children reports similar results: Fjørtoft et al (2001) found that green PA in pre-school children in Norway might stimulate learning, social interactions, and motor development (Fjørtoft, 2001), while a study in the USA found that children with attention-deficit hyperactivity disorder (ADHD) functioned better after PA in a green space (Taylor, Kuo, & Sullivan, 2001). Green space playing time was inversely associated with SDQ total difficulties, emotional symptoms, and peer problems in a study of Barcelona schoolchildren (Amoly et al., 2014), while Seeland et al (2009) found that outdoor spaces (parks, playgrounds, lakeside, public swimming pools) were particularly important for making friends in school-aged children in Zurich (Seeland, Dübendorfer, & Hansmann, 2009). A study in the US comparing PA in natural urban settings found that children aged 4-8 years performed better on an attention task following a nature walk but not an urban walk (Schutte, Torquati, & Beattie, 2015).

Two UK-based longitudinal studies in schoolchildren concluded that PA in green, natural environments did not improve self-esteem when compared with urban exercise, although sample sizes were small (n=25 and 75) and trials only conducted on a single day one week apart (Reed et al., 2013; Wood, Gladwell, & Barton, 2014).

While many studies report that green PA has potential benefits to mental health beyond PA alone, there is a relative dearth of information on this relationship in UK children. Furthermore, many of the studies mentioned above are cross-sectional, thus, longitudinal studies are required to promote green PA as a way of improving mental health issues.

Area deprivation and rural-urban designation as possible confounders of green space effects

While the effects of green space are, broadly, reported to increase PA levels and improve mental health, further studies report that these effects depend on additional characteristics of the environment. The evidence regarding the role of area deprivation and rural-urban status in the relationship between PA and mental health is less conclusive than that of green space, however, the differing results point to the need for further investigation and show that the relationships are likely dependent on the measures and other factors. In particular, deprivation and rural-urban designation have been shown to modify or confound the associations between green space and PA, and green space and mental health.

In a study using data from the Health Survey for England, people living in the greenest areas of England were found to be more likely to meet PA cut-offs than those in less green areas, but this association was stronger in urban areas rather than rural (Mytton, Townsend, Rutter, & Foster, 2012). Some urban green space might be specifically created to be accessible to young people, or more affluent neighbourhoods might be equipped with better facilities for activity. For example, residents of deprived areas in Bristol lived closer to green spaces but reported poorer accessibility, safety, and less frequent use (Jones, Hillsdon, & Coombes, 2009). PA in green spaces located in a safer or less polluted location, might produce different mental health effects to PA conducted in rural green space, which may be inaccessible or used for agricultural purposes and not well-catered for play (McCracken et al., 2016; Pouliou et al., 2015).

Summary – role of the environment

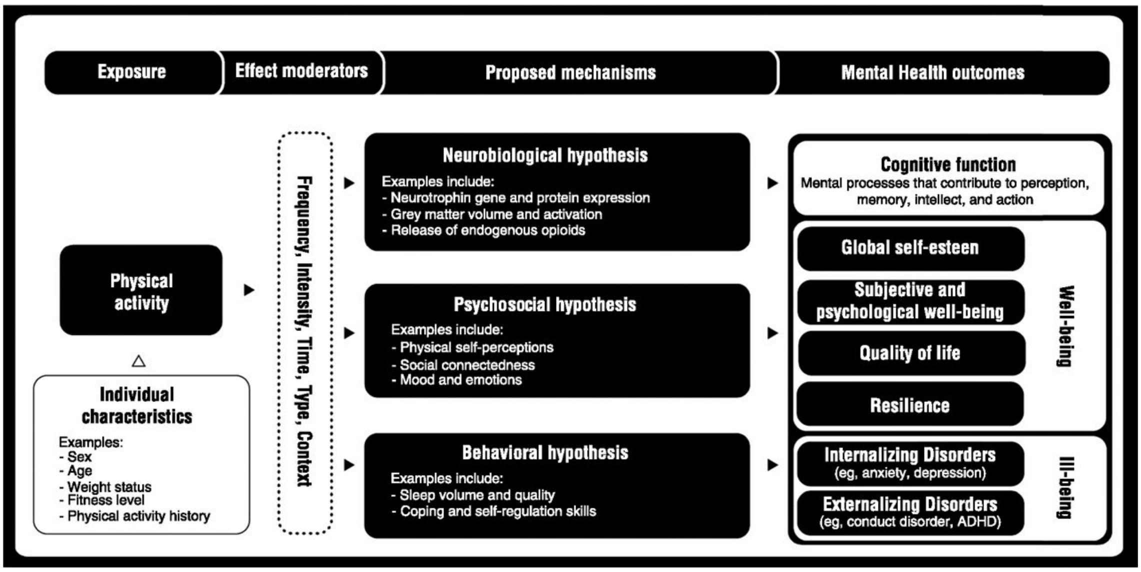
One of the challenges with the literature on the importance of environment and place in the relationship between PA, sedentary behaviour, and mental health is synthesising the results from the diversity of measures used. Proxy measures of deprivation, such as perceived neighbourhood safety, can overlap with rural-urban status characteristics such as traffic safety, and green space characteristics such as air quality. For the purpose of this literature review, I attempted to present the evidence separately, however, disentangling the effects of each is complex. Overall, the evidence highlights the potential importance of place; specifically, that green space may play an important role in the relationship between PA and mental health in children, and that adjusting for area deprivation and rural-urban designation will improve our understanding of this relationship.

1.7 Physical activity, sedentary behaviour, and mental health: conceptualising the pathways

The previous sections reviewed the literature on the relationship between PA and sedentary behaviours, and mental health, and explored the key correlates. The diversity of findings reflects the possibility that the studies examined are measuring different constructs and that the underlying mechanisms through which activity behaviours serve to operate on mental health may vary. It also demonstrates an absence of a common conceptual model to which studies investigating these relationships might adhere. Structuring these mechanisms within a framework could clarify these pathways and help interpret results.

A conceptual model presented by Lubans et al (2016) proposed that the child's individual characteristics have an impact on the physical activity levels of the child. These, in turn, are moderated by the characteristics of the physical activity, which operate via different hypothesised pathways. Mental health outcomes were subset into cognitive function, well-being, and ill-being. The three broad mechanisms through which PA can potentially improve mental health in children were identified as psychological, neurobiological, and behavioural mechanisms.

Figure 1-2: Conceptual model for the effect of PA on mental health in children and adolescents (Lubans et al., 2016)



One proposed psychosocial mechanism is based on the self-efficacy theory proposed by psychologist Albert Bandura, whereby individuals who are confident of their ability are more able to perform that behaviour (Bandura, 1977). Subsequently, the individual who performs a difficult task is able to initiate positive cognitive-behavioural change with anti-depressant effects (DeBoer, Powers, Utschig, Otto, & Smits, 2012; Tomson et al., 2003). An extension of this theory, termed the mastery hypothesis, suggests that gaining a sense of competence or mastery of physical skills through exercise allows the individual to become more confident and to carry this success into their everyday lives (Paluska & Schwenk, 2000).

The social interaction hypothesis suggests that psychological benefits can be derived from the development of relationships and mutual support, and that PA provides children these opportunities for social interaction and acceptance (Lubans et al., 2016). Arguably, the benefits conferred from the social support may arise from personal assistance in initiating and maintaining an exercise programme, thus, allowing the child to retain additional psychological or physiological benefits conferred by the activity (Paluska & Schwenk, 2000); although, outside of the context of PA, regular contact with emotionally supportive people may reduce allostatic load, which is a key measure of damaging levels of stress (McEwen, 2007). These psychosocial mechanisms propose that children can gain a sense of accomplishment and improve their self-esteem by engaging in PA, thus, enjoyable activities at an appropriate skill-level are important for achieving mental health benefits. Similarly, having supportive PA instruction or a facilitator who ensures that no children are excluded in group PA may help maximise the potential mental health benefits of social interaction.

There are neurobiological mechanisms which suggest that, in particular, higher intensity PA or greater duration leads to improved mental health. The endorphin hypothesis suggests that PA 'promotes psychological well-being by increasing the secretion of endorphins, which reduce the sensation of pain and produce a state of euphoria' (Kent, 2007). Studies have shown that endorphin secretion is activated by extended exercise but have not definitively proven that this improves mood; it may be that endorphins produce energy conservation which facilitates psychological effects but are not the direct cause (Paluska & Schwenk, 2000). The monoamine hypothesis suggests that transmission of primary monoamines (noradrenaline, dopamine, and serotonin), are enhanced by exercise and can ameliorate depressive and sleep disorders (Paluska & Schwenk, 2000). Animal studies have demonstrated that PA can produce effects in the cortex and hippocampal regions of the brain producing antidepressant effects: serotonergic and noradrenergic systems, atrial natriuretic peptide (ANP) concentrations, brain-derived neurotrophic factor (BDNF), have all been shown to respond positively to exercise (DeBoer et al., 2012; McEwen, 2007). The thermogenic hypothesis suggest that increases in body temperature, particularly elevations in brain temperature are responsible for decreased anxiety and improved mood, via releasing muscular tension and altering neuron activity (DeBoer et al., 2012; Paluska & Schwenk, 2000). Given that sustained PA or exercise appears to be underpinning the neurobiological mechanisms, measures of time in higher intensity activity may be the most accurate method of assessing their role in improving mental health.

Improvements in mental health via PA have also been proposed to function through improved sleep, self-regulation, and coping skills resulting in behavioural management strategies and change (Lubans et al., 2016). In line with this model, the distraction hypothesis suggests that PA might allow the child a diversion from stress and negative thoughts (DeBoer et al., 2012; Paluska & Schwenk, 2000), and that PA could reduce states of anxiety by allowing the child a 'time out' from daily worries (Bahrke & Morgan, 1978; Breus & O'Connor, 1998). To promote self-regulation, the frequency of PA is likely to be an important factor as habitual activity may help break the cycles of anxiety and worry. Additionally, distraction from negative thoughts and stress would be more easily accomplished if the type of activity is enjoyable for the child.

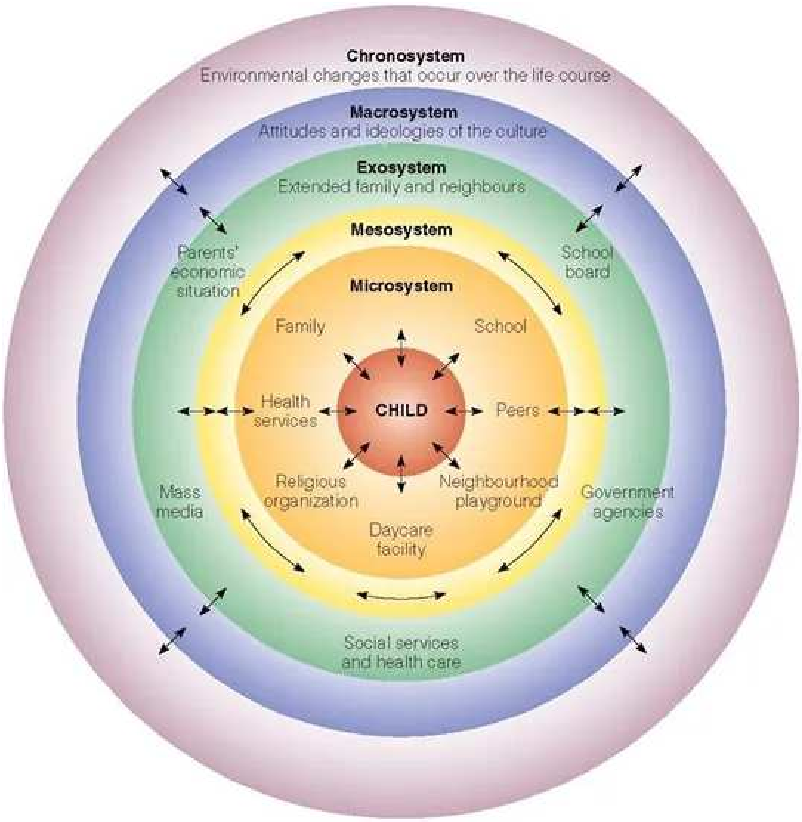
A recent systematic review found that there is insufficient evidence to determine the specific mechanisms responsible for mental health benefits in children, although the evidence was strongest for PA improving self-perception and self-esteem (Lubans et al., 2016). This thesis will not explicitly test these mechanisms—nor is this summary intended to be comprehensive—but this overview highlights that each of these proposed mechanisms may underpin differences in intensity, type, and frequency of activity undertaken, and their relationship to mental health. It is also important to note that these mechanisms are not necessarily mutually exclusive—it is likely that psychosocial, neurobiological, and behavioural mechanisms work together to produce mental health effects.

1.7.1 Conceptual framework

Lubans' framework is a useful starting point for examining the pathways through which PA affects mental health; however, there a number of limitations. First, sedentary behaviours are absent from the model. Evidence suggests that sedentary behaviours are not simply the absence of PA and should be considered independently. Secondly, the possibility of reverse causation or bidirectionality is not considered. While the main objective of this thesis is to evaluate the effect of PA/sedentary behaviour on mental health outcomes, understanding the significance of the reverse relationship could help clarify potential mechanisms as well as inform future study design or interventions. Finally, the model only considers individual risk factors, and the impact these have on PA behaviours only, and does not fully recognise the wider influences that could affect active behaviours and, in turn, mental health.

The literature has shown that a wide range of factors are important correlates of both exposure and outcome, and that these might confound, moderate, or mediate the associations. Integrating Lubans' framework with a broader multilevel approach to PA, sedentary behaviours, and mental health would help improve understanding of how these different levels of influence interact, and provide a stronger basis for designing policy, intervention, and future studies. Bronfenbrenner's ecological systems theory is one such framework that considers the interaction of systems external to the individual on child development (Bronfenbrenner, 2009). The wider environment is divided into the microsystem, mesosystem, exosystem, macrosystem, and chronosystem, which are arranged into a nested arrangement of interrelated structures, with the proximal systems having a greater direct impact on the child at the centre of the model. Figure 1-3 below illustrates the organisation of the systems.

Figure 1-3: Bronfenbrenner's Ecological Systems Theory Model

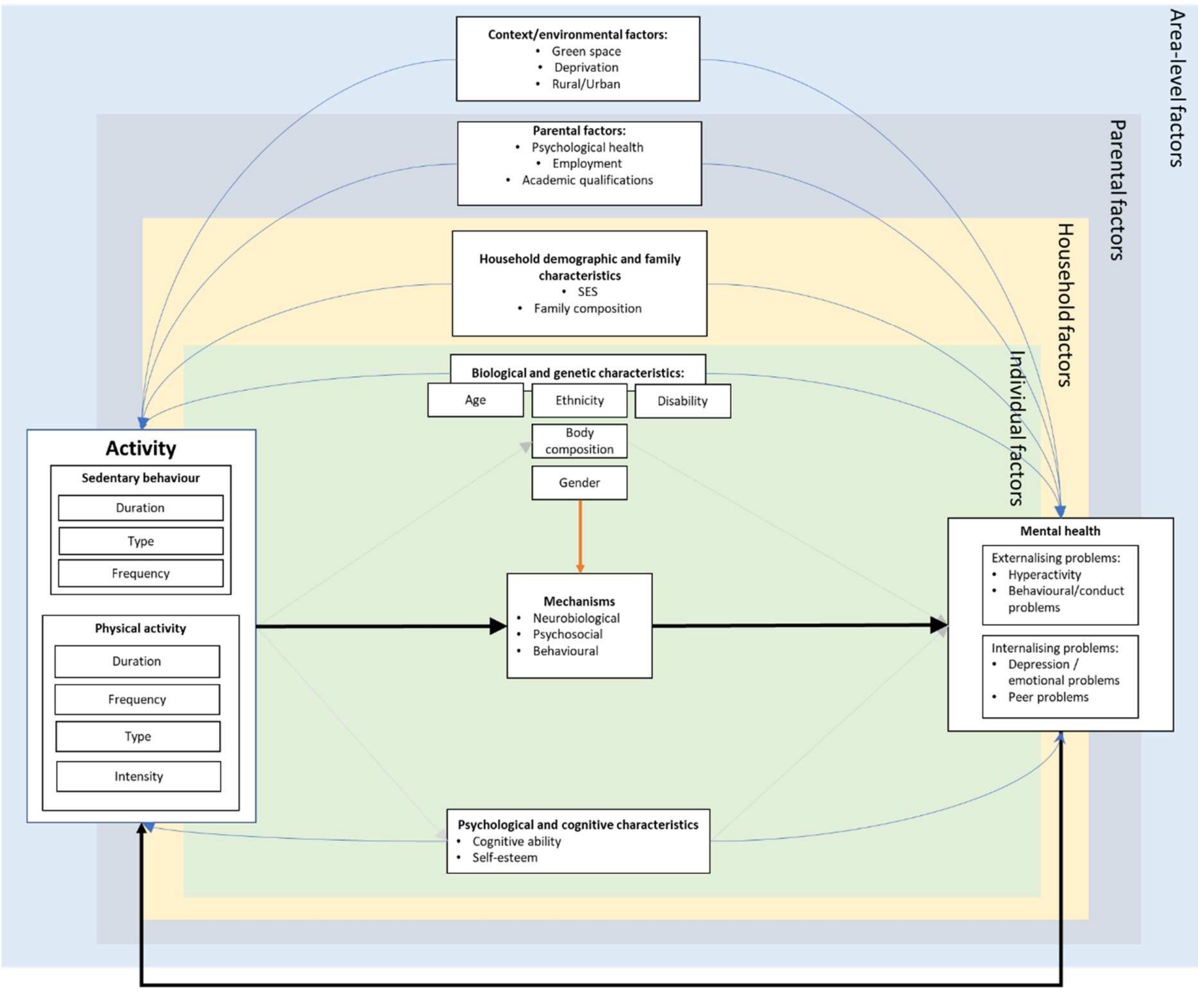


Informed by Bronfenbrenner's model, socio-ecological models of PA behaviours identified intrapersonal (biological, psychological), interpersonal (social, cultural), organisational, community, physical environment, and policy as determinants of behaviours and health outcomes (J. F. Sallis et al., 2008). Additionally, behaviour- and context-specific approaches can help identify the mechanisms of change (Giles-Corti, Timperio, Bull, & Pikora, 2005). For example, team sport participation was found to be associated with improved peer and social aspects of mental health functioning, and is likely to operate via improved social integration and interaction, developing social skills, and teamwork (Eime et al., 2013). Thus, structured consideration of these additional systems should be incorporated into Lubans' framework.

Potential correlates of PA, sedentary behaviour, and mental health have been identified in the previous sections, but the studies have not been considered within a framework. In my proposed framework, the child's individual characteristics consist of the biological and demographic correlates in section 1.5.1 and the psychological and cognitive correlates in section 1.5.2. At the microsystem level, where correlates have direct impact on the child in their immediate environment, the household demographic and family characteristics are considered. Parental factors have been conceptualised within a combination of the meso- and exosystem levels (where there may be interactions between the environments in which the child is not directly involved but may impact their experiences). For example, higher academic qualifications may result in higher PA levels via increased parental awareness of its importance as a health behaviour. Finally, area-level factors are situated within the macrosystem where the established environment is defined by the characteristics of the geographic location where the child resides.

Figure 1-4 below illustrates the proposed framework.

Figure 1-4: Proposed conceptual framework



In the proposed framework, I attempt to delineate the pathway from different dimensions of PA and sedentary behaviour, which are influenced by a range of proximal and distal factors via the mechanisms, through to the different domains of mental health functioning. The variables in the boxes joined by the blue arrows will be modelled as potential confounders in the relationship based on the extensive evidence presented on their effects on both PA/sedentary behaviour and mental health. Given the widely reported gender differences for both PA, sedentary behaviour, and mental health, gender will be considered as a moderator. The evidence on the direction of impact of cognitive ability, self-esteem, and body composition on PA/sedentary behaviour, and mental health is conflicting, thus, they will be treated empirically as confounders but their potential role as mediators will be discussed, as indicated by the grey arrows.

1.8 Summary

This literature review has outlined some of the evidence on the relationship between PA, sedentary behaviour, and mental health, and has identified key factors that may affect this relationship. The focus of this thesis is to determine whether levels of sedentary behaviour and PA are predictive of mental health outcomes. The majority of the evidence available, however, is cross-sectional and the direction of the association is unknown. Furthermore, few studies have considered the effects of both objectively-measured and reported activity, each of which has its merits. Objective measures are not as susceptible to bias as with reported measures, while reported measures provides an understanding of the activity undertaken. Fewer studies have investigated poor mental health as a predictor of low PA levels or increased sedentary behaviours, and this will be addressed.

A range of correlates of PA, sedentary behaviour, and mental health in children were identified at the individual and household levels, but were inconsistently reported in the literature. Given the evidence supporting their significance, this thesis will include these factors in the statistical models. This review has also shown that gender is potentially an effect modifier, and differences between them are not always investigated or consistently reported. Finally, while the importance of environmental factors to both PA levels and mental health are widely acknowledged, the role of the neighbourhood context in the relationship between them has not been considered.

To address these gaps in the literature, this thesis will explore the association between PA and mental health using data from the UK Millennium Cohort Study (MCS). The MCS is nationally-representative, longitudinal dataset which will allow this thesis to investigate the direction of causation. The wide range of information available on the child’s and family’s circumstances will allow analyses to be adjusted for potential confounders, and information on the environment will allow consideration of the role of place. I have adapted a framework proposed by Lubans et al to illustrate the pathways from exposure to outcome, and organised the variables into ‘levels’ to facilitate a conceptual differentiation, to provide structure for the analyses going forward, and to frame the interpretation of the results.

The main objectives of this theses are as follows:

1. To investigate whether objectively-measured sedentary time and PA at age 7 are predictive of mental health outcomes at age 11
2. To investigate the effects of environmental characteristics in the relationship between total PA and sedentary time at age 7 and mental health, and to explore the role of area-level factors;
3. To investigate whether reported measures of PA and sedentary screen time at two measured time points are predictive of mental health outcomes at subsequent times point; and whether there is evidence for reverse causation or bidirectionality of the association;

1.9 Thesis structure

This thesis is organised into six chapters.

Chapter 1 introduced and reviewed literature on the subject of the relationship between PA and mental health; a conceptual model was proposed, and the main objectives outlined.

Chapter 2 describes the dataset and variables used, as well as the analytic strategy and methods employed in the analyses.

Chapter 3 examines the longitudinal association between objectively-measured PA and sedentary time at age 7 and mental health outcomes at age 11.

Chapter 4 investigates the effects of the neighbourhood environment on the relationship between objectively-measured PA and sedentary time and mental health outcomes.

Chapter 5 explores the longitudinal association between parent-reported measures of PA and sedentary behaviour and mental health outcomes, and the evidence for bidirectionality.

Chapter 6 concludes the thesis with a discussion of the thesis as a whole and includes a summary of results, a discussion of main contributions, the implications for policy and research, and the strengths and limitations.

2 Methods

This chapter will provide a description of the dataset and the variables used in the analyses. As different statistical methods were used in Chapters 3, 4, and 5, a general overview of the analytical strategy will be presented here, with additional methodological details outlined in the relevant results chapters.

2.1 Participants – the Millennium Cohort Study

The Millennium Cohort Study (MCS) is a nationally-representative longitudinal study of children born in the UK between September 2000 and January 2002. Data are collected on a range of topics such as parental health; education; ethnicity; parental employment; childcare; income; and child development, providing a comprehensive resource to help understand the circumstances in which British children live and grow. The sample was drawn from a population of UK-resident children at age 9 months whose families were eligible for Child Benefit (Plewis, Calderwood, Hawkes, Hughes, & Joshi, 2007). The population was stratified by UK country (England, Wales, Scotland, and Northern Ireland) and further stratified into three strata in England ('ethnic minority', where the electoral ward population comprised at least 30% 'Black' or 'Asian' ; 'disadvantaged', which comprised the poorest 25% of wards based on the Child Poverty Index; and 'advantaged', which consisted of wards not in previously mentioned strata), and two strata in each of Wales, Scotland, and Northern Ireland ('disadvantaged' and 'advantaged') (Plewis et al., 2007). Children were over-sampled from disadvantaged electoral wards across the UK, from ethnic minority areas in England, and from Scotland, Wales, and Northern Ireland.

At MCS1, when the children were 9 months of age, 18,552 families were interviewed. At MCS2, when the children were 3 years old, a further 1,389 new families were identified as eligible for participation in the study, of which 692 families were productive at MCS2. In total, there are data available for 19,244 families (18,552 eligible from MCS1 plus 692 families from MCS2) (Hansen et al., 2012). A further four sweeps were carried out when the children were 5, 7, 11, and 14 years of age. At the time the analyses were undertaken, data for age 14 were not available. There were losses to follow-up at each sweep, which can be a source of bias if families lost are systematically different from those who were retained. Survey weights were calculated to account for the unequal probability of selection due to the stratified sampling design, as well as to account for the attrition between sweeps (Plewis et al., 2007).

At each sweep, a structured interview was conducted with the main respondent (usually the natural mother) and their partner (where present), using Computer Assisted Personal Interview (CAPI) and Computer Aided Self-Completion Interview (CASI) software. Fieldwork was conducted by the National Centre for Survey Research in Great Britain (NatCen). In Northern Ireland, the fieldwork was sub-contracted to the Northern Ireland Statistical Research Agency (NISRA).

Ethics approvals for the MCS were obtained from Multi-centre Research Ethics Committees (MREC) in the UK (South West MREC for MCS1, London MREC for MCS2 and MCS3, and Northern and Yorkshire MREC for MCS4 and MCS5) (Hansen et al., 2012). Data for this analysis was publicly available and obtained from the UK Data Archive, University of Essex.

2.1.1 MCS4 objective physical activity monitoring study

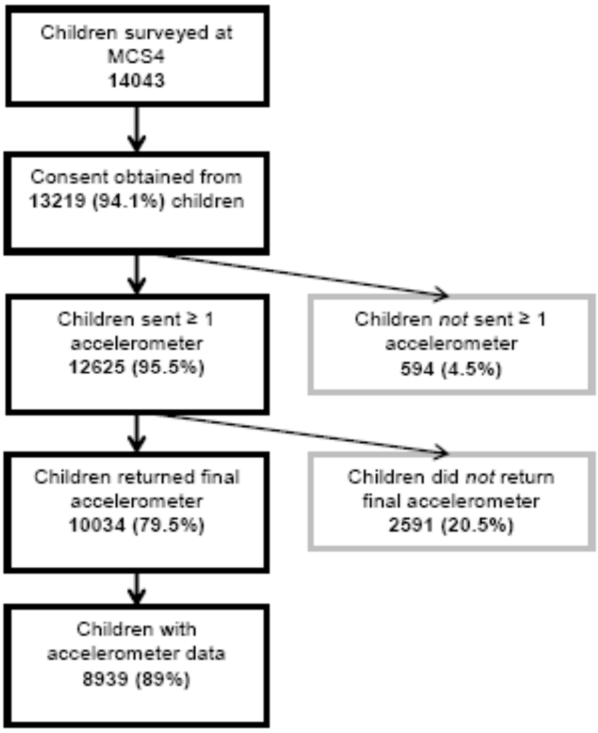
When the children were aged 7 years, a supplementary study was run by the Centre for Paediatric Epidemiology and Biostatistics at the Institute of Child Health (ICH), to conduct objective PA monitoring over seven days. During the interview, children were invited to participate in PA monitoring, and written consent was obtained from the guardian.

Consenting children were sent an Actigraph GT1M uni-axial accelerometer (Actigraph, Pensacola, Florida) between May 2008 and August 2009 by the physical activity fieldwork team at the Institute of Child Health (ICH). The Actigraph GT1M has been validated in children and used in PA monitoring studies, including the Avon Longitudinal Study of Parents and Children, the National Health and Nutrition Examination Survey, and the European Heart Study (C. J. Riddoch et al., 2004; Chris J Riddoch et al., 2007; Troiano et al., 2008). The accelerometers were programmed with a sampling epoch of 15 seconds and to record step counts, to commence on the day following receipt of the activity monitor. Children were instructed to wear the accelerometers for seven consecutive days during waking hours, except during swimming and bathing, as the accelerometers were not waterproof.

The parent of each child was asked to complete a timesheet, recording the following details: time the accelerometer was put on, time taken off, minutes not worn during the day (e.g. bathing), minutes spent swimming (not worn), minutes spent cycling (the accelerometer cannot accurately measure intensity while cycling), and whether the week was typical for the child. Accelerometers were returned by the parent using a prepaid return envelope.

Figure 2-1 below summarises MCS4 accelerometer study fieldwork.

Figure 2-1: MCS4 accelerometer study fieldwork (L. Griffiths et al., 2013)



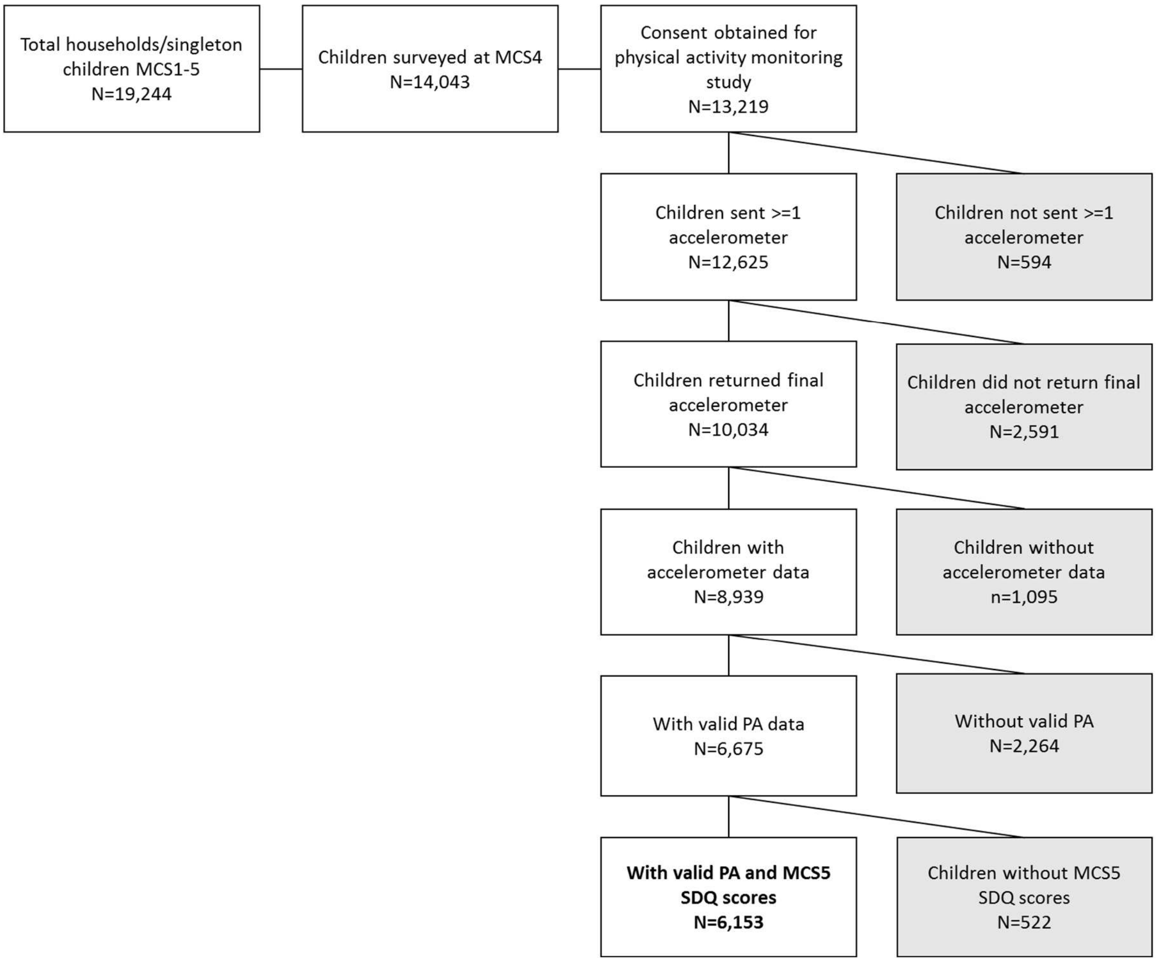
594 children (4.5%) who consented to the PA study were not sent an accelerometer either because one could not be sent during the requested time period, or their details were not transmitted to the ICH fieldwork team.

PA monitoring study participants

At age 7, 14,043 children were invited to participate in the Physical Activity Monitoring Study. Of the children who consented to participate (n=13,219), 8,939 (89.0%) returned accelerometers with data. Cleaning and processing were undertaken on the raw accelerometer data by the research team at ICH, and followed a three-stage standard operating procedure (SOP). Data processing consisted of data cleaning, valid wear-time classification, extreme count exclusion, and the creation of summary PA variables. Appropriate classification thresholds were obtained through a separate calibration study, which will be described in the following section. Full details on the study protocol and the data processing SOP stages are available in the MCS4 PA Technical Report (L. Griffiths et al., 2016).

After excluding invalid data based on the SOP, there were 6,675 children with valid accelerometer data. Of these, 522 did not have SDQ scores available at MCS5, yielding a final sample size of 6,153.

Figure 2-2: Number of children with valid PA data and MCS5 SDQ scores



Sensitivity analysis

The analytic sample size (n=6,153) for chapters 3 and 4 was considerably smaller than the total MCS4 sample (n=14,043), which could be a source of bias if children in the sample are systematically different. Rich et al compared the characteristics of the children who consented to study vs non-consenting, as well as children for whom reliable data (≥2 days lasting ≥10 h/day) were obtained and were not. In unadjusted analyses, for both consent and data reliability, children were more likely to be White, female, under/normal weight, and not have a disability or activity-limiting illness. At household level, the children in non-single parent homes and with fewer siblings were more likely to have data; their mothers were more likely to be employed and degree-holding, and household incomes were more likely to be higher (Rich et al., 2013).

As a sensitivity analysis, I undertook a comparison between the characteristics of the analytic sample (n=6,153) and all MCS children who were not included (n=13,091). Survey tabulations were conducted and Table 2-1 below shows the differences in the proportions in each categorical variable by sample.

Table 2-1: Survey weighted tabulations of categorical variables, by analytic and non-analytic samples (Proportions are weighted to account for sampling design and non-response. Ns are unweighted.)

	Analytic sample					
	No (N=13,091)		Yes (N=6,153)		Total (N=19,244)	
	N	%	N	%	N	%
Season PA study conducted						
Summer	162	39.9	2,696	46.2	2,858	45.8
Autumn	141	34.8	1,976	33.6	2,117	33.6
Winter	73	12.1	806	8.9	879	9.1
Spring	55	13.2	675	11.3	730	11.4
Total	431	100	6,153	100	6,584	100
p = 0.135						
Child's sex						
Male	3,719	53.2	2,994	49.6	6,713	51.6
Female	3,415	46.8	3,159	50.4	6,574	48.4
Total	7,134	100	6,153	100	13,287	100
p = 0.002						
Ethnicity						
White	5,569	80.6	5,423	89.4	10,992	84.4
Mixed	230	4.1	153	2.7	383	3.5
Indian	209	2.4	131	1.5	340	2
Pakistani and Bangladeshi	713	6.8	235	2.7	948	5
Black or Black British	297	4.5	134	2.2	431	3.5
Other	113	1.5	77	1.5	190	1.5
Total	7,131	100	6,153	100	13,284	100
p < 0.001						
MCS5 weight status						
Not overweight (incl underweight)	4,714	70	4,580	75.9	9,294	72.6
Overweight	1,558	22.3	1,159	19.4	2,717	21
Obese	565	7.8	295	4.7	860	6.4
Total	6,837	100	6,034	100	12,871	100
p < 0.001						
Special educational needs (SEN)						
No	6,249	86.6	5,633	90.8	11,882	88.5
Yes	885	13.4	520	9.2	1,405	11.5
Total	7,134	100	6,153	100	13,287	100
p < 0.001						
Does your child's illness limit their activity?						
No limiting illness	6,103	84.8	5,409	87.3	11,512	85.9
or, Not at all?	367	4.9	411	7.1	778	5.9
...Yes, a little,	418	6.3	239	3.9	657	5.2
...Yes, a lot,	246	4	94	1.7	340	3
Total	7,134	100	6,153	100	13,287	100

Analytic sample						
	No (N=13,091)		Yes (N=6,153)		Total (N=19,244)	
	N	%	N	%	N	%
p < 0.001						
MCS5 below OECD 60% median income						
Above 60% median	5,104	71.3	5,422	88	10,526	78.6
Below 60% median	2,030	28.7	731	12	2,761	21.4
Total	7,134	100	6,153	100	13,287	100
p < 0.001						
Number of siblings						
0	910	13.1	690	11.3	1,600	12.3
1	2,815	39.1	2,926	47.7	5,741	42.9
2	1,925	27.5	1,662	27	3,587	27.3
3	966	13	620	10	1,586	11.7
4+	518	7.2	255	4	773	5.8
Total	7,134	100	6,153	100	13,287	100
p < 0.001						
Both natural parents resident in household full-time						
No	2,968	42.1	1,622	17.1	4,590	32.2
Yes	4,166	57.9	4,531	82.9	8,697	67.8
Total	7,134	100	6,153	100	13,287	100
p < 0.001						
Highest academic qualification attained MCS1-5						
No degree	11,240	89.2	4,459	75.3	15,699	84.5
Degree or higher	1,810	10.8	1,694	24.7	3,504	15.5
Total	13,050	100	6,153	100	19,203	100
p < 0.001						
Maternal employment						
In work	2,860	42.3	1,529	26.1	4,389	35.3
Not in work	4,274	57.7	4,624	73.9	8,898	64.7
Total	7,134	100	6,153	100	13,287	100
p < 0.001						
Kessler 6 score at MCS5						
normal (0-12)	5,840	91.8	5,569	95.7	11,409	93.6
higher likelihood of SMI (13+)	468	8.2	241	4.3	709	6.4
Total	6,308	100	5,810	100	12,118	100
p < 0.001						

For the continuous variables, Table 2-2 below presents the differences in means by population.

Table 2-2: Survey weighted means of continuous variables, by analytic and non-analytic samples (Means are weighted to account for sampling design and non-response. Ns are unweighted.)

	Analytic sample			
No		Yes		p
N	Mean	N	Mean	
Age at interview to nearest 10th of year				
7,134	11.2	6,153	11.1	<0.001
MCS5 Emotional problems				
6,780	2.1	6,015	1.8	<0.001
MCS5 Peer problems				
6,787	1.6	6,016	1.3	<0.001
MCS5 Conduct problems				
6,784	1.7	6,014	1.3	<0.001
MCS5 Hyperactivity problems				
6,764	3.5	6,006	2.9	<0.001
MCS5 Total Difficulties				
3,749	8.8	6,153	7.2	<0.001
Weighted mean time (mins) spent in sedentary behaviour across all valid days				
431	385.5	6,153	391.7	0.115
Weighted mean time (mins) spent in light activity across all valid days				
431	283.6	6,153	280.5	0.230
Weighted mean time (mins) spent in MVPA across all valid days				
431	66.1	6,153	62.7	0.082
MCS4 BAS pattern construction score				
7,403	50.8	6,119	54.8	<0.001
MCS4 BAS word reading score				
7,365	108.5	6,047	114.3	<0.001
MCS5 self-esteem				
6,393	13.3	5,739	13.4	0.014

Similar to the results reported by Rich et al, in the analytic sample, the proportion of girls and White or White British children is higher. As expected, evidence of attrition in the more socially disadvantageous groups was evidenced by the higher proportions of children in the analytic sample who are above 60% median income, live in households where both natural parents are full-time resident, and whose mother is employed and degree educated. Lower proportions of children who have SEN, LSLI that restricts activity, and are overweight or obese are found in the analytic sample. Children whose mothers are depressed were less likely to be part of the analytic sample.

Mean cognitive scores and self-esteem were higher in children in the analytic sample, and SDQ scores in all domains were lower (indicating better mental health). The number of minutes children engaged in sedentary behaviour, light PA, and MVPA were not significantly different between the samples.

Weights for non-response and non-compliance

Given the significant differences reported between the samples, strategies to account for non-response and non-compliance in the PA study were implemented by the study investigators, described in a technical report (L. Griffiths et al., 2013). PA study-specific probability weights were generated at child-level using a binomial logistic regression model, which included the non-response weights from the first and second waves of the MCS and accounted for survey design features. Overall weights were derived by multiplying the predicted inverse probabilities by the MCS4 non-response adjusted sampling weights (L. Griffiths et al., 2013; Plewis et al., 2007). I generated weights for this analysis by (1) obtaining the PA study weights by dividing the combined PA/MCS4 weights by the MCS4 weights, and (2) by multiplying these by the MCS5 weights to produce the corrected weights for children who completed both the MCS4 PA study and MCS5 survey. These weights account for sample losses due non-compliance and non-reliable data losses in the PA study, and to non-response at MCS5.

2.1.2 Parent-reported physical activity at MCS3, 4, and 5

Parent-reported PA and sedentary behaviour variables were collected at ages 5, 7, and 11. As part of their interview, parents were asked questions on a range of activity-related behaviours such as the child's mode of school commute, frequency of club sports and exercise, and screen time. Full details on the reported PA questions are given in section 5.3.2 in Chapter 5. Analyses were limited to children whose parents had productive interviews at all three sweeps (n=11,604). Further information on the participants included in the reported PA analyses are given in section 5.3.1 in Chapter 5.

2.2 Measures

2.2.1 Strengths and Difficulties Questionnaire

Overview

The Strengths and Difficulties Questionnaire (SDQ) is a tool used to screen children and adolescents aged 4-17 years of age for potential mental health and behavioural problems. The parent-completed version consists of five components which rate four areas of difficulties (emotional symptoms, conduct problems, hyperactivity, and peer problems) and prosocial behaviour.

Each subscale consists of five items which are rated on a three-point where the respondent indicates whether the statement is not true, somewhat true, or certainly true. Item scores are added to produce a component score ranging from 0-10 which are grouped into ‘close to average’, ‘slightly raised’, ‘high’, and ‘very high’ (R. Goodman, 2015).

The sum of the difficulties components produces a total difficulties score ranging from 0-40. The problems components can be further grouped into internalising (emotional symptoms and peer problems) and externalising scores (hyperactivity and conduct problems) (Goodman et al., 2010). It has been widely used by researchers and clinicians and has been normalised on a UK population (Goodman et al., 2000).

The questionnaire and scoring instructions are shown in Appendix A.

Operationalisation

Parent- (from age 5), teacher- (from age 7), and self-rated SDQ (at age 11 years) questionnaires were available. In Chapters 3 and 4, SDQ scores from ages 7 and 11 were used and Chapter 5 used scores from ages 5, 7, and 11. For consistency, only parent-rated SDQ was used in the analyses. In the MCS data available from the UK Data Service, the individual SDQ items had been combined to create the total scores for each of the subscales, and the subscales added to create the total difficulties score. Estimates for specific subscales of the SDQ as well as the total difficulties scores were obtained to explore whether the PA/sedentary behaviour measure affected a particular aspect of children’s mental health functioning. In all analyses undertaken, SDQ scores were treated as continuous.

2.2.2 PA variables for objective analyses

Calibration study

In order to calibrate the Actigraph accelerometers and to determine appropriate intensity thresholds for the PA undertaken by children aged 7 years, a study was designed and undertaken whereby accelerometer counts were measured against energy expenditure. Seven- and eight-year-old children (n=53) at a school in North London engaged in seven activities (lying down watching television, sitting and playing a computer game, slow walking, brisk walking, jogging, hopscotch, and basketball) while wearing an Actigraph GT1M accelerometer and a COSMED K4b2 portable metabolic unit. Cut-offs were defined as <100 counts per minute (CPM) for sedentary behaviour and <=2240, <=3840, and >= 3841 for light, moderate, and vigorous activity, respectively (Pulsford et al., 2011).

In the literature, suggested cut-offs for children aged 7 were similar in CPM for vigorous activity but lower in CPM for moderate levels (Troiano et al., 2008), while others report much higher cut-offs for moderate activity (>3600 CPM) (Chris J Riddoch et al., 2007). Comparable cut-offs have been reported for a group of children aged 5-8 using the same method of calibration (COSMED portable metabolic unit) as in the MCS calibration study: 0-100, 101-2295, 2296-4011, and >4011 CPM for sedentary, light, moderate, and vigorous, respectively (Evenson et al., 2008). The comparison here is not intended to be exhaustive but illustrates the point that different cut-offs have been reported and can affect our understanding of PA intensity levels, and that this must be considered when interpreting results.

Weighted PA measures

Variables with the total valid time worn and minutes spent at the different levels of intensity were available in the dataset. Because the accelerometers were not worn for the same length of time or number of days for all children, the variables had to be standardised for wear time. The Technical Report (2013) for the MCS PA monitoring study provides details on how weights were defined to produce variables giving the total number of minutes at a given intensity with a standard day of duration (L. Griffiths et al., 2013). The syntax provided is shown in Appendix A and provides the code for creating these variables in Stata.

I used this syntax to create the summary variables, giving the weighted mean number of minutes spent at each intensity and created a new variable combining the minutes in the moderate and vigorous categories to produce an MVPA variable. The number of sedentary minutes was divided by 60 to make each unit correspond to one hour; light minutes by 30; and MVPA by 15. This was done in order to make the units more meaningful in the context of activity duration in the regression models, as well as to make each unit of activity at each intensity closer to the standard deviation: sedentary minutes (SD=50.12); light minutes (SD=38.25); MVPA (SD=22.22). These were the PA/sedentary time exposure variables used in chapters 3 and 4.

2.2.3 Correlates of PA, sedentary behaviour, and mental health: confounders and mediators

The variables described in this section were identified in section 1.5 as correlates of both PA/sedentary behaviour and mental health in children. Based on the evidence reviewed and the conceptual framework proposed in section 1.7.1, I modelled all factors as potential confounders in the relationship. A confounder is a variable that is associated with both exposure and outcome, and is not on the hypothesised pathway (MacKinnon, Krull, & Lockwood, 2000). Self-esteem, cognition, and body composition were identified in the literature as possible mediators; although, the treatment of mediators and confounders are identical statistically, and they differ only on conceptual grounds (MacKinnon et al., 2000). I grouped these factors into the categories previously described: children's biological and genetic characteristics, household demographic and family characteristics, maternal characteristics, and environmental characteristics. Unless otherwise stated, variables were available at MCS3 (age 5), MCS4 (age 7), and MCS5 (age 11).

Children's characteristics

For the child's ethnicity, the six-category ethnic grouping variable was used (white; mixed; Indian; Pakistani and Bangladeshi; black or black British; other). The child's age variable was rounded to the nearest tenth of a year. The child's weight status variable was created from the MCS obesity flag and dichotomised to limit small group sizes: non-overweight and overweight/obese. Parents were asked whether a long-standing limiting illness (LSLI) limited their child's activity; response options were 'No limiting illness', 'No, not at all', 'Yes, a little', or 'Yes, a lot'. The two categories of 'yes' responses were combined to limit small group sizes, giving three categories. Respondents were asked whether their child had Special Educational Needs (SEN) and a binary variable was available at ages 7 and 11.

The self-esteem variable (available at MCS5 only) is a reduced form of the ten item Rosenberg Self-Esteem Inventory (RSE) (Rosenberg, 1965), and consists of four items (e.g. 'I feel that I am a person of worth, at least on an equal plane with others'), each on a four-point scale (strongly agree, agree, disagree, strongly disagree), with the scores added to produce a self-esteem scale (Cronbach's alpha = 0.68). Cognitive ability was measured using two of the British Ability Scales (BAS) sub-tests at the age 7 survey: pattern construction, which measures spatial problem solving, and word reading, which measures educational knowledge of reading (Connelly, 2013). Variables with the age-based, standardised t-scores from the BAS pattern and reading tests at age 7 were provided in the MCS data.

Household characteristics

The evidence is equivocal as to whether family composition (including family structure and number of siblings) affects SDQ scores beyond what can be attributed to material advantage (R. H. Bradley & Corwyn, 2002; Brodersen et al., 2005; Kiernan & Mensah, 2009; Lipman et al., 2002; Anna Pearce et al., 2014; Spencer, 2005). The evidence, however, that poor children have worse mental health and SDQ outcomes is widely reported (Kiernan & Mensah, 2009; A. Pearce et al., 2013).

At each sweep, the two variables identifying the residence status of the natural mother and father were combined to create a binary family structure variable where both natural parents were resident in the household full-time or not. The number of siblings in the household was also considered (where there were more than four, these were combined into a 4+ category). Poverty at MCS3-5 was a binary variable indicating whether the cohort family income was below 60% of the UK median family income, based on scales from the Organisation for Economic Co-operation and Development (OECD).

Maternal characteristics

Maternal characteristics play an important role in children's mental health; there is evidence, particularly in girls, that maternal education might affect health-promoting behaviours (L. B. Sherar et al., 2009) and maternal employment improves SDQ scores (A. McMunn et al., 2012). Maternal depression is an established determinant of children's mental health and cognitive development and will be important to consider in the relationship between PA and mental health (Mensah & Kiernan, 2010).

Maternal depression at all three sweeps was measured using the Kessler-6 scale, which is used to identify individuals who are at higher risk of mental health issues. The scale was dichotomised into higher likelihood of serious mental illness (SMI) and lower likelihood of SMI, based on the cut-offs in the 0-24 scale where a score of 13+ indicated higher likelihood of SMI (Kessler et al., 2003). A binary maternal education variable was created by combining the top levels (degree and higher degree) of highest academic qualification obtained at MCS3, 4, and 5 into one category and combining the remaining categories (A-levels/HE diploma, GCSE A-C, GCSE D-G, other, and none) into the other. Maternal employment is a binary variable stating whether or not the mother was in work at MCS3, 4, and 5.

Neighbourhood characteristics

The neighbourhood environment is a potentially important determinant of well-being, and evidence suggests that environmental characteristics such as access to parks, traffic-controlled walking routes, and low incidence of crime or even perceived neighbourhood safety, for example, can affect both mental health and the types and frequency of PA participation (Lachowycz & Jones, 2011; J. F. Sallis et al., 2000). In Chapter 4, the role of green space, urban/rural classification, and area deprivation in the relationship between PA and mental health will be explored.

Ward-level green space in deciles for the whole of the UK linked to MCS sweeps 1-5 are publicly available via the UK Data Service. The lowest decile corresponds to areas with <21% green space coverage, and >94% green space coverage in the highest decile (Eirini Flouri, Papachristou, & Midouhas, 2018). The green space variable at age 7, contemporaneous with the PA study, was used for these analyses. Rural-urban classification variables are available for all four countries in the MCS data. Country-specific deprivation variables ranked in deciles were available in the MCS data. Because of their potential importance to PA levels, neighbourhood variables at age 7 were used so they were contemporaneous with the accelerometry data.

2.3 Statistical methods

2.3.1 Missing Data

Missing data are an issue in many studies and there are a number of strategies to deal with these depending on the mechanisms behind the missingness. There are three classifications for missing data mechanisms: missing completely at random (MCAR), missing at random (MAR), and missing not at random (MNAR). Data are MCAR when there are no systematic differences between the observed and unobserved values. MAR occurs when the systematic differences between the observed and unobserved values can be explained by the observed data. MNAR occurs when systematic differences between observed and unobserved values remain after accounting for observed data. Complete case analysis (where subjects with missing data are excluded) is one approach to deal with missingness, however this can lead to bias if data are not MCAR and the subjects with missing data differ from the complete cases. Exclusions can also lead to a loss of power if a large proportion of the sample are missing data. The precise mechanism behind the missingness is usually unknown, and whether data are MAR or MNAR is difficult to distinguish with observed data. Thus, the assumption is often made that data are MAR, which allows for different statistical approaches to modelling missing data that incorporate observed information into the model.

Multiple imputation is a method that accounts for the uncertainty around the missing data by creating multiple copies of the dataset, imputing values for missing data based on the observed data, and pooling them (Sterne et al., 2009). Imputation models use variables with complete data to predict the missing data, predicated on the MAR assumption that unobserved values are dependent on the observed values. The estimation model is subsequently fitted to each of the imputed datasets and these are combined to obtain an average overall estimate of the datasets. Rubin's rules take account of the variability in the results between imputed datasets (D. B. Rubin, 2004).

An alternative method for dealing with missing data is full information maximum likelihood (FIML) estimation. FIML estimates a likelihood function for each participant based on the available data so all observed data are used (Jakobsen, Gluud, Wetterslev, & Winkel, 2017). Its advantage compared with multiple imputation is that it does not require the step of imputation followed by analysis, and it can be used to simultaneously estimate multiple regression parameters. With the assumption that data are MAR, FIML produces less biased estimates than listwise or pairwise deletion, and produces results similar to that of multiple imputation methods (Enders & Bandalos, 2001).

With longitudinal data, missing data can take the form of unit non-response and item non-response. Unit non-response occurs when the participant is lost to follow-up and all data are missing for that point in time. Item non-response is when an observation is missing for a given number of variables.

In chapters 3 and 4, multiple imputation was used to handle to item missingness in the analyses using objective PA measures. Within the analytic sample, PA measures were complete for all children; item missingness was low (between <1%-7% with most covariates complete for all children). Full details on item missingness are presented in 3.3.1. A large number of children, however, were excluded from the analytic sample. To handle unit non-response, specific weights for the accelerometer-measured analyses were generated to account for both non-response at MCS5 and non-compliance with the PA study at MCS4, which is described in section 2.1.1.

In chapter 5, where reported PA measures are used at three time points, FIML is used to handle item missingness due to the complexity of the panel model, and unit attrition between MCS3-5 was accounted for by applying specific weights for response at age 11 (Mostafa, 2014).

2.3.2 Statistical analysis

Weights

Due to the stratified clustered sample design described in 2.1, children born to families in wards in the smaller countries and within the disadvantaged and ethnic minority strata had higher probabilities of selection. To account for the disproportionate stratified clustering, as well as unit non-response and study non-compliance (where applicable), standardised weights have been applied to all analyses. Detailed information on how the weights were derived can be found in the MCS Technical Report on Sampling (Plewis et al., 2007).

Models

In Chapter 3, multiple linear regression models were fitted to examine the association between sedentary time, light PA, and MVPA and each of the SDQ subscales using imputed datasets. Multiple imputation was performed in Stata/SE 15.1, using ***mi*** commands. Twenty imputed datasets were built using the weighted iterative chain algorithm, and estimates were combined using Rubin's rule. All variables modelled in the analyses using multiply imputed data were included in the imputation procedure.

Two-level, random intercept models were fitted in Chapter 4 to examine the association between sedentary time, light PA, and MVPA and each of the SDQ subscales, and to estimate the between-individual and -area variances using imputed datasets.

Cross-lagged, three wave panel models were run in Chapter 5 to obtain multiple regression parameters (unstandardized linear regression coefficients and ordinal logistic odds ratios) using reported PA and sedentary behaviour variables and the SDQ subscales using full information maximum likelihood estimation.

Full details of these models can be found in sections 3.2.3, 4.4.2, and 5.3.3.

2.3.3 Software

Analyses for Chapters 3 and 4 were conducted with Stata/SE 15.1. Descriptive statistics in Chapter 5 were obtained using Stata/SE 15.1; multivariable model estimates in Chapter 5 were obtained using MPlus version 6.12 (Muthén and Muthén, 1998-2011).

3 Investigating the relationship between objectively-measured physical activity, sedentary behaviour and SDQ outcomes

3.1 Introduction

When evaluating PA levels in young children, using objective measures has particular advantages. While adults are more likely to engage in structured and volitional PA, much of children's activity is incidental and sporadic in nature (Stuart JH Biddle et al., 2011). Where objective PA and sedentary measures are not used, there might be an over- or underestimation of PA and a misunderstanding of its effects on health outcomes.

While the use of objective PA measures in research avoids some of the biases of reported measures, they are not without their drawbacks. Portable metabolic systems, for example, are highly accurate for measuring energy expenditure; however, they are expensive and resource-intensive, requiring fitting and supervision (Pulsford et al., 2011). Methods such as these are intended for monitoring over shorter periods of time and on smaller sample sizes. Population-based studies have generally favoured less costly and more acceptable methods such as pedometers and accelerometers for objective-PA measures. Accelerometers have been favoured and used on a number of larger PA monitoring studies in children because of their, portability, validity, and acceptability (L. J. Griffiths et al., 2013; C. J. Riddoch et al., 2004; Chris J Riddoch et al., 2007; Troiano et al., 2008).

In Chapter 1, I described a growing body of literature on the relative benefits of PA on mental health outcomes in children but only a minority used objective measures (Martikainen et al., 2012; A. S. Page et al., 2010; Parfitt & Eston, 2005) and, of these, none used longitudinal data. Given the shortfall in the evidence, the aim of this chapter is to investigate the relationship between accelerometer-measured PA/sedentary behaviour and SDQ outcomes in UK children using a population-based sample. Analyses in this chapter will incorporate longitudinal measures of SDQ to determine if PA at age 7 is related to SDQ at age 11, while controlling for SDQ at age 7. Using the conceptual framework previously described in section 1.7.1, I will explore whether the dimensions of duration and intensity of PA/sedentary behaviour captured by the accelerometers are associated with mental health.

3.1.1 Objectives

Towards this aim, the following objectives will be undertaken in this chapter:

1. To describe the characteristics of the sample in relation to objectively-measured PA and mental health;

2. To describe the relationship between minutes of PA at different intensities (and sedentary behaviour) and mental health in children;
3. To estimate the effects of PA duration and intensity, and sedentary time, on mental health outcomes, adjusting for important individual characteristics and household socio-economic factors.

3.2 Methods

In the previous chapter, I described how the analytic sample was derived for the following analyses, and how the PA study-specific weights were generated. I defined the PA/sedentary behaviour exposures and the SDQ outcomes, and provided an overview of the potential confounders. In this section, I will set out the details of the analytic strategy and describe the specific models used in the analysis.

3.2.1 Cross-sectional analyses

Cross-sectional, descriptive analyses were undertaken using survey (`svy`) commands with the MCS weights accounting for survey design, study non-compliance, and unit non-response in Stata/SE 15.1. Descriptive tables were produced by estimating weighted proportions for each categorical variable and estimating weighted means for the continuous variables, by gender. Continuous variables included SDQ scores, minutes spent in sedentary, light, moderate, and vigorous activity, child's age to nearest tenth of year, self-esteem score, pattern construction score, and word reading score. Categorical variables included season activity monitoring was conducted, ethnicity, obesity, SEN, LSLI, income poverty, family structure, number of siblings, maternal education, maternal employment, and maternal depression. Gender differences were tested using a corrected weighted Pearson's chi-square statistic (design-based F statistic).

Bivariate analyses were conducted to describe the characteristics of children in relation to their PA/sedentary behaviour and mental health, and to quantify the relationship between the activity and mental health variables available in the dataset. Pearson's correlation coefficients were obtained to estimate the bivariate associations between PA/sedentary behaviour, SDQ, and continuous correlates. A simple linear regression model was run with categorical correlates as the predictor and PA variables and SDQ scores as continuous outcomes to produce effect estimates.

Variables

As outlined in the literature review, a range of variables were identified as important correlates and potential confounders of PA/sedentary behaviour and mental health. The operationalisation of these variables is described in section 2.2.3. Child characteristics included season of accelerometer wear (spring, summer, autumn, winter), ethnicity (white; mixed; Indian; Pakistani or Bangladeshi; black or black British; other), age to the nearest tenth of year, whether longstanding limiting illness (LSLI) affecting activity (no LSLI; yes – does not affect activity; yes – affects activity), whether the child had special educational needs (SEN), child's cognitive ability (age-standardised reading ability and pattern construction from the British Ability Scales; BAS), self-esteem (revised, five-item version of the Rosenberg self-esteem scale, alpha=0.679), and weight status (not overweight or overweight/obese). Maternal characteristics included employment (in work or not), depression (measured using the Kessler (K6) scale and dichotomised ('normal', 'higher likelihood of serious mental illness'), and highest level of educational attainment (degree educated or no degree). Household factors included family structure (both natural parents resident full time or not), number of siblings, and income poverty (household income below 60% of the UK median household income). Time-varying characteristics (LSLI, SEN, self-esteem, weight status, maternal employment, maternal depression, family structure, number of siblings, income poverty) for children and families were measured when the children were aged 11 years, except for children's cognitive ability, which was measured at age 7.

3.2.2 Missing data and imputation strategy

Of the 6,153 children included in these analyses, data were complete for all children for all physical activity and sedentary variables, sex, ethnicity, family composition, household income, number of siblings, and long-standing limiting illness. Data were missing for the following: emotional problems 2.2% (n=138); peer problems 2.2% (n=137); conduct problems 2.3% (n=139); hyperactivity 2.4% (n=147); total difficulties at MCS5 2.5% (n=151); total difficulties at MCS4 1.7% (n=107); SEN <0.1% (n=42); maternal employment 1.4% (n=88); maternal education 0.1% (n=6); Kessler K6 4.5% (n=275); BAS pattern construction 0.6% (n=34); BAS word reading 1.7% (n=106); self-esteem 6.7% (n=414); weight status 1.9% (n=119). Multiple imputation was performed to mitigate possible bias due to item non-response. Twenty imputed datasets were built using the weighted iterative chain algorithm, and estimates were combined using Rubin's rule–see section 2.3.1 for details. Two additional variables were created from the sum of the imputed variables: the Kessler-6 scale from the sum of the items, and total difficulties at MCS5 from the sum of the individual subscales.

Survey weights were applied to the imputation model to account for the sampling design, non-compliance in the accelerometer study, and non-response at MCS5.

3.2.3 Longitudinal modelling

In order to longitudinally assess whether PA at age 7 is associated with SDQ subscale scores at age 11 – models were adjusted for total difficulties score at age 7, as earlier mental health is a major determinant of subsequent mental. Rather than adjusting for the subscale at the previous sweep of the outcome in question, the total difficulties scores were used because of the possibility that an underlying mental health disorder might have different manifestations at different points in time. For example, conduct problems in childhood have been linked to depression in adolescence, depression with later anxiety, and ADHD with later oppositional defiant disorders (Costello, Mustillo, Erkanli, Keeler, & Angold, 2003; Stringaris, Lewis, & Maughan, 2014). The continuity from one diagnosis to another is termed heterotypic continuity has been observed across developmental stages in childhood or in transitions from childhood to adolescence to adulthood (Costello et al., 2003; Rutter, Kim-Cohen, & Maughan, 2006; Stringaris et al., 2014). Total difficulties at age 7 was included in all adjusted regression models. Observed effects of the PA and sedentary behaviour variables on SDQ scores could thus be ascribed to the independent variable in question rather than previous mental health status.

The longitudinal models were run using linear regression on imputed datasets (`mi estimate, svy: regress`) to estimate the association between PA/sedentary time at age 7 and SDQ outcomes at age 11. As explained in section 1.7.1, where the conceptual framework was outlined, subsets of variables were defined and these were progressively added to the models in a step-wise fashion, with more proximal child characteristics added first, extending outwards to the distal characteristics. The exception to this is the addition of self-esteem, weight status, and cognitive function, which were added in the final model.

The season that the activity monitor was worn was also included *a priori* into all adjusted regression models, given the importance of seasonal variation in PA (Atkin, Sharp, Harrison, Brage, & van Sluijs, 2015), and was defined as follows: Spring (21 March – 20 June); Summer (21 June – 20 September); Autumn (21 September – 20 December); Winter (21 December – 20 March).

While gender differences in both activity behaviours and mental health outcomes have been established in the literature (S. J. Biddle & Asare, 2011; Brodersen et al., 2005; K. R. Hesketh et al., 2014), a formal test for interaction was initially included in unadjusted models. Gender interactions were significant for sedentary time and emotional ($p<0.05$) and peer problems ($p<0.01$); for light PA and emotional problems ($p<0.05$); and for MVPA and peer problems ($p<0.001$) and total difficulties ($p<0.05$). Despite the absence of significant gender interactions in the other PA levels and SDQ subscales, models were run separately for boys and girls for consistency across models, and to highlight where pathways between activity and mental health might be gender specific in the presence of additional confounders. Initially, a minimally-adjusted model was run to measure the effect of PA/sedentary behaviour on SDQ. Subsequent models added the child, household, and maternal characteristics to observe any attenuation in effects. Potential mediators were added last to avoid effects in the main relationship being obscured by any indirect effects.

The models were run as follows:

i. Model 1: age, season, SDQ total difficulties score at MCS4
ii. Model 2: Model 1 + ethnicity, child disabilities (LSLI, SEN)
iii. Model 3: Model 2 + income poverty, number of siblings, family structure
iv. Model 4: Model 3 + maternal education, maternal employment, maternal depression
v. Model 5: Model 4 + obesity, self-esteem, cognitive scores

Unstandardised regression coefficients for each of the continuous SDQ dependent variables (four subscales and total difficulties) were obtained for each of the three summary PA/sedentary time variables as the independent variable.

3.3 Results

3.3.1 Descriptive characteristics

The following section will describe the characteristics of the sample with respect to PA, mental health, and potential confounders.

Table 3-1 below shows the descriptive characteristics of the sample (n=6,153). Weighted means (standard deviations) are presented for continuous variables (SDQ scores; minutes spent in sedentary, light, moderate, and vigorous activity; child's age to nearest tenth of year; pattern construction score; word reading score; and self-esteem score) and the weighted distribution (unweighted observations) for the categorical variables (season, ethnicity, obesity, SEN, LSLI, income poverty, maternal education, maternal employment, and maternal depression).

Table 3-1: Descriptive characteristics of the sample by gender

	Boys (n=2,994)			Girls (n=3,159)		
	% (N)	*Mean*	*SD*	*% (N)*	*Mean*	*SD*
Strengths and Difficulties Questionnaire (age 11)						
Emotional symptoms		1.79	1.92		1.89	2.09
*Peer problems **		1.47	1.72		1.28	1.65
*Conduct problems ****		1.54	1.59		1.26	1.51
*Hyperactivity ****		3.56	2.46		2.66	2.33

	Boys (n=2,994)			Girls (n=3,159)		
	% (N)	Mean	SD	% (N)	Mean	SD
*Total difficulties ****		8.36	5.80		7.08	5.69
Total difficulties (age 7)***		8.05	5.50		6.67	4.94
Physical activity variables						
*Sedentary time ****		382.05	48.99		399.09	50.54
*Light PA **		282.83	37.67		279.46	39.69
*MVPA ****		70.06	22.76		56.25	19.86
Age (to the nearest 10th of year)		11.15	0.32		11.15	0.33
British Ability Scales pattern construction score		53.78	10.73		54.27	10.32
British Ability Scales word reading score **		111.95	18.40		113.8	16.49
Self-esteem *		13.49	1.71		13.34	1.83
Season accelerometer was worn						
Summer	47.2 (1,330)			44.2 (1,366)		
Autumn	31.6 (929)			35.4 (1,047)		
Winter	9.6 (401)			9.4 (405)		
Spring	11.7 (334)			11 (341)		
Ethnicity						
White	85.1 (2,650)			85.0 (2,773)		
Mixed	3.3 (77)			2.8 (76)		
Indian	1.9 (55)			2.4 (76)		
Pakistani or Bangladeshi	5.3 (112)			4.9 (123)		
Black or Black British	3.1 (65)			3.1 (69)		
Other Ethnic group	1.3 (35)			1.9 (42)		
Child has special educational needs (SEN) ***						
No	87.3 (2,655)			93.4 (2,978)		
Yes	12.7 (339)			6.6 (181)		
Does LSLI limit your child's activity? ***						
No limiting illness	85.4 (2,576)			89.5 (2,833)		
No	7.2 (221)			6.2 (190)		
Yes	7.4 (197)			4.3 (136)		
Household income below 60% of the UK median household income						
No	81.8 (2,651)			80.5 (2,771)		
Yes	18.2 (343)			19.5 (388)		
Number of siblings in the household						
0	11.5 (329)			12.1 (361)		
1	44.8 (1,434)			45.1 (1,492)		
2	26.5 (788)			26.9 (874)		
3	12.7 (314)			10.3 (306)		
4+	4.6 (129)			5.6 (126)		
Both natural parents resident in household full-time						
No	36.2 (801)			35.9 (821)		
Yes	63.8 (2,193)			64.1 (2,338)		
Highest academic qualification mother attained up to MCS5						
No degree	81.3 (2,167)			81.0 (2,292)		
Degree or higher	18.7 (827)			19.0 (867)		
Mother in work						

	Boys (n=2,994)			Girls (n=3,159)		
	% (N)	Mean	SD	% (N)	Mean	SD
No	31.0 (702)			31.6 (772)		
Yes	69.0 (2,202)			68.4 (2,286)		
Maternal depression - Kessler K6 score						
Normal (0-12)	94.6 (2,708)			94.2 (2,861)		
Higher likelihood of serious mental illness (13+)	5.4 (119)			5.8 (122)		
Child's weight status ***						
Not overweight	75.7 (2,291)			70.2 (2,289)		
Overweight/obese	24.3 (650)			29.8 (804)		

Missing observations % (n) all children: Emotional problems 2.2% (138); peer problems 2.2% (137); conduct problems 2.3% (139); hyperactivity 2.4% (147); total difficulties at MCS5 2.5% (151); total difficulties at MCS4 1.7% (107); SEN <0.1% (42); maternal employment 1.4% (88); maternal education 0.1% (6); Kessler K6 4.5% (275); BAS pattern construction 0.6% (34); BAS word reading 1.7% (106); self-esteem 6.7% (414); weight status 1.9% (119)
** p<0.05, ** p<0.01, *** p<0.001; indicating sex differences using design-based F statistic*

Across all SDQ subscales except emotional problems, boys had higher mean scores than girls. Girls had a higher mean of daily sedentary minutes and lower means for all levels of PA than boys. Girls had higher mean scores than boys for reading assessments, but pattern construction scores did not significantly differ. Boys reported higher self-esteem than girls.

Most children undertook the PA measurement portion of the study in the summer (47% of boys, 44% of girls) and autumn (32% of boys, 35% of girls). The majority of children were White (85%). Over 12% of boys and 6% of girls had SEN; more than 14% of boys and 12% of girls had LSLI. More than 18% of children lived in households below 60% of the UK median income. About 64% of children lived with both natural parents, and 12% had no siblings. In this sample, approximately 19% of mothers were educated to degree levels, 69% were employed, and 5% were depressed.

3.3.2 Bivariate analysis

Relationship between objective PA, SDQ, and confounders

Table 3-2 and Table 3-3 in Appendix B show the correlation coefficients between PA, SDQ, and continuous confounders by gender.

For boys, peer problems were negatively correlated with MVPA, while conduct problems and hyperactivity were positively correlated with light and MVPA. Total difficulties were positively correlated with light PA. Conduct problems, hyperactivity, and total difficulties were negatively correlated with sedentary time. For girls, increased light and MVPA was correlated with more conduct problems, hyperactivity, and total difficulties. There was no correlation between peer problems and sedentary time or PA in girls. No relationships with PA variables and emotional problems were observed for either boys or girls.

In both boys and girls, PA variables were highly intercorrelated. Particularly between sedentary and light minutes, there was a very high negative correlation in both boys and girls (-0.889 and -0.925, respectively), precluding their inclusion in the same models.

Self-esteem and cognitive ability (pattern recognition and reading scores) in both genders showed strong negative correlations with all SDQ scales. In boys, cognitive ability was also positively correlated with sedentary time and negatively with light PA and MVPA.

The same relationships were observed for girls except light activity was not correlated with pattern construction scores. Self-esteem was not correlated with either sedentary time or PA in either gender.

Full correlation matrices are available in Table 3-2 and Table 3-3 in Appendix B.

Association between categorical confounders and SDQ

The results of the bivariate linear regression models estimating the associations between categorical confounders and SDQ are shown in Table 3-4 and Table 3-5 in Appendix B. Ethnicity was associated with conduct problems only in boys ($p=0.012$) and peer problems in girls ($p=0.032$). Children with SEN and LSLI had higher scores in all SDQ subscales ($p<0.01$). Children in income poor households and without both natural parents resident had worse mental health across all subscales ($p<0.01$). Number of siblings in the household was associated with all SDQ subscales in boys ($p<0.05$) and peer and conduct problems and total difficulties in girls ($p<0.001$); generally, having one sibling only improved scores while having 4+ significantly worsened scores. Children whose mothers had a degree, were in work, or were not depressed were less likely to have mental health problems ($p<0.001$). Overweight and obesity in boys was associated with more peer problems; girls' emotional, peer, and conduct problems and total difficulties scores were associated with overweight and obesity.

Association between categorical confounders and PA

Table 3-6 in Appendix B shows the regression coefficients for the relationship between categorical covariates and sedentary and PA variables for boys and girls.

For both genders, ethnicity was associated with sedentary ($p<0.05$) and light PA ($p<0.01$) but not MVPA. Having SEN was not associated with sedentary time or PA, and having LSLI was only associated with less MVPA in boys ($p=0.007$). Income poverty was associated with more MVPA in boys ($p=0.001$), and less sedentary time, more light PA, and MVPA in girls ($p<0.01$). Number of siblings was not associated with sedentary time or activity in boys, while girls with more siblings were less sedentary ($p<0.001$) and more lightly active ($p=0.002$). Girls with both parents resident in the household did less MVPA ($p<0.001$) but no other associations were observed. Children whose mothers had degrees were more likely to be sedentary (p<0.01) and less likely to do light PA (p=0.003), but maternal education was not associated with MVPA. Maternal employment was not associated with sedentary time or PA for either boys or girls, and maternal depression was associated with less sedentary time (p=0.007) and more light PA (p=0.005) in girls only. Overweight/obesity was associated with more light PA and less MVPA in boys (p=0.002); weight status was not associated with sedentary time and activity in girls.

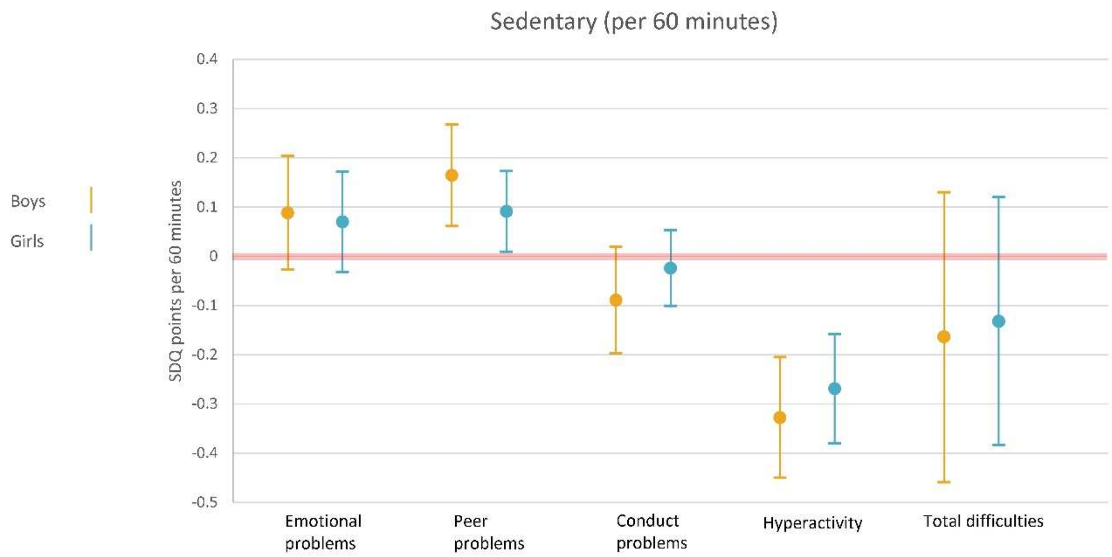
3.3.3 Multiple linear regression analyses

Multiple linear regression analyses were conducted with each of the PA variables (sedentary, light, and MVPA) as the main independent variable and each SDQ subscale at age 11 as the dependent variable. Models were first adjusted for age, season the PA monitoring took place, and SDQ total difficulties at age 7. Subsequent models were adjusted for covariates grouped into child characteristics, household characteristics, maternal characteristics, and potential mediators, which were added cumulatively to each model. All analyses were run separately by gender. Full estimates from the multiple linear regression models are presented in Table 3-7 and Table 3-8 in Appendix section II.

Sedentary minutes

The figure below shows the change in SDQ scores for each subscale per 60-minute increase in sedentary time. The point indicates the value of the unstandardized regression coefficients and the bars indicated the 95% confidence intervals of the estimate. Where the 95% CI crosses the y-axis line marked ‘0’, the estimate is not statistically significant. All estimates in the figures below are fully adjusted.

Figure 3-1: Change in SDQ scores per 60-minute increase in sedentary time, fully adjusted model

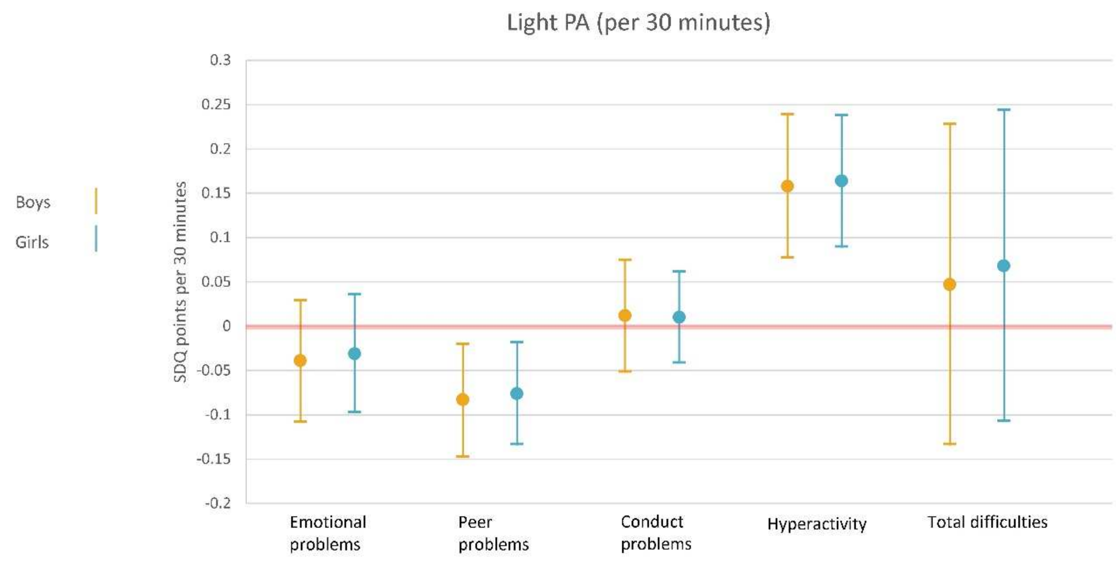


For boys and girls, a 60-minute increase in sedentary time at age 7 was associated with an increase in peer problems (b=0.164, 95% CI 0.061, 0.268 in boys; b=0.091, 95% CI 0.009, 0.173 in girls) and a decrease in hyperactivity (b=-0.328, 95% CI -0.450, -0.205 in boys; b=-0.269, 95% CI -0.380, -0.158 in girls) at age 11. No other associations between sedentary and SDQ scores were observed in the fully adjusted models. The estimates for all models are presented in Table 3-7and Table 3-8 in Appendix B section II.

Light minutes

Figure 3-2 below shows the change in SDQ scores per 30-minute increase in light PA in the fully adjusted model.

Figure 3-2: Change in SDQ scores per 30-minute increase in light PA, fully adjusted model



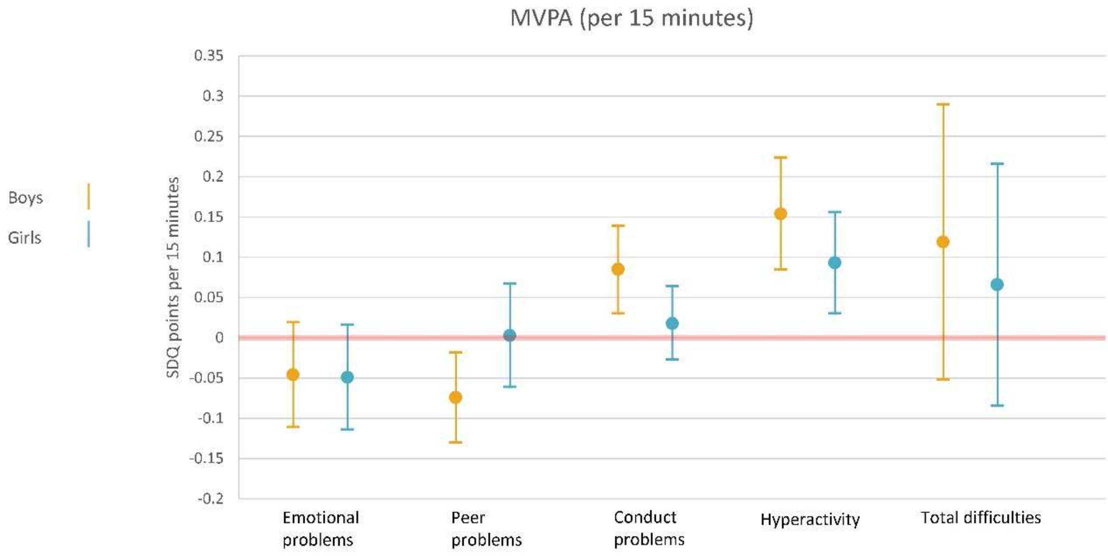
A 30-minute increase in light PA at age 7 was associated with a decrease in peer problems (b=-0.083 95% CI -0.147, -0.020 in boys; b=-0.076, 95% CI -0.133, -0.018 in girls) at age 11. Increases in light PA at age 7 was associated with increased hyperactivity (b=0.158, 95% CI 0.078, 0.239 in boys; b=0.164, 95% CI 0.090, 0.238 in girls) at age 11.

No additional relationships were observed between light PA and the other SDQ subscales.

MVPA

Figure 3-3 below shows the change in SDQ scores per 15-minute increase in MVPA in the fully adjusted model.

Figure 3-3: Change in SDQ scores per 15-minute increase in MVPA, fully adjusted model



For boys, increased time in MVPA at age 7 was associated with fewer peer problems (-0.074 points per 15 minutes, 95% CI -0.130, -0.018) and more hyperactivity (0.154 points per 15 minutes, 95% CI 0.085, 0.224) at age 11 in the fully adjusted models. Additionally, more conduct problems were also reported with increased MVPA (0.085 points per 15 minutes, 95% CI 0.030, 0.139).

For girls, only hyperactivity was associated with MVPA, where each additional 15 minutes MVPA was associated with a 0.093 (95% CI 0.030, 0.156) point increase. MVPA was predictive of more conduct problems in models 1 and 2 (adjusting for individual characteristics) but this was not significant after adjusting for maternal characteristics.

3.4 Discussion

3.4.1 Summary of results

In this chapter, using multivariable linear regression models, objectively-measured PA variables and SDQ scores, I explored whether the duration of sedentary behaviour, light PA, and MVPA at age 7 were associated with mental health outcomes at age 11. By examining each of the SDQ subscales as a separate outcome, I was able to observe that their relationships with PA and sedentary behaviour were not consistently in the expected direction: peer problems increased with less activity and more sedentary time; however, hyperactivity scores were lower in less active children.

The evidence that low levels of PA and high sedentary time in boys is potentially detrimental to their peer relations is strong, as the relationship was significant across all intensities of activity and in all adjusted models. Although not with MVPA, this relationship was observed in girls in the fully adjusted model as well.

The results demonstrated positive associations between both light activity and MVPA and hyperactivity in boys and girls. Similarly, sedentary time was negatively associated with hyperactive symptoms.

Only boys' MVPA was positively associated with more conduct problems. There were no relationships observed between emotional problems and total difficulties and either sedentary or active time in any of the models.

3.4.2 Comparisons with other findings

I found that increased sedentary time was associated with fewer hyperactive symptoms (while the reverse was true of more PA), and more conduct problems were observed in boys who engaged in more MVPA. Similar findings have been reported in other studies. Cross-sectional analyses on MCS children examining the effect of SDQ on PA found that externalising (hyperactivity and conduct problems) scores in both boys and girls were associated with a lower likelihood of being sedentary at age 7 (L. Griffiths et al., 2016). Several studies have also reported associations between higher levels of PA and, specifically, the hyperactivity subscale in children (Brodersen et al., 2005; L. Griffiths et al., 2016; van Egmond-Frohlich et al., 2012; Wiles et al., 2008). Rather than being detrimental to children's mental health function in the externalising domain, PA may be an outlet for hyperactivity or hyperactive symptoms classified as activity (Brodersen et al., 2005; L. Griffiths et al., 2016).

Accelerometer-measured increases in MVPA have been associated with improved emotional health in a cohort of 8-year old Finnish children, and inversely correlated with internalising difficulties in 10-11-year old children in the Avon Longitudinal Study of Parents and Children (Martikainen et al., 2012; A. S. Page et al., 2010). Findings from the present analysis show that MVPA was not associated with emotional problems in the fully adjusted models. In girls, this was surprising as studies have shown that the relationships between PA and emotional health were more pronounced in girls than boys (Brodersen et al., 2005).

A novel contribution of this thesis was that the inclusion of light PA measures in these analyses highlighted findings specific to PA intensity in a relatively neglected area of study. To my knowledge, no studies to date have examined the relationship between light PA and mental health outcomes in children. Light PA has been shown to be positively correlated with a range of factors such as sports participation, outdoor time, and reduced fat mass (Kwon, Janz, Burns, & Levy, 2011; van Sluijs et al., 2013) (Wilkie, Standage, Gillison, Cumming, & Katzmarzyk, 2018) through which improvements to mental health might be plausible.

Evidence of relationships between increased PA and reduced peer problems were present in both boys and girls, although only light activity was significant in girls. Furthermore, the effect size for MVPA was greater than light PA on peer problems for boys, demonstrating the importance of higher intensity activity. The literature supports these findings where higher intensity sport-specific activity was found to be protective in boys but not in girls (Tomson et al., 2003). Sedentary time was positively associated with peer problems in this study, but a study by Hinkley et al (2014) found only girls' peer problems increased with sedentary time (Hinkley et al., 2014).

The mechanisms behind these gender differences are complex and likely influenced by social and cultural norms, but it has been suggested that PA expectations may be different for boys and girls, and, as a result, can operate on mental health through different pathways (Lagerberg, 2005). For example, boys may be faced with more pressure or be expected to participate and perform well in organised sports or active games both in and outside of school (Ferron et al., 1999). In turn, this could lead to the consistently significant relationship between PA and peer relations in boys observed in this study.

The relationship between light PA and peer problems observed in girls is also important as it highlights the potential benefits of PA on peer relations in girls, who are less likely to be active. Qualitative work has shown that girls feel less supported in PA pursuits (Cardon et al., 2005), and the absence of expectation to participate might result in fewer benefits for their mental health – this might be some indication as to why there were no significant relationships observed for girls and MVPA, barring the hyperactivity subscale. Furthermore, because girls were less likely to engage in MVPA, there may not have been sufficient data to have observed any significant relationship in this domain.

A number of studies have reported null effects when reporting the association between PA and SDQ total difficulties (A. S. Page et al., 2010; Sagatun et al., 2007; Wiles et al., 2008) – given that the associations for the internalising and externalising subscales tended to be in opposite directions it is conceivable that, as in this study, any effects were likely neutralised.

3.4.3 Strengths and limitations

To my knowledge, this is the first study to explore the effects of objective PA on mental health using longitudinal measures in a nationally-representative, UK-based sample of children. By incorporating SDQ measures at age 11 and adjusting for previous mental health status, this study uses longitudinal data to understand how PA intensity and duration, and sedentary time might affect mental health through time. While other studies have reported relationships between PA and SDQ total difficulties only, with potentially important relationships going unobserved, this study has reported estimates for all subscales. In doing so, this study has shown that PA is potentially related to different aspects of mental health functioning in children.

In this study, PA and sedentary time were not included in the same models for both statistical and theoretical reasons. The objective PA and sedentary variables are examples of compositional data (where each comprises a proportion of a day), which have a negatively biased covariance structure and standard statistical methods should not be used (Leite, 2014). Collinearity is also problematic in simultaneously adjusting for compositional data (A. Page, Peeters, & Merom, 2015). Page et al (2015) point out that if PA is not a common cause of sedentary behaviour and the outcome, and is not an effect of sedentary behaviour on the causal pathway to the outcome, there is no need to adjust for PA (A. Page et al., 2015).

Self-esteem, cognitive ability, and body composition were treated as confounders in the final model to avoid making inferences about the direction of their effect on activity and mental health. However, some evidence suggests that activity can improve self-esteem and cognition, and reduce body weight, which would place these variables on the causal pathway. Adding mediators to the model would decrease the observable effect of PA/sedentary behaviour on mental health by partitioning the total effect into the direct and indirect effects (Richiardi, Bellocco, & Zugna, 2013; Schisterman, Cole, & Platt, 2009). Because of this, these variables were adjusted for in the final models (despite being proximal child characteristics), to avoid any effects of PA/sedentary behaviour on mental health being obscured by their addition. Nonetheless, after the addition of self-esteem, cognitive ability, and body composition were added to the model, the direction and significance of the associations observed were unchanged, and any effect size changes were small. For example, one hour increase of sedentary time resulted in a decrease in hyperactivity score of -0.291 (95% CI -0.406,-0.177) in girls in the model adjusted for all but the potential mediators, and -0.269 (95% CI -0.380,-0.158) in the fully adjusted model. Self-esteem, cognitive scores, and body composition were not strongly correlated (maximum $\rho=0.158$ ($p<0.001$) for reading scores and self-esteem in boys) see Table 3-2 and Table 3-3), thus, multicollinearity was not an issue.

Another limitation of the analysis is the long latent period between the PA study at age 7 and follow-up at age 11. Four years may be too long a period to observe effects of PA and sedentary behaviour levels on mental health. Interventions studies have shown that PA can have beneficial effects on depressive symptoms, however, the time span of the interventions were generally much shorter (Ahn & Fedewa, 2011). There is the possibility that the effects of PA or sedentary behaviour at age 7 on mental health at age 11 observed in these analyses may not have persisted or may have attenuated. If the effect of PA on mental health is short-term, this would have gone unobserved. Furthermore, the children's activity patterns may have changed over this period of time. Evidence suggests that physical activity levels decline from childhood to adolescence (S. J. Biddle et al., 2004; DeBate et al., 2009; Edwards et al., 2013), although there appear to be gender differences. In a study on activity tracking in early childhood, boys who were active at age 3 were more likely than girls to remain active by age 7; inactivity tracking was similar in boys and girls between ages 3 and 7 (Edwards et al., 2013). If PA and sedentary behaviour levels had substantially changed between sweeps, this would limit the conclusions that could be drawn on the strength of the relationship between activity and mental health. Nonetheless, there is no clearly defined 'optimal' time period between the measurement of PA/sedentary behaviour and follow-up, and further studies with repeated measures are needed to better understand the stability of PA/sedentary behaviour and the persistence of its effects.

An important strength of this study is its use of objective PA measures, which helps limit some of the biases inherent in reported measures of PA. However, the objective PA measures were only available at age 7, thus, the effect of patterns of objective PA over time cannot be estimated. PA data were necessarily aggregated into summary measures as children did not wear the accelerometer for the same number of hours in a day, nor the same number of days. As a result, summary measures could not account for activity differences by day of the week, nor could information on consecutive time or bouts of active or sedentary behaviour be incorporated in analyses. Evidence has suggested that temporal factors such as the time of day, whether a weekday or weekend, and sustained duration of activity can affect health outcomes (Colley et al., 2013; K. R. Hesketh et al., 2014; Tomporowski et al., 2011). The analyses adjusted for season, however, approximately 50% of children undertook the PA study in the summer time, which may have biased results if activities undertaken in these months (such as swimming and contact sports) were not compatible with accelerometer wear.

In a study examining the relationship between PA and cognition in children, Aggio et al (2016) found that objectively-measured PA was inversely associated with cognition, while frequency of sports club participation increased cognitive scores (D. Aggio et al., 2016). Sports clubs, as opposed to playing sports with friends or family, tend to be more structured, interactive, strategic and goal-oriented which help develop cognitive function (Best, 2010). These contextual differences between sport and other activities might also affect mental health similarly to cognition, and may be why these results are observed. Girls are less likely to engage in organised sports and so an hour of MVPA might not impart the same benefits.

As with PA, the context of sedentary time is important as well, and this analysis cannot capture the quality of the sedentary activity undertaken. Page et al (2010) describe a low correlation between sedentary time and screen entertainment, with the view that sedentary time and sedentary behaviours are different constructs (A. S. Page et al., 2010). Summary measures of sedentary time may in fact be conflating behaviours that affect mental health in opposing directions.

3.4.4 Conclusion

In this analysis, I found that higher levels of PA at age 7 reduce peer problems at age 11, while more sedentary time is associated with increased peer problems for both boys and girls. Caution must be taken when interpreting the association between objectively-measured PA and hyperactivity and conduct problems because of how externalising symptoms might be recorded. Policies aimed at increasing PA levels in children should consider the importance of activities that foster peer interaction and social inclusion. The context and content of PA and sedentary time warrants further consideration and will be explored in Chapters 4 and 5.

The work in this chapter resulted in the following publication: Ahn JV, Sera F, Cummins S, Flouri E. (2018) Associations between objectively measured physical activity and later mental health outcomes in children: findings from the UK Millennium Cohort Study. *J Epidemiol Community Health*, 72(2), 94-100.

Appendix A

Supplemental material i: The Strengths and Difficulties Questionnaire and scoring instructions

Strengths and Difficulties Questionnaire

For each item, please mark the box for Not True, Somewhat True or Certainly True. It would help us if you answered all items as best you can even if you are not absolutely certain or the item seems daft! Please give your answers on the basis of the child's behaviour over the last six months or this school year.

Child's Name .... Male/Female

Date of Birth..

	Not True	Somewhat True	Certainly True
Considerate of other people's feelings	☐	☐	☐
Restless, overactive, cannot stay still for long	☐	☐	☐
Often complains of headaches, stomach-aches or sickness	☐	☐	☐
Shares readily with other children (treats, toys, pencils etc.)	☐	☐	☐
Often has temper tantrums or hot tempers	☐	☐	☐
Rather solitary, tends to play alone	☐	☐	☐
Generally obedient, usually does what adults request	☐	☐	☐
Many worries, often seems worried	☐	☐	☐
Helpful if someone is hurt, upset or feeling ill	☐	☐	☐
Constantly fidgeting or squirming	☐	☐	☐
Has at least one good friend	☐	☐	☐
Often fights with other children or bullies them	☐	☐	☐
Often unhappy, down-hearted or tearful	☐	☐	☐
Generally liked by other children	☐	☐	☐
Easily distracted, concentration wanders	☐	☐	☐
Nervous or clingy in new situations, easily loses confidence	☐	☐	☐
Kind to younger children	☐	☐	☐
Often lies or cheats	☐	☐	☐
Picked on or bullied by other children	☐	☐	☐
Often volunteers to help others (parents, teachers, other children)	☐	☐	☐
Thinks things out before acting	☐	☐	☐
Steals from home, school or elsewhere	☐	☐	☐
Gets on better with adults than with other children	☐	☐	☐
Many fears, easily scared	☐	☐	☐
Sees tasks through to the end, good attention span	☐	☐	☐

Signature .... Date ....

Parent/Teacher/Other (please specify:)

Thank you very much for your help

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Scoring the Strengths & Difficulties Questionnaire for age 4-17

The 25 items in the SDQ comprise 5 scales of 5 items each. It is usually easiest to score all 5 scales first before working out the total difficulties score. 'Somewhat True' is always scored as 1, but the scoring of 'Not True' and 'Certainly True' varies with the item, as shown below scale by scale. For each of the 5 scales the score can range from 0 to 10 if all items were completed. These scores can be scaled up pro-rata if at least 3 items were completed, e.g. a score of 4 based on 3 completed items can be scaled up to a score of 7 (6.67 rounded up) for 5 items.

Table 1: Scoring symptom scores on the SDQ for 4-17 year olds

	Not True	Somewhat True	Certainly True
Emotional problems scale			
ITEM 3: Often complains of headaches… *(I get a lot of headaches…)*	0	1	2
ITEM 8: Many worries… *(I worry a lot)*	0	1	2
ITEM 13: Often unhappy, downhearted… *(I am often unhappy….)*	0	1	2
ITEM 16: Nervous or clingy in new situations… *(I am nervous in new situations…)*	0	1	2
ITEM 24: Many fears, easily scared *(I have many fears…)*	0	1	2
Conduct problems Scale			
ITEM 5: Often has temper tantrums or hot tempers *(I get very angry)*	0	1	2
ITEM 7: Generally obedient… *(I usually do as I am told)*	2	1	0
ITEM 12: Often fights with other children… *(I fight a lot)*	0	1	2
ITEM 18: Often lies or cheats *(I am often accused of lying or cheating)*	0	1	2
ITEM 22: Steals from home, school or elsewhere *(I take things that are not mine)*	0	1	2
Hyperactivity scale			
ITEM 2: Restless, overactive… *(I am restless…)*	0	1	2
ITEM 10: Constantly fidgeting or squirming *(I am constantly fidgeting….)*	0	1	2
ITEM 15: Easily distracted, concentration wanders *(I am easily distracted)*	0	1	2
ITEM 21: Thinks things out before acting *(I think before I do things)*	2	1	0
ITEM 25: Sees tasks through to the end… *(I finish the work I am doing)*	2	1	0
Peer problems scale			
ITEM 6: Rather solitary, tends to play alone *(I am usually on my own)*	0	1	2
ITEM 11: Has at least one good friend *(I have one goof friend or more)*	2	1	0
ITEM 14: Generally liked by other children *(Other people my age generally like me)*	2	1	0
ITEM 19: Picked on or bullied by other children… *(Other children or young people pick on me)*	0	1	2
ITEM 23: Gets on better with adults than with other children *(I get on better with adults than with people my age)*	0	1	2
Prosocial scale			
ITEM 1: Considerate of other people's feelings *(I try to be nice to other people)*	0	1	2
ITEM 4: Shares readily with other children… *(I usually share with others)*	0	1	2
ITEM 9: Helpful if someone is hurt… *(I am helpful is someone is hurt…)*	0	1	2
ITEM 17: Kind to younger children *(I am kind to younger children)*	0	1	2
ITEM 20: Often volunteers to help others… *(I often volunteer to help others)*	0	1	2

Total difficulties score: This is generated by summing scores from all the scales except the prosocial scale. The resultant score ranges from 0 to 40, and is counted as missing of one of the 4 component scores is missing.

'Externalising' and 'internalising' scores: The externalising score ranges from 0 to 20 and is the sum of the conduct and hyperactivity scales. The internalising score ranges from 0 to 20 and is the sum of the emotional and peer problems scales. Using these two amalgamated scales may be preferable to using the four separate scales in community samples, whereas using the four separate scales may add more value in high-risk samples *(see Goodman & Goodman. 2009 Strengths and difficulties questionnaire as a dimensional measure of child mental health. J Am Acad Child Adolesc Psychiatry 48(4), 400-403).*

Generating impact scores

When using a version of the SDQ that includes an 'impact supplement', the items on overall distress and impairment can be summed to generate an impact score that ranges from 0 to 10 for parent- and self-report, and from 0 to 6 for teacher-report.

Table 2: Scoring the SDQ impact supplement

	Not at all	Only a little	A medium amount	A great deal
Parent report:				
Difficulties upset or distress child	0	0	1	2
Interfere with HOME LIFE	0	0	1	2
Interfere with FRIENDSHIPS	0	0	1	2
Interfere with CLASSROOM LEARNING	0	0	1	2
Interfere with LEISURE ACTIVITIES	0	0	1	2
Teacher report:				
Difficulties upset or distress child	0	0	1	2
Interfere with PEER RELATIONS	0	0	1	2
Interfere with CLASSROOM LEARNING	0	0	1	2
Self-report report:				
Difficulties upset or distress child	0	0	1	2
Interfere with HOME LIFE	0	0	1	2
Interfere with FRIENDSHIPS	0	0	1	2
Interfere with CLASSROOM LEARNING	0	0	1	2
Interfere with LEISURE ACTIVITIES	0	0	1	2

Responses to the questions on chronicity and burden to others are not included in the impact score. When respondents have answered 'no' to the first question on the impact supplement (i.e. when they do not perceive themselves as having any emotional or behavioural difficulties), they are not asked to complete the questions on resultant distress or impairment; the impact score is automatically scored zero in these circumstances.

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Cut-points for SDQ scores: original three-band solution and newer four-band solution

Although SDQ scores can be used as continuous variables, it is sometimes convenient to categorise scores. The initial bandings presented for the SDQ scores were 'normal', 'borderline' and 'abnormal'. These bandings were defined based on a population-based UK survey, attempting to choose cutpoints such that 80% of children scored 'normal', 10% 'borderline' and 10% 'abnormal'.

More recently a four-fold classification has been created based on an even larger UK community sample. This four-fold classification differs from the original in that it (1) divided the top 'abnormal' category into two groups, each containing around 5% of the population, (2) renamed the four categories (80% 'close to average', 10% 'slightly raised, 5% 'high' and 5% 'very high' for all scales except prosocial, which is 80% 'close to average', 10% 'slightly lowered', 5% 'low' and 5% 'very low'), and (3) changed the cut-points for some scales, to better reflect the proportion of children in each category in the larger dataset.

Table 3: Categorising SDQ scores for 4-17 year olds

	Original three-band categorisation			Newer four-band categorisation			
	Normal	Borderline	Abnormal	Close to average	Slightly raised (/slightly lowered)	High (/Low)	Very high (very low)
Parent completed SDQ							
Total difficulties score	0-13	14-16	17-40	0-13	14-16	17-19	20-40
Emotional problems score	0-3	4	5-10	0-3	4	5-6	7-10
Conduct problems score	0-2	3	4-10	0-2	3	4-5	6-10
Hyperactivity score	0-5	6	7-10	0-5	6-7	8	9-10
Peer problems score	0-2	3	4-10	0-2	3	4	5-10
Prosocial score	6-10	5	0-4	8-10	7	6	0-5
Impact score	0	1	2-10	0	1	2	3-10
Teacher completed SDQ							
Total difficulties score	0-11	12-15	16-40	0-11	12-15	16-18	19-40
Emotional problems score	0-4	5	6-10	0-3	4	5	6-10
Conduct problems score	0-2	3	4-10	0-2	3	4	5-10
Hyperactivity score	0-5	6	7-10	0-5	6-7	8	9-10
Peer problems score	0-3	4	5-10	0-2	3-4	5	6-10
Prosocial score	6-10	5	0-4	6-10	5	4	0-3
Impact score	0	1	2-10	0	1	2	3-10
Self-completed SDQ							
Total difficulties score	0-15	16-19	20-40	0-14	15-17	18-19	20-40
Emotional problems score	0-5	6	7-10	0-4	5	6	7-10
Conduct problems score	0-3	4	5-10	0-3	4	5	6-10
Hyperactivity score	0-5	6	7-10	0-5	6	7	8-10
Peer problems score	0-3	4-5	6-10	0-2	3	4	5-10
Prosocial score	6-10	5	0-4	7-10	6	5	0-4
Impact score	0	1	2-10	0	1	2	3-10

Note that both these systems only provide a rough-and-ready way of screening for disorders; combining information from SDQ symptom and impact scores from multiple informants is better, but still far from perfect.

Supplemental material ii: Stata syntax to create summary physical activity and sedentary time variables adjusted for total valid time (L. Griffiths et al., 2013)

Appendix Q: Stata syntax for total valid time adjustment

```
use <"Name main daily data Stata file">, clear
keep if ISVALIDDAY == 1 & RELIABLE == 1
egen mcsidkey = concat(MCSID DCNUM00)
egen N_DAYS_V = total(ISVALIDDAY == 1), by(mcsidkey)
bysort mcsidkey:egen nrec=seq()

* Standard day
gen standard_day = 735

* Weights (with alpha calculated separately for sedentary behaviour, light and moderate
to vigorous)
gen w0=(1/(TOTTIMEDAY/standard_day))^1.35
gen w1=(1/(TOTTIMEDAY/standard_day))^0.65
gen w23=(1/(TOTTIMEDAY/standard_day))^0.25

* Sedentary behaviour
gen wTOTPATY0  = TOTPATY0 * w0
egen TOTPATY0_W = total(wTOTPATY0), by(mcsidkey)
gen MNPATY0_W = TOTPATY0_W/N_DAYS_V

* Light activity
gen wTOTPATY1  = TOTPATY1 * w1
egen TOTPATY1_W = total(wTOTPATY1), by(mcsidkey)
gen MNPATY1_W = TOTPATY1_W/N_DAYS_V

* Moderate activity
gen wTOTPATY2  = TOTPATY2 * w23
egen TOTPATY2_W = total(wTOTPATY2), by(mcsidkey)
gen MNPATY2_W = TOTPATY2_W/N_DAYS_V

* Vigorous activity
gen wTOTPATY3  = TOTPATY3 * w23
egen TOTPATY3_W = total(wTOTPATY3), by(mcsidkey)
```

100

```
gen MNPATY3_W = TOTPATY3_W/N_DAYS_V

* Label new variables and keep summary values
label var TOTPATY0_W "Weighted total time (mins) spent in sedentary behaviour across all valid days"
label var MNPATY0_W "Weighted mean time (mins) spent in sedentary behaviour across all valid days"
label var TOTPATY1_W  " Weighted total time (mins) spent in light activity across all valid days"
label var MNPATY1_W  "Weighted mean time (mins) spent in light activity across all valid days"
label var TOTPATY2_W  " Weighted total time (mins) spent in moderate activity across all valid days"
label var MNPATY2_W "Weighted mean time (mins) spent in moderate activity across all valid days"
label var TOTPATY3_W    " Weighted total time (mins) spent in vigorous activity across all valid days"
label var MNPATY3_W "Weighted mean time (mins) spent in vigorous activity across all valid days"
keep if nrec == 1
drop nrec
```

Appendix B

I. Correlation matrices and bivariate relationships

Table 3-2: correlations between physical activity, Strengths and Difficulties scores, and continuous covariates, boys

	EMO	PEER	COND	HYP	TD	PA0	PA1	PA2	AGE	SELF	PAT	READ
EMO	1											
PEER	0.471***	1										
COND	0.392***	0.367***	1									
HYP	0.353***	0.334***	0.539***	1								
TD	0.732***	0.698***	0.745***	0.797***	1							
PA0	<0.001	0.047	-0.086**	-0.147***	-0.072**	1						
PA1	0.017	-0.014	0.059*	0.125***	0.071**	-0.889***	1					
PA2	-0.028	-0.082**	0.084**	0.104***	0.032	-0.665***	0.257***	1				
AGE	-0.053*	-0.04	-0.035	-0.048*	-0.059**	0.024	-0.043	0.022	1			
SELF	-0.160***	-0.159***	-0.114***	-0.143***	-0.193***	-0.016	0.001	0.034	0.059**	1		
PAT	-0.123***	-0.097***	-0.116***	-0.206***	-0.190***	0.061**	-0.046*	-0.055**	0.011	0.059*	1	
READ	-0.189***	-0.155***	-0.191***	-0.287***	-0.285***	0.134***	-0.141***	-0.056*	-0.066**	0.158***	0.330***	1

* p<0.05, ** p<0.01, *** p<0.001

EMO=MCS5 Emotional problems; PEER=MCS5 Peer problems; COND=MCS5 Conduct problems; HYP=MCS5 Hyperactivity problems; TD=MCS5 Total Difficulties; PA0=Weighted mean time (minutes) spent in sedentary behaviour across all valid days; PA1=Weighted mean time (minutes) spent in light activity across all valid days; PA2=Weighted mean time (minutes) spent in moderate-to-vigorous activity across all valid days; AGE=Age at interview to nearest 10th of year; SELF=MCS5 self-esteem (RSE); PAT=MCS4 BAS pattern construction score; READ=MCS4 BAS word reading score

Table 3-3: correlations between physical activity, Strengths and Difficulties scores, and continuous covariates, girls

	EMO	PEER	COND	HYP	TD	PA0	PA1	PA2	AGE	SELF	PAT	READ
EMO	1											
PEER	0.474***	1										
COND	0.364***	0.329***	1									
HYP	0.381***	0.361***	0.507***	1								
TD	0.763***	0.702***	0.704***	0.793***	1							
PA0	-0.043	-0.002	-0.086***	-0.166***	-0.107***	1						
PA1	0.042	-0.011	0.070**	0.150***	0.092***	-0.925***	1					
PA2	0.016	0.02	0.072***	0.112***	0.077***	-0.668***	0.342***	1				
AGE	-0.03	-0.037	-0.029	-0.081***	-0.062**	0.02	-0.018	-0.016	1			
SELF	-0.194***	-0.148***	-0.126***	-0.205***	-0.233***	0.017	-0.002	-0.032	0.038	1		
PAT	-0.134***	-0.120***	-0.099***	-0.168***	-0.180***	0.051*	-0.038	-0.046*	0.056**	0.089***	1	
READ	-0.157***	-0.156***	-0.183***	-0.295***	-0.273***	0.106***	-0.100***	-0.063**	-0.079***	0.132***	0.302***	1

* p<0.05, ** p<0.01, *** p<0.001

EMO=MCS5 Emotional problems; PEER=MCS5 Peer problems; COND=MCS5 Conduct problems; HYP=MCS5 Hyperactivity problems; TD=MCS5 Total Difficulties; PA0=Weighted mean time (minutes) spent in sedentary behaviour across all valid days; PA1=Weighted mean time (minutes) spent in light activity across all valid days; PA2=Weighted mean time (minutes) spent in moderate-to-vigorous activity across all valid days; AGE=Age at interview to nearest 10th of year; SELF=MCS5 self-esteem (RSE); PAT=MCS4 BAS pattern construction score; READ=MCS4 BAS word reading score

Table 3-4: Regression coefficients estimated for Strengths and Difficulties scores and categorical covariates, boys

	Emotional b (se)	Peer b (se)	Conduct b (se)	Hyperactivity b (se)	Total Difficulties b (se)
Ethnicity (ref: White)					
Mixed	0.016 (0.301)	-0.148 (0.209)	-0.234 (0.176)	0.059 (0.260)	-0.299 (0.746)
Indian	0.283 (0.382)	0.012 (0.578)	-0.059 (0.274)	-0.804 (0.424)	-0.565 (0.997)
Pakistani or Bangladeshi	0.086 (0.179)	0.218 (0.154)	0.015 (0.165)	-0.424 (0.286)	-0.090 (0.620)
Black or Black British	-0.093 (0.326)	0.395 (0.280)	0.001 (0.199)	-0.112 (0.412)	0.045 (0.903)
Other	0.010 (0.490)	1.172 (0.631)	-0.817 (0.229)***	-0.325 (0.598)	0.044 (1.052)
Constant	1.783 (0.055)	1.440 (0.053)	1.563 (0.048)	3.597 (0.069)	8.378 (0.181)
Wald test (p-value)	0.976	0.170	**0.012**	0.299	0.991
Has the school told you your child has special educational needs? (ref: No)					
Yes	1.385 (0.181)***	1.429 (0.179)***	1.019 (0.150)***	2.336 (0.180)***	6.156 (0.512)***
Constant	1.619 (0.050)	1.289 (0.045)	1.418 (0.042)	3.265 (0.063)	7.584 (0.148)
Wald test (p-value)	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Does your child's illnesses limit their activity (ref: no limiting illness)					
No	0.308 (0.197)	0.337 (0.202)	0.170 (0.189)	0.069 (0.255)	0.876 (0.654)
Yes	1.672 (0.206)***	1.117 (0.202)***	1.127 (0.176)***	2.148 (0.329)***	6.072 (0.659)***
Constant	1.640 (0.055)	1.362 (0.049)	1.446 (0.047)	3.389 (0.066)	7.828 (0.173)
Wald test (p-value)	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
MCS5 below OECD 60% median income (ref: above 60% median)					
Below 60% median	0.523 (0.157)***	0.304 (0.114)**	0.777 (0.121)***	1.014 (0.186)***	2.627 (0.425)***
Constant	1.696 (0.051)	1.417 (0.051)	1.406 (0.044)	3.378 (0.063)	7.891 (0.167)
Wald test (p-value)	**0.001**	**0.008**	**<0.001**	**<0.001**	**<0.001**
MCS5 Number of siblings (ref: 0)					
1	-0.186 (0.205)	-0.474 (0.187)*	-0.071 (0.180)	-0.635 (0.213)**	-1.378 (0.658)*
2	-0.182 (0.214)	-0.441 (0.205)*	0.173 (0.184)	-0.527 (0.229)*	-0.976 (0.685)
3	0.501 (0.277)	-0.062 (0.234)	0.342 (0.205)	-0.441 (0.299)	0.371 (0.791)

	Emotional	**Peer**	**Conduct**	**Hyperactivity**	**Total Difficulties**
	b (se)	**b (se)**	**b (se)**	**b (se)**	**b (se)**
4+	0.068 (0.278)	-0.011 (0.277)	0.589 (0.277)*	-0.116 (0.390)	0.447 (0.904)
Constant	1.854 (0.191)	1.809 (0.171)	1.460 (0.165)	4.043 (0.186)	9.166 (0.604)
Wald test (p-value)	**0.017**	**0.003**	**0.003**	**0.041**	**0.003**
Both natural parents resident in household full-time (ref: No)					
Yes	-0.478 (0.105)***	-0.454 (0.110)***	-0.565 (0.109)***	-0.886 (0.145)***	-2.390 (0.375)***
Constant	2.094 (0.092)	1.760 (0.093)	1.904 (0.094)	4.122 (0.125)	9.878 (0.319)
Wald test (p-value)	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Highest academic qualification attained MCS1-5 (ref: no degree)					
Degree or higher	-0.447 (0.098)***	-0.468 (0.095)***	-0.600 (0.089)***	-1.022 (0.139)***	-2.529 (0.316)***
Constant	1.877 (0.060)	1.557 (0.057)	1.660 (0.052)	3.753 (0.074)	8.838 (0.189)
Wald test (p-value)	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Main in work (ref: Not in work)					
Main in work	-0.789 (0.118)***	-0.741 (0.117)***	-0.847 (0.109)***	-0.612 (0.146)***	-2.999 (0.374)***
Constant	2.345 (0.109)	1.989 (0.105)	2.140 (0.104)	3.988 (0.130)	10.466 (0.351)
Wald test (p-value)	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Maternal depression - Kessler 6 score at MCS5 (ref: normal (0-12)					
Higher likelihood of SMI (13+)	1.669 (0.325)***	1.272 (0.240)***	1.526 (0.226)***	1.663 (0.313)***	6.133 (0.802)***
Constant	1.641 (0.047)	1.345 (0.049)	1.401 (0.041)	3.410 (0.063)	7.794 (0.156)
Wald test (p-value)	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Child MCS5 weight status (ref: not overweight)					
Overweight/obese	0.282 (0.150)	0.325 (0.123)**	0.059 (0.098)	-0.016 (0.160)	0.667 (0.417)
Constant	1.701 (0.049)	1.387 (0.056)	1.521 (0.054)	3.559 (0.074)	8.156 (0.184)
Wald test (p-value)	0.060	0.008	0.547	0.922	0.111

*** p<0.05, ** p<0.01, *** p<0.001**

Table 3-5: Regression coefficients estimated for Strengths and Difficulties scores and categorical covariates, girls

	Emotional b (se)	Peer b (se)	Conduct b (se)	Hyperactivity b (se)	Total Difficulties b (se)
Ethnicity (ref: White)					
Mixed	-0.022 (0.269)	0.197 (0.265)	-0.007 (0.209)	-0.395 (0.301)	-0.227 (0.763)
Indian	-0.320 (0.376)	-0.169 (0.256)	0.043 (0.317)	-0.115 (0.366)	-0.629 (1.071)
Pakistani or Bangladeshi	0.024 (0.227)	0.703 (0.236)**	0.004 (0.128)	0.492 (0.239)*	1.215 (0.541)*
Black or Black British	-0.241 (0.293)	-0.147 (0.180)	-0.147 (0.206)	-0.125 (0.308)	-0.787 (0.771)
Other	-0.241 (0.469)	0.385 (0.215)	-0.173 (0.209)	0.362 (0.411)	0.334 (1.043)
Constant	1.905 (0.056)	1.248 (0.044)	1.263 (0.041)	2.646 (0.060)	7.061 (0.154)
Wald test (p-value)	0.876	**0.032**	0.931	0.192	0.200
Has the school told you your child has special educational needs? (ref: No)					
Yes	1.265 (0.250)***	1.098 (0.246)***	0.846 (0.192)***	2.089 (0.253)***	5.305 (0.730)***
Constant	1.806 (0.051)	1.211 (0.046)	1.201 (0.036)	2.518 (0.056)	6.728 (0.141)
Wald test (p-value)	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Does your child's illnesses limit their activity (ref: no limiting illness)					
No	0.455 (0.230)*	0.044 (0.149)	0.157 (0.164)	0.508 (0.294)	1.173 (0.640)
Yes	2.362 (0.283)***	1.015 (0.246)***	0.750 (0.240)**	1.915 (0.370)***	6.050 (0.897)***
Constant	1.756 (0.049)	1.237 (0.045)	1.214 (0.039)	2.540 (0.056)	6.739 (0.139)
Wald test (p-value)	**<0.001**	**<0.001**	**0.006**	**<0.001**	**<0.001**
MCS5 below OECD 60% median income (ref: above 60% median)					
Below 60% median	0.632 (0.181)***	0.773 (0.139)***	0.864 (0.121)***	0.876 (0.169)***	3.156 (0.455)***
Constant	1.770 (0.050)	1.140 (0.042)	1.096 (0.035)	2.495 (0.054)	6.495 (0.138)
Wald test (p-value)	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
MCS5 Number of siblings (ref: 0)					
1	-0.134 (0.154)	-0.430 (0.134)**	0.172 (0.100)	-0.392 (0.181)*	-0.783 (0.386)*
2	0.012 (0.181)	-0.337 (0.135)*	0.303 (0.119)*	-0.212 (0.203)	-0.235 (0.423)
3	0.130 (0.205)	0.159 (0.203)	0.464 (0.154)**	-0.290 (0.238)	0.440 (0.568)

	Emotional b (se)	Peer b (se)	Conduct b (se)	Hyperactivity b (se)	Total Difficulties b (se)
4+	0.420 (0.315)	0.468 (0.280)	0.779 (0.228)***	-0.029 (0.327)	1.601 (0.757)*
Constant	1.911 (0.139)	1.530 (0.123)	1.009 (0.093)	2.922 (0.169)	7.370 (0.348)
Wald test (p-value)	0.129	**<0.001**	**<0.001**	0.132	**<0.001**
Both natural parents resident in household full-time (ref: No)					
Yes	-0.470 (0.115)***	-0.448 (0.092)***	-0.567 (0.088)***	-0.784 (0.114)***	-2.272 (0.294)***
Constant	2.188 (0.105)	1.570 (0.086)	1.618 (0.076)	3.156 (0.102)	8.527 (0.270)
Wald test (p-value)	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Highest academic qualification attained MCS1-5 (ref: no degree)					
Degree or higher	-0.365 (0.097)***	-0.418 (0.081)***	-0.454 (0.071)***	-0.854 (0.101)***	-2.085 (0.271)***
Constant	1.960 (0.061)	1.366 (0.051)	1.345 (0.041)	2.822 (0.061)	7.486 (0.157)
Wald test (p-value)	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Main in work (ref: Not in work)					
Main in work	-0.381 (0.126)**	-0.578 (0.091)***	-0.491 (0.085)***	-0.633 (0.131)***	-2.071 (0.325)***
Constant	2.153 (0.117)	1.671 (0.084)	1.597 (0.076)	3.086 (0.118)	8.494 (0.291)
Wald test (p-value)	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Maternal depression - Kessler 6 score at MCS5 (ref: normal (0-12)					
Higher likelihood of SMI (13+)	1.349 (0.264)***	0.781 (0.164)***	0.879 (0.168)***	1.565 (0.235)***	4.528 (0.561)***
Constant	1.784 (0.049)	1.205 (0.044)	1.178 (0.037)	2.497 (0.055)	6.663 (0.141)
Wald test (p-value)	**<0.003**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Child's MCS5 weight status (ref: not overweight)					
Overweight/obese	0.370 (0.115)**	0.427 (0.103)***	0.158 (0.078)*	0.197 (0.115)	1.162 (0.313)***
Constant	1.768 (0.056)	1.145 (0.047)	1.198 (0.036)	2.592 (0.063)	6.693 (0.151)
Wald test (p-value)	**<0.001**	**<0.001**	**0.042**	0.088	**<0.001**

*** p<0.05, ** p<0.01, *** p<0.001**

Table 3-6: Regression coefficients estimated for sedentary, light PA, and MVPA, and categorical covariates

	Boys			**Girls**		
	Sedentary	**Light PA**	**MVPA**	**Sedentary**	**Light PA**	**MVPA**
	b(se)	**b(se)**	**b(se)**	**b(se)**	**b(se)**	**b(se)**
Ethnicity (ref: White)						
Mixed	0.050 (0.120)	-0.120 (0.204)	0.046 (0.159)	0.410 (0.110)***	-0.720 (0.217)***	-0.205 (0.126)
Indian	0.341 (0.132)**	-0.330 (0.151)*	-0.635 (0.325)	0.251 (0.144)	-0.377 (0.240)	-0.324 (0.178)
Pakistani or Bangladeshi	-0.083 (0.165)	0.238 (0.264)	-0.087 (0.204)	-0.015 (0.093)	0.065 (0.168)	-0.160 (0.120)
Black or Black British	0.113 (0.138)	-0.499 (0.320)	0.697 (0.471)	-0.060 (0.096)	-0.001 (0.131)	0.284 (0.196)
Other	-0.229 (0.091)*	0.595 (0.157)***	-0.223 (0.171)	0.266 (0.186)	-0.517 (0.291)	-0.081 (0.251)
Constant	6.363 (0.021)	9.433 (0.031)	4.667 (0.040)	6.632 (0.021)	9.351 (0.033)	3.764 (0.033)
Wald test (p-value)	**0.014**	**<0.001**	0.194	**0.001**	**0.005**	0.064
Has the school told you your child has special educational needs? (ref: No)						
Yes	0.003 (0.058)	0.047 (0.098)	-0.119 (0.105)	0.006 (0.077)	0.014 (0.120)	-0.057 (0.131)
Constant	6.367 (0.025)	9.420 (0.038)	4.689 (0.048)	6.651 (0.020)	9.315 (0.032)	3.751 (0.030)
Wald test (p-value)	0.954	0.634	0.256	0.934	0.909	0.666
Does your child's illnesses limit their activity (ref: no limiting illness)						
No	-0.071 (0.086)	0.224 (0.103)*	-0.191 (0.184)	-0.057 (0.073)	0.077 (0.104)	0.088 (0.151)
Yes	0.019 (0.080)	0.135 (0.134)	-0.385 (0.126)**	-0.018 (0.118)	0.039 (0.186)	0.013 (0.195)
Constant	6.371 (0.025)	9.402 (0.038)	4.713 (0.048)	6.656 (0.020)	9.309 (0.032)	3.744 (0.032)
Wald test (p-value)	0.673	0.075	**0.007**	0.738	0.752	0.844
MCS5 below OECD 60% median income (ref: above 60% median)						
Below 60% median	-0.141 (0.075)	0.033 (0.123)	0.503 (0.146)***	-0.253 (0.055)***	0.304 (0.092)**	0.342 (0.096)***
Constant	6.393 (0.020)	9.422 (0.032)	4.579 (0.036)	6.701 (0.020)	9.256 (0.033)	3.683 (0.029)
Wald test (p-value)	0.060	0.791	**0.001**	**<0.001**	**0.001**	**<0.001**
MCS5 Number of siblings (ref: 0)						
1	0.008 (0.074)	-0.014 (0.108)	0.017 (0.131)	-0.047 (0.057)	0.101 (0.092)	-0.036 (0.091)
2	0.079 (0.081)	-0.066 (0.121)	-0.151 (0.135)	-0.126 (0.064)*	0.218 (0.099)*	0.030 (0.101)

	Boys			**Girls**		
	Sedentary	**Light PA**	**MVPA**	**Sedentary**	**Light PA**	**MVPA**
	b(se)	**b(se)**	**b(se)**	**b(se)**	**b(se)**	**b(se)**
3	-0.080 (0.084)	0.190 (0.129)	-0.088 (0.160)	-0.256 (0.079)**	0.393 (0.129)**	0.197 (0.144)
4+	-0.037 (0.095)	-0.068 (0.184)	0.312 (0.339)	-0.364 (0.105)***	0.544 (0.186)**	0.237 (0.140)
Constant	6.355 (0.065)	9.431 (0.096)	4.700 (0.116)	6.753 (0.054)	9.140 (0.087)	3.725 (0.083)
Wald test (p-value)	0.316	0.396	0.275	**<0.001**	**0.002**	0.145
Both natural parents resident in household full-time (ref: No)						
Yes	0.001 (0.053)	0.047 (0.078)	-0.111 (0.097)	0.076 (0.043)	-0.036 (0.067)	-0.248 (0.065)***
Constant	6.367 (0.046)	9.398 (0.070)	4.741 (0.086)	6.603 (0.038)	9.338 (0.059)	3.909 (0.057)
Wald test (p-value)	0.984	0.543	0.255	0.079	0.592	**<0.001**
Highest academic qualification attained MCS1-5 (ref: no degree)						
Degree or higher	0.123 (0.042)**	-0.178 (0.059)**	-0.113 (0.090)	0.126 (0.041)**	-0.194 (0.064)**	-0.101 (0.066)
Constant	6.344 (0.026)	9.461 (0.040)	4.695 (0.049)	6.627 (0.023)	9.352 (0.038)	3.770 (0.036)
Wald test (p-value)	**0.004**	**0.003**	0.210	**0.003**	**0.003**	0.131
Main in work (ref: Not in work)						
Main in work	-0.024 (0.052)	0.055 (0.080)	-0.001 (0.104)	0.049 (0.042)	-0.050 (0.070)	-0.078 (0.067)
Constant	6.386 (0.049)	9.385 (0.074)	4.672 (0.096)	6.611 (0.038)	9.361 (0.063)	3.812 (0.058)
Wald test (p-value)	0.643	0.493	0.992	0.247	0.475	0.247
Maternal depression - Kessler 6 score at MCS5 (ref: normal (0-12))						
Higher likelihood of SMI (13+)	-0.092 (0.094)	0.023 (0.113)	0.314 (0.205)	-0.202 (0.075)**	0.327 (0.115)**	0.157 (0.145)
Constant	6.370 (0.022)	9.436 (0.034)	4.642 (0.042)	6.673 (0.021)	9.283 (0.033)	3.729 (0.032)
Wald test (p-value)	0.326	0.836	0.126	**0.007**	**0.005**	0.278
Child's MCS5 weight status (ref: not overweight)						
Overweight/obese	-0.036 (0.055)	0.267 (0.086)**	-0.372 (0.117)**	-0.031 (0.043)	0.121 (0.065)	-0.124 (0.076)
Constant	6.378 (0.023)	9.357 (0.034)	4.767 (0.044)	6.655 (0.023)	9.285 (0.036)	3.796 (0.035)
Wald test (p-value)	0.506	**0.002**	**0.002**	0.477	0.062	0.103

*** p<0.05, ** p<0.01, *** p<0.001**

II. Multivariable linear regression model results

Table 3-7: Change in Strengths and Difficulties scores per 60 minutes sedentary time, 30 minutes light PA, and 15 minutes MVPA in boys

	Model 1		Model 2		Model 3		Model 4		Model 5	
SDQ subscale	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Emotional										
sedentary	0.102	-0.019,0.222	0.088	-0.031,0.207	0.091	-0.029,0.211	0.083	-0.032,0.199	0.088	-0.028,0.204
light	-0.036	-0.105,0.034	-0.035	-0.103,0.033	-0.040	-0.107,0.028	-0.031	-0.099,0.037	-0.039	-0.108,0.029
MVPA	-0.066	-0.137,0.005	-0.052	-0.122,0.018	-0.048	-0.119,0.022	-0.051	-0.116,0.015	-0.046	-0.111,0.019
Peer										
sedentary	0.188 ***	0.079,0.297	0.181 **	0.072,0.291	0.178 **	0.071,0.285	0.169 **	0.068,0.269	0.164 **	0.061,0.268
light	-0.084 *	-0.152,-0.016	-0.085 *	-0.153,-0.018	-0.087 **	-0.152,-0.022	-0.080 *	-0.143,-0.017	-0.083 *	-0.147,-0.020
MVPA	-0.096 **	-0.159,-0.032	-0.089 **	-0.153,-0.025	-0.084 **	-0.146,-0.021	-0.082 **	-0.139,-0.025	-0.074 **	-0.130,-0.018
Conduct										
sedentary	-0.071	-0.185,0.043	-0.079	-0.194,0.036	-0.080	-0.190,0.030	-0.087	-0.192,0.017	-0.089	-0.197,0.019
light	-0.007	-0.070,0.056	-0.003	-0.068,0.061	0.003	-0.058,0.064	0.010	-0.050,0.070	0.012	-0.051,0.075
MVPA	0.087 **	0.029,0.144	0.092 **	0.034,0.151	0.086 **	0.027,0.146	0.085 **	0.032,0.139	0.085 **	0.030,0.139
Hyperactivity										
sedentary	-0.333 ***	-0.454,-0.213	-0.354 ***	-0.476,-0.232	-0.357 ***	-0.477,-0.237	-0.347 ***	-0.468,-0.226	-0.328 ***	-0.450,-0.205
light	0.146 ***	0.063,0.228	0.158 ***	0.078,0.238	0.168 ***	0.091,0.245	0.164 ***	0.086,0.241	0.158 ***	0.078,0.239
MVPA	0.171 ***	0.096,0.246	0.182 ***	0.112,0.253	0.174 ***	0.103,0.245	0.168 ***	0.098,0.237	0.154 ***	0.085,0.224
Total difficulties										
sedentary	-0.115	-0.424,0.194	-0.163	-0.478,0.152	-0.168	-0.476,0.140	-0.182	-0.472,0.107	-0.164	-0.459,0.130
light	0.019	-0.166,0.204	0.034	-0.152,0.219	0.044	-0.138,0.225	0.062	-0.117,0.241	0.047	-0.133,0.228
MVPA	0.096	-0.093,0.286	0.134	-0.056,0.323	0.128	-0.064,0.319	0.120	-0.051,0.291	0.119	-0.052,0.290

Model 1 Adjusted for age, season, Total Difficulties at age 7
Model 2 Adjusted for Model 1 + ethnicity, limiting illness, SEN
Model 3 Adjusted for Model 2 + income, siblings, family structure
Model 4 Adjusted for Model 3 + maternal education, maternal depression, maternal employment
Model 5 Adjusted for Model 4 + weight status, self-esteem, BAS pattern construction, BAS reading
*** p<0.05, ** p<0.01, *** p<0.001**

Table 3-8: Change in Strengths and Difficulties scores per 60 minutes sedentary time, 30 minutes light PA, and 15 minutes MVPA in girls

	Model 1		Model 2		Model 3		Model 4		Model 5	
SDQ subscale	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Emotional										
sedentary	0.043	-0.066,0.152	0.044	-0.059,0.147	0.060	-0.045,0.165	0.072	-0.031,0.175	0.070	-0.032,0.172
light	-0.015	-0.084,0.053	-0.016	-0.082,0.049	-0.024	-0.092,0.044	-0.032	-0.099,0.034	-0.031	-0.097,0.036
MVPA	-0.036	-0.112,0.039	-0.038	-0.110,0.034	-0.048	-0.117,0.021	-0.050	-0.118,0.017	-0.049	-0.114,0.016
Peer										
sedentary	0.070	-0.016,0.155	0.063	-0.021,0.148	0.093 *	0.010,0.176	0.092 *	0.010,0.174	0.091 *	0.009,0.173
light	-0.063 *	-0.119,-0.007	-0.061 *	-0.116,-0.006	-0.074 *	-0.131,-0.016	-0.074 *	-0.131,-0.016	-0.076 *	-0.133,-0.018
MVPA	0.011	-0.060,0.083	0.016	-0.057,0.089	-0.003	-0.068,0.062	-0.002	-0.067,0.064	0.003	-0.061,0.067
Conduct										
sedentary	-0.072	-0.152,0.007	-0.073	-0.151,0.005	-0.030	-0.108,0.048	-0.026	-0.103,0.051	-0.024	-0.101,0.053
light	0.035	-0.018,0.088	0.034	-0.017,0.086	0.015	-0.037,0.066	0.011	-0.040,0.063	0.010	-0.041,0.062
MVPA	0.047 *	0.003,0.091	0.046 *	0.002,0.090	0.020	-0.025,0.065	0.020	-0.025,0.065	0.018	-0.027,0.064
Hyperactivity										
sedentary	-0.295 ***	-0.410,-0.180	-0.295 ***	-0.408,-0.182	-0.301 ***	-0.416,-0.186	-0.291 ***	-0.406,-0.177	-0.269 ***	-0.380,-0.158
light	0.178 ***	0.099,0.256	0.175 ***	0.099,0.252	0.181 ***	0.104,0.259	0.173 ***	0.096,0.251	0.164 ***	0.090,0.238
MVPA	0.115 ***	0.051,0.179	0.115 ***	0.051,0.180	0.108 **	0.043,0.173	0.108 **	0.043,0.172	0.093 **	0.030,0.156
Total difficulties										
sedentary	-0.255	-0.531,0.021	-0.260	-0.520,0.001	-0.178	-0.441,0.086	-0.153	-0.411,0.105	-0.132	-0.383,0.120
light	0.134	-0.053,0.322	0.133	-0.043,0.309	0.098	-0.084,0.281	0.079	-0.101,0.259	0.068	-0.107,0.244
MVPA	0.137	-0.031,0.305	0.140	-0.027,0.307	0.077	-0.077,0.231	0.076	-0.078,0.229	0.066	-0.084,0.216

Model 1 Adjusted for age, season, Total Difficulties at age 7
Model 2 Adjusted for Model 1 + ethnicity, limiting illness, SEN
Model 3 Adjusted for Model 2 + income, siblings, family structure
Model 4 Adjusted for Model 3 + maternal education, maternal depression, maternal employment
Model 5 Adjusted for Model 4 + weight status, self-esteem, BAS pattern construction, BAS reading
*** p<0.05, ** p<0.01, *** p<0.001**

4 The effect of environment and place on the relationship between physical activity and mental health: ward green space, area deprivation, and rural-urban designation

4.1 Introduction

In the previous chapter, I examined the association between PA/sedentary behaviour and mental health outcomes and found that results varied depending on PA intensity, SDQ subscale, and the child's gender.

In summary, the findings were:

- Both boys and girls who were more sedentary had more peer problems;
- Boys who spent more time engaged in light activity and MVPA had fewer peer problems; girls who were more lightly active had fewer peer problems;
- Boys who did more MVPA had more conduct problems; and
- Children who were more sedentary had fewer hyperactive symptoms; more activity was associated with more hyperactive symptoms.

This chapter expands on the previous chapter by considering some of the wider contextual factors in the relationship between PA and mental health. In particular, this chapter will focus on the role of green space in the relationship between PA and mental health, and, in doing so, will explore whether the role of green space is confounded by additional contextual factors such as area deprivation and rural-urban designation. The potential importance of ward-level clustering will be considered by employing multilevel modelling techniques.

4.2 Background

As reported in the Chapter 1, the effects of place and green space in particular, are important to children's PA levels and their mental health outcomes. Exposure or access to green space, for example, has been shown to improve developmental, cognitive, and mental health outcomes in children (Daniel Aggio et al., 2015; Amoly et al., 2014; Feng & Astell-Burt, 2017; Eirini Flouri et al., 2018; McCormick, 2017; McCracken et al., 2016). By offering an environment that is safer and healthier for play, green spaces may encourage activity in young people (P. Dadvand et al., 2014; Lachowycz & Jones, 2011; J. F. Sallis et al., 2008). The role of green space in the relationship between PA and mental health may additionally be modified by whether the area in question is rural or urban, and on its relative deprivation. For example, access, usability, availability, and quality of green space and PA facilities are associated with rural-urban and deprivation characteristics of the geographical region such as neighbourhood and road safety, and local resources available for appropriate spaces for active play (K. Davison & Lawson, 2006; McCracken et al., 2016; Pouliou et al., 2015). Therefore, it is not only important to consider the role of green space in the relationship between PA and mental health, but to consider how the relationship might be confounded by area rural-urban status and deprivation. Finally, there may be area-level factors that have not been measured but may exert residual environmental effects. For example, a study by Boyle et al (2002) found that between-neighbourhood differences accounted for a significant proportion of the differences in behavioural problems and that these were not accounted for by family and neighbourhood variables measuring socioeconomic disadvantage (Boyle & Lipman, 2002).

4.3 Research questions

Despite the importance of green space in both PA levels and mental health outcomes, there is an absence of population-level studies that examine the role of green space in the relationship between PA and mental health in children. This chapter will address this gap in the literature by answering the following questions:

1. Are children who live in areas of greater green space less sedentary? Are they more active?
2. Do children who live in areas of greater green space have fewer symptoms of mental health problems?
3. Are neighbourhood deprivation and rural-urban designations associated with green space? What are their relationships to PA and mental health?
4. Is level of green space a significant factor in the relationship between PA and mental health?
5. Does the relationship between PA and mental health in children vary by levels of green space?
6. Do contextual factors such as rural-urban designation and deprivation confound the role of green space on PA and mental health?
7. What is the relationship between PA/sedentary behaviour and mental health after adjusting for ward-level characteristics and accounting for clustering in the sample?
8. To what extent does adjusting for ward characteristics account for variability in SDQ scores between wards?

The following section will describe the methods used to address the research questions.

4.4 Methods

4.4.1 Analytic sample and additional variables

The final sample used for this model has been previously described in section 2.1.1. The confounders at individual-level used in these analyses are identical to those in the previous analysis and are described in sections 2.2.3 and 3.2.1. The geographical and area-level variables are described below.

Green space

The primary variable of interest at area-level is green space. In the MCS data, the original variable on green space was available at Lower layer Super Output Area (LSOA) level in England only; these areas typically include 600 homes and 1,500 residents (Ioaekeimidi, Midouhas, & Church, 2017). These data were obtained through the 2001 Generalised Land Use Database (GLUD), which defines nine categories of land use: domestic buildings, non-domestic buildings, roads, paths, rail, water, other land uses (largely hardstanding), domestic gardens, and green space (identified as green spaces larger than 5m^2, excluding domestic gardens).

Green space data for the whole of the UK are available at ward-level through the Coordination of Information on the Environment (CORINE; EEA, 2000), which was derived from satellite imagery but is sensitive only to larger green spaces. The Centre for Research on Environment Society and Health (CRESH) derived UK-wide, ward-level indicators by developing a regression model predicting the known GLUD green space percentage for the wards in England using the CORINE imagery and population census data from 2001. This model predicted the known England LSOA green space values well, and was applied to the rest of the UK to obtain ward-level green space estimates (Elizabeth A Richardson & Mitchell, 2010). These green space data estimate the percentage coverage of all green spaces larger than $5m^2$ (excluding domestic gardens) for each ward in the UK and were linked to MCS sweeps 1-5. The lowest decile corresponds to areas with <21% green space coverage and >94% coverage in the highest decile (Eirini Flouri et al., 2018). The green space variable at age 7, contemporaneous with the PA study, was used for these analyses. In the MCS, these data were complete for all children in the analytic sample.

Rural-urban designation

The definition of rurality and urbanicity, and any sub-designations, differs between Scotland, Northern Ireland, and England/Wales, thus a single UK-wide variable on rural-urban designation is not available. The following country-specific variables were used.

In England and Wales, the 2005 ONS Rural Urban Morphology Code defines 3 categories at LSOA level: urban >10,000 inhabitants; town and fringe; and village, hamlet and isolated dwellings .

In Scotland, the Scottish Executive Urban Rural Classification 2005-2006 defines 6 categories: large urban areas (>125,000 people), other urban areas (10,000-125,000 people), accessible small towns (3,000-10,000 people and within 30 minutes drive from nearest settlement >10,000), remote small towns (3,000-10,000 people and >30 minutes drive from nearest settlement >10,000), accessible rural (<3,000 people , and within 30 minutes drive from nearest settlement >10,000), remote rural (<3,000 people , and >30 minutes drive from nearest settlement >10,000) (Scottish Executive, 2006).

The Northern Ireland Statistics and Research Agency defines eight classification bands: A – Belfast, B – Derry City, C – large town (population 18,000+), D – medium town (10,000 - 17,999), E – small town (5,000 - 9,999), F – intermediate settlement (2,500 - 4,999), and G – village (1,000 - 2,499); with bands A-E comprising 'urban' and F-H comprising 'rural'. In the MCS data, a 3-fold category variable is available for Northern Ireland and defines the geographical units as urban, mixed urban-rural, and rural.

A three-category rural-urban variable was created based on the variables available for the three countries (rural; towns/mixed; and rural). However, as the categories are not equivalent between countries, they were compared by adding interaction terms between the UK country and rural-urban designation variable. Rural-urban designation and country were complete for all children in the analytic sample.

Deprivation

Neighbourhood deprivation in the MCS data was measured using the Index of Multiple Deprivation (IMD) for England (2004), Wales (2005), Northern Ireland (2005), and Scotland (2004), and were linked at Lower layer Super Output Area level. In England, IMD measures deprivation in seven weighted domains: income (22.5%), employment (22.5%), education, skills and training (13.5%), health and disability (13.5%), crime (9.3%), barriers to housing and services (9.3%), and living environment (9.3%). Welsh domains and weights are: income (23.5%), employment (23.5%), health (14.0%), education (14.0%), access to services (10.0%), community safety (5.0%), physical environment (9.3%), and housing (5.0%). Northern Irish domains and weights are: income (25%), employment (25%), education, skills and training (15%), health and disability (15%), access to services (10%), living environment (10%), and crime (5%). In Scotland, the domains and weights are: income (28%), employment (28%), health (14%), education, skills and training (14%), geographic access to services (9%), crime (5%), and housing (2%).

These country-specific deprivation variables are available in deciles in MCS data, where the first decile is the most deprived and the tenth the least deprived. Country-specific estimates IMD variables were compared by adding interaction terms between the UK country and IMD variable in multiple linear regression analyses. Ward-level deprivation in the MCS was complete for all children in the analytic sample.

Country

A variable identifying the child's residence in England, Wales, Scotland, or Northern Ireland was also included in the models. Because of the country-specific definitions and weighting of the rural-urban designation and the deprivation variables, an interaction term was added between each of IMD and rural-urban designation, and the country. Estimates for these variables are presented to prevent the loss of power with country-specific analyses.

4.4.2 Plan of analysis

Descriptive statistics; bivariate associations with green space (Questions 1-3)

Weighted proportions and unweighted number of observations of children at each decile of green space coverage, in urban, town or mixed rural-urban, and rural settings, and deprivation deciles were obtained. Using linear regression, the relationship between green space and sedentary time, light PA and MVPA was estimated. These models were weighted (MCS5 and PA), unadjusted, and run separately by sex. Green space was treated as a continuous variable. The association between green space and SDQ scores was estimated in the same way. Spearman correlation coefficients were obtained for deprivation deciles, rural-urban designation by country, and green space deciles.

Multilevel models (Questions 4-8)

Random intercept models

To evaluate the effect of environmental characteristics in the relationship between PA and SDQ, ward-level variables (green space, area deprivation, and rural-urban designation) have been included in the models. With the inclusion of ward-level characteristics, due to the clustering in the sample, we cannot assume that these observations are independent.

Multilevel models (also called mixed models or random effects models) incorporate the clustered structure of the data by including random parameters. The random parameter is allowed to vary for the higher-level unit and cluster-specific estimates can be obtained. In a random intercept model, two components are estimated: the fixed component which is assumed to be invariant across clusters, and a random component which represents the deviation of each cluster from the fixed component. This can be expressed as:

$$Y_{ij} = \beta_0 + \beta_1 x_{ij} + u_j + e_{ij}$$

Where:

$$e_{ij} \sim N(0, \sigma^2),$$

$$u_j \sim N(0, \tau^2).$$

The relationship between the outcome (*Yij*) for individual *i* within cluster *j* and exposure *x*; β_0 is the fixed component intercept and u_j the random component representing the cluster-specific deviation from β_0. The residual variability is portioned into 'between' and 'within' cluster variance, represented by τ^2 and σ^2, respectively. The assumption in a random intercept model is that the magnitude of effect of the exposure on the outcome is the same for every cluster, but the variation of the relationship might be affected by clustering. (In a random slopes model, the 'within' cluster variance is allowed to vary across clusters, thus, σ^2_j replaces σ^2.)

The extent to which the total variability in the outcome is attributable to the clusters can be measured by the intraclass correlation coefficient (ICC). ICC is a ratio of the between-cluster residual variance and the total residual variance:

$$\text{ICC} = \tau^2 / \tau^2 + \sigma^2$$

A large ICC is indicative of similarities between individuals within the cluster (Nezlek, 2011).

In the analyses undertaken in this chapter, the 'within' effect refers to the level 1 variance in SDQ within the ward cluster, attributable to child/household differences, while the 'between' effect refers to the level 2 variance in the outcome attributable to differences between wards. As a result, a multilevel model with random intercept allows the following questions to be answered, accounting for clustering in wards: first, what is the relationship between PA and mental health, adjusting for environmental factors (RQ7); second, how much variation in SDQ scores are at ward level (RQ8)?

Two-level, random intercept-only linear regression models were fitted separately for boys and girls on imputed datasets using Stata/SE 15.1 `mi estimate` and `mixed` commands as follows:

Model 0	$SDQ_{ij} = \beta_0 + u_{0j} + e_{ij}$
Model 1	$SDQ_{ij} = \beta_0 + \beta_1 PA_{ij} + u_j + e_{ij}$
Model 2	$SDQ_{ij} = \beta_0 + \beta_1 PA_{ij} + \beta_2 GreenSpace_{ij} + u_j + e_{ij}$
Model 3	$SDQ_{ij} = \beta_0 + \beta_1 PA_{ij} + \beta_2 GreenSpace_{ij} + \beta_1 PA_{ij} * \beta_2 GreenSpace_{ij} + u_j + e_{ij}$
Model 4	$SDQ_{ij} = \beta_0 + \beta_1 PA_{ij} + \beta_2 GreenSpace_{ij} + \beta_3 RuralUrban_{nij} + \beta_4 Deprivation_{ij} + \beta_5 Country_{nij} + \beta_3 RuralUrban_{nij} * \beta_5 Country_{nij} + \beta_4 Deprivation_{ij} * \beta_5 Country_{nij} + u_j + e_{ij}$
Model 5	$SDQ_{ij} = \beta_0 + \beta_1 PA_{ij} + \beta_2 GreenSpace_{ij} + \beta_3 RuralUrban_{nij} + \beta_4 Deprivation_{ij} + \beta_5 Country_{nij} + \beta_3 RuralUrban_{nij} * \beta_5 Country_{nij} + \beta_4 Deprivation_{ij} * \beta_5 Country_{nij} + \Sigma \beta_n x_{nij} + u_j + e_{ij}$

Where:

Y_{ij} is the outcome for ward '*i*' at child '*j*' (i.e. emo_{ij}, $peer_{ij}$, $cond_{ij}$, $hyper_{ij}$, td_{ij}); β_0 is the intercept; $\beta_1 x_{ij}$ is the coefficient for PA (i.e. $\beta_1 Sed_{ij,}$ $\beta_1 Light_{ij,}$ $\beta_1 MVPA_{ij}$); $\beta_n x_{nij}$ is the coefficient for each of the additional covariates specified in the model; u_j is the between-ward residual (i.e. the difference between the intercept of the overall line and the intercept of the ward line); and e_{ij} is the within-ward residual.

Initially, an empty model was fitted to estimate the proportion of total variance in SDQ scores due to differences between wards. Subsequently, for each of the combinations of activity (sedentary, light, MVPA) and SDQ (emotional, peer, conduct, hyperactivity, total difficulties), a series of five models was run to evaluate the relationship between PA and SDQ. In a random intercept model, the child- and area-level characteristics are treated the same mathematically and added as the $\beta_n x_{nij}$ parameter. Because the values for each of the area-level variables are identical for children within the same ward, these are interpreted as the effect of the ward characteristic on the outcome (Pillinger, (n.d.)). Intraclass correlation coefficients (ICC) were calculated to determine the proportion of total variance attributable to between-ward differences across all models.

Physical activity variables were added in Model 1 to observe whether sedentary and active time affects SDQ scores, accounting for ward level clustering. Green space was added in Model 2 to estimate effects of ward green space coverage on the relationship between PA and SDQ. An interaction term between sedentary and PA measures and green space was added in Model 3 to test whether the effect of PA on SDQ varies by ward level green space. If the interaction term was not significant, it was excluded from subsequent models. In Model

4, neighbourhood deprivation and rural-urban designation were added to measure any effect on mental health outcomes and to explore whether green space effects were confounded by these contextual factors; an interaction term between each UK country and country-specific IMD was included for the reasons described in section 4.4.1. Finally, the fully adjusted model (Model 5) included all individual-level confounders described in section 2.2.3 to determine whether associations between PA/sedentary behaviour variables and SDQ outcomes persisted.

Survey commands (`svy`) cannot be applied with Stata `mixed` multilevel modelling commands, however, probability weights (`pweight`) can be specified. In the MCS, ward-level weights are not available to apply at the higher level. One approach suggests that suitable variables on which the sampling design depend can be incorporated to reduce bias (Sterba, 2009). In this case, the variable (PTTYPE2) incorporates higher level characteristics, as children were oversampled from wards from the smaller countries (Wales, Scotland, and Northern Ireland), with higher deprivation, and greater ethnic density. Eight dummy variables for each of the strata were included in the models, with the advantaged children living in England as the baseline (see section 2.1 for a description of the strata in the MCS).

Imputation model

Item missingness for potential confounders and mediators were described in section 3.2.2, and are identical to the sample used for these analyses. For the imputation model, green space, area deprivation, and rural-urban designation were added to inform the model described but did not require any imputation as these were fully observed. Similar to the incompatibility discussed in the previous section between `mixed` and `svy` commands in Stata in the previous section, `mi impute` commands cannot be combined with `mixed` commands. This can be problematic as use of a single-level imputation model can result in misestimation of MI variance parameters (Andridge, 2011). There is no consensus on how to impute multilevel data, and most commercially available statistical software do not provide imputation methods designed for hierarchical data (Andridge, 2011; Speidel, Drechsler, & Sakshaug, 2018; White, Royston, & Wood, 2011). However, inclusion of design variables in imputation models can help reduce bias (Reiter, Raghunathan, & Kinney, 2006), thus, ward identifiers and dummy variables for the strata were included in the imputation model to approximate clustering.

4.5 Results

4.5.1 Descriptive statistics

In the analytic sample (n=6,153), 13.7% were living in wards with the least green space coverage and 5.9% of children were living in wards in the greenest decile.

Table 4-1 below shows the unweighted number and percentage of children in each of the deciles of green space coverage.

Table 4-1: Number and percentage of children by green space decile

Ward green space coverage deciles	*N*	*%*
Least green decile	844	13.7
2	787	12.8
3	677	11.0
4	708	11.5
5	658	10.7
6	663	10.8
7	494	8.0
8	484	7.9
9	477	7.8
Greenest decile	361	5.9
Total	6,153	100

Table 4-2 below shows the shows the number and percentage of children in rural-urban classifications by country. The majority of children (72.8%) overall live in urban areas; higher percentages of children are from rural areas in Northern Ireland (44.7%) and Scotland (27.2%), with only 10.6% from rural areas in England and Wales. In the MCS, children were oversampled from wards with higher ethnic density in England, which are predominantly urban areas, which is reflected in the high percentage of urban residence in England and Wales.

Table 4-2: Number and percentage of children by country specific rural-urban designation

England and Wales	*N*	*%*
Urban > 10K	3,814	79.1
Town and Fringe	501	10.4
Village, Hamlet & Isolated Dwellings	509	10.6
Total	4,823	100

Northern Ireland	*N*	*%*
Urban	276	45.5
Mixed Urban-Rural	60	9.9
Rural	271	44.7
Total	607	100

Scotland	*N*	*%*
Urban Areas	391	54.2
Small Towns	135	18.7
Rural	196	27.2
Total	722	100

Rural-urban (all countries)	*N*	*%*
Urban	4,481	72.8
Mixed / town	696	11.3
Rural	976	15.9
Total	6,153	100

Table 4-3 below shows the number and percentage of children in IMD deciles by country.

Table 4-3: Number and percentage of children by country-specific IMD deciles

	Overall		*England*		*Wales*		*Northern Ireland*		*Scotland*	
IMD decile	*N*	*%*	*N*	*%*	*N*	*%*	*N*	*%*	*N*	*%*
Most deprived decile	559	11.6	414	10.4	60	8.8	50	11.8	35	9.0
2	586	10.1	366	9.2	108	14.2	64	12.4	48	7.7
3	598	10.3	389	9.8	85	9.0	67	10.7	57	9.8
4	560	8.5	351	8.8	89	10.4	64	10.1	56	9.9
5	595	10.4	397	10.0	54	4.7	74	11.9	70	9.7
6	600	10.0	391	9.8	64	7.6	52	8.0	94	13.6
7	570	9.4	384	9.6	73	8.6	43	8.3	70	10.0
8	623	9.3	398	10.0	75	9.3	66	9.6	84	9.5
9	684	9.6	412	10.3	107	13.5	68	9.2	97	10.2
Least deprived decile	777	10.9	483	12.1	124	13.9	59	8.1	111	10.5
Total	6,152	100	3,984	100	839	100	607	100	722	100

4.5.2 Bivariate associations

Green space and PA

The sedentary, light and MVPA variables were regressed on the green space variable to explore whether deciles of green space coverage were associated with sedentary or active time. The results are presented in Table 4-4 below:

Table 4-4: Change in units of PA and sedentary time per increase in green space decile by gender

		Boys		Girls	
		b	*SE*	*b*	*SE*
Sedentary	*Coefficient*	-0.003	0.008	-0.004	0.007
	Intercept	6.383	0.050	6.671	0.042
Light PA	*Coefficient*	0.015	0.013	0.020	0.012
	Intercept	9.356	0.08	9.224	0.068
MVPA	*Coefficient*	-0.021	0.015	-0.017	0.011
	Intercept	4.767	0.096	3.828	0.062

p<0.05, **p<0.01, ***p<0.001

Green space was not significantly associated with sedentary time or PA for either boys or girls.

Green space and SDQ

The SDQ variables were regressed on the green space variable to explore whether green space was associated with the SDQ subscales. The results are presented in Table 4-5 below for boys and girls.

Table 4-5: Change in SDQ scores per increase in green space decile by gender

		Boys		Girls	
		b	*SE*	*b*	*SE*
Emotional problems	*Coefficient*	-0.023	0.018	-0.042**	0.015
	Intercept	1.897	0.101	2.084	0.093
Peer problems	*Coefficient*	-0.028	0.017	-0.041**	0.015
	Intercept	1.604	0.08	1.477	0.086
Conduct problems	*Coefficient*	-0.016	0.014	-0.031*	0.013
	Intercept	1.620	0.079	1.402	0.069
Hyperactivity	*Coefficient*	-0.020	0.022	-0.055**	0.017
	Intercept	3.653	0.113	2.914	0.097
Total difficulties	*Coefficient*	-0.089	0.056	-0.166***	0.046
	Intercept	8.771	0.280	7.861	0.261

p<0.05, **p<0.01, ***p<0.001

In girls, increases in green space coverage were significantly associated ($p<0.05$) with lower SDQ scores in all subscales and fewer total difficulties: -0.042 points for emotional problems, -0.041 points for peer problems, -0.031 points for conduct problems, -0.055 points for hyperactivity, and -0.166 points for total difficulties for each increase in green space decile.

Greater green space coverage was not associated with SDQ scores in boys.

Green space and neighbourhood characteristics (IMD and rural-urban designation)

Spearman's correlation coefficients were obtained to assess the relationship between green space and deprivation, and green space and rural-urban designation, both by country. Table 4-6 below shows the correlation coefficients.

Table 4-6: Correlation between green space deciles and deprivation, and rural-urban designation by country

	Deprivation		*Rural-urban designation*	
Green space in deciles	*Coefficient*	*p-value*	*Coefficient*	*p-value*
England (n=3985)	**0.399**	<0.001	**0.637**	<0.001
Wales (n=839)	**0.098**	0.004	**0.612**	<0.001
Scotland (n=722)	0.050	0.183	**0.767**	<0.001
Northern Ireland (n=607)	0.023	0.463	**0.901**	<0.001

More green space was positively correlated with lower deprivation in England and Wales, but not for the Scotland and Northern Ireland. In all countries, less urban settings were strongly positively correlated with more green space.

4.5.3 Multilevel models[1]: interpreting fixed effects

The main results for each SDQ subscale by level of PA are described below. Full tables are available in Appendix C. Each table presents the coefficients for the total effect of sedentary, light PA, and MVPA time on each SDQ subscales for the five models. (Interpretation of the random parameters will be discussed later in section 4.5.4.). For Models 2 through 5, green space coefficients and—in Model 3 only, green space*PA interaction terms—are presented. Country-specific estimates for rural-urban designation and neighbourhood deprivation are presented for Models 4 and 5 in a separate table following the main table.

Emotional problems

As in the previous chapter, there were no significant relationships between sedentary or active time and emotional problems for boys or girls in any of the models.

See Appendix C section I for full results.

Peer problems

Sedentary

Unadjusted and green space adjusted models for boys and girls did not show an association between sedentary time and peer problems. For boys, increased sedentary time was

[1] In interpreting the green space, deprivation, and rural-urban designation coefficients, I am describing the controlled direct effect of these covariates on SDQ; that is, the effect of green space when PA is fixed at a given level, thus blocking the mediated effects of green space through PA. It is not to be read as the conditional total causal effect (which is the effect of PA on SDQ in these models) (Westreich & Greenland, 2013).

associated with more peer problems after adjusting for neighbourhood characteristics (b=0.117, 95% CI 0.002, 0.231) and in the fully adjusted model (b=0.163, 95% CI 0.059, 0.267). In fully adjusted models, sedentary time was positively associated with peer problems in girls (b=0.088, 95% CI 0.005, 0.171).

In fully adjusted models, boys in less deprived wards in England had fewer peer problems (b=-0.040, 95% CI -0.079, -0.001). For girls in Scotland, residence at the town level, compared with living in an urban setting, was associated with fewer peer problems (b=-0.811, 95% CI -1.452, -0.170). Green space was not a significant factor in any of the models, nor was there evidence of interaction between sedentary time and green space on peer problems.

See Table 4-13 and Table 4-14 in Appendix C section II for full results.

Light PA

Increases in light PA in boys and girls were predictive of fewer peer problems in fully adjusted models (b=-0.079, 95% CI -0.143, -0.016 in boys; b=-0.073, 95% CI -0.131, -0.014 in girls).

Except where peer problems were fewer in girls living at town level in Scotland compared with living in an urban area, neighbourhood characteristics were not found to be significant factors in the relationship. There was no evidence of interaction between light PA and green space on peer problems.

See Table 4-15 and Table 4-16 in Appendix C section II for full results.

MVPA

For girls, MVPA was not associated with peer problems in any of the models; however, more MVPA in boys was associated with fewer peer problems across all models (b=-0.078, 95% CI -0.135, -0.022 after all adjustments). In Model 4, lower deprivation in England, Wales, and Scotland were protective of peer problems but after fully adjusting, this effect remained for England only (b=-0.040, 95% CI -0.079, -0.002). Rural-urban designation and green space were not significant factors, nor was there any evidence of green space and MVPA interactions on peer problems.

See Table 4-17 and Table 4-18 in Appendix C section II for full results.

Conduct problems

Sedentary

More sedentary time was predictive of lower conduct problems in boys in Models 1 and 2 (b=-0.130, 95% CI -0.254, -0.006); however, green space was not significant and there was no evidence of sedentary*green space interaction. Sedentary time was not associated with conduct problems in boys after further adjusting for neighbourhood characteristics and remaining confounders.

In girls, increased sedentary time was associated with fewer conduct problems in unadjusted and green space models (b=-0.125, 95% CI -0.215, -0.034), and conduct scores were lower in greener neighbourhoods (b=-0.036, 95% CI -0.063, -0.009). The interaction between sedentary time and green space was not significant, however. After adjusting for neighbourhood characteristics in Model 4, the effect of sedentary time on conduct problems was reduced (b=-0.117, 95% CI -0.206, -0.028) and green space was no longer significant. Country-specific estimates for rural-urban designation showed that girls residing in town/fringe in Wales (b=-0.631, 95% CI -0.948, -0.314) and rural areas in Northern Ireland (b=-0.613, 95% CI -1.199, -0.027) had fewer conduct problems when compared with girls in urban areas. Lower deprivation was associated with fewer conduct problems in girls in England (b=-0.058, 95% CI -0.092, -0.024), Wales (b=-0.135, 95% CI -0.202, -0.068), and Scotland (b=-0.125, 95% CI -0.200, -0.050). After adjusting for all confounders, however, sedentary time was not found to be a significant predictor of conduct problems in girls.

See Table 4-19 and Table 4-20 in Appendix C section III for full results.

Light PA

No relationships were found between light PA and conduct problems in boys, and there was no evidence of interaction between light PA and green space.

In girls, light PA was associated with more conduct problems in the unadjusted (b=0.065, 95% CI 0.004, 0.125) and green space adjusted models (b=0.067, 95% CI 0.006, 0.127). Green space was associated with lower conduct problems in Model 2 (b=-0.037, 95% CI -0.064, -0.009) but not after further adjustment. There was no evidence of an interaction between light PA and green space on conduct problems.

For girls, in Model 4, each unit of light PA associated with an increase in conduct problems (b=0.063 95% CI 0.003, 0.122); however, living in towns in Wales (b=-0.641, 95% CI -0.959, -0.323) and in rural Northern Ireland (b=-0.611, 95% CI -1.201, -0.022) was associated with fewer conduct problems when compared with urban areas in their respective countries. Lower deprivation was associated with fewer conduct problems in girls in England (b=-0.059, 95% CI -0.094, -0.025), Wales (b=-0.135, 95% CI -0.201, -0.068), and Scotland (b=-0.125, 95% CI -0.199, -0.050). In the fully adjusted model, light PA was not predictive of conduct problems in girls.

See Table 4-21 and Table 4-22 in Appendix C section III for full results.

MVPA

For boys, increases in MVPA were associated with more conduct problems across all models (except in Model 3 where an interaction term between MVPA and green space was added). In Model 4, each 15 minutes of MVPA was associated with an increase of 0.064 (95% CI 0.002, 0.126) points, although lower scores were observed for boys in less deprived wards in England (b=-0.105, 95% CI -0.140, -0.070), Wales (b=-0.070, 95% CI -0.134, -0.007), and Scotland (b=-0.112, 95% CI -0.181, -0.044). In the fully adjusted model, MVPA remained positively associated with conduct problems (b=0.072, 95% CI 0.019, 0.126), however, neighbourhood deprivation was no longer significant.

For girls, in green space adjusted models, each unit MVPA was associated with more conduct problems (b=0.061, 95% CI 0.009, 0.112) but living in a greener ward decreased this effect (b=-0.034, 95% CI -0.061, -0.008); however, green space was not significant after further adjustment. In Model 4, increases in MVPA were associated with more conduct problems (b=0.056, 95% CI 0.006, 0.107). Lower deprivation was associated with fewer conduct problems in girls in England (b=-0.059, 95% CI -0.093, -0.025), Wales (b=-0.137, 95% CI -0.203, -0.071), and Scotland (b=-0.126, 95% CI -0.201, -0.051). In the fully adjusted model, MVPA was not predictive of conduct problems in girls.

There were no significant interactions between MVPA and green space on conduct problems for either gender.

See Table 4-23 and Table 4-24 in Appendix C section III for full results.

Hyperactivity

Sedentary

Across all models, increased sedentary time was associated with lower hyperactivity scores for boys and girls. More green space was associated with less hyperactivity in girls in Model 2 (b=-0.057, 95% CI -0.091, -0.022), but this was not significant after further adjustments and no further relationships with green space were observed for either boys or girls.

In Model 4, sedentary time was negatively associated with hyperactivity in both boys (b=-0.429, 95% CI -0.571, -0.286) and girls (b=-0.414, 95% CI -0.546, -0.283). Hyperactivity scores were lower in less deprived wards in England (b=-0.162, 95% CI -0.208, -0.117) and Scotland (b=-0.224, 95% CI -0.329, -0.119) for boys, and England (b=-0.079, 95% CI -0.127, -0.031), Wales (b=-0.209, 95% CI -0.287, -0.132), and Scotland (b=-0.099, 95% CI -0.193, -0.005) for girls. Girls living in rural England had less hyperactive symptoms than in urban wards (b=-0.525, 95% CI -0.964, -0.087).

In fully adjusted models, each additional 60 minutes of sedentary time was associated with a -0.331 (95% CI -0.450, -0.213) point decrease in hyperactivity scores in boys and -0.264 (95% CI -0.374, -0.154) points in girls. The relationship between rurality and lower hyperactivity in girls was no longer observed; however, girls living in towns in England and in rural Scotland had fewer hyperactive symptoms compared with urban residence (respectively, b=-0.487, 95% CI -0.833, -0.142 and b=-0.775 95% CI -1.404, -0.145). The relationship between hyperactivity and deprivation in England and Scotland was no longer significant; only girls in Wales from less deprived wards had lower hyperactivity scores (b=-0.085, 95% CI -0.139, -0.030). There was no evidence of interaction between sedentary time and green space on hyperactivity.

See Table 4-25 and Table 4-26 in Appendix C section IV for full results.

Light PA and MVPA

Across all models, increases in activity (both light and moderate-to-vigorous) were positively associated with hyperactivity. Greener space was associated with lower scores in girls only in Model 2 (b=-0.060, 95% CI -0.095, -0.025 for light PA; b=-0.053, 95% CI -0.089, -0.017 for MVPA) but this was not significant after further adjustment.

Each additional unit of PA (30 minutes for light PA and 15 minutes for MVPA) was associated with increased hyperactivity scores in boys (b=0.159, 95% CI 0.081, 0.238 for light PA; b=0.157, 95% CI 0.092, 0.223 for MVPA) and girls (b=0.160, 95% CI 0.087, 0.234 for light PA; b=0.094, 95% CI 0.029, 0.158 for MVPA). Lower hyperactivity scores were observed for girls living in towns in England (b=-0.487, 95% CI -0.835, -0.139 for light PA; -0.464, 95% CI -0.812, -0.116 for MVPA) and in rural Scotland (b=-0.754, 95% CI -1.388, -0.120 for light PA; -0.820, 95% CI -1.447, -0.193 for MVPA) than in urban areas in the respective countries. Less deprivation in Wales was also protective of hyperactivity in girls (b=-0.083, 95% CI -0.137, -0.029 for light PA; -0.086, 95% CI -0.143, -0.029 for MVPA).

In Model 4, lower deprivation was associated with fewer hyperactivity symptoms for boys in England (b=-0.168, 95% CI -0.215, -0.122) and Scotland (b=-0.235, 95% CI -0.339, -0.131); however, this was no longer significant after adjusting for all confounders. There was no evidence of interaction between light PA and green space on hyperactivity.

See Table 4-27, Table 4-28, Table 4-29, and Table 4-30 in Appendix C section IV for full results.

Total difficulties

Sedentary

For boys and girls, increased sedentary time was associated with fewer total difficulties in Models 1-4; after adjusting for deprivation and rural-urban designation, each additional sedentary hour was associated with a decrease in total difficulties of -0.415 (95% CI -0.791, -0.038) points in boys and -0.620 (95% CI -0.952, -0.289) points in girls.

More green space was predictive of fewer total difficulties in girls (b=-0.163, 95% CI -0.256, -0.070) in Model 2 but this was not significant after adjusting further for neighbourhood context.

In Model 4, girls living in towns in Wales and in rural Northern Ireland had fewer total difficulties than their urban counterparts (b=-1.254, 95% CI -2.456, -0.052 and b=-2.395, 95% CI -4.308, -0.482, respectively). Lower deprivation was associated with fewer total difficulties in England (b=-0.433, 95% CI -0.553, -0.313 for boys; b=-0.230, 95% CI -0.346, -0.114 for girls) Wales (b=-0.333, 95% CI -0.562, -0.104 for boys; b=-0.577, 95% CI -0.790, -0.364 for girls), and Scotland (b=-0.511, 95% CI -0.769, -0.253 for boys; b=-0.379, 95% CI -0.634, -0.124 for girls). After adjusting for remaining confounders, however, sedentary time was no longer predictive of total difficulties in either boys or girls. No green space effects nor green space*sedentary time interactions were significant.

See Table 4-31 and Table 4-32 in Appendix C section V for full results.

Light PA

Light PA was associated with greater total difficulties across Models 1-4 for both genders (Model 4: b=0.282, 95% CI 0.047, 0.517 for boys; b=0.349, 95% CI 0.126, 0.571 for girls). More green space was associated with fewer total difficulties in girls (b=-0.167, 95% CI -0.262, -0.073) in Model 2 but this was not significant after further adjustment.

In Model 4, girls living outside of urban areas in Wales (for towns, b=-1.311, 95% CI -2.531,-0.091; for rural, b=-1.561, 95% CI -3.072,-0.051) and rural Northern Ireland (b=-2.393, 95% CI -4.308,-0.477) had lower total difficulties scores.

Less deprivation in England (b=-0.438, 95% CI -0.558, -0.318 for boys; b=-0.235, 95% CI -0.351, -0.119 for girls), Wales (b=-0.335, 95% CI -0.564, -0.105 for boys; b=-0.575, 95% CI -0.788, -0.363 for girls) and Scotland (b=-0.521, 95% CI -0.779, -0.263 for boys; b=-0.378, 95% CI -0.632, -0.124 for girls) was associated with fewer total difficulties.

In the fully adjusted model, however, light PA no longer predicted total difficulties in either boys or girls. No green space*light PA interactions were significant.

See Table 4-33 and Table 4-34 in Appendix C section V for full results.

MVPA

MVPA was not associated with total difficulties scores in any models for boys. For girls, each 15 minutes of MVPA was associated with an increase in total difficulties in Models 1-4 (b=0.258, 95% CI 0.053, 0.462 after adjusting for neighbourhood characteristics). In the green space adjusted model, girls in greener wards had fewer total difficulties (b=-0.157, 95% CI -0.250, -0.064) but this was not significant after further adjustment.

In Model 4, lower total difficulties scores were observed for girls who lived in rural Northern Ireland (b=-2.287, 95% CI -4.204, -0.371) and in less deprived wards in England (b=-0.237, 95% CI -0.350, -0.124), Wales (b=-0.585, 95% CI -0.795, -0.374) and Scotland (b=-0.384, 95% CI -0.639, -0.128). After adjusting for remaining confounders, however, MVPA was no longer associated with total difficulties in girls. No green space*MVPA interactions were significant for either gender.

See Table 4-35 and Table 4-36 in Appendix C section V for full results.

4.5.4 Multilevel models: interpreting random effects

Initially, a null model without explanatory variables was fitted in order to estimate whether there was clustering in mean SDQ score at ward level. High between-ward variation would indicate the presence of clustering and that accounting for between-individual variation alone would result in underestimated standard errors (Rabe-Hesketh & Skrondal, 2008).

The area-effects section in the tables in Appendix C show the random effects parameters (variance and 95% CI) and the intraclass correlation coefficients (ICC)(%).

The ICC from the null model indicate the proportion of total variance attributable to between-ward level differences in SDQ scores by gender. Where just the intercept is fitted in Model 0, respectively for boys and girls, the ICCs (expressed as percentages) were 9.3% and 8.7% for emotional problems, 10.0% and 10.6% for peer problems, 12.4% and 7.2% for conduct problems, 9.0% and 7.7% for hyperactivity, and 11.9% and 9.4% for total difficulties. The proportion of total variance attributable to between-ward differences is higher for boys than girls across most subscales, except peer problems; however, these models do not include any explanatory variables.

The addition of a PA/sedentary variable, green space, and an interaction term (Models 1-3) did not result in substantial changes in either between-child nor between-ward variances, and ICCs remained broadly the same, across all SDQ outcomes and PA intensities. The introduction of neighbourhood context variables in Model 4 resulted in decreases in variance at ward level. More substantial differences were observed in Model 5, where variances at both individual and ward levels decrease. In fully adjusted models, ICCs across the sedentary and PA models for boys and girls were, respectively, 8.5-8.6% and 7.0% for emotional problems, 6.2-6.3% and 9.1-9.2% for peer problems, 8.3-8.8% and 5.0% for conduct problems, 8.8-9.0% and 4.5-4.7% for hyperactivity, and 8.6-8.7% and 5.9% for total difficulties[2].

4.6 Discussion

4.6.1 Summary of results

In this chapter, descriptive and multilevel analyses were undertaken to explore the effect of ward green space, deprivation, and rural-urban designation on children's PA and mental health. In bivariate analyses, green space showed no significant relationship or any patterns in its relationship with sedentary time, light PA, or MVPA for either gender. Higher green space coverage was not associated with SDQ in boys but was associated with lower scores in all subscales in girls. Green space was positively associated with deprivation in England and Wales only, and with rural-urban designation in all countries.

In the multilevel models, as in the single-level models from Chapter 3, there were no effects of sedentary time or PA on emotional health in either boys or girls.

In fully adjusted models, sedentary time at age 7 was predictive of more peer problems and fewer hyperactive symptoms at age 11 for both boys and girls. Increases in light PA were associated with fewer peer problems and more hyperactive symptoms. MVPA was positively associated with improvements in peer problems but worse conduct scores for boys only, and more hyperactive symptom for both boys and girls.

In green space adjusted models for girls only, there was evidence that more green space was associated with fewer conduct problems, hyperactivity symptoms, and total difficulties in sedentary, light PA, and MVPA models. However, after further adjustment, green space effects were no longer significant. There was no evidence of an interaction between green space and sedentary time or PA on mental health in these analyses.

In fully adjusted models, living in towns in Scotland was protective of peer problems in girls for sedentary and light PA models; girls living in towns in England and rural Scotland were less hyperactive in all models; in towns in England in Scotland, girls had fewer total difficulties for all models. Increased deprivation worsened peer scores for boys in England in sedentary and

[2] Ranges of percentages are presented where ICCs differed slightly by sedentary, light, and MVPA exposure.

MVPA fully adjusted models and, for girls in Wales, deprivation increased hyperactive symptoms in sedentary, light PA and MVPA fully adjusted models.

ICCs decreased from the null models to fully adjusted models in all subscales for both boys and girls, except hyperactivity in boys. Proportions of variance due to between-ward effects ranged from 4.5% (hyperactivity in girls) to 8.5% (total difficulties in boys) in fully adjusted models.

4.6.2 Strengths and limitations; comparisons with other findings

This chapter explored the role of neighbourhood context in the relationship between PA at age 7 and mental health at age 11 using MCS data. To my knowledge, it is the first study to have incorporated green space, deprivation, and rural-urban measures in multilevel models to evaluate the importance of place.

Green space was not associated with SDQ scores in any of the final models (question 4); adjusting for neighbourhood context (deprivation and rural-urban designation) in Model 4 removed any green space associations observed in Model 2 for conduct problems and hyperactivity (question 6). The addition of an interaction term between PA variables and green space (Model 3) showed that there was no evidence of differential effects of PA on SDQ scores by green space decile (question 5).

The null results observed could be due to the limitations in how green space was measured and the absence of information on green space usage. The percentage coverage of green space data by ward were not available in the MCS data and the ward identifiers were pseudonymised, preventing linkage to the original data. The available green space measure in deciles was treated as continuous on the assumption that more green space exposure is better, although it may not be a straightforward dose-response effect. A limitation of the green space measure is that the underlying data used to derive it were negatively skewed, with the lowest decile corresponding to wards with <21% green space coverage and >94% in the highest decile. The lowest deciles were more heterogenous in coverage than the higher deciles, thus, the difference in coverage between the first and second decile will be substantially larger than the difference between the ninth and tenth deciles, and this could result in diminished effects at higher deciles. Nonetheless, by using green space deciles, the challenges in analysing a measure with resulting distribution was not skewed like the original measure. Additionally, bivariate regression analyses of SDQ on green space showed small effect sizes (e.g. a decrease in Total Difficulties score of -0.17 points per greener decile for girls – see Table 4-6), thus, use of the original green space coverage percentage measures may have rendered any effects undetectable or difficult to interpret. An alternative measure where groups are more homogenous in the percentage of green space coverage may better detect possible mental health effects.

There was also an underlying assumption that the PA measured was conducted in these spaces. As the green space measure was based on satellite imagery, no information can be derived on its accessibility or usability. It is plausible that green space use, rather that its presence alone, determines the potential benefit of mental health (McCracken et al., 2016). A study that employed GPS and accelerometry to determine the amount of time spent engaged in PA in green spaces have found positive associations between green PA and emotional well-being (T. Sanders, Feng, Fahey, Lonsdale, & Astell-Burt, 2015). Further research employing measures of children’s active green space use is needed to gain insight into the potential benefits for mental health outcomes.

The use of multilevel models highlighted the potential importance of place and how they differ by gender: ICCs in the externalising subscales (conduct problems and hyperactivity) are roughly 4% higher for boys; for peer problems ICCs were approximately 3% higher in girls. This meant that unmeasured ward characteristics accounted for a greater proportion of variability in girls’ peer problems, and boys’ conduct problems and hyperactivity. To my knowledge, no studies have been conducted with children in examining gender differences in the effect of context on mental health; however, a study in adults showed that between-neighbourhood differences in self-rated health differed by gender, and aspects of the residential environment affected women’s health more than men (Stafford, Cummins, Macintyre, Ellaway, & Marmot, 2005). Gender-based parental approaches to their children’s play, safety, and social engagement, affected by environmental conditions, might mean that some contextual factors impact the relationship of PA to different aspects of mental health. While some of the environmental factors explored by Stafford et al (2005) (e.g. integration, family ties, trust, tolerance, crime, access to public transport, health services) may not be directly applicable to children, it highlights the ways future research could consider additional characteristics of place, how they might impact children’s mental health, and why this might be different for boys and girls.

With respect to the neighbourhood context, deprivation and rural-urban designation were significant factors in some of the PA and SDQ relationships; these differed by gender and country of residence. There are no known studies that examine these factors or equivalents, thus, these results are novel. The deprivation measures in deciles were available in the MCS data and are based on the country-specific rank order of relative area deprivation. Deciles are commonly used for measuring relative deprivation to produce more meaningful effect sizes;

for example, using the rank order of relative deprivation in England's LSOAs would result in an ordinal variable with up to 32,488 levels and this would yield small effect sizes (Department for Communities and Local Government, 2015). However, these relative measures of deprivation cannot quantify the magnitude of deprivation (so might miss any thresholds where deprivation shows effects on outcomes), nor can it identify deprived households in less deprived areas (and vice versa) so the households within the sample may not be representative of the area. Within decile, the experience of deprivation may be wide ranging in some and uniform in others, which might serve to obscure differences in outcomes.

Because there are no available UK-wide measures for these factors, a composite variable was created and an interaction for country was included to account for the differences in these measures. A limitation of this is that the sample sizes were smaller for some strata and effects may not have been detectable. Although, a study conducted on the environmental influences on PA in MCS children found no associations with rurality (Pouliou et al., 2015), where an objective binary measure (urban>10k vs rural) was used. Using deciles allows the modelling of deprivation, despite the use of different measures in the UK countries.

To reduce the amount of item missingness in the sample, multiple imputation techniques were employed; however, due to the limitations of the software and the statistical challenges in dealing with multilevel data, the models specified for imputation could not take into account the hierarchical structure of the data. The sampling strata, as a higher-level design variable, were included in the imputation model to approximate the clustering, and the extent of item missingness was minimal, but the potential bias due to misestimate of variance parameters could not be eliminated.

Within the conceptual framework, the hypothesis that distal, area-level factors would have an impact on the relationship between PA/sedentary behaviour and mental health was not confirmed. It could be that the measure does not capture the mechanisms through which green space might actually operate on PA/sedentary behaviour and mental health. For example, park green space may allow children to play with others and improve their mental health via psychosocial mechanisms where the same might not be true for children in rural green space. Environmental factors are complex and the important dimensions of green space with respect to PA and mental health in children may not have been captured. In particular, additional work needs to be carried out to understand if PA actually undertaken within green space has an impact on this relationship. Finally, a measure of green space that incorporates accessibility and safety would further clarify any potential mental health implications.

Appendix C

I. Emotional problems – multilevel model results

Table 4-7: Change in emotional problems per 60 minutes sedentary time; variance attributable to ward differences

	Model 0		Model 1		Model 2		Model 3		Model 4		Model 5	
Emotional problems - boys												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Sedentary	.	.	-0.002	-0.131,0.127	-0.003	-0.132,0.127	-0.127	-0.366,0.111	0.008	-0.122,0.138	0.091	-0.022,0.205
Green space	.	.	.	.	-0.028	-0.066,0.010	-0.209	-0.494,0.076	-0.012	-0.075,0.050	-0.042	-0.094,0.010
Sedentary x green space	.	.	.	.	.	.	0.028	-0.017,0.073	.	.	.	.
Random effects												
Constant	1.763	1.666,1.860	1.774	0.954,2.593	1.917	1.045,2.788	2.720	1.185,4.256	2.174	1.281,3.068	3.045	-0.101,6.192
Ward-level variance	0.360	0.252,0.514	0.360	0.252,0.514	0.359	0.251,0.513	0.358	0.250,0.514	0.336	0.234,0.483	0.228	0.154,0.338
Child-level variance	3.501	3.147,3.894	3.501	3.147,3.894	3.498	3.143,3.893	3.494	3.141,3.887	3.472	3.120,3.863	2.433	2.212,2.676
Intraclass Correlation Coefficient (ICC)(%)	9.3%		9.3%		9.3%		9.3%		8.8%		8.6%	
Emotional problems - girls												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Sedentary	.	.	-0.096	-0.208,0.016	-0.096	-0.208,0.016	-0.187	-0.395,0.021	-0.095	-0.206,0.017	0.039	-0.058,0.136
Green space	.	.	.	.	**-0.041**	-0.072,-0.009	-0.173	-0.421,0.075	-0.014	-0.071,0.043	-0.010	-0.059,0.039
Sedentary x green space	.	.	.	.	.	.	0.020	-0.016,0.056	.	.	.	.
Random effects												
Constant	1.878	1.778,1.977	2.517	1.752,3.281	2.717	1.922,3.513	3.320	1.869,4.770	2.640	1.805,3.474	1.292	-1.555,4.138
Ward-level variance	0.360	0.235,0.550	0.363	0.239,0.551	0.352	0.231,0.535	0.352	0.232,0.535	0.332	0.215,0.513	0.207	0.129,0.332
Child-level variance	3.792	3.428,4.195	3.785	3.422,4.187	3.781	3.419,4.183	3.779	3.418,4.179	3.765	3.403,4.165	2.766	2.537,3.015
Intraclass Correlation Coefficient (ICC)(%)	8.7%		8.7%		8.5%		8.5%		8.1%		7.0%	

*Significant fixed effects estimates are in **bold** (p<0.05)*
Model 0: random effects only
Model 1: Model 0 + PA
Model 2: Model 1 + green space
*Model 3: Model 2 + PA*green space*
Model 4: Model 2 + rural-urban designation and area deprivation
Model 5: Model 4 + all confounders

Table 4-8 : Country-specific effects of rural-urban designation and neighbourhood deprivation (models 4 and 5 only) – emotional problems and sedentary time

Emotional problems	Boys				Girls			
	Model 4		Model 5		Model 4		Model 5	
	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Sedentary time	0.008	-0.122,0.138	0.091	-0.022,0.205	-0.095	-0.206,0.017	0.039	-0.058,0.136
Rural-urban designation								
England								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-0.104	-0.563,0.354	0.106	-0.239,0.452	0.075	-0.338,0.488	0.035	-0.311,0.382
Rural	0.034	-0.568,0.635	0.227	-0.178,0.632	-0.117	-0.571,0.338	0.011	-0.368,0.389
Wales								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	0.231	-0.378,0.841	0.347	-0.243,0.938	-0.073	-0.702,0.557	-0.128	-0.682,0.426
Rural	-0.151	-0.647,0.344	-0.188	-0.750,0.374	-0.253	-0.872,0.367	-0.059	-0.683,0.565
Scotland								
Urban (baseline)	.	.	.	.	.	.	.	.
Towns	0.368	-0.630,1.367	0.461	-0.283,1.205	-0.389	-1.072,0.294	-0.671	-1.471,0.129
Rural	0.530	-0.111,1.171	**0.604**	0.022,1.187	-0.271	-0.822,0.279	-0.289	-0.840,0.262
Northern Ireland								
Urban (baseline)	.	.	.	.	.	.	.	.
Mixed urban rural	-0.586	-1.644,0.473	-0.144	-1.158,0.869	-0.114	-1.086,0.859	-0.125	-0.899,0.649
Rural	-0.038	-0.814,0.737	0.092	-0.539,0.722	**-0.803**	-1.574,-0.031	-0.485	-1.146,0.176
Neighbourhood deprivation								
England	**-0.070**	-0.112,-0.028	0.015	-0.026,0.055	-0.012	-0.057,0.032	**0.055**	0.009,0.101
Wales	**-0.069**	-0.137,0.000	-0.003	-0.068,0.063	**-0.111**	-0.195,-0.027	-0.023	-0.101,0.056
Scotland	-0.085	-0.195,0.025	0.036	-0.048,0.119	**-0.122**	-0.212,-0.031	-0.015	-0.106,0.077
Northern Ireland	0.023	-0.071,0.116	0.069	-0.024,0.161	-0.058	-0.209,0.092	0.014	-0.115,0.142

*Significant estimates are in **bold** (p<0.05)*

Table 4-9: Change in emotional problems per 30 minutes light PA; variance attributable to ward differences

	Model 0		Model 1		Model 2		Model 3		Model 4		Model 5	
Emotional problems - boys												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Light PA	.	.	0.032	-0.043,0.107	0.034	-0.041,0.109	0.108	-0.026,0.243	0.030	-0.045,0.105	-0.045	-0.111,0.021
Green space	.	.	.	.	-0.028	-0.066,0.010	0.132	-0.130,0.395	-0.013	-0.076,0.049	-0.042	-0.095,0.010
Light PA x green space	.	.	.	.	.	.	-0.017	-0.044,0.010	.	.	.	.
Random effects												
Constant	1.763	1.666,1.860	1.461	0.742,2.180	1.587	0.868,2.306	0.887	-0.408,2.181	1.941	1.165,2.716	4.047	1.060,7.035
Ward-level variance	0.360	0.252,0.514	0.359	0.250,0.514	0.357	0.249,0.513	0.354	0.246,0.510	0.336	0.233,0.484	0.228	0.153,0.340
Child-level variance	3.501	3.147,3.894	3.500	3.146,3.894	3.496	3.141,3.892	3.494	3.140,3.888	3.471	3.118,3.862	2.435	2.214,2.678
Intraclass Correlation Coefficient (ICC)(%)	9.3%		9.3%		9.3%		9.2%		8.8%		8.6%	
Emotional problems - girls												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Light PA	.	.	0.063	-0.010,0.136	0.064	-0.009,0.137	0.106	-0.030,0.243	0.063	-0.010,0.135	-0.012	-0.075,0.050
Green space	.	.	.	.	**-0.041**	-0.073,-0.010	0.045	-0.172,0.261	-0.014	-0.071,0.043	-0.010	-0.059,0.039
Light PA x green space	.	.	.	.	.	.	-0.009	-0.033,0.014	.	.	.	.
Random effects												
Constant	1.878	1.778,1.977	1.292	0.616,1.969	1.482	0.803,2.160	1.091	-0.143,2.325	1.432	0.737,2.127	1.623	-1.314,4.560
Ward-level variance	0.360	0.235,0.550	0.364	0.240,0.553	0.353	0.232,0.537	0.353	0.233,0.537	0.333	0.216,0.515	0.208	0.130,0.334
Child-level variance	3.792	3.428,4.195	3.784	3.421,4.185	3.780	3.418,4.182	3.779	3.417,4.179	3.764	3.402,4.164	2.766	2.537,3.015
Intraclass Correlation Coefficient (ICC)(%)	8.7%		8.8%		8.5%		8.6%		8.1%		7.0%	

*Significant fixed effects estimates are in **bold** (p<0.05)*
Model 0: random effects only
Model 1: Model 0 + PA
Model 2: Model 1 + green space
*Model 3: Model 2 + PA*green space*
Model 4: Model 2 + rural-urban designation and area deprivation
Model 5: Model 4 + all confounders

Table 4-10: Country-specific effects of rural-urban designation and neighbourhood deprivation (models 4 and 5 only) – emotional problems and light PA

Emotional problems	Boys				Girls			
	Model 4		Model 5		Model 4		Model 5	
	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Light PA	0.030	-0.045,0.105	-0.045	-0.111,0.021	0.063	-0.010,0.135	-0.012	-0.075,0.050
Rural-urban designation								
England								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-0.104	-0.563,0.354	0.106	-0.239,0.452	0.075	-0.338,0.488	0.035	-0.311,0.382
Rural	0.034	-0.568,0.635	0.227	-0.178,0.632	-0.117	-0.571,0.338	0.011	-0.368,0.389
Wales								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	0.231	-0.378,0.841	0.347	-0.243,0.938	-0.073	-0.702,0.557	-0.128	-0.682,0.426
Rural	-0.151	-0.647,0.344	-0.188	-0.750,0.374	-0.253	-0.872,0.367	-0.059	-0.683,0.565
Scotland								
Urban (baseline)	.	.	.	.	.	.	.	.
Towns	0.368	-0.630,1.367	0.461	-0.283,1.205	-0.389	-1.072,0.294	-0.671	-1.471,0.129
Rural	0.530	-0.111,1.171	0.604	0.022,1.187	-0.271	-0.822,0.279	-0.289	-0.840,0.262
Northern Ireland								
Urban (baseline)	.	.	.	.	.	.	.	.
Mixed urban rural	-0.586	-1.644,0.473	-0.144	-1.158,0.869	-0.114	-1.086,0.859	-0.125	-0.899,0.649
Rural	-0.038	-0.814,0.737	0.092	-0.539,0.722	-0.803	-1.574,-0.031	-0.485	-1.146,0.176
Neighbourhood deprivation								
England	**-0.069**	-0.111,-0.027	0.016	-0.025,0.056	-0.013	-0.057,0.031	**0.055**	0.009,0.101
Wales	**-0.069**	-0.137,0.000	-0.003	-0.069,0.063	**-0.110**	-0.194,-0.026	-0.023	-0.102,0.055
Scotland	-0.084	-0.194,0.025	0.038	-0.046,0.121	**-0.121**	-0.212,-0.031	-0.015	-0.106,0.077
Northern Ireland	0.023	-0.071,0.116	0.069	-0.023,0.162	-0.058	-0.208,0.093	0.013	-0.116,0.142

*Significant estimates are in **bold** ($p<0.05$)*

Table 4-11: Change in emotional problems per 15 minutes MVPA; variance attributable to ward differences

	Model 0		Model 1		Model 2		Model 3		Model 4		Model 5	
Emotional problems - boys												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
MVPA	.	.	-0.044	-0.120,0.032	-0.045	-0.122,0.031	-0.012	-0.167,0.144	-0.053	-0.129,0.024	-0.041	-0.105,0.023
Green space	.	.	.	.	-0.029	-0.066,0.009	0.006	-0.118,0.129	-0.011	-0.073,0.051	-0.042	-0.094,0.010
MVPA x green space	.	.	.	.	.	.	-0.008	-0.033,0.018	.	.	.	.
Random effects												
Constant	1.763	1.666,1.860	1.969	1.598,2.341	2.117	1.704,2.530	1.963	1.214,2.711	2.480	1.997,2.962	3.720	0.686,6.754
Ward-level variance	0.360	0.252,0.514	0.360	0.253,0.512	0.358	0.251,0.511	0.361	0.253,0.515	0.334	0.233,0.479	0.227	0.153,0.336
Child-level variance	3.501	3.147,3.894	3.497	3.144,3.889	3.493	3.139,3.887	3.491	3.138,3.884	3.466	3.116,3.856	2.436	2.214,2.679
Intraclass Correlation Coefficient (ICC)(%)	9.3%		9.3%		9.3%		9.4%		8.8%		8.5%	
Emotional problems - girls												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
MVPA	.	.	0.017	-0.058,0.093	0.015	-0.060,0.090	0.077	-0.068,0.223	0.016	-0.060,0.091	-0.038	-0.102,0.026
Green space	.	.	.	.	**-0.040**	-0.072,-0.008	0.012	-0.080,0.104	-0.014	-0.071,0.043	-0.010	-0.059,0.039
MVPA x green space	.	.	.	.	.	.	-0.014	-0.038,0.010	.	.	.	.
Random effects												
Constant	1.878	1.778,1.977	1.813	1.521,2.105	2.020	1.688,2.353	1.788	1.237,2.340	1.961	1.590,2.331	1.754	-1.135,4.643
Ward-level variance	0.360	0.235,0.550	0.359	0.235,0.549	0.349	0.228,0.533	0.349	0.229,0.533	0.328	0.211,0.510	0.207	0.129,0.333
Child-level variance	3.792	3.428,4.195	3.792	3.428,4.195	3.789	3.425,4.191	3.786	3.423,4.187	3.772	3.409,4.174	2.764	2.536,3.013
Intraclass Correlation Coefficient (ICC)(%)	8.7%		8.7%		8.4%		8.4%		8.0%		7.0%	

*Significant fixed effects estimates are in **bold** ($p<0.05$)*
Model 0: random effects only
Model 1: Model 0 + PA
Model 2: Model 1 + green space
*Model 3: Model 2 + PA*green space*
Model 4: Model 2 + rural-urban designation and area deprivation
Model 5: Model 4 + all confounders

Table 4-12: Country-specific effects of rural-urban designation and neighbourhood deprivation (models 4 and 5 only) – emotional problems and MVPA

Emotional problems	Boys				Girls			
	Model 4		Model 5		Model 4		Model 5	
	b	95% CI	b	95% CI	b	95% CI	b	95% CI
MVPA	-0.053	-0.129,0.024	-0.041	-0.105,0.023	0.016	-0.060,0.091	-0.038	-0.102,0.026
Rural-urban designation								
England								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-0.109	-0.566,0.348	0.108	-0.240,0.456	0.086	-0.329,0.501	0.034	-0.314,0.382
Rural	0.023	-0.576,0.621	0.225	-0.182,0.633	-0.106	-0.562,0.351	0.004	-0.376,0.385
Wales								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	0.227	-0.381,0.834	0.348	-0.249,0.946	-0.054	-0.688,0.579	-0.140	-0.694,0.413
Rural	-0.151	-0.643,0.341	-0.178	-0.737,0.381	-0.237	-0.858,0.384	-0.070	-0.694,0.554
Scotland								
Urban (baseline)	.	.	.	.	.	.	.	.
Towns	0.333	-0.647,1.312	0.442	-0.301,1.185	-0.393	-1.074,0.288	-0.681	-1.481,0.118
Rural	0.486	-0.151,1.124	**0.603**	0.021,1.185	-0.283	-0.827,0.260	-0.276	-0.831,0.279
Northern Ireland								
Urban (baseline)	.	.	.	.	.	.	.	.
Mixed urban rural	-0.570	-1.624,0.484	-0.141	-1.144,0.861	-0.126	-1.091,0.840	-0.126	-0.900,0.648
Rural	-0.080	-0.859,0.698	0.065	-0.567,0.698	**-0.786**	-1.552,-0.020	-0.490	-1.150,0.171
Neighbourhood deprivation								
England	**-0.072**	-0.114,-0.031	0.015	-0.026,0.055	-0.015	-0.058,0.029	**0.055**	0.009,0.100
Wales	-0.068	-0.137,0.000	-0.003	-0.068,0.063	**-0.112**	-0.196,-0.028	-0.022	-0.100,0.056
Scotland	-0.091	-0.200,0.018	0.034	-0.050,0.117	**-0.122**	-0.212,-0.033	-0.014	-0.105,0.077
Northern Ireland	0.021	-0.073,0.114	0.068	-0.023,0.160	-0.058	-0.207,0.090	0.014	-0.114,0.143

*Significant estimates are in **bold** (p<0.05)*

II. Peer problems – multilevel model results

Table 4-13: Change in peer problems per 60 minutes sedentary time; variance attributable to ward differences

	Model 0		Model 1		Model 2		Model 3		Model 4		Model 5	
Peer problems - boys												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Sedentary	.	.	0.095	-0.020,0.211	0.094	-0.022,0.210	0.039	-0.167,0.246	**0.117**	0.002,0.231	**0.163**	0.059,0.267
Green space	.	.	.	.	-0.024	-0.059,0.011	-0.104	-0.373,0.165	0.027	-0.036,0.090	0.011	-0.042,0.065
Sedentary x green space	.	.	.	.	.	.	0.012	-0.030,0.055	.	.	.	.
Random effects												
Constant	1.428	1.340,1.516	0.822	0.077,1.567	0.946	0.138,1.753	1.300	-0.042,2.641	1.150	0.302,1.998	1.195	-1.975,4.365
Ward-level variance	0.310	0.198,0.487	0.311	0.199,0.487	0.303	0.192,0.478	0.301	0.190,0.477	0.258	0.162,0.411	0.136	0.075,0.245
Child-level variance	2.791	2.481,3.141	2.785	2.473,3.136	2.785	2.471,3.139	2.785	2.471,3.139	2.752	2.440,3.104	2.069	1.872,2.286
Intraclass Correlation Coefficient (ICC)(%)	10.0%		10.1%		9.8%		9.8%		8.6%		6.2%	
Peer problems - girls												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Sedentary	.	.	-0.010	-0.096,0.075	-0.010	-0.096,0.075	-0.115	-0.289,0.059	0.004	-0.082,0.090	**0.088**	0.005,0.171
Green space	.	.	.	.	-0.029	-0.058,0.001	-0.182	-0.383,0.019	0.025	-0.022,0.071	0.031	-0.015,0.077
Sedentary x green space	.	.	.	.	.	.	0.023	-0.006,0.052	.	.	.	.
Random effects												
Constant	1.264	1.181,1.346	1.332	0.752,1.912	1.474	0.850,2.099	2.172	0.961,3.383	1.627	0.965,2.289	2.047	-0.667,4.762
Ward-level variance	0.275	0.180,0.421	0.275	0.180,0.421	0.264	0.169,0.413	0.266	0.171,0.416	0.245	0.152,0.393	0.182	0.118,0.279
Child-level variance	2.323	2.088,2.585	2.323	2.088,2.585	2.323	2.088,2.585	2.320	2.085,2.581	2.291	2.062,2.546	1.811	1.627,2.016
Intraclass Correlation Coefficient (ICC)(%)	10.6%		10.6%		10.2%		10.3%		9.6%		9.1%	

*Significant fixed effects estimates are in **bold** ($p<0.05$)*
Model 0: random effects only
Model 1: Model 0 + PA
Model 2: Model 1 + green space
*Model 3: Model 2 + PA*green space*
Model 4: Model 2 + rural-urban designation and area deprivation
Model 5: Model 4 + all confounders

Table 4-14: Country-specific effects of rural-urban designation and neighbourhood deprivation (models 4 and 5 only) – peer problems and sedentary time

Peer problems	Boys				Girls			
	Model 4		Model 5		Model 4		Model 5	
	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Sedentary	**0.117**	0.002,0.231	**0.163**	0.059,0.267	0.004	-0.082,0.090	**0.088**	0.005,0.171
Rural-urban designation								
England								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-0.072	-0.473,0.328	0.075	-0.240,0.390	-0.162	-0.516,0.193	-0.208	-0.533,0.116
Rural	-0.144	-0.628,0.340	-0.035	-0.392,0.321	-0.171	-0.537,0.195	-0.129	-0.466,0.208
Wales								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-0.282	-0.701,0.138	-0.269	-0.896,0.358	-0.264	-0.710,0.183	-0.240	-0.711,0.230
Rural	-0.362	-0.877,0.152	-0.366	-0.983,0.251	-0.154	-0.758,0.450	0.035	-0.568,0.637
Scotland								
Urban (baseline)	.	.	.	.	.	.	.	.
Towns	0.240	-0.656,1.135	0.272	-0.411,0.954	**-0.677**	-1.190,-0.163	**-0.811**	-1.452,-0.170
Rural	-0.293	-0.896,0.309	-0.303	-0.796,0.190	-0.303	-0.897,0.291	-0.367	-0.976,0.243
Northern Ireland								
Urban (baseline)	.	.	.	.	.	.	.	.
Mixed urban rural	-0.486	-1.209,0.237	-0.140	-0.708,0.429	0.044	-0.699,0.786	-0.076	-0.704,0.553
Rural	-0.460	-1.112,0.191	-0.438	-0.988,0.112	**-0.555**	-1.022,-0.089	-0.404	-0.867,0.060
Neighbourhood deprivation								
England	**-0.094**	-0.140,-0.048	**-0.040**	-0.079,-0.001	**-0.081**	-0.115,-0.047	-0.006	-0.041,0.029
Wales	**-0.091**	-0.151,-0.030	-0.061	-0.122,0.001	**-0.119**	-0.218,-0.021	-0.040	-0.138,0.057
Scotland	-0.089	-0.176,-0.002	-0.018	-0.093,0.056	-0.034	-0.112,0.044	0.058	-0.009,0.125
Northern Ireland	-0.034	-0.113,0.045	-0.011	-0.086,0.065	-0.043	-0.119,0.033	0.031	-0.035,0.097

*Significant estimates are in **bold** (p<0.05)*

Table 4-15: Change in peer problems per 30 minutes light PA; variance attributable to ward differences

	Model 0		Model 1		Model 2		Model 3		Model 4		Model 5	
Peer problems - boys												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Light PA	.	.	-0.021	-0.093,0.050	-0.020	-0.092,0.052	0.033	-0.099,0.164	-0.028	-0.099,0.043	**-0.079**	-0.143,-0.016
Green space	.	.	.	.	-0.024	-0.059,0.011	0.090	-0.174,0.354	0.025	-0.039,0.089	0.010	-0.044,0.064
Light PA x green space	.	.	.	.	.	.	-0.012	-0.039,0.015	.	.	.	.
Random effects												
Constant	1.428	1.340,1.516	1.630	0.947,2.312	1.738	1.080,2.395	1.241	-0.005,2.487	2.152	1.475,2.829	2.973	-0.265,6.212
Ward-level variance	0.310	0.198,0.487	0.310	0.198,0.486	0.302	0.191,0.477	0.300	0.189,0.475	0.260	0.163,0.414	0.137	0.076,0.246
Child-level variance	2.791	2.481,3.141	2.791	2.479,3.141	2.791	2.478,3.144	2.790	2.477,3.144	2.759	2.449,3.109	2.075	1.879,2.291
Intraclass Correlation Coefficient (ICC)(%)	10.0%		10.0%		9.8%		9.7%		8.6%		6.2%	
Peer problems - girls												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Light PA	.	.	-0.017	-0.074,0.040	-0.016	-0.073,0.042	0.034	-0.078,0.146	-0.022	-0.079,0.035	**-0.073**	-0.131,-0.014
Green space	.	.	.	.	-0.028	-0.058,0.001	0.073	-0.102,0.248	0.025	-0.022,0.071	0.031	-0.014,0.077
Light PA x green space	.	.	.	.	.	.	-0.011	-0.029,0.008	.	.	.	.
Random effects												
Constant	1.264	1.181,1.346	1.419	0.879,1.960	1.551	1.012,2.090	1.089	0.047,2.131	1.858	1.293,2.423	3.278	0.438,6.119
Ward-level variance	0.275	0.180,0.421	0.275	0.179,0.421	0.263	0.168,0.413	0.265	0.169,0.415	0.243	0.151,0.392	0.181	0.118,0.278
Child-level variance	2.323	2.088,2.585	2.323	2.088,2.584	2.323	2.089,2.585	2.321	2.087,2.582	2.291	2.062,2.545	1.808	1.626,2.010
Intraclass Correlation Coefficient (ICC)(%)	10.6%		10.6%		10.2%		10.2%		9.6%		9.1%	

*Significant fixed effects estimates are in **bold** (p<0.05)*
Model 0: random effects only
Model 1: Model 0 + PA
Model 2: Model 1 + green space
*Model 3: Model 2 + PA*green space*
Model 4: Model 2 + rural-urban designation and area deprivation
Model 5: Model 4 + all confounders

Table 4-16: Country-specific effects of rural-urban designation and neighbourhood deprivation (models 4 and 5 only) – peer problems and light PA

Peer problems	Boys				Girls			
	Model 4		Model 5		Model 4		Model 5	
	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Light PA	-0.028	-0.099,0.043	**-0.079**	-0.143,-0.016	-0.022	-0.079,0.035	**-0.073**	-0.131,-0.014
Rural-urban designation								
England								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-0.068	-0.468,0.333	0.079	-0.237,0.395	-0.157	-0.510,0.196	-0.204	-0.526,0.119
Rural	-0.137	-0.626,0.353	-0.031	-0.390,0.327	-0.166	-0.530,0.199	-0.119	-0.455,0.216
Wales								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-0.275	-0.695,0.146	-0.264	-0.898,0.369	-0.254	-0.700,0.191	-0.225	-0.697,0.247
Rural	-0.357	-0.872,0.159	-0.363	-0.982,0.255	-0.147	-0.751,0.456	0.044	-0.559,0.648
Scotland								
Urban (baseline)	.	.	.	.	.	.	.	.
Towns	0.255	-0.636,1.147	0.298	-0.377,0.972	**-0.675**	-1.186,-0.165	**-0.801**	-1.437,-0.165
Rural	-0.254	-0.861,0.352	-0.263	-0.761,0.234	-0.308	-0.902,0.286	-0.379	-0.986,0.229
Northern Ireland								
Urban (baseline)	.	.	.	.	.	.	.	.
Mixed urban rural	-0.492	-1.223,0.238	-0.159	-0.743,0.425	0.040	-0.700,0.781	-0.075	-0.700,0.551
Rural	-0.444	-1.096,0.207	-0.412	-0.962,0.138	**-0.549**	-1.016,-0.083	-0.397	-0.860,0.066
Neighbourhood deprivation								
England	**-0.092**	-0.138,-0.045	-0.038	-0.077,0.001	**-0.082**	-0.116,-0.047	-0.006	-0.041,0.029
Wales	**-0.091**	-0.151,-0.031	-0.061	-0.123,0.001	**-0.120**	-0.218,-0.022	-0.041	-0.138,0.056
Scotland	-0.085	-0.173,0.002	-0.015	-0.089,0.059	-0.034	-0.112,0.044	0.058	-0.009,0.125
Northern Ireland	-0.033	-0.112,0.046	-0.010	-0.085,0.066	-0.043	-0.119,0.033	0.030	-0.036,0.096

*Significant estimates are in **bold** ($p<0.05$)*

Table 4-17: Change in peer problems per 15 minutes MVPA; variance attributable to ward differences

	Model 0		Model 1		Model 2		Model 3		Model 4		Model 5	
Peer problems - boys												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
MVPA	.	.	**-0.083**	-0.151,-0.015	**-0.084**	-0.152,-0.016	-0.095	-0.220,0.030	**-0.098**	-0.165,-0.031	**-0.078**	-0.135,-0.022
Green space	.	.	.	.	-0.026	-0.060,0.009	-0.037	-0.139,0.064	0.027	-0.035,0.090	0.011	-0.044,0.065
MVPA x green space	.	.	.	.	.	.	0.003	-0.018,0.023	.	.	.	.
Random effects												
Constant	1.428	1.340,1.516	1.814	1.492,2.136	1.947	1.597,2.298	1.999	1.396,2.602	2.365	1.974,2.755	2.420	-0.725,5.564
Ward-level variance	0.310	0.198,0.487	0.314	0.199,0.496	0.305	0.191,0.486	0.306	0.192,0.487	0.259	0.162,0.415	0.140	0.077,0.253
Child-level variance	2.791	2.481,3.141	2.774	2.462,3.126	2.775	2.460,3.130	2.774	2.460,3.129	2.739	2.427,3.091	2.070	1.873,2.288
Intraclass Correlation Coefficient (ICC)(%)	10.0%		10.2%		9.9%		9.9%		8.6%		6.3%	
Peer problems - girls												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
MVPA	.	.	0.035	-0.029,0.099	0.033	-0.031,0.098	0.086	-0.054,0.226	0.024	-0.040,0.088	0.000	-0.061,0.062
Green space	.	.	.	.	-0.028	-0.057,0.001	0.016	-0.067,0.099	0.025	-0.022,0.071	0.032	-0.015,0.078
MVPA x green space	.	.	.	.	.	.	-0.012	-0.035,0.011	.	.	.	.
Random effects												
Constant	1.264	1.181,1.346	1.133	0.898,1.367	1.278	1.010,1.545	1.082	0.578,1.586	1.556	1.231,1.881	2.486	-0.153,5.125
Ward-level variance	0.275	0.180,0.421	0.274	0.179,0.419	0.263	0.168,0.412	0.265	0.170,0.413	0.244	0.152,0.393	0.183	0.120,0.281
Child-level variance	2.323	2.088,2.585	2.321	2.088,2.582	2.322	2.088,2.582	2.320	2.086,2.580	2.290	2.062,2.544	1.815	1.629,2.021
Intraclass Correlation Coefficient (ICC)(%)	10.6%		10.6%		10.2%		10.2%		9.6%		9.2%	

*Significant fixed effects estimates are in **bold** ($p<0.05$)*
Model 0: random effects only
Model 1: Model 0 + PA
Model 2: Model 1 + green space
*Model 3: Model 2 + PA*green space*
Model 4: Model 2 + rural-urban designation and area deprivation
Model 5: Model 4 + all confounders

Table 4-18: Country-specific effects of rural-urban designation and neighbourhood deprivation (models 4 and 5 only) – peer problems and MVPA

Peer problems	Boys				Girls			
	Model 4		Model 5		Model 4		Model 5	
	b	95% CI	b	95% CI	b	95% CI	b	95% CI
MVPA	**-0.098**	-0.165,-0.031	**-0.078**	-0.135,-0.022	0.024	-0.040,0.088	0.000	-0.061,0.062
Rural-urban designation								
England								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-0.077	-0.472,0.318	0.076	-0.240,0.392	-0.164	-0.519,0.191	-0.220	-0.548,0.107
Rural	-0.157	-0.642,0.328	-0.039	-0.402,0.323	-0.170	-0.538,0.199	-0.141	-0.480,0.197
Wales								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-0.280	-0.694,0.134	-0.264	-0.888,0.359	-0.259	-0.708,0.190	-0.250	-0.725,0.224
Rural	-0.351	-0.870,0.168	-0.351	-0.967,0.265	-0.152	-0.760,0.456	0.030	-0.571,0.631
Scotland								
Urban (baseline)	.	.	.	.	.	.	.	.
Towns	0.182	-0.730,1.093	0.238	-0.460,0.936	**-0.666**	-1.173,-0.158	**-0.806**	-1.449,-0.162
Rural	-0.334	-0.932,0.265	-0.308	-0.806,0.190	-0.308	-0.903,0.287	-0.362	-0.980,0.255
Northern Ireland								
Urban (baseline)	.	.	.	.	.	.	.	.
Mixed urban rural	-0.459	-1.151,0.233	-0.131	-0.685,0.423	0.049	-0.694,0.791	-0.064	-0.699,0.570
Rural	-0.531	-1.184,0.121	-0.487	-1.040,0.066	-0.556	-1.023,-0.090	-0.426	-0.887,0.035
Neighbourhood deprivation								
England	**-0.097**	-0.142,-0.051	**-0.040**	-0.079,-0.002	**-0.080**	-0.114,-0.046	-0.006	-0.041,0.030
Wales	**-0.091**	-0.152,-0.030	-0.060	-0.121,0.002	**-0.120**	-0.218,-0.021	-0.041	-0.140,0.058
Scotland	**-0.096**	-0.184,-0.008	-0.022	-0.098,0.054	-0.034	-0.112,0.044	0.057	-0.010,0.124
Northern Ireland	-0.038	-0.117,0.040	-0.012	-0.087,0.063	-0.043	-0.119,0.033	0.029	-0.036,0.095

*Significant estimates are in **bold** (p<0.05)*

III. Conduct problems – multilevel model results

Table 4-19: Change in conduct problems per 60 minutes sedentary time; variance attributable to ward differences

	Model 0		Model 1		Model 2		Model 3		Model 4		Model 5	
Conduct problems - boys												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Sedentary	·	·	**-0.130**	-0.254,-0.006	**-0.130**	-0.254,-0.006	-0.111	-0.337,0.115	-0.108	-0.228,0.012	-0.081	-0.188,0.026
Green space	·	·	·	·	-0.023	-0.054,0.008	0.005	-0.257,0.266	0.036	-0.020,0.092	0.008	-0.036,0.052
Sedentary x green space	·	·	·	·	·	·	-0.004	-0.046,0.037	·	·	·	·
Random effects												
Constant	1.517	1.431,1.603	2.343	1.542,3.143	2.463	1.621,3.304	2.339	0.884,3.794	2.711	1.884,3.539	1.287	-1.386,3.960
Ward-level variance	0.330	0.236,0.459	0.323	0.231,0.451	0.319	0.228,0.447	0.320	0.228,0.448	0.272	0.189,0.393	0.156	0.102,0.237
Child-level variance	2.337	2.098,2.604	2.329	2.089,2.596	2.328	2.087,2.596	2.327	2.086,2.596	2.278	2.047,2.536	1.639	1.474,1.823
Intraclass Correlation Coefficient (ICC)(%)	12.4%		12.2%		12.0%		12.1%		10.7%		8.7%	
Conduct problems - girls												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Sedentary	.	.	**-0.125**	-0.215,-0.034	**-0.125**	-0.216,-0.034	**-0.172**	-0.335,-0.008	**-0.117**	-0.206,-0.028	-0.015	-0.093,0.063
Green space	.	.	.	.	**-0.036**	-0.063,-0.009	-0.104	-0.320,0.112	0.011	-0.032,0.054	0.011	-0.029,0.050
Sedentary x green space	.	.	.	.	.	.	0.010	-0.022,0.043	.	.	.	.
Random effects												
Constant	1.241	1.172,1.311	2.071	1.466,2.676	2.248	1.602,2.894	2.559	1.449,3.669	2.299	1.657,2.940	1.665	-0.815,4.144
Ward-level variance	0.156	0.104,0.234	0.151	0.100,0.229	0.150	0.099,0.228	0.151	0.100,0.228	0.119	0.073,0.192	0.077	0.045,0.132
Child-level variance	2.024	1.818,2.254	2.016	1.809,2.247	2.010	1.802,2.243	2.009	1.802,2.241	1.984	1.779,2.212	1.474	1.331,1.633
Intraclass Correlation Coefficient (ICC)(%)	7.2%		7.0%		7.0%		7.0%		5.6%		5.0%	

*Significant fixed effects estimates are in **bold** (p<0.05)*
Model 0: random effects only
Model 1: Model 0 + PA
Model 2: Model 1 + green space
*Model 3: Model 2 + PA*green space*
Model 4: Model 2 + rural-urban designation and area deprivation
Model 5: Model 4 + all confounders

Table 4-20: Country-specific effects of rural-urban designation and neighbourhood deprivation (models 4 and 5 only) – conduct problems and sedentary time

Conduct problems	Boys				Girls			
	Model 4		Model 5		Model 4		Model 5	
	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Sedentary	-0.108	-0.228,0.012	-0.081	-0.188,0.026	**-0.117**	-0.206,-0.028	-0.015	-0.093,0.063
Rural-urban designation								
England								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-0.278	-0.622,0.066	-0.073	-0.357,0.210	-0.163	-0.476,0.149	-0.203	-0.471,0.064
Rural	-0.170	-0.638,0.297	0.036	-0.267,0.340	-0.249	-0.564,0.066	-0.134	-0.407,0.140
Wales								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-0.462	-1.033,0.110	-0.456	-0.979,0.067	**-0.631**	-0.948,-0.314	**-0.518**	-0.890,-0.146
Rural	0.023	-0.581,0.627	-0.055	-0.404,0.295	-0.367	-0.898,0.165	-0.113	-0.601,0.374
Scotland								
Urban (baseline)	.	.	.	.	.	.	.	.
Towns	-0.327	-1.196,0.542	-0.198	-0.901,0.505	-0.141	-0.621,0.340	-0.241	-0.614,0.132
Rural	-0.332	-0.872,0.208	-0.205	-0.642,0.231	-0.045	-0.748,0.658	-0.112	-0.736,0.513
Northern Ireland								
Urban (baseline)	.	.	.	.	.	.	.	.
Mixed urban rural	0.100	-0.803,1.002	0.510	-0.462,1.483	-0.141	-0.896,0.614	-0.043	-0.729,0.643
Rural	-0.470	-1.165,0.226	-0.312	-0.864,0.240	-0.613	-1.199,-0.027	-0.304	-0.816,0.207
Neighbourhood deprivation	b	95% CI	b	95% CI	b	95% CI	b	95% CI
England	**-0.106**	-0.142,-0.070	-0.026	-0.057,0.005	**-0.058**	-0.092,-0.024	0.007	-0.022,0.036
Wales	**-0.071**	-0.134,-0.007	0.002	-0.054,0.057	**-0.135**	-0.202,-0.068	-0.053	-0.111,0.005
Scotland	**-0.115**	-0.185,-0.046	-0.013	-0.081,0.054	**-0.125**	-0.200,-0.050	-0.034	-0.101,0.033
Northern Ireland	-0.097	-0.209,0.014	-0.036	-0.134,0.062	-0.044	-0.126,0.039	0.037	-0.035,0.109

*Significant estimates are in **bold** ($p<0.05$)*

Table 4-21: Change in conduct problems per 30 minutes light PA; variance attributable to ward differences

	Model 0		Model 1		Model 2		Model 3		Model 4		Model 5	
Conduct problems - boys												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Light PA	.	.	0.048	-0.028,0.123	0.049	-0.027,0.124	0.046	-0.087,0.179	0.042	-0.031,0.115	0.015	-0.049,0.079
Green space	.	.	.	.	-0.023	-0.054,0.007	-0.029	-0.281,0.222	0.037	-0.018,0.093	0.009	-0.035,0.053
Light PA x green space	.	.	.	.	.	.	0.001	-0.025,0.026	.	.	.	.
Random effects												
Constant	1.517	1.431,1.603	1.069	0.354,1.784	1.176	0.476,1.877	1.201	-0.068,2.470	1.634	0.921,2.346	0.676	-2.126,3.478
Ward-level variance	0.330	0.236,0.459	0.331	0.237,0.461	0.326	0.233,0.456	0.326	0.233,0.457	0.276	0.191,0.397	0.158	0.104,0.240
Child-level variance	2.337	2.098,2.604	2.333	2.093,2.602	2.332	2.091,2.602	2.332	2.090,2.602	2.282	2.050,2.540	1.642	1.476,1.825
Intraclass Correlation Coefficient (ICC)(%)	12.4%		12.4%		12.3%		12.3%		10.8%		8.8%	
Conduct problems - girls												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Light PA	.	.	**0.065**	0.004,0.125	**0.067**	0.006,0.127	0.084	-0.028,0.195	**0.063**	0.003,0.122	0.006	-0.045,0.058
Green space	.	.	.	.	**-0.037**	-0.064,-0.009	-0.002	-0.198,0.195	0.011	-0.032,0.054	0.011	-0.029,0.050
Light PA x green space	.	.	.	.	.	.	-0.004	-0.024,0.017	.	.	.	.
Random effects												
Constant	1.241	1.172,1.311	0.635	0.065,1.205	0.799	0.237,1.360	0.640	-0.397,1.678	0.944	0.351,1.537	1.520	-0.878,3.918
Ward-level variance	0.156	0.104,0.234	0.154	0.102,0.231	0.152	0.101,0.230	0.153	0.101,0.230	0.120	0.075,0.194	0.077	0.045,0.132
Child-level variance	2.024	1.818,2.254	2.019	1.812,2.249	2.012	1.804,2.245	2.012	1.804,2.244	1.986	1.781,2.214	1.474	1.331,1.632
Intraclass Correlation Coefficient (ICC)(%)	7.2%		7.1%		7.0%		7.0%		5.7%		5.0%	

*Significant fixed effects estimates are in **bold** ($p<0.05$)*
Model 0: random effects only
Model 1: Model 0 + PA
Model 2: Model 1 + green space
*Model 3: Model 2 + PA*green space*
Model 4: Model 2 + rural-urban designation and area deprivation
Model 5: Model 4 + all confounders

Table 4-22: Country-specific effects of rural-urban designation and neighbourhood deprivation (models 4 and 5 only) – conduct problems and light PA

Conduct problems	Boys				Girls			
	Model 4		Model 5		Model 4		Model 5	
	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Light PA	0.042	-0.031,0.115	0.015	-0.049,0.079	**0.063**	0.003,0.122	0.006	-0.045,0.058
Rural-urban designation								
England								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-0.282	-0.625,0.060	-0.076	-0.357,0.205	-0.162	-0.477,0.153	-0.203	-0.471,0.065
Rural	-0.177	-0.642,0.288	0.034	-0.266,0.334	-0.253	-0.567,0.062	-0.133	-0.407,0.140
Wales								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-0.465	-1.039,0.108	-0.460	-0.982,0.062	**-0.641**	-0.959,-0.323	**-0.518**	-0.890,-0.147
Rural	0.022	-0.581,0.624	-0.062	-0.407,0.283	-0.370	-0.897,0.157	-0.114	-0.601,0.373
Scotland								
Urban (baseline)	.	.	.	.	.	.	.	.
Towns	-0.327	-1.196,0.542	-0.198	-0.901,0.505	-0.154	-0.635,0.328	-0.242	-0.616,0.131
Rural	-0.332	-0.872,0.208	-0.205	-0.642,0.231	-0.039	-0.743,0.665	-0.111	-0.734,0.512
Northern Ireland								
Urban (baseline)	.	.	.	.	.	.	.	.
Mixed urban rural	0.106	-0.810,1.022	0.523	-0.466,1.512	-0.147	-0.902,0.608	-0.044	-0.729,0.642
Rural	-0.489	-1.184,0.207	-0.316	-0.867,0.235	**-0.611**	-1.201,-0.022	-0.303	-0.816,0.210
Neighbourhood deprivation	b	95% CI	b	95% CI	b	95% CI	b	95% CI
England	**-0.107**	-0.144,-0.071	-0.027	-0.058,0.004	**-0.059**	-0.094,-0.025	0.007	-0.022,0.036
Wales	**-0.071**	-0.134,-0.007	0.002	-0.054,0.058	**-0.135**	-0.201,-0.068	-0.053	-0.111,0.005
Scotland	**-0.119**	-0.189,-0.048	-0.015	-0.084,0.054	**-0.125**	-0.199,-0.050	-0.034	-0.101,0.033
Northern Ireland	-0.099	-0.210,0.013	-0.037	-0.136,0.062	-0.043	-0.126,0.039	0.038	-0.035,0.110

Significant estimates are in ***bold*** *($p<0.05$)*

Table 4-23: Change in conduct problems per 15 minutes MVPA; variance attributable to ward differences

	Model 0		Model 1		Model 2		Model 3		Model 4		Model 5	
Conduct problems - boys												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
MVPA	.	.	**0.080**	0.016,0.144	**0.079**	0.015,0.143	0.054	-0.070,0.177	**0.064**	0.002,0.126	**0.072**	0.019,0.126
Green space	.	.	.	.	-0.021	-0.052,0.009	-0.047	-0.147,0.052	0.036	-0.019,0.091	0.008	-0.036,0.051
MVPA x green space	.	.	.	.	.	.	0.006	-0.014,0.026	.	.	.	.
Random effects												
Constant	1.517	1.431,1.603	1.144	0.849,1.440	1.254	0.929,1.579	1.370	0.780,1.960	1.717	1.352,2.082	0.531	-2.097,3.159
Ward-level variance	0.330	0.236,0.459	0.311	0.222,0.436	0.308	0.219,0.433	0.309	0.220,0.434	0.265	0.182,0.383	0.148	0.097,0.228
Child-level variance	2.337	2.098,2.604	2.330	2.093,2.593	2.329	2.091,2.593	2.328	2.090,2.593	2.280	2.051,2.535	1.635	1.472,1.817
Intraclass Correlation Coefficient (ICC)(%)	12.4%		11.8%		11.7%		11.7%		10.4%		8.3%	
Conduct problems - girls												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
MVPA	.	.	**0.063**	0.011,0.114	**0.061**	0.009,0.112	0.091	-0.018,0.200	**0.056**	0.006,0.107	0.012	-0.033,0.058
Green space	.	.	.	.	**-0.034**	-0.061,-0.008	-0.009	-0.090,0.072	0.011	-0.032,0.054	0.011	-0.029,0.050
MVPA x green space	.	.	.	.	.	.	-0.007	-0.027,0.013	.	.	.	.
Random effects												
Constant	1.241	1.172,1.311	1.007	0.805,1.209	1.184	0.952,1.416	1.070	0.641,1.499	1.308	1.028,1.589	1.503	-0.888,3.893
Ward-level variance	0.156	0.104,0.234	0.152	0.101,0.229	0.151	0.100,0.228	0.152	0.101,0.229	0.118	0.073,0.190	0.077	0.045,0.132
Child-level variance	2.024	1.818,2.254	2.020	1.813,2.250	2.014	1.806,2.246	2.013	1.806,2.245	1.988	1.784,2.216	1.474	1.331,1.633
Intraclass Correlation Coefficient (ICC)(%)	7.2%		7.0%		7.0%		7.0%		5.6%		5.0%	

*Significant fixed effects estimates are in **bold** (p<0.05)*
Model 0: random effects only
Model 1: Model 0 + PA
Model 2: Model 1 + green space
*Model 3: Model 2 + PA*green space*
Model 4: Model 2 + rural-urban designation and area deprivation
Model 5: Model 4 + all confounders

Table 4-24: Country-specific effects of rural-urban designation and neighbourhood deprivation (models 4 and 5 only) – conduct problems and MVPA

Conduct problems	Boys				Girls			
	Model 4		Model 5		Model 4		Model 5	
	b	95% CI	b	95% CI	b	95% CI	b	95% CI
MVPA	**0.064**	0.002,0.126	**0.072**	0.019,0.126	**0.056**	0.006,0.107	0.012	-0.033,0.058
Rural-urban designation								
England								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-0.277	-0.620,0.066	-0.073	-0.354,0.208	-0.154	-0.469,0.161	-0.203	-0.472,0.066
Rural	-0.164	-0.626,0.299	0.042	-0.257,0.341	-0.233	-0.552,0.085	-0.131	-0.407,0.144
Wales								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-0.465	-1.033,0.103	-0.454	-0.970,0.062	**-0.602**	-0.917,-0.287	**-0.514**	-0.885,-0.143
Rural	0.011	-0.584,0.606	-0.060	-0.409,0.288	-0.344	-0.880,0.192	-0.110	-0.598,0.378
Scotland								
Urban (baseline)	.	.	.	.	.	.	.	.
Towns	-0.289	-1.151,0.573	-0.159	-0.849,0.532	-0.128	-0.609,0.352	-0.238	-0.610,0.135
Rural	-0.316	-0.842,0.211	-0.170	-0.598,0.258	-0.068	-0.766,0.630	-0.116	-0.742,0.510
Northern Ireland								
Urban (baseline)	.	.	.	.	.	.	.	.
Mixed urban rural	0.083	-0.821,0.987	0.490	-0.476,1.456	-0.148	-0.904,0.608	-0.043	-0.729,0.644
Rural	-0.427	-1.117,0.264	-0.270	-0.817,0.278	-0.594	-1.185,-0.002	-0.303	-0.816,0.211
Neighbourhood deprivation								
England	**-0.105**	-0.140,-0.070	-0.024	-0.054,0.006	**-0.059**	-0.093,-0.025	0.007	-0.021,0.036
Wales	**-0.070**	-0.134,-0.007	0.000	-0.055,0.056	**-0.137**	-0.203,-0.071	-0.054	-0.111,0.004
Scotland	**-0.112**	-0.181,-0.044	-0.008	-0.074,0.057	**-0.126**	-0.201,-0.051	-0.034	-0.102,0.033
Northern Ireland	-0.095	-0.205,0.015	-0.035	-0.132,0.063	-0.045	-0.127,0.037	0.037	-0.035,0.109

*Significant estimates are in **bold** (p<0.05)*

IV. Hyperactivity – multilevel model results

Table 4-25: Change in hyperactivity per 60 minutes sedentary time; variance attributable to ward differences

	Model 0		Model 1		Model 2		Model 3		Model 4		Model 5	
Hyperactivity - boys												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Sedentary	.	.	**-0.466**	-0.611,-0.321	**-0.467**	-0.612,-0.321	**-0.579**	-0.845,-0.312	**-0.429**	-0.571,-0.286	**-0.331**	-0.450,-0.213
Green space	.	.	.	.	-0.015	-0.060,0.030	-0.178	-0.508,0.153	0.065	-0.007,0.136	0.010	-0.049,0.070
Sedentary x green space	.	.	.	.	.	.	0.025	-0.025,0.076	.	.	.	.
Random effects												
Constant	3.525	3.402,3.648	6.495	5.554,7.436	6.573	5.580,7.566	7.294	5.542,9.045	6.920	5.920,7.919	5.263	1.548,8.978
Ward-level variance	0.570	0.396,0.820	0.551	0.378,0.804	0.546	0.373,0.800	0.544	0.370,0.798	0.460	0.306,0.692	0.332	0.213,0.516
Child-level variance	5.771	5.372,6.199	5.636	5.253,6.047	5.637	5.255,6.048	5.635	5.253,6.046	5.503	5.128,5.904	3.373	3.102,3.667
Intraclass Correlation Coefficient (ICC)(%)	9.0%		8.9%		8.8%		8.8%		7.7%		9.0%	
Hyperactivity - girls												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Sedentary	.	.	**-0.425**	-0.558,-0.291	**-0.425**	-0.559,-0.291	**-0.503**	-0.743,-0.263	**-0.414**	-0.546,-0.283	**-0.264**	-0.374,-0.154
Green space	.	.	.	.	**-0.057**	-0.091,-0.022	-0.171	-0.464,0.123	0.028	-0.026,0.083	0.032	-0.014,0.077
Sedentary x green space	.	.	.	.	.	.	0.017	-0.025,0.060	.	.	.	.
Random effects												
Constant	2.647	2.539,2.756	5.470	4.566,6.373	5.751	4.825,6.678	6.269	4.609,7.930	5.838	4.897,6.780	11.215	8.246,14.184
Ward-level variance	0.399	0.266,0.599	0.378	0.253,0.565	0.364	0.239,0.554	0.366	0.241,0.557	0.331	0.216,0.509	0.134	0.068,0.264
Child-level variance	4.765	4.388,5.175	4.658	4.299,5.047	4.648	4.288,5.039	4.645	4.286,5.035	4.583	4.232,4.963	2.842	2.622,3.081
Intraclass Correlation Coefficient (ICC)(%)	7.7%		7.5%		7.3%		7.3%		6.7%		4.5%	

*Significant fixed effects estimates are in **bold** ($p<0.05$)*
Model 0: random effects only
Model 1: Model 0 + PA
Model 2: Model 1 + green space
*Model 3: Model 2 + PA*green space*
Model 4: Model 2 + rural-urban designation and area deprivation
Model 5: Model 4 + all confounders

Table 4-26: Country-specific effects of rural-urban designation and neighbourhood deprivation (models 4 and 5 only) – hyperactivity and sedentary time

Hyperactivity	Boys				Girls			
	Model 4		Model 5		Model 4		Model 5	
	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Sedentary	**-0.429**	-0.571,-0.286	**-0.331**	-0.450,-0.213	**-0.414**	-0.546,-0.283	**-0.264**	-0.374,-0.154
Rural-urban designation								
England								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-0.394	-0.921,0.134	-0.020	-0.456,0.416	-0.412	-0.836,0.012	**-0.487**	-0.833,-0.142
Rural	-0.180	-0.822,0.462	0.099	-0.327,0.525	**-0.525**	-0.964,-0.087	-0.343	-0.700,0.013
Wales								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-0.472	-1.765,0.820	-0.518	-1.189,0.153	-0.289	-0.803,0.226	-0.203	-0.621,0.215
Rural	-0.565	-1.500,0.369	-0.542	-1.188,0.105	-0.757	-1.408,-0.106	-0.425	-0.924,0.074
Scotland								
Urban (baseline)	.	.	.	.	.	.	.	.
Towns	-0.098	-1.088,0.891	0.204	-0.468,0.876	0.269	-0.637,1.176	-0.053	-0.636,0.530
Rural	-0.417	-1.213,0.378	-0.445	-1.131,0.242	-0.709	-1.330,-0.089	**-0.775**	-1.404,-0.145
Northern Ireland								
Urban (baseline)	.	.	.	.	.	.	.	.
Mixed urban rural	-1.109	-2.296,0.077	-0.164	-1.146,0.818	-0.229	-1.087,0.629	-0.363	-1.183,0.458
Rural	-0.288	-1.405,0.828	0.295	-0.656,1.245	-0.430	-1.117,0.257	-0.041	-0.603,0.521
Neighbourhood deprivation								
England	**-0.162**	-0.208,-0.117	-0.039	-0.085,0.006	**-0.079**	-0.127,-0.031	0.023	-0.011,0.057
Wales	-0.100	-0.212,0.013	-0.016	-0.096,0.064	**-0.209**	-0.287,-0.132	**-0.085**	-0.139,-0.030
Scotland	**-0.224**	-0.329,-0.119	-0.044	-0.143,0.055	**-0.099**	-0.193,-0.005	0.046	-0.033,0.125
Northern Ireland	-0.128	-0.307,0.052	-0.015	-0.183,0.153	-0.093	-0.204,0.018	0.014	-0.079,0.107

Significant estimates are in ***bold*** *(p<0.05)*

Table 4-27: Change in hyperactivity per 30 minutes light PA; variance attributable to ward differences

	Model 0		Model 1		Model 2		Model 3		Model 4		Model 5	
Hyperactivity - boys												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Light PA	.	.	**0.249**	0.149,0.349	**0.250**	0.150,0.349	**0.271**	0.095,0.446	**0.237**	0.140,0.334	**0.159**	0.081,0.238
Green space	.	.	.	.	-0.017	-0.063,0.028	0.028	-0.280,0.335	0.068	-0.003,0.140	0.013	-0.047,0.073
Light PA x green space	.	.	.	.	.	.	-0.005	-0.038,0.028	.	.	.	.
Random effects												
Constant	3.525	3.402,3.648	1.183	0.245,2.120	1.260	0.324,2.195	1.064	-0.567,2.694	1.980	1.041,2.919	1.668	-2.223,5.560
Ward-level variance	0.570	0.396,0.820	0.565	0.388,0.822	0.558	0.381,0.817	0.557	0.381,0.816	0.461	0.306,0.695	0.329	0.212,0.511
Child-level variance	5.771	5.372,6.199	5.676	5.289,6.092	5.678	5.291,6.093	5.678	5.291,6.093	5.535	5.158,5.939	3.404	3.128,3.703
Intraclass Correlation Coefficient (ICC)(%)	9.0%		9.1%		9.0%		8.9%		7.7%		8.8%	
Hyperactivity - girls												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Light PA	.	.	**0.250**	0.163,0.337	**0.253**	0.165,0.340	**0.313**	0.150,0.476	**0.246**	0.160,0.332	**0.160**	0.087,0.234
Green space	.	.	.	.	**-0.060**	-0.095,-0.025	0.065	-0.182,0.311	0.027	-0.028,0.083	0.031	-0.015,0.077
Light PA x green space	.	.	.	.	.	.	-0.013	-0.040,0.014	.	.	.	.
Random effects												
Constant	2.647	2.539,2.756	0.317	-0.492,1.126	0.584	-0.231,1.399	0.020	-1.454,1.495	0.817	-0.020,1.653	8.136	5.218,11.053
Ward-level variance	0.399	0.266,0.599	0.387	0.261,0.573	0.371	0.246,0.561	0.375	0.248,0.566	0.338	0.220,0.518	0.136	0.070,0.267
Child-level variance	4.765	4.388,5.175	4.671	4.306,5.067	4.660	4.294,5.058	4.656	4.291,5.053	4.594	4.238,4.980	2.844	2.623,3.083
Intraclass Correlation Coefficient (ICC)(%)	7.7%		7.6%		7.4%		7.4%		6.8%		4.6%	

*Significant fixed effects estimates are in **bold** (p<0.05)*
Model 0: random effects only
Model 1: Model 0 + PA
Model 2: Model 1 + green space
*Model 3: Model 2 + PA*green space*
Model 4: Model 2 + rural-urban designation and area deprivation
Model 5: Model 4 + all confounders

Table 4-28: Country-specific effects of rural-urban designation and neighbourhood deprivation (models 4 and 5 only) – hyperactivity and light PA

Hyperactivity	Boys				Girls			
	Model 4		Model 5		Model 4		Model 5	
	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Light PA	**0.237**	0.140,0.334	**0.159**	0.081,0.238	**0.246**	0.160,0.332	**0.160**	0.087,0.234
Rural-urban designation								
England								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-0.404	-0.926,0.117	-0.030	-0.460,0.401	-0.413	-0.840,0.014	**-0.487**	-0.835,-0.139
Rural	-0.202	-0.842,0.437	0.091	-0.335,0.516	**-0.543**	-0.985,-0.102	-0.353	-0.711,0.006
Wales								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-0.478	-1.780,0.824	-0.526	-1.197,0.144	-0.332	-0.870,0.205	-0.228	-0.651,0.195
Rural	-0.559	-1.491,0.373	-0.548	-1.181,0.086	**-0.776**	-1.420,-0.131	-0.440	-0.939,0.059
Scotland								
Urban (baseline)	.	.	.	.	.	.	.	.
Towns	-0.181	-1.184,0.822	0.157	-0.507,0.820	0.224	-0.675,1.122	-0.076	-0.659,0.508
Rural	-0.519	-1.313,0.276	-0.526	-1.215,0.163	**-0.683**	-1.310,-0.056	**-0.754**	-1.388,-0.120
Northern Ireland								
Urban (baseline)	.	.	.	.	.	.	.	.
Mixed urban rural	-1.077	-2.261,0.107	-0.127	-1.112,0.857	-0.248	-1.101,0.606	-0.373	-1.193,0.447
Rural	-0.386	-1.510,0.739	0.244	-0.716,1.203	-0.433	-1.122,0.257	-0.037	-0.599,0.526
Neighbourhood deprivation								
England	**-0.168**	-0.215,-0.122	-0.043	-0.089,0.003	**-0.082**	-0.130,-0.034	0.022	-0.012,0.055
Wales	-0.101	-0.214,0.012	-0.015	-0.095,0.066	**-0.208**	-0.285,-0.131	**-0.083**	-0.137,-0.029
Scotland	**-0.235**	-0.339,-0.131	-0.050	-0.151,0.050	**-0.098**	-0.192,-0.004	0.048	-0.031,0.127
Northern Ireland	-0.133	-0.314,0.047	-0.018	-0.187,0.152	-0.091	-0.202,0.020	0.017	-0.076,0.110

*Significant estimates are in **bold** (p<0.05)*

Table 4-29: Change in hyperactivity per 15 minutes MVPA; variance attributable to ward differences

	Model 0		Model 1		Model 2		Model 3		Model 4		Model 5	
Hyperactivity - boys												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
MVPA	.	.	**0.184**	0.107,0.261	**0.183**	0.106,0.260	**0.258**	0.091,0.424	**0.158**	0.080,0.235	**0.157**	0.092,0.223
Green space	.	.	.	.	-0.010	-0.056,0.036	0.066	-0.078,0.210	0.070	0.000,0.140	0.012	-0.047,0.071
MVPA x green space	.	.	.	.	.	.	-0.017	-0.047,0.014	.	.	.	.
Random effects												
Constant	3.525	3.402,3.648	2.668	2.295,3.041	2.718	2.311,3.125	2.378	1.602,3.155	3.443	2.956,3.930	2.772	-0.974,6.518
Ward-level variance	0.570	0.396,0.820	0.549	0.378,0.797	0.546	0.375,0.796	0.547	0.375,0.798	0.454	0.301,0.684	0.330	0.208,0.524
Child-level variance	5.771	5.372,6.199	5.704	5.313,6.125	5.705	5.314,6.125	5.700	5.310,6.119	5.570	5.188,5.981	3.389	3.119,3.682
Intraclass Correlation Coefficient (ICC)(%)	9.0%		8.8%		8.7%		8.8%		7.5%		8.9%	
Hyperactivity - girls												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
MVPA	.	.	**0.170**	0.078,0.262	**0.167**	0.074,0.259	0.164	-0.009,0.338	**0.164**	0.073,0.255	**0.094**	0.029,0.158
Green space	.	.	.	.	**-0.053**	-0.089,-0.017	-0.055	-0.174,0.064	0.029	-0.026,0.084	0.032	-0.014,0.078
MVPA x green space	.	.	.	.	.	.	0.001	-0.032,0.033	.	.	.	.
Random effects												
Constant	2.647	2.539,2.756	2.012	1.655,2.368	2.284	1.863,2.704	2.293	1.627,2.959	2.478	2.017,2.939	9.210	6.308,12.111
Ward-level variance	0.399	0.266,0.599	0.384	0.253,0.582	0.373	0.243,0.572	0.372	0.243,0.572	0.330	0.212,0.513	0.141	0.073,0.272
Child-level variance	4.765	4.388,5.175	4.726	4.361,5.122	4.717	4.350,5.114	4.717	4.350,5.114	4.651	4.294,5.038	2.865	2.641,3.109
Intraclass Correlation Coefficient (ICC)(%)	7.7%		7.5%		7.3%		7.3%		6.6%		4.7%	

Significant fixed effects estimates are in ***bold*** *($p<0.05$)*
Model 0: random effects only
Model 1: Model 0 + PA
Model 2: Model 1 + green space
*Model 3: Model 2 + PA*green space*
Model 4: Model 2 + rural-urban designation and area deprivation
Model 5: Model 4 + all confounders

Table 4-30: Country-specific effects of rural-urban designation and neighbourhood deprivation (models 4 and 5 only) – hyperactivity and MVPA

Hyperactivity	Boys				Girls			
	Model 4		Model 5		Model 4		Model 5	
	b	95% CI	b	95% CI	b	95% CI	b	95% CI
MVPA	**0.158**	0.080,0.235	**0.157**	0.092,0.223	**0.164**	0.073,0.255	**0.094**	0.029,0.158
Rural-urban designation								
England								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-0.396	-0.934,0.142	-0.025	-0.462,0.412	-0.375	-0.802,0.053	**-0.464**	-0.812,-0.116
Rural	-0.174	-0.804,0.455	0.107	-0.316,0.529	**-0.469**	-0.909,-0.030	-0.306	-0.661,0.049
Wales								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-0.495	-1.779,0.790	-0.523	-1.162,0.117	-0.190	-0.683,0.302	-0.154	-0.570,0.262
Rural	-0.609	-1.534,0.317	-0.576	-1.238,0.086	**-0.678**	-1.334,-0.021	-0.391	-0.891,0.109
Scotland								
Urban (baseline)	.	.	.	.	.	.	.	.
Towns	-0.024	-0.963,0.914	0.276	-0.362,0.913	0.299	-0.629,1.226	-0.038	-0.623,0.546
Rural	-0.452	-1.260,0.355	-0.435	-1.134,0.264	**-0.783**	-1.394,-0.171	**-0.820**	-1.447,-0.193
Northern Ireland								
Urban (baseline)	.	.	.	.	.	.	.	.
Mixed urban rural	-1.147	-2.368,0.074	-0.179	-1.195,0.838	-0.258	-1.100,0.583	-0.383	-1.188,0.422
Rural	-0.190	-1.310,0.929	0.394	-0.556,1.344	-0.359	-1.045,0.326	0.009	-0.555,0.573
Neighbourhood deprivation								
England	**-0.165**	-0.212,-0.118	-0.038	-0.084,0.007	**-0.084**	-0.132,-0.036	0.022	-0.013,0.056
Wales	-0.099	-0.212,0.014	-0.017	-0.098,0.063	**-0.215**	-0.296,-0.133	**-0.086**	-0.143,-0.029
Scotland	-0.221	-0.326,-0.117	-0.036	-0.135,0.063	**-0.102**	-0.199,-0.006	0.046	-0.033,0.126
Northern Ireland	-0.122	-0.300,0.056	-0.013	-0.181,0.155	-0.096	-0.205,0.013	0.015	-0.077,0.107

*Significant estimates are in **bold** (p<0.05)*

V. Total difficulties – multilevel model results

Table 4-31: Change in total difficulties per 60 minutes sedentary time; variance attributable to ward differences

	Model 0		Model 1		Model 2		Model 3		Model 4		Model 5	
Total difficulties - boys												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Sedentary	.	.	**-0.501**	-0.885,-0.118	**-0.504**	-0.889,-0.119	**-0.773**	-1.427,-0.120	**-0.415**	-0.791,-0.038	-0.160	-0.454,0.134
Green space	.	.	.	.	-0.087	-0.202,0.028	-0.479	-1.302,0.345	0.119	-0.077,0.314	-0.012	-0.150,0.126
Sedentary x green space	.	.	.	.	.	.	0.061	-0.069,0.191	.	.	.	.
Random effects												
Constant	8.222	7.913,8.531	11.417	8.955,13.879	11.869	9.169,14.568	13.606	9.322,17.890	12.958	10.228,15.689	10.722	2.716,18.728
Ward-level variance	4.191	2.965,5.926	4.141	2.913,5.887	4.048	2.831,5.790	4.023	2.804,5.771	3.339	2.319,4.808	1.381	0.849,2.246
Child-level variance	31.143	28.188,34.409	30.998	28.036,34.272	30.996	28.016,34.293	30.988	28.020,34.270	30.195	27.296,33.401	14.478	13.004,16.120
Intraclass Correlation Coefficient (ICC)(%)	11.9%		11.8%		11.6%		11.5%		10.0%		8.7%	
Total difficulties - girls												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Sedentary	.	.	**-0.653**	-0.986,-0.321	**-0.654**	-0.988,-0.321	**-0.977**	-1.603,-0.351	**-0.620**	-0.952,-0.289	-0.146	-0.401,0.108
Green space	.	.	.	.	**-0.163**	-0.256,-0.070	-0.636	-1.394,0.123	0.048	-0.101,0.197	0.060	-0.058,0.179
Sedentary x green space	.	.	.	.	.	.	0.071	-0.040,0.182	.	.	.	.
Random effects												
Constant	7.027	6.750,7.303	11.369	9.118,13.619	12.180	9.815,14.546	14.329	9.986,18.672	12.399	10.011,14.786	16.353	9.193,23.512
Ward-level variance	2.905	1.956,4.314	2.878	1.946,4.256	2.714	1.798,4.095	2.735	1.818,4.114	2.388	1.519,3.756	0.890	0.567,1.398
Child-level variance	27.936	25.034,31.174	27.671	24.788,30.890	27.609	24.719,30.837	27.576	24.703,30.783	27.200	24.332,30.404	14.221	12.875,15.708
Intraclass Correlation Coefficient (ICC)(%)	9.4%		9.4%		8.9%		9.0%		8.1%		5.9%	

*Significant fixed effects estimates are in **bold** (p<0.05)*
Model 0: random effects only
Model 1: Model 0 + PA
Model 2: Model 1 + green space
*Model 3: Model 2 + PA*green space*
Model 4: Model 2 + rural-urban designation and area deprivation
Model 5: Model 4 + all confounders

Table 4-32: Country-specific effects of rural-urban designation and neighbourhood deprivation (models 4 and 5 only) – total difficulties and sedentary time

Total difficulties	Boys				Girls			
	Model 4		Model 5		Model 4		Model 5	
	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Sedentary	**-0.415**	-0.791,-0.038	-0.160	-0.454,0.134	**-0.620**	-0.952,-0.289	-0.146	-0.401,0.108
Rural-urban designation								
England								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-0.869	-2.234,0.497	0.095	-0.839,1.029	-0.672	-1.792,0.449	**-0.839**	-1.649,-0.030
Rural	-0.478	-2.348,1.391	0.329	-0.646,1.303	-1.058	-2.253,0.137	-0.583	-1.479,0.313
Wales								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-0.982	-3.169,1.204	-0.866	-2.452,0.720	**-1.254**	-2.456,-0.052	-1.077	-2.176,0.022
Rural	-1.057	-2.875,0.762	-1.166	-2.467,0.134	-1.539	-3.069,-0.009	-0.561	-1.827,0.705
Scotland								
Urban (baseline)	.	.	.	.	.	.	.	.
Towns	0.102	-2.842,3.045	0.737	-0.899,2.373	-0.972	-2.589,0.646	**-1.799**	-3.411,-0.187
Rural	-0.547	-2.407,1.313	-0.360	-1.681,0.960	-1.321	-3.226,0.585	-1.534	-3.376,0.308
Northern Ireland								
Urban (baseline)	.	.	.	.	.	.	.	.
Mixed urban rural	-2.046	-5.078,0.986	0.060	-2.675,2.796	-0.422	-2.991,2.147	-0.629	-2.628,1.369
Rural	-1.279	-3.958,1.399	-0.361	-2.304,1.583	**-2.395**	-4.308,-0.482	-1.228	-2.745,0.289
Neighbourhood deprivation								
England	**-0.433**	-0.553,-0.313	-0.089	-0.196,0.018	**-0.230**	-0.346,-0.114	0.077	-0.013,0.166
Wales	**-0.333**	-0.562,-0.104	-0.076	-0.249,0.096	**-0.577**	-0.790,-0.364	**-0.198**	-0.371,-0.025
Scotland	**-0.511**	-0.769,-0.253	-0.041	-0.220,0.139	**-0.379**	-0.634,-0.124	0.054	-0.152,0.260
Northern Ireland	-0.243	-0.634,0.147	0.004	-0.346,0.353	-0.234	-0.592,0.124	0.101	-0.191,0.392

*Significant estimates are in **bold** (p<0.05)*

Table 4-33: Change in total difficulties per 30 minutes light PA; variance attributable to ward differences

	Model 0		Model 1		Model 2		Model 3		Model 4		Model 5	
Total difficulties - boys												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Light PA	.	.	**0.307**	0.065,0.549	**0.311**	0.068,0.554	**0.453**	0.039,0.867	**0.282**	0.047,0.517	0.051	-0.128,0.231
Green space	.	.	.	.	-0.090	-0.205,0.025	0.215	-0.591,1.021	0.121	-0.074,0.316	-0.010	-0.147,0.127
Light PA x green space	.	.	.	.	.	.	-0.032	-0.115,0.050	.	.	.	.
Random effects												
Constant	8.222	7.913,8.531	11.417	8.955,13.879	11.869	9.169,14.568	13.606	9.322,17.890	12.958	10.228,15.689	10.722	2.716,18.728
Ward-level variance	4.191	2.965,5.926	4.141	2.913,5.887	4.048	2.831,5.790	4.023	2.804,5.771	3.339	2.319,4.808	1.381	0.849,2.246
Child-level variance	31.143	28.188,34.409	30.998	28.036,34.272	30.996	28.016,34.293	30.988	28.020,34.270	30.195	27.296,33.401	14.478	13.004,16.120
Intraclass Correlation Coefficient (ICC)(%)	11.9%		11.8%		11.6%		11.5%		10.0%		8.7%	
Total difficulties - girls												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Light PA	.	.	**0.360**	0.136,0.584	**0.367**	0.142,0.591	**0.538**	0.108,0.968	**0.349**	0.126,0.571	0.078	-0.098,0.255
Green space	.	.	.	.	**-0.167**	-0.262,-0.073	0.185	-0.476,0.846	0.047	-0.103,0.197	0.060	-0.059,0.179
Light PA x green space	.	.	.	.	.	.	-0.038	-0.109,0.033	.	.	.	.
Random effects												
Constant	7.027	6.750,7.303	3.667	1.576,5.758	4.432	2.357,6.507	2.834	-1.087,6.755	5.067	2.888,7.246	14.762	7.668,21.855
Ward-level variance	2.905	1.956,4.314	2.918	1.975,4.310	2.747	1.822,4.142	2.765	1.838,4.160	2.413	1.534,3.795	0.891	0.567,1.402
Child-level variance	27.936	25.034,31.174	27.724	24.835,30.949	27.657	24.762,30.892	27.634	24.751,30.852	27.244	24.373,30.453	14.224	12.879,15.709
Intraclass Correlation Coefficient (ICC)(%)	9.4%		9.5%		9.0%		9.1%		8.1%		5.9%	

*Significant fixed effects estimates are in **bold** (p<0.05)*
Model 0: random effects only
Model 1: Model 0 + PA
Model 2: Model 1 + green space
*Model 3: Model 2 + PA*green space*
Model 4: Model 2 + rural-urban designation and area deprivation
Model 5: Model 4 + all confounders

Table 4-34: Country-specific effects of rural-urban designation and neighbourhood deprivation (models 4 and 5 only) – total difficulties and light PA

Total difficulties	Boys				Girls			
	Model 4		Model 5		Model 4		Model 5	
	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Light PA	**0.282**	0.047,0.517	0.051	-0.128,0.231	**0.349**	0.126,0.571	0.078	-0.098,0.255
Rural-urban designation								
England								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-0.878	-2.235,0.480	0.089	-0.840,1.019	-0.670	-1.797,0.458	**-0.837**	-1.647,-0.027
Rural	-0.499	-2.370,1.372	0.324	-0.645,1.294	-1.081	-2.277,0.115	-0.586	-1.483,0.311
Wales								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-0.981	-3.179,1.217	-0.873	-2.450,0.704	**-1.311**	-2.531,-0.091	-1.088	-2.183,0.008
Rural	-1.039	-2.860,0.782	-1.176	-2.469,0.117	**-1.561**	-3.072,-0.051	-0.568	-1.831,0.695
Scotland								
Urban (baseline)	.	.	.	.	.	.	.	.
Towns	0.010	-2.952,2.973	0.717	-0.913,2.347	-1.041	-2.652,0.571	**-1.811**	-3.422,-0.201
Rural	-0.630	-2.474,1.215	-0.407	-1.716,0.903	-1.285	-3.200,0.631	-1.525	-3.368,0.319
Northern Ireland								
Urban (baseline)	.	.	.	.	.	.	.	.
Mixed urban rural	-2.013	-5.019,0.993	0.082	-2.666,2.829	-0.452	-3.015,2.111	-0.637	-2.634,1.360
Rural	-1.390	-4.062,1.282	-0.377	-2.317,1.562	**-2.393**	-4.308,-0.477	-1.222	-2.739,0.296
Neighbourhood deprivation								
England	**-0.438**	-0.558,-0.318	-0.091	-0.198,0.016	**-0.235**	-0.351,-0.119	0.076	-0.013,0.166
Wales	**-0.335**	-0.564,-0.105	-0.075	-0.248,0.097	**-0.575**	-0.788,-0.363	**-0.197**	-0.370,-0.024
Scotland	**-0.521**	-0.779,-0.263	-0.044	-0.224,0.137	**-0.378**	-0.632,-0.124	0.055	-0.151,0.261
Northern Ireland	-0.250	-0.641,0.141	0.003	-0.347,0.353	-0.231	-0.588,0.125	0.102	-0.189,0.393

Significant estimates are in ***bold*** *(p<0.05)*

Table 4-35: Change in total difficulties per 15 minutes MVPA; variance attributable to ward differences

	Model 0		Model 1		Model 2		Model 3		Model 4		Model 5	
Total difficulties - boys												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
MVPA	.	.	0.135	-0.088,0.359	0.132	-0.091,0.356	0.206	-0.235,0.647	0.072	-0.150,0.294	0.110	-0.058,0.279
Green space	.	.	.	.	-0.083	-0.197,0.031	-0.008	-0.365,0.348	0.126	-0.065,0.318	-0.012	-0.149,0.125
MVPA x green space	.	.	.	.	.	.	-0.016	-0.090,0.057	.	.	.	.
Random effects												
Constant	8.222	7.913,8.531	7.592	6.518,8.666	8.020	6.888,9.152	7.685	5.600,9.770	9.987	8.679,11.296	9.367	1.510,17.224
Ward-level variance	4.191	2.965,5.926	4.138	2.926,5.853	4.058	2.854,5.769	4.057	2.851,5.772	3.323	2.313,4.776	1.370	0.837,2.243
Child-level variance	31.143	28.188,34.409	31.122	28.173,34.380	31.120	28.155,34.397	31.115	28.155,34.388	30.301	27.410,33.497	14.475	13.009,16.106
Intraclass Correlation Coefficient (ICC)(%)	11.9%		11.7%		11.5%		11.5%		9.9%		8.6%	
Total difficulties - girls												
Fixed effects	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
MVPA	.	.	**0.283**	0.076,0.489	**0.274**	0.068,0.480	**0.417**	0.020,0.813	**0.258**	0.053,0.462	0.067	-0.083,0.216
Green space	.	.	.	.	**-0.157**	-0.250,-0.064	-0.037	-0.304,0.230	0.049	-0.100,0.197	0.060	-0.058,0.178
MVPA x green space	.	.	.	.	.	.	-0.032	-0.103,0.039	.	.	.	.
Random effects												
Constant	7.027	6.750,7.303	5.969	5.171,6.767	6.780	5.856,7.704	6.247	4.757,7.738	7.321	6.262,8.381	15.147	8.330,21.964
Ward-level variance	2.905	1.956,4.314	2.843	1.911,4.230	2.694	1.779,4.079	2.702	1.787,4.086	2.328	1.467,3.697	0.885	0.562,1.392
Child-level variance	27.936	25.034,31.174	27.833	24.942,31.060	27.775	24.877,31.010	27.759	24.867,30.986	27.369	24.486,30.591	14.229	12.888,15.710
Intraclass Correlation Coefficient (ICC)(%)	9.4%		9.3%		8.8%		8.9%		7.8%		5.9%	

*Significant fixed effects estimates are in **bold** ($p<0.05$)*
Model 0: random effects only
Model 1: Model 0 + PA
Model 2: Model 1 + green space
*Model 3: Model 2 + PA*green space*
Model 4: Model 2 + rural-urban designation and area deprivation
Model 5: Model 4 + all confounders

Table 4-36: Country-specific effects of rural-urban designation and neighbourhood deprivation (models 4 and 5 only) – total difficulties and MVPA

Total difficulties	Boys				Girls			
	Model 4		Model 5		Model 4		Model 5	
	b	95% CI	b	95% CI	b	95% CI	b	95% CI
MVPA	0.072	-0.150,0.294	0.110	-0.058,0.279	**0.258**	0.053,0.462	0.067	-0.083,0.216
Rural-urban designation								
England								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-0.882	-2.249,0.485	0.095	-0.836,1.026	-0.611	-1.740,0.518	**-0.826**	-1.640,-0.012
Rural	-0.491	-2.335,1.353	0.336	-0.632,1.304	-0.971	-2.175,0.233	-0.561	-1.459,0.336
Wales								
Urban (baseline)	.	.	.	.	.	.	.	.
Town and Fringe	-1.013	-3.186,1.160	-0.866	-2.441,0.710	-1.100	-2.299,0.099	-1.047	-2.146,0.052
Rural	-1.100	-2.892,0.693	-1.179	-2.488,0.129	-1.415	-2.967,0.136	-0.538	-1.808,0.731
Scotland								
Urban (baseline)	.	.	.	.	.	.	.	.
Towns	0.122	-2.787,3.031	0.792	-0.822,2.406	-0.920	-2.536,0.696	**-1.785**	-3.382,-0.188
Rural	-0.649	-2.482,1.184	-0.326	-1.645,0.993	-1.431	-3.294,0.432	-1.561	-3.406,0.284
Northern Ireland								
Urban (baseline)	.	.	.	.	.	.	.	.
Mixed urban rural	-2.055	-5.147,1.037	0.037	-2.717,2.790	-0.471	-3.013,2.072	-0.639	-2.626,1.349
Rural	-1.250	-3.936,1.437	-0.292	-2.233,1.649	**-2.287**	-4.204,-0.371	-1.201	-2.721,0.319
Neighbourhood deprivation								
England	**-0.440**	-0.560,-0.320	-0.087	-0.194,0.019	**-0.237**	-0.350,-0.124	0.076	-0.013,0.166
Wales	**-0.332**	-0.563,-0.102	-0.078	-0.251,0.095	**-0.585**	-0.795,-0.374	**-0.199**	-0.372,-0.026
Scotland	**-0.518**	-0.776,-0.260	-0.034	-0.214,0.145	**-0.384**	-0.639,-0.128	0.054	-0.152,0.259
Northern Ireland	-0.242	-0.632,0.148	0.006	-0.343,0.355	-0.239	-0.593,0.115	0.101	-0.189,0.390

*Significant estimates are in **bold** (p<0.05)*

5 Reported measures of physical activity and sedentary behaviour

5.1 Introduction

In the previous chapters, objective measures of PA were used to examine whether the different intensities of PA were associated with SDQ scores. Results showed that sedentary time was detrimental to peer relationships in children, while light PA (boys and girls) and MVPA (boys only) at age 7 were found to improve peer problems at age 11. There was also evidence that higher levels of PA were related to worse externalising outcomes: boys who engaged in more MVPA had more conduct problems, and hyperactive symptoms were worse in children who were more active at both light and MVPA levels. Sedentary time was associated with lower hyperactivity scores.

The value of accelerometer measures is that they allow for objective estimates of PA, particularly in children who often engage in short bursts of PA or movements that are not readily subject to quantification or recall in PA questionnaires. The positive association observed between increased PA time and the conduct and hyperactivity subscales, however, demonstrate the importance of knowing what activities children are doing, as externalising mental health symptoms may be indistinguishable from PA with accelerometer measures. Conducting additional analyses using reported measures in children may provide some context to the PA and may highlight potential pathways through which more structured or volitional PA behaviours affect mental health outcomes.

The purpose of this chapter is:

1. To investigate the association between specific types of PA and sedentary behaviour and mental health outcomes;
2. To investigate causality in any observed relationships which suggest that PA predicts mental health, vice versa, or reciprocally, and whether this relationship changes or is stronger at particular ages; and
3. To examine this relationship longitudinally, using three time points of data.

Reported PA measures have been used extensively in PA research because of their lower cost and participant burden compared with accelerometers or other objective measures. Depending on form length and content, questionnaires can explore important PA characteristics such as the type, frequency, and intensity of activity, and derive a substantial picture of an individual's PA over a defined period of time. While self-reported validated measures exist for adult populations, children's validated self-reported measures are restricted to children older than 8 years of age as self-report in younger children is unreliable

(Stuart JH Biddle et al., 2011; Craig et al., 2003; Hagstromer, Oja, & Sjostrom, 2006). Studies conducted on younger children have reported mixed results on validity (Sarker et al., 2015; Wen, van der Ploeg, Kite, Cashmore, & Rissel, 2010).

Their limitations notwithstanding, reported measures can be useful in furthering our understanding of whether specific PA and sedentary behaviours affect children's mental health (Wen et al., 2010). Participation in team sports or competitive activities have been reported to provide mental health benefits via increased socialisation and challenge (Dimech & Seiler, 2011; Eime et al., 2013; Lau, Fox, & Cheung, 2004; Pyle, McQuivey, Brassington, & Steiner, 2003). Active commuting might provide mental health benefits beyond other forms of light or moderate activity via exposure to a natural environment or a sense of independence (Kyttä, 2004; Sugiyama, Leslie, Giles-Corti, & Owen, 2008).

Sedentary screen time might detrimentally affect mental health outcomes in children beyond the effects of inactivity alone. Exposure to violent electronic games, for example, has been linked to a range of poor mental health behaviours and outcomes, including social dysfunction, aggression and violence (Browne & Hamilton-Giachritsis, 2005; Ferguson, 2015). Despite increases in mobile digital technology, television remains the preferred device overall in children 5-15 years of age (Ofcom, 2014). Fewer than 4.7% of households in the UK did not have a TV in 2015 (Broadcasters' Audience Research Board, 2015) and the potential harms of excessive television exposure, particularly in childhood, have been widely reported (Christakis & Zimmerman, 2007; Courage & Howe, 2010; Hinkley et al., 2014).

The previous chapters explored whether PA levels predicted mental health, but this chapter will also investigate whether mental health predicts active and sedentary reported behaviours. If poor mental health leads to lower PA levels this, in turn, might exacerbate mental health issues. A longitudinal study by Griffiths et al on MCS children found that higher SDQ externalising scores decreased sedentary time and increased active time, more internalising problems increased sedentary time in girls, and internalising problems reduced MVPA in boys (L. Griffiths et al., 2016).

In the MCS, parental reports on select aspects of both PA and sedentary screen time are available at three time points – ages 5, 7, and 11 years – which opens up the possibility for a longitudinal investigation of the reciprocity of the effects of different types of PA and sedentary behaviours on mental health. Much of the evidence on reported activity and mental health is cross-sectional, and longitudinal studies in children have been limited to two measurement points (Dimech & Seiler, 2011; Eime et al., 2013; Findlay & Coplan, 2008; L. J. Griffiths, Dowda, Dezateux, & Pate, 2010). Analysing data from three time points will further allow identification of whether any effects are present at unique points in time, stronger at one time point, or persist between MCS sweeps.

While a comprehensive investigation of the relationship between parent-reported activity and objective measurement is beyond the scope of this thesis, a comparison between these will be undertaken to explore whether these represent analogous constructs.

5.2 Research questions:

1. What is the relationship between reported activity measures of physical activity and accelerometer-measured activity?
2. What is the relationship between reported measures of physical activity and mental health?
3. Do different types of PA/sedentary behaviour show a relationship with different aspects of mental health functioning?
4. Is there a specific age or time window at which PA and sedentary behaviours have a stronger effect on mental health outcomes compared to other times and vice versa?
5. Does PA/sedentary behaviour affect mental health outcomes or vice versa? Are there reciprocal effects?

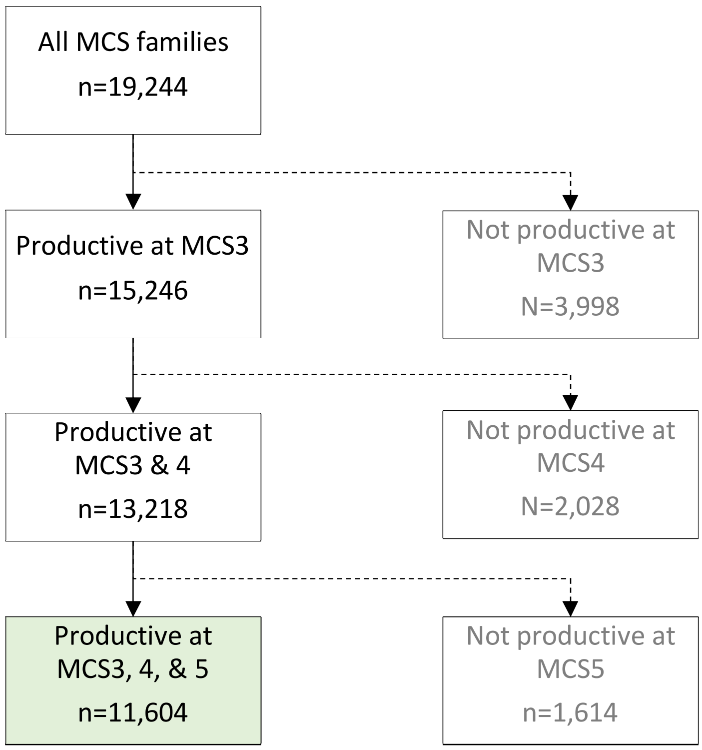
5.3 Methods

5.3.1 Participants – MCS Sweeps 3, 4, and 5

Of the 19,244 children enrolled in the MCS, the sample for these analyses were limited to singletons and first of multiples who were productive at MCS3-5.

Figure 5-1 below shows the cumulative number of productive and unproductive families at each sweep, and the sample that completed surveys at MCS3-5.

Figure 5-1: Number of families productive at MCS3, 4, and 5



After excluding those who did not have data from all three sweeps, the analytic sample was reduced to 11,604.

Missing data

Of the 11,604 children in the analytic sample, data were missing for the variables shown in Table 5-1 below.

Table 5-1: Missing data at MCS3, 4, and 5

	MCS3 % (n)	MCS4 % (n)	MCS5 % (n)
Emotional problems	2.5 (315)	2.6 (292)	3.1 (372)
Peer problems	2.5 (319)	2.6 (284)	3 (365)
Conduct problems	2.3 (298)	2.4 (268)	3 (368)
Hyperactivity	3.2 (355)	2.8 (310)	2.8 (387)
Total difficulties	3.3 (399)	3.2 (356)	3.2 (402)
Sports participation	0.3 (31)	0.4 (30)	0.5 (69)
Active commuting	1.8 (219)	1.2 (110)	1.4 (159)
TV viewing	0.3 (34)	0.5 (33)	0.5 (72)
Electronic gaming	0.3 (35)	0.5 (38)	0.5 (74)
Ethnicity		0 (0)	
Age	0 (0)	<0.1 (7)	0 (0)
Body composition	1.1 (120)	1.4 (142)	3 (325)
LSLI	<0.1 (4)	<0.1 (2)	0 (0)
SEN	n/a	<0.1% (50)	0.8 (90)

BAS Reading score	n/a	2.1 (337)	n/a
BAS Pattern score	n/a	2.1 (228)	n/a
Self-esteem	n/a	n/a	8.5 (951)
Number of siblings	<0.1 (1)	0 (0)	0 (0)
Access to car	n/a	0.7 (40)	1.5 (175)
Maternal depression (K6)	6.2 (741)	6.5 (715)	7.5 (818)
Maternal education	0.5 (37)	0.3 (18)	0.3 (17)
Maternal employment	<0.1 (1)	0 (0)	1.4 (0)
Income poverty	0.5 (0)	0.1 (0)	0 (0)
Both parents in household	0 (0)	0 (0)	0 (0)

Note: Ethnicity is a time-invariant characteristic; British Ability Scales scores were available at MCS4 only; Rosenberg self-esteem score was available at MCS5 only

To address the problem of missing data, a full information maximum likelihood (FIML) approach was used. FIML maximises the available data by estimating a likelihood function for each individual based on variables that are present. Model fit is obtained by summing across the fit functions for the individual cases, producing a model fit for all cases (Jakobsen et al., 2017). FIML produces unbiased parameter estimates and standard errors with data that are assumed to be MAR and MCAR (Enders & Bandalos, 2001). In the cross-lagged panel models, FIML was used instead of MI due to the complexities of the dataset. Multiple imputation models would have to be specified for MCS3-4 and MCS3-5 for each of the combinations of activity and SDQ subscale; for each of these multiply imputed datasets, a model would have to be specified for each direction of the association between PA/sedentary behaviour and SDQ, and at both time points. FIML allows the simultaneous estimation of multiple regression parameters in both directions across different points in time.

5.3.2 Variables

A number of different measures of PA and sedentary behaviour were available at MCS3-5. This section describes the reported PA (mode of school commute and sports/exercise frequency) and sedentary behaviour (weekday hours of television and electronic games) variables used in these analyses.

Main dependent and independent variables

The main variables (reported PA and sedentary behaviour and the Strengths and Difficulties Questionnaire subscales) are simultaneously modelled as both the dependent and independent variables in these analyses: these methods will be explained in greater detail in section 5.3.3 of this chapter describing the cross-lagged panel models.

Strengths and Difficulties Questionnaire (SDQ)

SDQ was previously described in section 2.2.1. In addition to the SDQ scores from MCS5, all parent-reported SDQ scores from MCS4 and MCS3 were also included in these analyses.

Reported measures of physical activity

Mode of school commute (MCS3-5):

The mode of school transportation variable was created using two variables at each sweep that asked the parent, 'How does CHILD usually travel to school?' and 'How does CHILD travel back to school?' Active commuting options were walking and cycling; other modes were 'car or other vehicle', 'school or local authority bus, minibus', 'public transport, such as bus or a train', 'someone else cycles' (MCS3 and 4 only); and 'other'. Categories of invalid/missing data were 'don't know', 'refusal', and 'not applicable'. Few children cycled either to or from school: at MCS3, 0.6% of children (n=71) cycled either to or from school; at MCS4, 0.9% cycled (n=106); at MCS5, 2.2% cycled (n=260). Because of the low proportion of cyclists, the walking and cycling categories were combined to form an active transportation category. Active commuters were divided into those who walked or cycled both to and from school, and those who were active one way only with any other mode of transport in the other direction. Children taken to school by car or other vehicle both ways constituted another category. Any remaining combinations of transport, including a small number of children at MCS3 (n=8) and MCS4 (n=9) who were taken to and/or from school on a bicycle ridden by someone else, were collapsed into a 'mixed transportation' category. Thus, a four-category ordered variable combining the to-and-from school transport variables was created: 'active both ways', 'active one way', 'mixed transport', and 'car or vehicle only'.

Sports participation / exercise (MCS3-5, number of times per week):

At MCS 3-5, the main respondent was asked 'On average how many days a week does CHILD go to a club or class to do sport or any other physical activity like swimming, gymnastics, football, dancing etc.?' Valid responses were 'five or more days a week', 'four days a week', 'three days a week', 'two days a week', 'one day a week', and 'less often or not at all'. Categories of invalid or missing data were 'don't know', 'refusal', and 'not applicable'. In this analysis, children's sports participation three or more times a week were combined in a single category to limit small group sizes, resulting in a four-category variable ('<1 day or not at all', '1 day', '2 days', '3+days').

Reported measures of screen-based sedentary behaviour

Computer and console games (MCS3-5):

The main respondent was asked, 'On a normal weekday during term time, how many hours does CHILD spend playing electronic games on a computer or games console?' Valid categories were 'None', 'Less than an hour', '1 hour to less than 3 hours', '3 hours to less than 5 hours', '5 hours to less than 7 hours', and '7 hours or more'. Categories of invalid data were 'don't know', 'refusal', and 'not applicable'. To limit small group sizes, categories from three or more hours of playing time were collapsed to produce a four-category variable (3+ hours, 1 to <3 hours, <1 hour, and none). Computer and console electronic games will be referred to as electronic games for brevity.

Television, DVD, and video watching (MCS3-5):

The main respondent was asked, ‘On a normal week day during term time, how many hours does CHILD spend watching television, videos or DVDs?’[3] Valid categories were ‘None’, ‘Less than an hour’, ‘1 hour to less than 3 hours’, ‘3 hours to less than 5 hours’, ‘5 hours to less than 7 hours’, and ‘7 hours or more’. Categories of invalid data were ‘don’t know’, ‘refusal’, and ‘not applicable’. To limit small group sizes, categories from three or more hours of viewing time, and ‘less than an hour’ and ‘none’, were collapsed to produce a three-category variable (3+ hours, 1 to <3 hours, <1 hour or none). For the sake of brevity, I will refer to this variable as television or TV but will be understood to encompass television, DVD, and video viewing.

Additional confounders

Car access

In school commute analyses, car access was considered, given that this would facilitate car travel for school commutes. At MCS4 and MCS5, respondents were asked ‘How many cars or vans do you have the regular use?’ Response options were ‘none’, ‘one’, ‘two’, and ‘three or more’. Invalid or missing responses were ‘refusal’, ‘don’t know’, and not applicable’. A binary variable was created with families who did not have access and those who indicated any regular car access.

Confounders at MCS sweeps 3 and 4

Questionnaire responses on the child’s age, weight status, long-standing limiting illness, and special educational needs at MCS3 and MCS4 were included, in addition to these variables at MCS5 described in section 2.2.3. Maternal characteristics—depression (Kessler-6 scores) and employment—at MCS3 and MCS4 were additionally included. Binary maternal education variables (degree/no degree) at MCS sweeps 3, 4, and 5 were included, rather than the binary variable indicating the highest level of maternal educational attainment by MCS5 used in Chapters 3 and 4, to adjust for sweep specific effects of maternal education. Finally, household poverty, family structure, and number of siblings at MCS3 and 4 were additionally included.

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[3] At MCS5, this question was modified to include watching programmes or films on a computer or mobile device.

5.3.3 Statistical analyses

Analyses were performed on the productive children available from MCS3-5 (n=11,604) and separate estimates obtained for boys and girls. Descriptive statistics of unweighted numbers of observations and weighted proportions were obtained using Stata/SE 15.1. To explore the relationship between reported and accelerometer measures of physical activity and sedentary behaviour, Kendall's tau correlation coefficients were obtained.

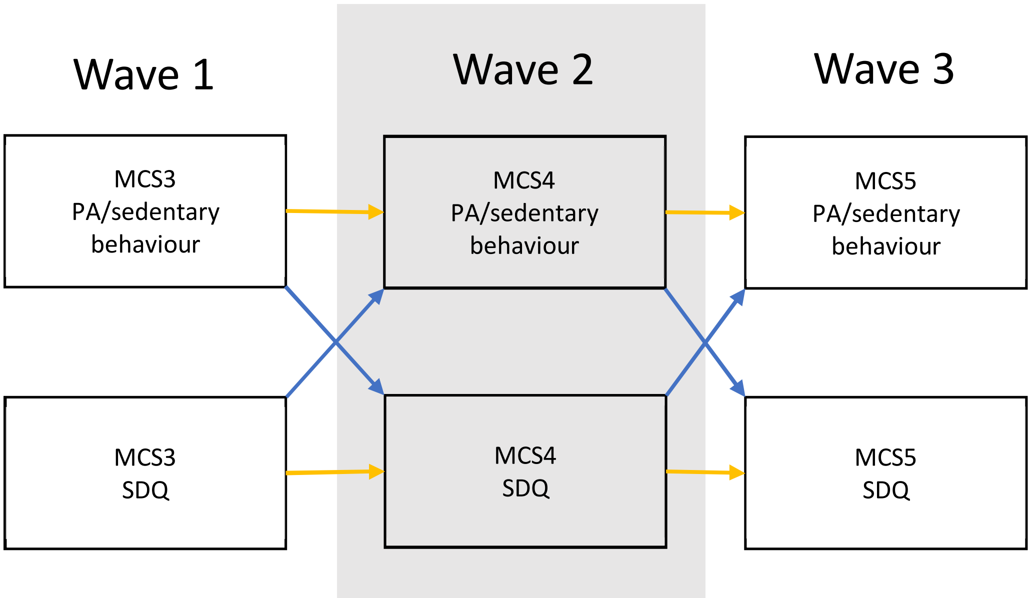
Cross-lagged panel model estimates were obtained using MPlus version 6.12 (Muthén and Muthén, 1998-2011), with FIML estimation to account for item missingness. Weights accounting for survey design and sample attrition up to the age 11 survey were applied to cross-lagged models.

Cross-lagged panel modelling

This section describes the background and uses of cross-lagged panel modelling, the strategy of analysis, and a description of the models.

Cross-lagged panel models, also known as cross-lagged structural equation models and autoregressive models, allow for the simultaneous estimation of multiple regression parameters using repeatedly measured variables or constructs to explore questions of causal ordering. Figure 5-2 shows a path diagram for a three-wave, two variable cross-lagged model.

Figure 5-2: Cross-lagged three-wave, two variable panel model



Each of the SDQ and PA variables is regressed on its own lagged score and the score of the other variable at the previous MCS sweep or wave. The parameters of interest in these analyses were the autoregressive and cross-lagged estimates, represented by the yellow and blue arrows, respectively. Autoregressive effects show the stability of the individual-differences standings on a construct over time. Cross-lagged estimates show the effect of a construct at one time point or wave on a different construct at a later measurement occasion. The cross-lagged effects are controlled by the previous levels of the construct being predicted (autoregressive effect), thus, significant cross-lagged estimates can be interpreted as a variable at an earlier wave having some influence on the later variable. At a given wave, if only one of the two cross-lagged estimates are statistically significant, then this suggests the direction of the association is unidirectional (i.e. PA at Wave 1 affects SDQ at Wave 2 but not vice versa). If both are significant, then this suggests the effects are reciprocal (i.e. PA at Wave 1 affects SDQ at Wave 2 AND SDQ at Wave 1 affects PA at Wave 2).

Although causal relationships in cross-lagged models can be implied, caution must be exercised in interpretation and results must not be represented as true causation. According to Little et al (2007), three barriers to causal inference include the exogeneity assumption, the omitted variable problem, and the proxy variable problem (Little, Preacher, Selig, & Card, 2007). The exogenous variable assumption is violated when the variables assumed to be without predictors at the initial time point in the period considered are not the true cause, which occurs at an earlier point in time. The omitted variable problem occurs when there is an unmeasured or omitted variable that causes the co-varying variables assumed to be in a causal relationship. The proxy variable problem is when the measured variable might be only a proxy of the intended construct (Little et al., 2007). To limit the extent to which the exogeneity assumption and omitted variable problems might affect causal interpretation, a broad range of confounders were included at all three waves and correlations of the residual variances of endogenous variables were modelled. To address the proxy variable problem, care will be taken to interpret results within the limits of the specific measures used.

Modelling strategy

The cross-lagged modelling was conducted using MPlus version 6.12 (Muthén and Muthén, 1998-2011). All models incorporated appropriate weights, accounting for the stratified cluster sampling design and sample attrition, to obtain estimates. Time varying confounders were the child's age, weight status, long-standing limiting illness, special educational needs (SEN)(MCS4 and 5 only), self-esteem (available at MCS5 only), cognition (MCS4 only), maternal depression, maternal employment, income poverty, family structure, and number of siblings. Ethnicity was the only time invariant confounder included. Models estimating the relationship between school commute and SDQ scores were additionally adjusted for car ownership. Separate estimates for boys and girls were obtained by specifying gender as a known class.

Where the predictor variables are categorical (as with the PA and sedentary variables), standardised coefficients cannot be produced, thus, unstandardized linear regression coefficients were estimated where SDQ was the outcome variable. Where the PA/sedentary behaviour variable was the outcome, and SDQ the predictor, ordinal logistic regression odds ratios and 95% confidence intervals were estimated.

5.4 Results

5.4.1 Descriptive statistics and unadjusted relationships between reported PA and sedentary variables and SDQ

Descriptive statistics were obtained using Stata/SE 15.1 to obtain unweighted numbers of observations and weighted proportions; gender differences were tested using a corrected weighted Pearson chi-square statistic. Weighted mean SDQ scores for each of the PA and sedentary behaviours were obtained and adjusted Wald's tests performed to measure the overall significance of the relationship.

School commuting

Of the 11,604 children included, data on mode of school commute were missing for 2.0% (n=229) at MCS3, 1.0% of children (n=110) at MCS4, and 1.4% of children (n=159) at MCS5.

Table 5-2: Weighted percentages and unweighted observations of boys and girls by mode of school commute for MCS3-5

Mode of school commute	*MCS3 % (n)*		*MCS4 % (n)*		*MCS5 % (n)*	
	Boys (n=5,683)	***Girls (n=5,692)***	***Boys (n=5,759)***	***Girls (n=5,735)***	***Boys (n=5,715)***	***Girls (n=5,730)***
Car or other vehicle	38.3 (2,302)	40.0 (2,378)	39.2 (2,366)	40.2 (2,362)	34.0 (2,063)	36.0 (2,168)
Mixed transport	5.1 (342)	4.0 (288)	5.9 (382)	4.7 (352)	7.2 (465)	6.7 (446)
Active one way	5.5 (317)	5.2 (298)	5.5 (322)	5.5 (319)	5.3 (313)	6.3 (352)
Active both ways	51.1 (2,722)	50.8 (2,728)	49.4 (2,689)	49.6 (2,702)	53.5 (2,874)	51.0 (2,764)
p-value for gender differences[¥]	0.082		0.171		**0.041**	

[¥] *P-value for corrected weighted Pearson chi-square statistic*

At each sweep, the majority of children were either actively commuting or taken by vehicle both ways, with approximately 50% actively commuting. Gender differences in commuting patterns were observed at age 11 only (p=0.041).

School commuting and SDQ

To assess the cross-sectional relationship between school commuting and SDQ, I estimated the weighted mean score of each subscale by school commute type at MCS3-5.

Full estimates are presented in Appendix D section I.

Mean SDQ scores for boys and girls who were actively commuting in MCS3 were higher in all subscales than children who were driven to school by car. Apart from differences between car transport and active transport, there were no other differences between other commuting groups.

At age 7, differences between active and car commuters are different for all subscales except hyperactivity in boys and conduct problems in girls (where 95% CIs overlap).

At age 11, only mean conduct problems scores were different between car and active commuting boys; differences in all SDQ subscales except emotional problems persist between car and active commuting for girls.

Adjusted Wald's tests were performed to assess the overall difference in mean subscale score by commute type for boys and girls. At MCS4, the differences in mean scores for peer problems by school commute type were not significant for boys (p=0.25). At MCS5, the differences in mean scores for peer problems by school commute type were not significant for boys (p=0.12) nor girls (p=0.53), and for emotional problems for boys only (p=0.32). For all other subscales across MCS3-5, mean SDQ scores differed by commute type (p<0.05).

Frequency of sport and exercise

Of 11,604 children, data on frequency of sports/exercise were missing for 0.27% of children (n=31) at MCS3, 0.26% of children (n=30) at MCS4, 0.59% of children (n=69) at MCS5.

Table 5-3 shows the weighted percentage (unweighted observations) of boys and girls in each category of frequency of exercise at MCS3-5.

Table 5-3: Percentages of boys and girls by weekly frequency of sports participation, MCS3-5

Sports participation	*MCS3 % (n)*		*MCS4 % (n)*		*MCS5 % (n)*	
	Boys (n=5,797)	***Girls (n=5,776)***	***Boys (n=5,801)***	***Girls (n=5,773)***	***Boys (n=5,774)***	***Girls (n=5,761)***
<1 day or none	50.8 (2,870)	44.3 (2,490)	32.9 (1,788)	32.2 (1,814)	24.4 (1,323)	27.7 (1,537)
1 day	28.3 (1,646)	27.3 (1,574)	25.1 (1,479)	27.1 (1,576)	19.1 (1,113)	24.5 (1,374)
2 days	13.7 (822)	17.0 (1,017)	21.0 (1,269)	21.4 (1,230)	21.0 (1,215)	20.0 (1,152)
3+ days	7.2 (459)	11.4 (695)	21.1 (1,265)	19.3 (1,153)	35.4 (2,123)	27.9 (1,698)
p-value for gender differences¥	**<0.001**		0.083		**<0.001**	

¥ *P-value for corrected weighted Pearson chi-square statistic*

At age 5, a higher proportion of girls participated in sports/exercise more than three days a week (11.4% of girls compared with 7.2% of boys), but by age 11 boys participate in more sports (35.4% vs 27.9%). At age 5, more boys participated in sports less than once per week than girls (50.8% vs 44.3%), and by age 11 the reverse was true (27.7% of girls active <1 day vs 24.4% of boys). Gender differences in frequency of sports participation were significant at MCS3 and MCS5 ($p<0.001$) but not MCS4 ($p=0.083$).

Sports participation and SDQ

To assess the cross-sectional relationship between sports participation and SDQ, I estimated the weighted mean score of each SDQ subscale by categories of weekly sports frequency at MCS3-5.

Full estimates are presented in Appendix D section II.

For both genders and across all three sweeps, there appears to be a dose-response pattern where greater frequency of sports/exercise is associated with lower SDQ scores. Differences in mean SDQ scores for children participating in sports most often compared with least often are significant across all sweeps for both genders. Adjusted Wald's tests showed that the overall difference in mean subscale score by sports participation were significant ($p<0.01$) for boys and girls across all SDQ subscales and sweeps.

Television viewing

Of 11,604 children data were missing for 0.29% (n=34) at MCS3, 0.28% (n=33) at MCS4, and 0.62% at MCS5 (n=72).

Table 5-4 below shows the weighted percentage (unweighted observations) of boys and girls in each category of TV watching at MCS3-5.

Table 5-4: Percentages of boys and girls by hours of weekday term-time watching TV or videos, MCS3-5

Television	*MCS3 % (n)*		*MCS4 % (n)*		*MCS5 % (n)*	
	Boys (n=5,797)	***Girls (n=5,773)***	***Boys (n=5,798)***	***Girls (n=5,773)***	***Boys (n=5,771)***	***Girls (n=5,761)***
3+ hours	16.0 (901)	14.3 (800)	16.9 (959)	13.8 (799)	15.9 (816)	17.0 (907)
1 hour to <3 hours	64.9 (3,751)	63.2 (3,640)	64.5 (3,743)	65.9 (3,744)	67.7 (3,947)	68.0 (3,915)
<1 hour or none	19.1 (1,145)	22.5 (1,333)	18.6 (1,096)	20.3 (1,230)	16.4 (1,008)	15.0 (939)
p-value for gender differences[¥]	**<0.001**		**<0.001**		0.131	

[¥] *P-value for corrected weighted Pearson chi-square statistic*

At ages 5 and 7, a greater proportion of boys spend 3+ hours watching television than girls but by age 11, more girls watch 3+ hours of TV than boys (17.0% vs 15.9%), although the difference was not statistically significant ($p=0.131$).

Television and SDQ

To assess the cross-sectional relationship between television watching and SDQ, I estimated the weighted mean score of each SDQ subscale by categories of weekday duration of TV watching at MCS3-5.

Full estimates are presented in Appendix D section III.

For all children at all sweeps mean SDQ scores are higher in the 3+ hours category than both the 1 hour to <3 hour and <1 to none categories. Adjusted Wald's tests showed that the overall difference in mean subscale score by weekday television time duration were significant for both genders (p<0.01) across all SDQ subscales and sweeps.

Computer and video game console playing

Of 11,604 children, data were missing for 0.30% (n=35) at MCS3, 0.33% (n=38) at MCS4, and 0.64% at MCS5 (n=74).

Table 5-5 below shows the weighted percentages (unweighted observations) of boys and girls in each category of TV watching at MCS3-5.

Table 5-5: Percentages of boys and girls by hours of weekday term-time playing electronic games, MCS3-5

Electronic games	***MCS3 % (n)***		***MCS4 % (n)***		***MCS5 % (n)***	
	Boys (n=5,796)	***Girls (n=5,773)***	***Boys (n=5,796)***	***Girls (n=5,770)***	***Boys (n=5,769)***	***Girls (n=5,761)***
3+ hours	3.7 (200)	2.0 (118)	5.7 (318)	2.2 (137)	9.4 (501)	3.4 (182)
1 hour to <3 hours	24.2 (1,416)	15.8 (891)	37.5 (2,144)	25.0 (1,432)	51.4 (2,940)	29.1 (1,646)
<1 hour	43.2 (2,541)	46.5 (2,682)	46.3 (2,736)	58.8 (3,402)	30.2 (1,807)	47.2 (2,716)
none	28.9 (1,639)	35.7 (2,082)	10.5 (598)	14.0 (799)	9.0 (521)	20.3 (1,217)
p-value for gender differences[¥]	**<0.001**		**<0.001**		**<0.001**	

[¥] *P-value for corrected weighted Pearson chi-square statistic*

At all ages, a greater proportion of boys spend more time playing electronic games than girls. By age 11, over 60% of boys are playing at least 1 hour per day compared with 32.5% of girls. Only 9% of boys play no electronic games at age 11, compared with 20.3% of girls. All gender differences were significant (p<0.001)

Computer and video game console playing and SDQ

To assess the cross-sectional relationship between electronic games and SDQ, I estimated the weighted mean score of each SDQ subscale by categories of weekday duration of game time at MCS3-5.

Full estimates are presented in Appendix D section IV.

At MCS3, boys who played <1 hour had lower mean SDQ scores that children who played 3+ hours, except in emotional problems. Girls who played <1 hour had lower mean scores for peer problems and total difficulties than 3+ hours. Differences in mean scores between children who played 3+ hours and not at all were not significant except in peer problems where boys who did not play at all had lower scores than in the 3+ hours category.

At MCS4, mean scores between children who played electronic games most were not significantly different from those who never played. Children who played electronic games for <1 hour had lower SDQ scores across subscales except for girls' emotional problems and hyperactivity where differences in means were not significant.

Except in peer and conduct problems in boys at MCS5, scores were higher in children who played electronic games most compared with children who never played. For both mean SDQ scores in children who played electronic games the most were higher than in children who played <1 hour. Adjusted Wald's tests showed that the overall difference in mean subscale score by weekday electronic game duration were significant (p<0.05) for boys and girls (p<0.01) across all SDQ subscales and sweeps.

5.4.2 Correlation between reported and accelerometer-measured activity

The MCS4 accelerometer measures (minutes of sedentary, light, and MVPA) were compared with the reported activity and sedentary measures at age 7 using Kendall's tau correlation coefficients. Kendall's tau (T_b) is used to measure the association between two ordinal or continuous measures whose relationship is not assumed to normally distributed (Akoglu, 2018). Values range from -1 (100% negative association) to +1 (perfect correlation). While interpretation of the strength of the coefficient is not universal, informal guidelines suggest that coefficients of >0.8 correspond to strong positive, >0.5 moderate positive, >0.2 weak positive, 0 no relationship, <-0.2 weak negative, <-0.5 moderate negative, <-0.8 strong negative (Khamis, 2008).

Table 5-6 presents the correlation coefficients separately for boys and girls.

Table 5-6: Correlations between reported PA/screen time and accelerometer-measured PA

Boys T_b	**Sedentary (60 min)**	**Light (30 min)**	**MVPA (15 min)**
Sports participation	-0.017	-0.011	***0.061**
Active commuting	-0.020	-0.013	***0.073**
TV	-0.007	0.007	0.006
Electronic gaming	-0.027	**0.040**	-0.003
Girls T_b	**Sedentary**	**Light**	**MVPA**
Sports participation	0.012	-0.009	-0.005
Active commuting	-0.019	-0.019	***0.090**
TV	*0.028**	-0.022	-0.019
Electronic gaming	0.017	-0.017	-0.004

Boys: sports participation (n=2,933); active commuting (n=2,913); TV (n=2,933); electronic gaming (n=2,931)
Girls: sports participation (n=3,071); active commuting (n=3,047); TV (n=3,071); electronic gaming (n=3,070)

Kendall's T_b correlation coefficient significance levels: * p<0.05, ** p<0.01, *** p<0.001

For boys, MVPA and more frequent sports participation were positively correlated (τ_b=0.06, p<0.001), as well as MVPA and active commuting (τ_b=0.07, p<0.001). Light PA and less frequent electronic gaming were also positively correlated (τ_b=0.04, p=0.005). Sedentary time was not associated with any of the parent-reported activity measures. For girls, MVPA and active commuting were positively correlated (τ_b=0.09, p<0.001). Sedentary time and fewer hours of TV were also positively correlated (τ_b=0.03, p=0.049). Light PA was not associated with any of the parent-reported activity measures.

Although significant, the correlations reported between the accelerometer-measured and reported activity variables were very weak. This indicates that the intensity and duration of PA and sedentary time measured by the accelerometers likely represent different dimensions of activity than the reported active commuting, sports participation, and screen-time behaviours. The subsequent analyses will provide evidence for how type different the types and the frequency of PA and sedentary behaviours are associated with mental health.

5.4.3 Cross-lagged panel models

For each type of reported PA and SDQ subscale, estimates for the cross-lagged and autoregressive effects were obtained, adjusting for the full range of confounders described in section 5.3.3.

Each of the figures in the following section displays only the statistically significant regression coefficients (p<0.05, where SDQ is the outcome) and ordered logistic odds ratios, where 95% CIs do not overlap the null value (OR=1.00, where the sedentary behaviour or PA is the outcome). Tables of the full cross-lagged and autoregressive estimates are presented in Appendix D section V.

Mode of school commute

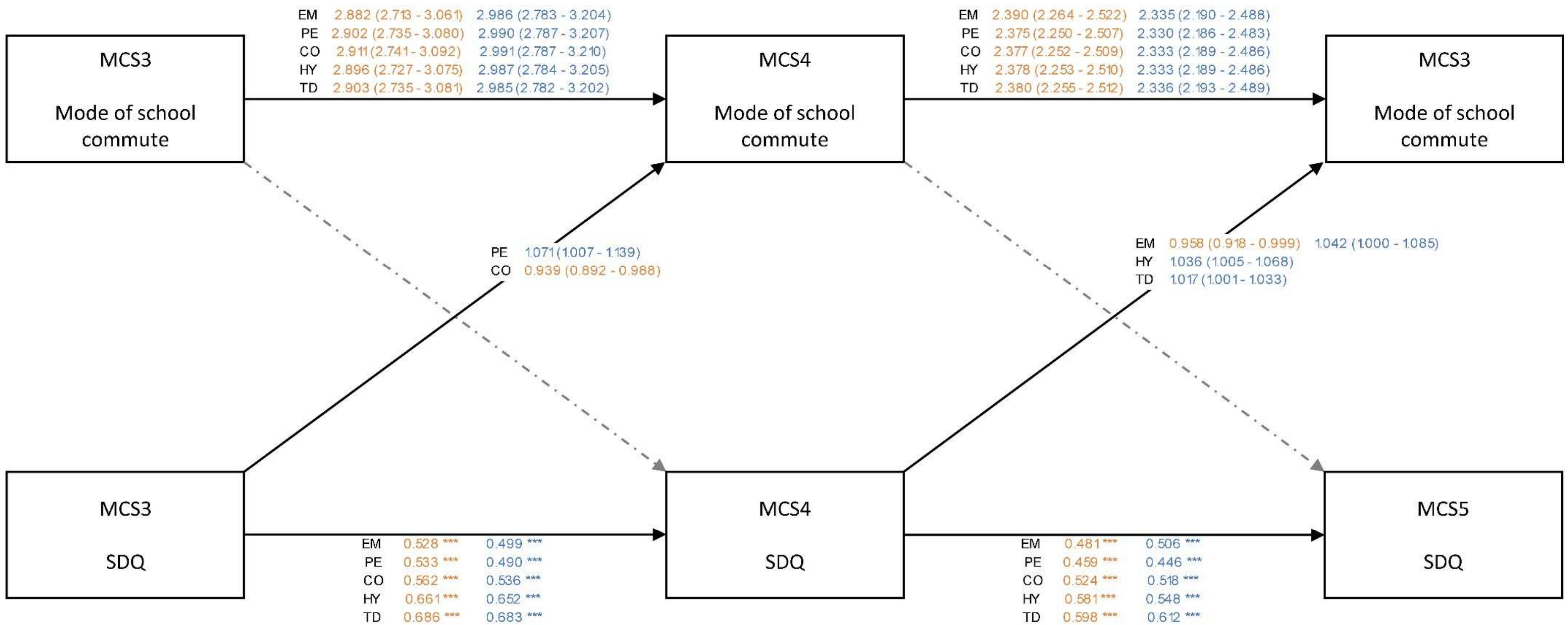
The significant estimates of the auto-regressive paths in all models show that for each additional point in SDQ score, there is an increase of approximately 0.5-0.7 points between Waves 1 and 2 and 0.4-0.6 points between Waves 2 and 3. Odds of actively commuting at Wave 2 for children who engage in more active commutes at Wave 1 are approximately three times that of children who are driven to school, and double between Waves 2 and 3.

For both boys and girls, mode of school commute at ages 5 and 7 have no effect on SDQ scores at ages 7 and 11, respectively.

For boys, each point increase in conduct problems at age 5, the odds of actively commuting both ways at age 7 versus the other modes of transport combined is 0.939 (95% CI 0.892, 0.988) times lower, given the other variables in the model are held constant. At age 7, each point increase in emotional problems results in 0.958 (95% CI 0.918, 0.999) lower odds of actively commuting at age 11.

For girls, more peer problems at age 5 increases the odds of actively commuting at age 7 (aOR 1.071, 95% CI 1.007, 1.139), given the other variables in the model are held constant. Odds of actively commuting at age 11 increase with greater emotional problems (aOR 1.042, 95% CI 1.000, 1.085), hyperactivity (aOR 1.036, 95% CI 1.005, 1.068), and total difficulties (aOR 1.017 95% CI 1.001, 1.033) at age 7.

Figure 5-3: Three-wave cross-lagged panel model estimating the relationship between mode of school commute and SDQ subscales



Unstandardised regression coefficients are presented where MCS is the outcome; significance levels: * p<0.05, ** p<0.01, ***p<0.001

Ordered logistic odds ratios and 95% confidence intervals in parentheses are presented where mode of school commute is the outcome

Orange = boys, blue = girls
EM = emotional problems, PE = peer problems, CO = conduct problems, HY = hyperactivity, TD = total difficulties
- · - · - ▶ indicates no significant estimates

Sports participation / exercise

The significant auto-regressive estimates show that for each additional point in SDQ score, there is an increase of approximately 0.5-0.7 points between Waves 1 and 2 and 0.4-0.6 points between Waves 2 and 3. Odds of more frequent sports participation at Wave 2 are 2.1 times higher for children who participate in sport at Wave 1 than children who never participate in sport, and 1.6-1.8 times between Waves 2 and 3.

For boys, each increase in sports and exercise frequency at age 5 was associated with a -0.087 ($p<0.001$) point decrease in emotional problems, -0.053 ($p=0.018$) point decrease in peer problems, and a -0.155 ($p=0.021$) point decrease in total difficulties at age 7. Higher frequency of sports and exercise in boys aged 7 was also associated with -0.057 ($p=0.025$) and -0.069 ($p=0.004$) point decreases in emotional and peer problems, respectively, at age 11.

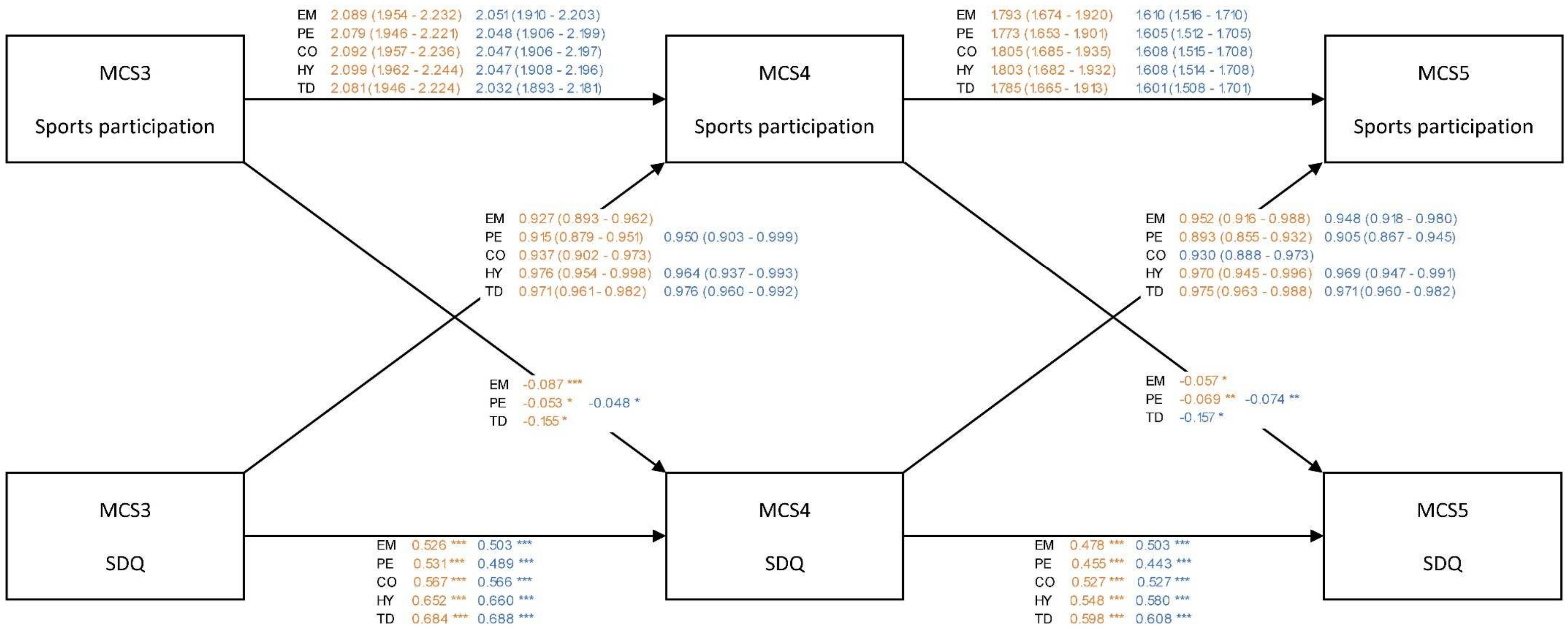
For each increase in sports and exercise frequency at age 5, girls' peer problems at age7 decreased by -0.048 ($p=0.025$) points. More frequent sports and exercise at age 7 was associated with fewer peer problems ($b=-0.074$, $p=0.001$) and total difficulties ($b=-0.157$, $p=0.010$) at age 11.

Boys who had higher scores in all SDQ domains age 5 had lower odds of sports participation at age 7. For each SDQ point increase at age 5 in boys, the odds of more frequent sports participation were lower at age 7 for emotional problems (aOR 0.927, 95% CI 0.893, 0.962), peer problems (aOR 0.915, 95% CI 0.879, 0.951), conduct problems (aOR 0.937, 95% CI 0.902, 0.973), hyperactivity (aOR 0.976, 95% CI 0.954, 0.998), and total difficulties (aOR 0.971, 95% CI 0.961, 0.982).

For each SDQ point increase at age 7 in boys, the odds of more frequent sports participation were lower at age 11 for emotional problems (aOR 0.952, 95% CI 0.916, 0.988), peer problems (aOR 0.893, 95% CI 0.855, 0.932), hyperactivity (aOR 0.970, 95% CI 0.945, 0.996), and total difficulties (aOR 0.975, 95% CI 0.963, 0.988). No association was observed for higher conduct problems at age 7 and sports/exercise frequency at age 11 in boys.

Girls with higher SDQ scores at age 5 had lower odds of more frequent sports and exercise at age 7 for peer problems (aOR 0.950, 95% 0.903, 0.999), hyperactivity (aOR 0.964, 95% 0.937, 0.993), and total difficulties (aOR 0.976, 95% 0.960, 0.992). At age 7, SDQ point increases resulted in lower odds of sports and exercise frequency at age 11 for emotional problems (aOR 0.948, 95% CI 0.918, 0.980), peer problems (aOR 0.905, 95% CI 0.867, 0.945), conduct problems (aOR 0.930, 95% CI 0.888, 0.973), hyperactivity (aOR 0.969, 95% CI 0.947, 0.991), and total difficulties (aOR 0.971, 95% CI 0.960, 0.982).

Figure 5-4: Three-wave cross-lagged panel model estimating the relationship between sports participation and SDQ subscales



Unstandardised regression coefficients are presented where SDQ is the outcome; significance levels: * p<0.05, ** p<0.01, ***p<0.001

Ordered logistic odds ratios and 95% confidence intervals in parentheses are presented where sports partcipation is the outcome

Orange = boys, blue = girls
EM = emotional problems, PE = peer problems, CO = conduct problems, HY = hyperactivity, TD = total difficulties

Television and videos

The significant estimates of the auto-regressive paths in all models suggest that for each additional point in SDQ score, there is an increase of approximately 0.5-0.7 points between Waves 1 and 2 and 0.4-0.6 points between Waves 2 and 3. Odds of decreasing the number of hours watching television at Wave 2 for children who watch TV less than 3 hours at Wave 1 are roughly three times that of children who watch more than 3 hours, and 2.3-2.5 times between Waves 2 and 3.

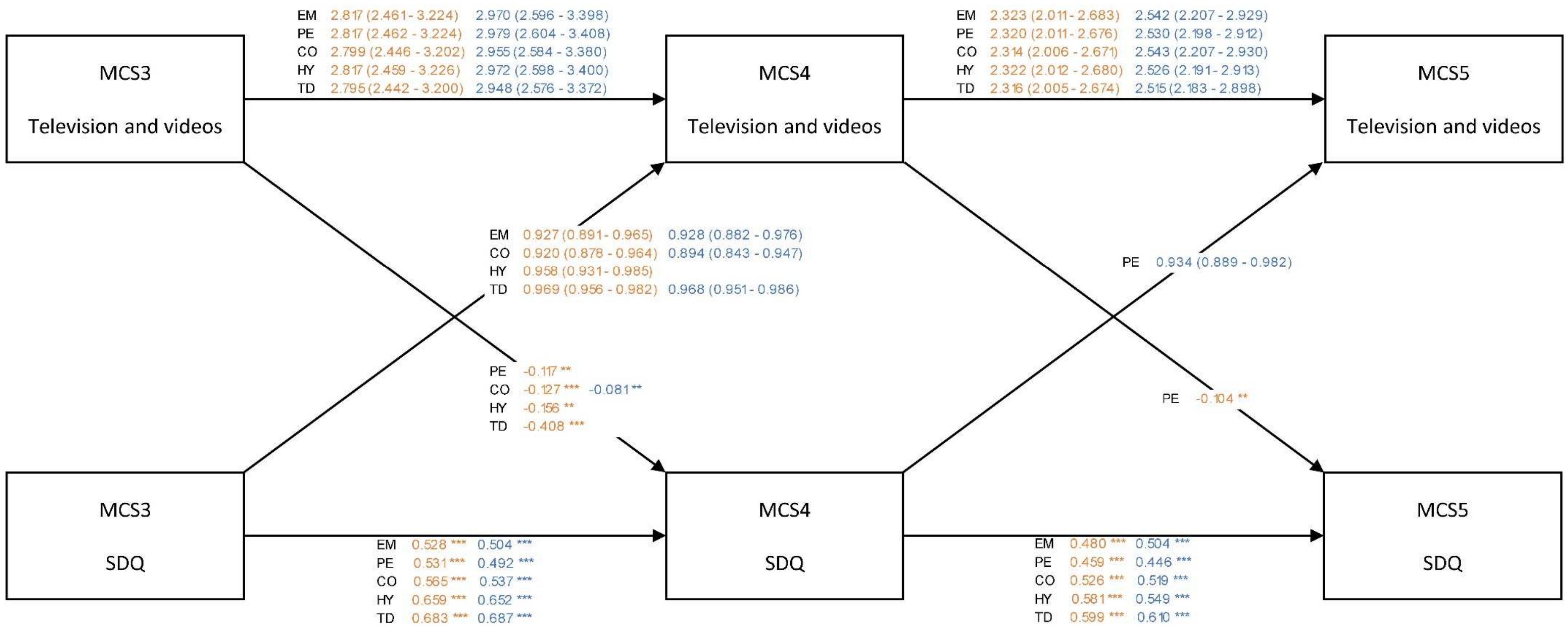
At age 5, boys who watched television less frequently had lower SDQ scores at age 7 in all domains, except emotional problems: -0.117 ($p=0.002$) points for peer problems, -0.127 ($p<0.001$) points for conduct problems, -0.156 ($p=0.001$) points for hyperactivity, and -0.408 ($p<0.001$) points for total difficulties. By age 11, only peer problems were associated with less television exposure at age 7 ($b=-0.104$, $p=0.006$).

In girls, decreases in number of hours of television at age 5 predicted lower conduct problems at age 7 only ($b=-0.081$, $p=0.004$). Television exposure at age 7 did not predict SDQ scores at age 11 in girls.

For boys, each point increase in SDQ scores at age 5 resulted in lower odds of less frequent television exposure for emotional problems (aOR 0.927, 95% CI 0.891, 0.965), conduct problems (aOR 0.920, 95% CI 0.878, 0.964), hyperactivity (aOR 0.958, 95% CI 0.931, 0.985), and total difficulties (aOR 0.969, 95% CI 0.956, 0.982). SDQ scores at age 7 did not predict television exposure at age 11.

For girls, greater emotional problems (aOR 0.928, 95% CI 0.882, 0.976), conduct problems (aOR 0.894, 95% CI 0.843, 0.947) and total difficulties (aOR 0.968, 95% CI 0.951, 0.986) at age 5 predicted lower odds of fewer hours of television at age 7. More peer problems at age 7 was associated with lower odds of less television exposure (aOR 0.934, 95% CI 0.889, 0.982).

Figure 5-5: Three-wave cross-lagged panel model estimating the relationship between television and video viewing and SDQ subscales



Unstandardised regression coefficients are presented where SDQ is the outcome; significance levels: * p<0.05, ** p<0.01, ***p<0.001

Ordered logistic odds ratios and 95% confidence intervals in parentheses are presented where television and video frequency is the outcome

Orange = boys, blue = girls
EM = emotional problems, PE = peer problems, CO = conduct problems, HY = hyperactivity, TD = total difficulties

Electronic games

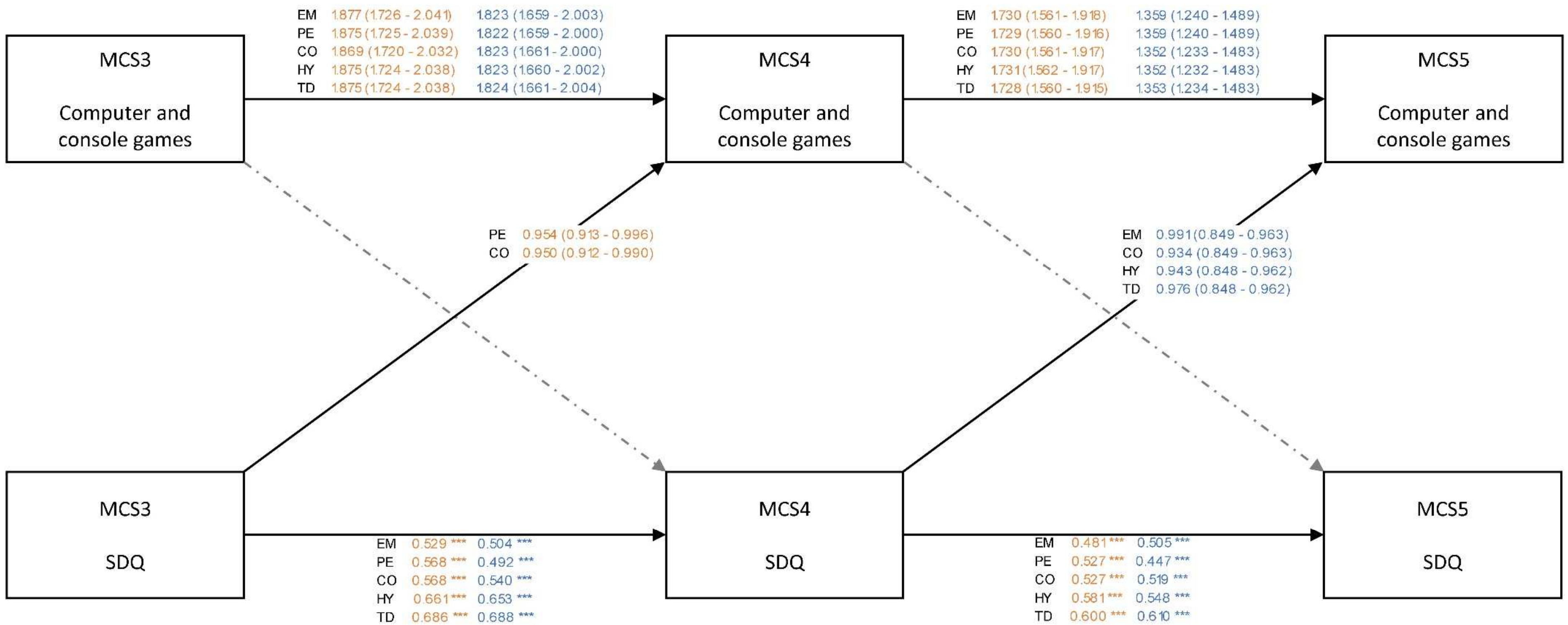
The significant auto-regressive estimates show that for each additional point in SDQ score, there is an increase of approximately 0.5-0.7 points between Waves 1 and 2 and 0.4-0.6 points between Waves 2 and 3. Odds of decreasing computer and console game time at Wave 2 for children who play games less than 3 hours at Wave 1 are roughly three times that of children who play more than 3 hours, and 2.3-2.5 times between Waves 2 and 3.

Number of hours playing electronic games at either age 5 or 7 was not predictive of mental health at subsequent waves, respectively, for boys nor girls.

For boys, more peer and conduct problems at age 5 was associated with lower odds of playing electronic games less frequently (respectively, aOR 0.954, 95% CI 0.913, 0.996 and aOR 0.950, 95% CI 0.912, 0.990). SDQ at age 7 did not predict electronic gaming at 11 in boys.

For girls, SDQ at age 5 did not predict electronic gaming at age 7; however, odds of less frequent gaming at age 11 were lower with greater emotional problems (aOR 0.991, 95% CI 0.849, 0.963), conduct problems (aOR 0.934, 95% CI 0.849, 0.963), hyperactivity (aOR 0.943, 95% CI 0.848, 0.962), and total difficulties (aOR 0.976, 95% CI 0.848, 0.962) at age 7.

Figure 5-6: Three-wave cross-lagged panel model estimating the relationship between computer and console games and SDQ subscales



Unstandardised regression coefficients are presented where MCS is the outcome; significance levels: * p<0.05, ** p<0.01, ***p<0.001

Ordered logistic odds ratios and 95% confidence intervals in parentheses are presented where computer and console gaming is the outcome

Orange = boys, blue = girls
EM = emotional problems, PE = peer problems, CO = conduct problems, HY = hyperactivity, TD = total difficulties
–·–·–▶ indicates no significant estimates

5.5 Discussion

5.5.1 Summary of results

In this chapter, the relationship between reported measures of PA/sedentary behaviour and SDQ were examined. I found that the benefit of greater activity was dependent on type, with active commuting having no effects, while sports participation was found to be beneficial for peer problems in both boys and girls, for emotional problems in boys, and for total difficulties in boys and girls but at different time points. Similarly, the disbenefits of sedentary behaviour were type specific: at age 5, electronic gaming was not found to predict any SDQ outcomes at age 7, while television was found to be harmful for peer problems, conduct problems, hyperactivity, and total difficulties in boys; only conduct problems were increased with more TV viewing in girls. However, only the relationship with TV viewing and peer problems persisted for boys at age 11. Table 5-7 below summarises the effects of reported activities on SDQ.

Table 5-7: Summary of lagged effects of reported activity at ages 5 and 7 and SDQ at ages 7 and 11

	Effect of activity at age 5 on SDQ at age 7				Effect of activity at age 7 on SDQ at age 11			
	Commute	Sport	TV	Electronic Games	Commute	Sport	TV	Electronic Games
Emotional problems		Boys				Boys		
Peer problems		Boys, Girls	Boys			Boys, Girls	Boys	
Conduct problems			Boys, Girls					
Hyperactivity			Boys					
Total difficulties		Boys	Boys			Girls		

A negative significant relationship (where more active behaviour/less sedentary behaviour is predictive of decreased SDQ scores) is denoted in orange for boys and blue for girls.

There was also evidence that SDQ scores at earlier sweeps were predictive of both active and sedentary behaviours at later sweeps. Boys with more conduct problems at age 5 were less likely to actively commute at age 7, while girls with more peer problems at age 5 were more likely to actively commute at age 7. Higher SDQ scores in all subscales at earlier sweeps was predictive of less sport participation at both ages 7 (MCS3-4) and 11 (MCS4-5); although, conduct problems were predictive of less sport in boys at MCS3-4 only, while for girls this was at MCS4-5. Emotional and conduct problems, and total difficulties predicted television viewing at MCS3-4 for both boys and girls; hyperactivity predicted TV viewing in boys only. None of these relationships persisted at MCS4-5; however, more peer problems at age 7 predicted more TV viewing at age 11 in girls. Gender differences were clearly seen for the effect of mental health on electronic games: peer and conduct problems were predictive of more electronic gaming at MCS3-4 in boys only; conduct problems, hyperactivity, and total difficulties were predictive of more frequent gaming at MCS4-5 in girls only.

Table 5-8 below summarises the effect of SDQ scores on reported activities.

Table 5-8: Summary of lagged effects of SDQ at ages 5 and 7 on reported activity at ages 7 and 11

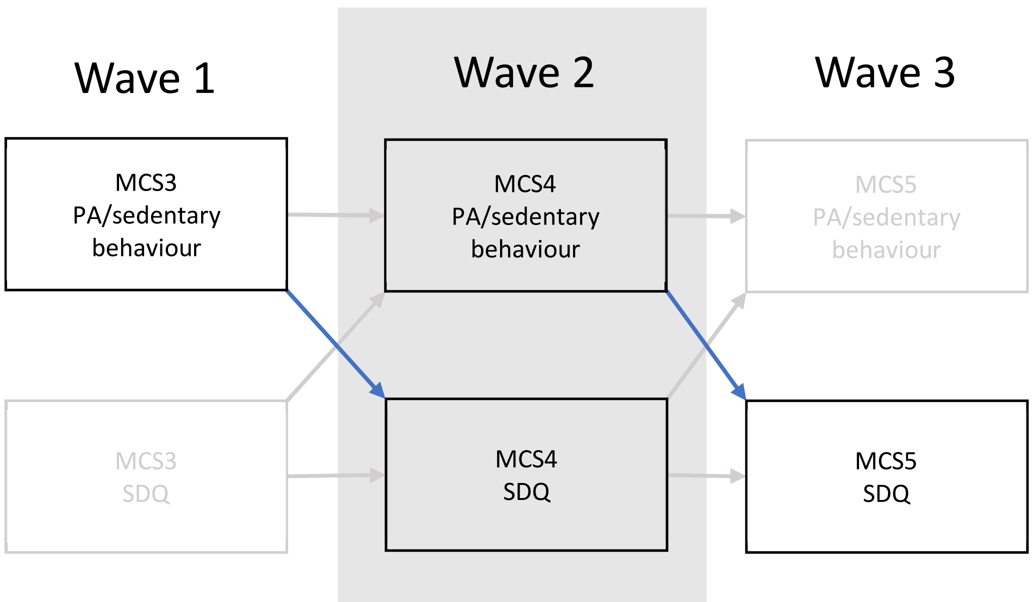
	Effect of SDQ at age 5 on activity at age 7				**Effect of SDQ at age 7 on activity at age 11**			
	Commute	Sport	TV	Electronic Games	Commute	Sport	TV	Electronic Games
Emotional problems		orange / blue	orange / blue		orange / blue +	orange / blue		
Peer problems	blue +	orange / blue		orange		orange / blue	blue	
Conduct problems	orange	orange	orange / blue	orange		blue		blue
Hyperactivity		orange / blue	orange		blue +	orange / blue		blue
Total difficulties		orange / blue	orange / blue		blue +	orange / blue		blue

A negative significant relationship (where higher SDQ scores are associated with less active/more sedentary behaviour) is denoted in orange for boys and blue for girls. The '+' sign indicates that an increase in SDQ problems is associated with greater activity/less sedentary behaviour.

5.5.2 The effect of PA/SB on mental health

This section will discuss the cross-lagged effects of active and sedentary behaviours at one wave on SDQ scores at the subsequent wave. Figure 5-7 below highlights the relationships in question.

Figure 5-7: Cross-lagged effect of active and sedentary behaviours on SDQ scores



Active commuting

The null effect of active commuting on SDQ scores was an unexpected finding, given that NICE guidance promotes active commuting as a means to improve well-being in children (National Institute for Health and Care Excellence, 2009, 2012). While there is evidence that active commuting improves mental health and well-being in adults (Abou-Zeid & Ben-Akiva, 2012; Martin, Goryakin, & Suhrcke, 2014; Office for National Statistics, 2014), the evidence is limited in young children (Hulley et al., 2008; Mann, Silver, & Stein, 2018; Sun, Liu, & Tao, 2015).

Studies have shown that distance is a strong predictor of active commuting in children (D'Haese, De Meester, De Bourdeaudhuij, Deforche, & Cardon, 2011; Garnham-Lee, Falconer, Sherar, & Taylor, 2017; Panter et al., 2013); however distance to school was only available at one sweep (MCS4). Actively commuting a given distance instead of passive commuting the same distance may impart mental health benefits: a study by Lambiase et al (2010) showed that actively commuting children exhibited lower stress responses than children who were driven (Lambiase, Barry, & Roemmich, 2010). Given that the uptake and maintenance of active commuting in children may be improved by commutes of reasonable distance (J. R. Panter, A. P. Jones, E. M. F. van Sluijs, & S. J. Griffin, 2010), distance might be an important factor that was absent from these analyses. Mental health benefits might only be derived after reaching a distance threshold (Hulley et al., 2008). Finally, environmental factors such as parental perceptions of safety, air pollution, and traffic, were found to be predictors of active commuting (Hume et al., 2009; Jenna R. Panter et al., 2010; Timperio et al., 2006). Taken together, the evidence suggests that a potential moderating effect of distance, and confounding or moderating effects of unmeasured environmental factors, could be why null results were observed for active commuting.

Sports/exercise

The finding that greater participation in club sports or exercise at an earlier wave was predictive of fewer peer problems at a subsequent wave in both boys and girls is broadly consistent with the literature (Dimech & Seiler, 2011; Eime et al., 2013; Findlay & Coplan, 2008). A study by Griffiths et al (2010) on MCS children additionally found that boys and girls aged 5 playing sport more frequently at had fewer emotional and externalising problems (conduct problems and hyperactivity) (L. J. Griffiths et al., 2010). Although this study was cross-sectional so the direction of causality cannot be inferred, other studies have hypothesised that high intensity activity can serve as an outlet for children to mitigate or alleviate externalising symptoms (Brodersen et al., 2005; McKune, Pautz, & Lombard, 2003). The absence of a predictive association between sports and externalising disorders could be more nuanced: a study on the effects of PA on ADHD showed that specific symptoms (inattention and hyperactivity) were more amenable to PA intervention than others (impulsivity), and perhaps these were not captured by the SDQ (Gapin & Etnier, 2014).

Improvements to emotional problems at both waves was found only for boys, which could be due to gendered attitudes towards sport and exercise: boys report greater interest and enjoyment in sports and high intensity activities than girls, and this positive perception of activity might potentially alleviate depressive symptoms (Cairney et al., 2012; Cardon et al., 2005; DeBate et al., 2009; Women in Sport, 2017).

Television

The cross-lagged models showed that multiple aspects mental health functioning, mostly in boys, was affected by television exposure, which is reported in other studies (Mark Hamer et al., 2009; Parkes, Sweeting, Wight, & Henderson, 2013). In a study by Vandewater et al (2006), greater television exposure was found to be associated with less time in active play, in creative play, and interacting with family members (Vandewater, Bickham, & Lee, 2006). In another study, higher television exposure predicted peer rejection, teasing, insult, and assault by other students (L. S. Pagani et al., 2010). These studies show that inadequate social development in the home, extending to decreased social interaction and play with peers may be driving the results observed for the effect of television time on peer problems. This does not, however, explain why the results for peer problems were only observed for boys in this thesis. In the studies mentioned, gender differences were not explored or were not a significant factor (L. S. Pagani et al., 2010; Vandewater et al., 2006). A study on adolescents in Spain observed that displacement effects of MVPA time with screen media time occurred in boys but not girls (Lizandra, Devís-Devís, Valencia-Peris, Tomás, & Peiró-Velert, 2018). If similar displacement effects were occurring in this sample, then the relationships observed in boys could be due to the absence of higher intensity PA, mirroring the relationships observed for boys and sports participation.

Violent programme content has been found to increase antisocial behaviours in children 6-12 year olds and decrease the amount of time spent with friends when not watching television (Bickham & Rich, 2006), while viewing non-violent programming was not associated with conduct problems nor peer problems in either boys or girls (Bickham & Rich, 2006; Christakis & Zimmerman, 2007). As programming content information is not available in the dataset, it could be that boys in the MCS are watching more violent content than girls between the ages of 5 to 7. A longitudinal study found that violent television programming was associated with subsequent aggressive behaviour in boys and not in girls (Christakis & Zimmerman, 2007). Thus, the content of TV programming could be an underlying confounder or moderator in these gender differences.

Electronic games

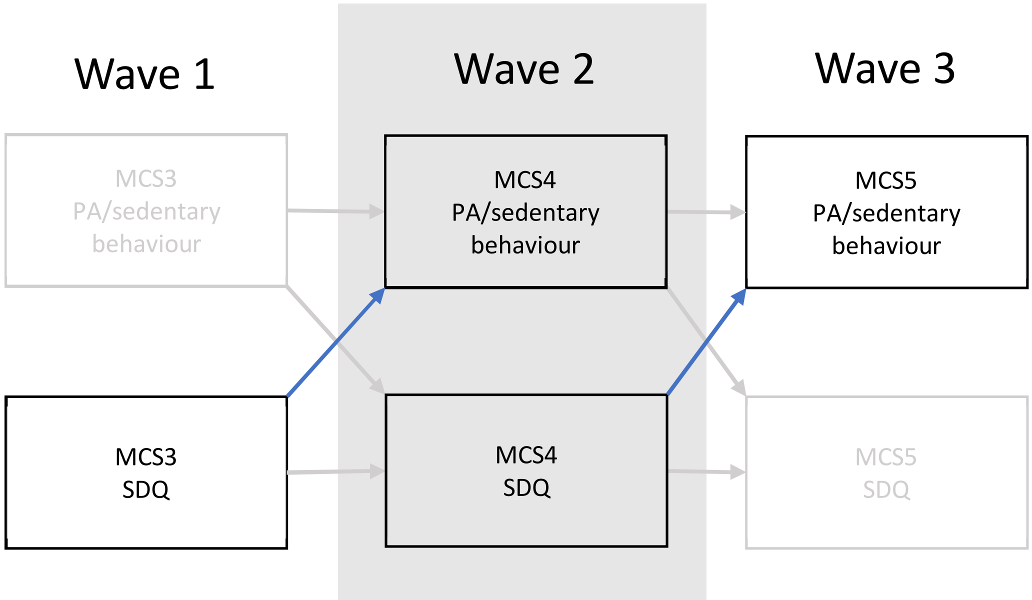
The results showed that electronic game playing time was not predictive of mental health at later time points in children. This is in line with a similar study using MCS data looking at the which found that electronic games use at age 5 was not associated with any SDQ scores in models adjusted for a comprehensive range of child and parental confounders (Parkes et al., 2013). The null results observed here might be because the content of the games played was unknown. Educational or creative content, non-violent, or physically active games might have positive influences on mental health (Gentile et al., 2009; Granic, Lobel, & Engels, 2014; M. Griffiths, 2004; Hammond, Jones, Hill, Green, & Male, 2014), which might cancel out any negative effects resulting from harmful game content. In addition to content, the context of the electronic gaming–games played with family or friends in person, or with friends online—can improve social interactions (Durkin & Barber, 2002; Granic et al., 2014)

A report by Ofcom (2011) found that, of children aged 5-7, 41% of parents had concerns about the content in electronic gaming compared with 56% at ages 12-15 (Ofcom, 2011). Concerns might be lower at younger ages because access to inappropriate content in electronic gaming might be more easily managed at younger ages due to online controls and age-restricted purchasing. The children examined in this study may be too young to have had excessive exposure to harmful content. However, the absence of association does not preclude potential harms to excessive exposure: in other studies, electronic games use in children, particularly where content was deemed violent, was associated with worse mental health and aggression (Browne & Hamilton-Giachritsis, 2005; Ferguson, 2015; M. Griffiths, 1999).

5.5.3 The effect of mental health on PA/SB

This section will focus on the cross-lagged effects of SDQ scores at one wave active and sedentary behaviours at the subsequent wave. Figure 5-8 below highlights the relationships in question.

Figure 5-8: Cross-lagged effect of SDQ scores on active and sedentary behaviours



Active commuting

How mental health might predict active commuting behaviours is difficult to contextualise as there are no studies to my knowledge that have investigated this relationship. The findings in these analyses are not consistent in direction: for boys, worse mental health appears to predict lower odds of active commuting, while for girls, the opposite appears true. Given that parental perception of route safety is a significant predictor of active commuting to school (Yeung, Wearing, & Hills, 2008), parents might wish to supervise more closely children with mental health issues by transporting them directly to and from school. Mediation via parental concerns for safety and trust might account for the observation that conduct problems and emotional problems predicted less active commuting in boys.

It has been suggested that biological maturation might be a factor in commuting behaviours, where children who are earlier maturing are more likely to actively commute than those who are late-maturing (Garnham-Lee et al., 2017). According to hypotheses on biological maturity and health behaviours, children who mature earlier might have psychosocial problems due to poorer body image, increased distress and anxiety from physical changes, and feeling different from their peer group, and that these problems disproportionately affect girls (L. B. Sherar, Cumming, Eisenmann, Baxter-Jones, & Malina, 2010). By age 11, 20% of girls in the MCS had begun puberty, compared with 5% of boys (L. J. Griffiths et al., 2016), thus, biological maturity could be confounding the association, where girls with early pubertal markers might be more likely to actively commute and have mental health disorders. Although normal puberty in girls can begin at eight years of age, information on pubertal status in the MCS is not available before age 11 so its effect cannot be measured. While these findings indicate that mental health can affect active commuting behaviours in children, they are not replicated in any supporting evidence and should be interpreted with caution.

Sports/exercise

Better mental health was predictive of sports participation in both boys and girls at Waves 2 and 3 with few exceptions, which is consistent with the evidence available. Peer influence and social relationships were found to be an important factors in children's involvement in sport in both cross-sectional and longitudinal studies (Dimech & Seiler, 2011; Eime et al., 2013; Findlay & Coplan, 2008; Howie, Lukacs, Pastor, Reuben, & Mendola, 2010; Ullrich-French & Smith, 2009). More conduct problems and hyperactivity symptoms were associated with less sports participation, which reflects the hypothesis that children with ADHD, conduct, and behavioural problems may have difficulty with structured sports, where failure to focus on strategy and rules, and acting impulsively or aggressively can disqualify participation (Johnson & Rosen, 2000; H. Lee, Dunn, & Holt, 2014).

While emotional problems at one time point were negatively predictive of future sports participation in this thesis, results are not comparable to existing evidence as it is predominantly cross-sectional or on older children (Boone & Leadbeater, 2006; Donaldson & Ronan, 2006; L. J. Griffiths et al., 2010; C. E. Sanders, Field, Diego, & Kaplan, 2000). To my knowledge, there are no longitudinal studies that specifically examine how emotional or depressive symptoms affect sports participation in young children.

Television and electronic games

There is considerable cross-sectional evidence that demonstrates a positive association between mental health disorder and screen time exposure, however, no studies look specifically at whether poor mental health predicts increased time engaged in reported sedentary screen behaviours. Studies have hypothesised that television watching is motivated by a number of factors including habit, entertainment, stimulation, passing time, learning, social learning, escape, companionship, and relaxation (A. M. Rubin, 1979; Tiggemann, 2005). It is plausible that these factors could be underlying the observed associations. Children with emotional difficulties might use television as an escape from feeling of anxiety, worry, or depression. Furthermore, parents could manage symptoms of mental health disorder through screen entertainment (Canadian Paediatric Society, 2017; Courage & Howe, 2010), which might be why SDQ scores predict viewing time in this study. Screen time might be used to placate or reward a distressed child, leading to screen media dependence, which could hinder a child's social functioning and development (Domoff et al., 2019).

A study on gender differences in electronic game play highlighted that many games are targeted to males and that the gaming environment is male-dominated (Greenberg, Sherry, Lachlan, Lucas, & Holmstrom, 2008). It could be that mental health is not as strong a predictor of game playing in boys compared with girls because greater lengths of game time are normalised for boys, and game time resulting from mental health issues might be obscured. More peer problems at age 5 does predict increased gaming at age 7 in boys, which might be driven by the motivation for social interaction through gaming (Greenberg et al., 2008).

5.5.4 The timing of the observed relationships: evidence for sensitive periods

The timing of the effects of SDQ and screen time behaviours appeared to be important for both boys and girls. In boys, exposure to increased television at age 5 had detrimental effects on all SDQ subscales at age 7 except emotional problems, whereas harmful effects were only observed for peer problems at age 11. This indicates that boys are potentially more sensitive to prolonged television exposure at younger ages. Other studies have reported similar results: television exposure in children 29 months of age was more strongly predictive of age 10 developmental risks than exposure at 53 months (L. S. Pagani et al., 2010), while television viewing in 2-5 year olds was associated with antisocial behaviour in children aged 7-10 (Christakis & Zimmerman, 2007). Overexposure to television affects development in very young children: spatial, cognitive, and social development all show signs of impairment with excessive television (Lin et al., 2015), and these could underlie the psychological harms observed. Similarly, a longitudinal study by Mistry et al (2007) found that early exposure was predictive of behavioural problems and emotional reactivity, sustained exposure was more harmful for attention problems and aggressive externalising behaviour, and concurrent exposure more harmful for social skills (Mistry et al., 2007), indicating that both timing and persistence of the behaviour are important factors. Reciprocally, worse mental health at age 5 was more strongly predictive of television watching in children at age 7 than in the subsequent wave, indicating that younger children are potentially at greater risk of television exposure to manage mental health symptoms. Similarly, worse mental health at age 5 in boys and age 7 in girls predicted increased electronic gaming at the subsequent sweep. Understanding the motivators behind electronic gaming, and how these differ by gender, might clarify the mechanisms behind the timing of these relationships to mental health.

5.5.5 Strengths and limitations

This chapter represents a unique contribution to the study of the relationship between active and sedentary behaviours and mental health in children in a number of ways. I used cross-lagged models and data from three time points to build evidence for causation. This demonstrated the reciprocal predictive effects of activity behaviours and mental health, and highlighted the importance of timing. By identifying the potential of sports participation as a means of improving mental health in children, this study has strengthened the evidence base for policy development, particularly in campaigns targeting girls (Girls Active, This Girl Can).

This study also highlighted that mental health problems can, reciprocally, increase sedentary screen behaviours. Cross-sectional evidence has shown a relationship between mental health and screen time, and a study using MCS data demonstrated that higher SDQ scores at age 5 predicted decreased sedentary time (L. Griffiths et al., 2016), however, no studies to my knowledge have explored this direction of association using reported measures over three measurement points. A greater understanding of when these effects might be stronger and possible gender differences will help target interventions to modify potentially harmful behaviours resulting from mental health problems.

While the cross-lagged models have shown evidence for reciprocal effects, due to the statistical methods used and the corresponding output (ordered logistic odds ratios to predict activity and linear regression coefficients to predict SDQ scores), it cannot be determined which predictive effect is stronger.

Another limitation is that this study analysed the independent effect of each single-item reported PA and sedentary behaviours, which have not been validated. A systematic review on reported screen time measures found that single-item reported measures can lack content validity and are subject to measurement error and possible social desirability bias, however, the value of their use in epidemiological studies was recognised (M. J. Bryant, Lucove, Evenson, & Marshall, 2007). Other studies have reported the validity of self-reported PA measures in children (Stuart JH Biddle et al., 2011; Hardie Murphy, Rowe, Belton, & Woods, 2015; J. F. Sallis, Buono, Roby, Micale, & Nelson, 1993), however, no studies to my knowledge have used validated single-item, reported measures of parent-reported PA, thus, comparisons cannot be made.

By analysing the types of sedentary screen time separately, some associations might have been missed: one study found that a summative measure of both screen behaviours increased SDQ scores in children aged 5 (L. J. Griffiths et al., 2010) and another found an association between screen use and depressive symptoms (Kremer et al., 2014). However, as screen-based technologies become more widely used for increasingly diverse applications, it may be essential to differentiate between screen time behaviours to determine their effects. While not without limitations, the exploration of these measures independently has highlighted that these screen behaviours are not equivalent and that specifying the type and content of the activity will help elucidate potential mechanisms in future work.

Effect sizes were small, thus, the clinical significance of modifying activity behaviours may be questionable. However, the relationship and effect sizes may change in study participants' adolescent data, so it is important to monitor changes to recognise at what point problems might begin.

5.5.6 Future directions

Given the differences observed between the effects of TV and electronic games on mental health in children (with the latter having no effect), further research examining the effect of screen time should ensure that measures account for the different constructs. While monitoring viewing content is challenging, 50-66% of young children and adolescents do not have restrictions around media content (Council on Communications and Media, 2013; Ofcom, 2014). The evidence demonstrates that content and context might moderate the association between both TV and electronic games (Bickham & Rich, 2006; Christakis & Zimmerman, 2007; Durkin & Barber, 2002; Gentile et al., 2009; Granic et al., 2014; M. Griffiths, 1999; Hammond et al., 2014). Future studies should seek to understand how these factors, rather than the medium itself, might impact mental health.

Australian and Canadian health guidelines recommend less than two hours of screen time in children (Canadian Paediatric Society, 2017; Department of Health, 2017); however, no such guideline has been established in the UK. A recent report by the Royal College of Paediatrics and Child Health opposed the view that screen time is harmful, pointing to the mediating effects of decreased exercise, sleep, and social interaction, among others, and concluded that the technological landscape changes too rapidly to recommend any guidance (Viner et al., 2019). There is a definite need for studies to explore these potential mediating effects on the relationship between screen time and mental health to help define a robust national guideline, targeting areas of greatest potential harm. An established guideline would additionally allow evaluation of health outcomes in children meeting guidelines in future epidemiological studies.

Future research should expand upon the findings here regarding the benefits of sport participation on mental health by incorporating information on motivators and barriers to sport. In young children, parental and wider family involvement or support in active behaviours may influence both the levels of and attitudes towards activity in children as well as their mental health effects (Eriksson, Nordqvist, & Rasmussen, 2008; Trost et al., 2003). Additionally, an exploration of how attitudes and perceptions of motivators and barriers to sport differ for boys and girls might help clarify the mechanisms through which sport operates on different aspects of mental health functioning.

In these analyses, only screen time measures were used for sedentary behaviour, but other activities such as reading and studying may impact mental health differently. In the MCS, there were data on reading but at ages 5 and 7, the question focused on the parent reading to the child, and at age 11 the question asked how often the child read for enjoyment. As this reading item lacked consistency across sweeps, the effect of reading on mental health was not explored, but future studies should measure this and other non-screen time sedentary behaviours to explore their relationship to mental health.

Although active commuting was not found to be predictive of SDQ scores in these analyses, the limitations of the measure may have affected results. Factors such as distance of commute, perceptions of safety, and parental commuting behaviours and support were absent but could capture important aspects of active commuting obscured in the single measure used in these analyses, and future studies should consider these. Furthermore, any relationship between active commuting and effects on mental health may change for older children. At the time of the MCS interviews at age 11, 94% of the children were still in primary school, with 4% at secondary school and 2% at middle school (data not shown). Of the children in secondary school, 23% took public transport or school bus and 24% are driven to school, compared to, respectively, 7% and 35% in the complete sample. Changes in biological maturity might also contribute to changing commuting patterns. The relationship between active commuting and mental health outcomes might undergo change in this transitional period and warrants further investigation through adolescence.

While the focus of this thesis was primarily to investigate the effect of PA and sedentary behaviour on mental health, the results from this chapter have shown that there is strong evidence for reverse causality and reciprocity. To my knowledge, no studies have examined the impact of mental health on specific types of active and sedentary behaviours. Additional work needs to be carried out to confirm the conclusions from this chapter, particularly on the effects of poor mental health on reduced sports involvement and increased TV viewing. Understanding the cycle of poor mental health and inactivity will help better inform policy and interventions that consider both the inactivity as well as the potential cause of inactivity.

Appendix D

I. Relationship between mode of school commute and SDQ, MCS3-5

Table 5-9: Weighted mean SDQ scores and 95% confidence intervals by mode of school commute at MCS3

MCS3	Car or other vehicle	Mixed transport	Active one way	Active both ways
Boys				
Emotional problems	1.27 (1.17,1.37)	1.39 (1.16,1.61)	1.2 (0.99,1.40)	1.44 (1.37,1.52)
Peer problems	1.09 (1.03,1.16)	1.47 (1.21,1.73)	1.12 (0.92,1.33)	1.33 (1.26,1.40)
Conduct problems	1.47 (1.39,1.56)	1.95 (1.68,2.22)	1.56 (1.38,1.75)	1.84 (1.76,1.92)
Hyperactivity	3.45 (3.32,3.59)	4.01 (3.62,4.39)	3.75 (3.45,4.04)	3.78 (3.65,3.90)
Total difficulties	7.27 (6.96,7.58)	8.84 (7.97,9.72)	7.6 (7.01,8.19)	8.37 (8.11,8.63)
Girls				
Emotional problems	1.3 (1.23,1.37)	1.73 (1.44,2.02)	1.44 (1.22,1.67)	1.52 (1.43,1.60)
Peer problems	0.91 (0.84,0.97)	1.31 (1.06,1.57)	1.02 (0.81,1.22)	1.13 (1.06,1.20)
Conduct problems	1.22 (1.15,1.28)	1.65 (1.41,1.89)	1.54 (1.29,1.80)	1.46 (1.39,1.53)
Hyperactivity	2.81 (2.68,2.94)	2.97 (2.64,3.31)	3.03 (2.72,3.34)	3.11 (3.00,3.23)
Total difficulties	6.21 (5.97,6.46)	7.61 (6.76,8.47)	7.02 (6.27,7.76)	7.21 (6.96,7.46)

Table 5-10: Weighted mean SDQ scores and 95% confidence intervals by mode of school commute at MCS4

MCS4	Car or other vehicle	Mixed transport	Active one way	Active both ways
Boys				
Emotional problems	1.43 (1.34,1.52)	1.53 (1.27,1.79)	1.42 (1.21,1.63)	1.67 (1.57,1.76)
Peer problems	1.32 (1.24,1.41)	1.61 (1.29,1.94)	1.28 (1.08,1.48)	1.38 (1.29,1.47)
Conduct problems	1.44 (1.36,1.52)	1.88 (1.59,2.18)	1.54 (1.30,1.77)	1.68 (1.60,1.75)
Hyperactivity	3.69 (3.56,3.83)	4.18 (3.79,4.57)	3.74 (3.40,4.08)	3.91 (3.77,4.04)
Total difficulties	7.87 (7.57,8.18)	9.2 (8.16,10.23)	7.91 (7.20,8.63)	8.58 (8.28,8.88)
Girls				
Emotional problems	1.5 (1.42,1.59)	1.43 (1.23,1.62)	1.53 (1.30,1.75)	1.66 (1.58,1.75)
Peer problems	1 (0.93,1.07)	1.13 (0.93,1.32)	1.03 (0.84,1.21)	1.23 (1.17,1.30)
Conduct problems	1.16 (1.09,1.23)	1.37 (1.13,1.60)	1.29 (1.10,1.49)	1.29 (1.22,1.36)
Hyperactivity	2.79 (2.66,2.91)	3.06 (2.71,3.42)	2.79 (2.53,3.04)	3.05 (2.93,3.16)
Total difficulties	6.42 (6.17,6.67)	6.96 (6.25,7.66)	6.61 (6.01,7.21)	7.2 (6.96,7.44)

Table 5-11: Weighted mean SDQ scores and 95% confidence intervals by mode of school commute at MCS5

MCS5	Car or other vehicle	Mixed transport	Active one way	Active both ways
Boys				
Emotional problems	1.84 (1.73,1.95)	1.88 (1.65,2.11)	1.62 (1.41,1.83)	1.83 (1.73,1.93)
Peer problems	1.48 (1.38,1.59)	1.69 (1.45,1.93)	1.32 (1.11,1.53)	1.51 (1.42,1.59)
Conduct problems	1.43 (1.34,1.52)	1.79 (1.60,1.99)	1.37 (1.08,1.65)	1.71 (1.61,1.80)
Hyperactivity	3.46 (3.31,3.61)	4.04 (3.76,4.32)	3.3 (3.01,3.58)	3.7 (3.57,3.83)
Total difficulties	8.19 (7.83,8.55)	9.37 (8.67,10.06)	7.61 (6.82,8.40)	8.76 (8.42,9.11)
Girls				
Emotional problems	1.93 (1.81,2.04)	1.97 (1.73,2.21)	2.15 (1.86,2.44)	1.97 (1.87,2.07)
Peer problems	1.16 (1.06,1.25)	1.38 (1.19,1.57)	1.38 (1.17,1.60)	1.33 (1.25,1.41)
Conduct problems	1.13 (1.05,1.21)	1.3 (1.12,1.47)	1.5 (1.23,1.77)	1.34 (1.27,1.40)
Hyperactivity	2.47 (2.34,2.61)	2.8 (2.50,3.10)	2.82 (2.54,3.09)	2.82 (2.72,2.93)
Total difficulties	6.67 (6.32,7.02)	7.4 (6.68,8.11)	7.85 (7.09,8.61)	7.46 (7.20,7.72)

II. Relationship between sports participation and SDQ, MCS3-5

Table 5-12: Weighted mean SDQ scores and 95% confidence intervals by sports participation at MCS3

MCS3	*<1 day or none*	*1 day*	*2 days*	*3+ days*
Boys				
Emotional problems	1.56 (1.47,1.64)	1.24 (1.16,1.32)	1.16 (1.04,1.29)	0.97 (0.84,1.11)
Peer problems	1.5 (1.43,1.57)	1.07 (0.99,1.15)	0.92 (0.82,1.03)	0.82 (0.67,0.97)
Conduct problems	1.95 (1.87,2.03)	1.51 (1.43,1.60)	1.40 (1.27,1.53)	1.37 (1.21,1.52)
Hyperactivity	3.97 (3.84,4.10)	3.50 (3.35,3.64)	3.30 (3.10,3.49)	3.09 (2.84,3.34)
Total difficulties	8.95 (8.67,9.22)	7.31 (7.03,7.59)	6.79 (6.36,7.21)	6.25 (5.75,6.75)
Girls				
Emotional problems	1.75 (1.65,1.85)	1.29 (1.20,1.38)	1.11 (1.01,1.20)	1.08 (0.98,1.19)
Peer problems	1.32 (1.24,1.40)	0.94 (0.86,1.02)	0.77 (0.69,0.85)	0.68 (0.60,0.77)
Conduct problems	1.67 (1.58,1.76)	1.28 (1.20,1.35)	1.04 (0.96,1.11)	1.02 (0.91,1.14)
Hyperactivity	3.45 (3.32,3.57)	2.83 (2.69,2.97)	2.43 (2.27,2.58)	2.43 (2.26,2.60)
Total difficulties	8.17 (7.87,8.47)	6.34 (6.07,6.61)	5.33 (5.04,5.61)	5.22 (4.88,5.55)

Table 5-13: Weighted mean SDQ scores and 95% confidence intervals by sports participation at MCS4

MCS4	*<1 day or none*	*1 day*	*2 days*	*3+ days*
Boys				
Emotional problems	2.06 (1.93,2.19)	1.57 (1.46,1.69)	1.24 (1.14,1.35)	1.1 (1.01,1.19)
Peer problems	1.9 (1.78,2.01)	1.35 (1.24,1.46)	1.08 (0.99,1.18)	0.89 (0.79,0.98)
Conduct problems	2.06 (1.94,2.19)	1.54 (1.44,1.64)	1.33 (1.23,1.43)	1.25 (1.15,1.34)
Hyperactivity	4.4 (4.24,4.57)	3.88 (3.74,4.03)	3.46 (3.29,3.62)	3.35 (3.21,3.50)
Total difficulties	10.38 (10.01,10.75)	8.28 (7.94,8.63)	7.11 (6.77,7.46)	6.57 (6.26,6.88)
Girls				
Emotional problems	1.86 (1.75,1.97)	1.55 (1.45,1.66)	1.47 (1.35,1.59)	1.29 (1.19,1.39)
Peer problems	1.41 (1.31,1.51)	1.13 (1.04,1.21)	0.99 (0.89,1.10)	0.79 (0.70,0.87)
Conduct problems	1.5 (1.41,1.60)	1.26 (1.18,1.34)	1.09 (1.00,1.18)	0.96 (0.86,1.05)
Hyperactivity	3.39 (3.22,3.56)	2.95 (2.81,3.08)	2.63 (2.47,2.80)	2.47 (2.31,2.63)
Total difficulties	8.09 (7.73,8.45)	6.88 (6.60,7.15)	6.17 (5.81,6.54)	5.5 (5.17,5.83)

Table 5-14: Weighted mean SDQ scores and 95% confidence intervals by sports participation at MCS5

MCS5	*<1 day or none*	*1 day*	*2 days*	*3+ days*
Boys				
Emotional problems	2.36 (2.22,2.50)	2.03 (1.88,2.18)	1.72 (1.55,1.90)	1.43 (1.34,1.52)
Peer problems	2.16 (2.02,2.29)	1.77 (1.63,1.91)	1.44 (1.30,1.58)	0.96 (0.88,1.04)
Conduct problems	1.97 (1.82,2.11)	1.76 (1.62,1.89)	1.58 (1.42,1.74)	1.28 (1.19,1.37)
Hyperactivity	4.2 (4.00,4.41)	3.88 (3.69,4.06)	3.48 (3.26,3.71)	3.18 (3.04,3.32)
Total difficulties	10.66 (10.17,11.15)	9.44 (8.97,9.91)	8.22 (7.60,8.84)	6.86 (6.55,7.17)
Girls				
Emotional problems	2.41 (2.26,2.57)	2.11 (1.96,2.26)	1.74 (1.61,1.88)	1.57 (1.48,1.67)
Peer problems	1.64 (1.52,1.75)	1.43 (1.32,1.54)	1.05 (0.96,1.13)	0.97 (0.90,1.05)
Conduct problems	1.53 (1.44,1.63)	1.33 (1.22,1.44)	1.16 (1.06,1.25)	1.05 (0.98,1.12)
Hyperactivity	3.16 (3.03,3.30)	2.76 (2.61,2.92)	2.5 (2.35,2.66)	2.33 (2.20,2.46)
Total difficulties	8.74 (8.35,9.12)	7.62 (7.23,8.01)	6.45 (6.11,6.79)	5.93 (5.65,6.21)

III. Relationship between television and SDQ, MCS3-5

Table 5-15: Weighted mean SDQ scores and 95% confidence intervals by television at MCS3

MCS3	3+ hours	1 hour to <3 hours	<1 hour or none
Boys			
Emotional problems	1.62 (1.47,1.78)	1.34 (1.27,1.41)	1.26 (1.16,1.37)
Peer problems	1.59 (1.45,1.72)	1.21 (1.15,1.27)	1.09 (0.98,1.20)
Conduct problems	2.09 (1.93,2.24)	1.65 (1.58,1.72)	1.57 (1.46,1.69)
Hyperactivity	4.18 (3.97,4.39)	3.6 (3.50,3.70)	3.52 (3.35,3.70)
Total difficulties	9.41 (8.92,9.91)	7.78 (7.56,8.01)	7.45 (7.05,7.84)
Girls			
Emotional problems	1.75 (1.60,1.91)	1.39 (1.32,1.46)	1.37 (1.26,1.47)
Peer problems	1.31 (1.17,1.44)	1.01 (0.96,1.07)	0.98 (0.87,1.08)
Conduct problems	1.67 (1.51,1.83)	1.36 (1.30,1.42)	1.24 (1.15,1.32)
Hyperactivity	3.35 (3.14,3.55)	3.01 (2.91,3.11)	2.67 (2.51,2.82)
Total difficulties	8.05 (7.53,8.58)	6.76 (6.55,6.98)	6.23 (5.90,6.56)

Table 5-16: Weighted mean SDQ scores and 95% confidence intervals by television at MCS4

MCS4	3+ hours	1 hour to <3 hours	<1 hour or none
Boys			
Emotional problems	1.95 (1.78,2.11)	1.51 (1.43,1.59)	1.38 (1.24,1.51)
Peer problems	1.65 (1.50,1.80)	1.33 (1.26,1.41)	1.23 (1.12,1.34)
Conduct problems	1.87 (1.72,2.02)	1.58 (1.51,1.66)	1.41 (1.29,1.53)
Hyperactivity	4.39 (4.20,4.59)	3.79 (3.69,3.89)	3.53 (3.32,3.74)
Total difficulties	9.84 (9.35,10.33)	8.18 (7.92,8.43)	7.53 (7.10,7.96)
Girls			
Emotional problems	1.86 (1.68,2.04)	1.57 (1.49,1.64)	1.43 (1.31,1.54)
Peer problems	1.4 (1.26,1.54)	1.11 (1.05,1.17)	0.96 (0.87,1.05)
Conduct problems	1.58 (1.42,1.74)	1.22 (1.16,1.27)	1.09 (1.00,1.19)
Hyperactivity	3.4 (3.19,3.61)	2.95 (2.85,3.04)	2.54 (2.36,2.71)
Total difficulties	8.2 (7.69,8.70)	6.8 (6.60,7.01)	6.02 (5.66,6.39)

Table 5-17: Weighted mean SDQ scores and 95% confidence intervals by television at MCS5

MCS5	3+ hours	1 hour to <3 hours	<1 hour or none
Boys			
Emotional problems	2.24 (1.99,2.49)	1.77 (1.70,1.85)	1.65 (1.51,1.78)
Peer problems	1.88 (1.70,2.06)	1.46 (1.38,1.53)	1.35 (1.21,1.48)
Conduct problems	1.94 (1.75,2.13)	1.56 (1.48,1.63)	1.45 (1.33,1.56)
Hyperactivity	4.05 (3.78,4.31)	3.56 (3.45,3.66)	3.51 (3.31,3.71)
Total difficulties	10.1 (9.36,10.84)	8.35 (8.09,8.60)	7.93 (7.46,8.39)
Girls			
Emotional problems	2.33 (2.14,2.53)	1.91 (1.81,2.00)	1.83 (1.68,1.98)
Peer problems	1.59 (1.42,1.75)	1.23 (1.17,1.30)	1.16 (1.02,1.29)
Conduct problems	1.55 (1.41,1.69)	1.24 (1.17,1.30)	1.12 (1.01,1.23)
Hyperactivity	3.19 (3.00,3.39)	2.62 (2.53,2.72)	2.47 (2.27,2.67)
Total difficulties	8.64 (8.10,9.19)	6.99 (6.74,7.25)	6.56 (6.09,7.03)

IV. Relationship between electronic games and SDQ, MCS3-5

Table 5-18: Weighted mean SDQ scores and 95% confidence intervals by electronic games at MCS3

MCS3	*3+ hours*	*1 hour to <3 hours*	*<1 hour*	*none*
Boys				
Emotional problems	1.55 (1.27,1.83)	1.39 (1.28,1.50)	1.29 (1.20,1.38)	1.45 (1.35,1.54)
Peer problems	1.87 (1.54,2.20)	1.30 (1.19,1.40)	1.10 (1.02,1.17)	1.35 (1.25,1.45)
Conduct problems	2.01 (1.69,2.33)	1.91 (1.80,2.02)	1.57 (1.48,1.65)	1.70 (1.60,1.80)
Hyperactivity	4.12 (3.55,4.69)	3.82 (3.64,4.01)	3.42 (3.30,3.53)	3.89 (3.73,4.06)
Total difficulties	9.47 (8.28,10.67)	8.40 (8.01,8.80)	7.36 (7.08,7.64)	8.36 (7.99,8.73)
Girls				
Emotional problems	1.68 (1.28,2.08)	1.4 (1.26,1.53)	1.31 (1.24,1.39)	1.60 (1.51,1.69)
Peer problems	1.39 (1.05,1.73)	1.15 (1.03,1.27)	0.95 (0.88,1.02)	1.10 (1.02,1.18)
Conduct problems	1.61 (1.24,1.98)	1.46 (1.34,1.58)	1.25 (1.18,1.31)	1.50 (1.40,1.60)
Hyperactivity	3.17 (2.73,3.62)	3.08 (2.91,3.25)	2.81 (2.70,2.93)	3.14 (2.99,3.30)
Total difficulties	7.85 (6.79,8.92)	7.08 (6.70,7.46)	6.31 (6.06,6.56)	7.32 (6.99,7.65)

Table 5-19: Weighted mean SDQ scores and 95% confidence intervals by electronic games at MCS4

MCS5	*3+ hours*	*1 hour to <3 hours*	*<1 hour*	*none*
Boys				
Emotional problems	2.11 (1.84,2.39)	1.54 (1.44,1.64)	1.42 (1.34,1.50)	1.91 (1.68,2.13)
Peer problems	1.86 (1.58,2.13)	1.35 (1.26,1.44)	1.23 (1.16,1.30)	1.76 (1.58,1.95)
Conduct problems	1.99 (1.77,2.22)	1.67 (1.57,1.78)	1.43 (1.35,1.51)	1.87 (1.70,2.04)
Hyperactivity	4.29 (3.96,4.62)	3.90 (3.76,4.04)	3.69 (3.57,3.81)	4.09 (3.78,4.40)
Total difficulties	10.25 (9.45,11.05)	8.45 (8.12,8.78)	7.74 (7.46,8.02)	9.48 (8.80,10.15)
Girls				
Emotional problems	1.81 (1.40,2.23)	1.63 (1.52,1.74)	1.49 (1.42,1.56)	1.84 (1.67,2.01)
Peer problems	1.58 (1.23,1.93)	1.14 (1.05,1.22)	1.05 (0.99,1.11)	1.33 (1.19,1.48)
Conduct problems	1.59 (1.27,1.90)	1.35 (1.26,1.44)	1.15 (1.09,1.21)	1.39 (1.24,1.54)
Hyperactivity	3.46 (3.00,3.91)	3.08 (2.91,3.25)	2.81 (2.71,2.91)	3.04 (2.80,3.28)
Total difficulties	8.43 (7.20,9.65)	7.13 (6.80,7.46)	6.48 (6.27,6.69)	7.58 (7.01,8.14)

Table 5-20: Weighted mean SDQ scores and 95% confidence intervals by electronic games at MCS5

MCS5	*3+ hours*	*1 hour to <3 hours*	*<1 hour*	*none*
Boys				
Emotional problems	2.24 (2.01,2.48)	1.90 (1.80,1.99)	1.61 (1.52,1.71)	1.74 (1.54,1.94)
Peer problems	1.98 (1.75,2.20)	1.52 (1.44,1.60)	1.29 (1.20,1.38)	1.66 (1.39,1.93)
Conduct problems	1.85 (1.65,2.06)	1.65 (1.57,1.73)	1.43 (1.34,1.52)	1.60 (1.37,1.83)
Hyperactivity	4.13 (3.83,4.44)	3.71 (3.60,3.83)	3.32 (3.18,3.45)	3.64 (3.33,3.95)
Total difficulties	10.22 (9.46,10.98)	8.79 (8.50,9.07)	7.63 (7.31,7.96)	8.60 (7.79,9.42)
Girls				
Emotional problems	2.78 (2.38,3.18)	2.01 (1.88,2.14)	1.92 (1.82,2.01)	1.89 (1.76,2.03)
Peer problems	1.96 (1.66,2.26)	1.36 (1.26,1.45)	1.19 (1.11,1.27)	1.27 (1.15,1.38)
Conduct problems	1.75 (1.40,2.10)	1.38 (1.29,1.47)	1.16 (1.09,1.23)	1.29 (1.18,1.40)
Hyperactivity	3.76 (3.33,4.19)	2.87 (2.72,3.01)	2.54 (2.42,2.65)	2.64 (2.46,2.83)
Total difficulties	10.25 (9.20,11.30)	7.60 (7.26,7.94)	6.80 (6.51,7.08)	7.09 (6.66,7.52)

V. Autoregressive and cross-lagged estimates

Table 5-21: Autoregressive and cross-lagged estimates for the relationship between mode of school commute and SDQ scores at ages 5, 7, and 11

Mode of school commute

	PA4 ON PA3	**PA5 ON PA4**	**PA4 ON SDQ3**	**PA5 ON SDQ4**	**SDQ4 ON SDQ3**	**SDQ5 ON SDQ4**	**SDQ4 on PA3**	**SDQ5 ON PA4**
	aOR (95% CI)	aOR (95% CI)	aOR (95% CI)	aOR (95% CI)	b (p-value)	b (p-value)	b (p-value)	b (p-value)
Boys								
EM	2.882 (2.713 - 3.061)	2.390 (2.264 - 2.522)	1.050 (0.993 - 1.109)	**0.958 (0.918 - 0.999)**	0.528 (<0.001)	0.481 (<0.001)	0.026 (0.128)	<0.001 (0.995)
PE	2.902 (2.735 - 3.080)	2.375 (2.250 - 2.507)	0.965 (0.916 - 1.015)	0.988 (0.939 - 1.041)	0.533 (<0.001)	0.459 (<0.001)	0.022 (0.205)	-0.005 (0.801)
CO	2.911 (2.741 - 3.092)	2.377 (2.252 - 2.509)	**0.939 (0.892 - 0.988)**	0.991 (0.945 - 1.039)	0.562 (<0.001)	0.524 (<0.001)	0.006 (0.680)	0.028 (0.068)
HY	2.896 (2.727 - 3.075)	2.378 (2.253 - 2.510)	0.982 (0.949 - 1.015)	1.000 (0.970 - 1.031)	0.661 (<0.001)	0.581 (<0.001)	0.022 (0.317)	0.007 (0.748)
TD	2.903 (2.735 - 3.081)	2.380 (2.255 - 2.512)	0.991 (0.975 - 1.007)	0.994 (0.980 - 1.009)	0.686 (<0.001)	0.598 (<0.001)	0.061 (0.185)	0.019 (0.682)
Girls								
EM	2.986 (2.783 - 3.204)	2.335 (2.190 - 2.488)	0.963 (0.917 - 1.012)	**1.042 (1.000 - 1.085)**	0.499 (<0.001)	0.506 (<0.001)	0.032 (0.051)	0.019 (0.303)
PE	2.990 (2.787 - 3.207)	2.330 (2.186 - 2.483)	**1.071 (1.007 - 1.139)**	1.022 (0.969 - 1.078)	0.490 (<0.001)	0.446 (<0.001)	0.009 (0.533)	0.026 (0.073)
CO	2.991 (2.787 - 3.210)	2.333 (2.189 - 2.486)	0.944 (0.888 - 1.003)	1.015 (0.965 - 1.068)	0.536 (<0.001)	0.518 (<0.001)	-0.002 (0.902)	0.007 (0.616)
HY	2.987 (2.784 - 3.205)	2.333 (2.189 - 2.486)	1.013 (0.978 - 1.049)	**1.036 (1.005 - 1.068)**	0.652 (<0.001)	0.548 (<0.001)	0.031 (0.151)	-0.002 (0.897)
TD	2.985 (2.782 - 3.202)	2.336 (2.193 - 2.489)	0.998 (0.980 - 1.016)	**1.017 (1.001 - 1.033)**	0.683 (<0.001)	0.612 (<0.001)	0.062 (0.195)	0.048 (0.267)

SDQ3 = SDQ at MCS3 (age 5), SDQ4 = SDQ at MCS4 (age 7), SDQ5 = SDQ at MCS5 (age 11)
PA3 = mode of school commute at MCS3, PA4 = mode of school commute at MCS4, PA5 = mode of school commute at MCS5
EM = emotional problems, PE = peer problems, CO = conduct problems, HY = hyperactivity, TD = total difficulties
Ordinal logistic odds ratios are presented for PA and sedentary behaviour outcomes
Unstandardised regression coefficients are presented for SDQ outcomes
All significant cross-lagged estimates are in ***bold****: estimates are significant where the lower limit of 95% CI > aOR=1.000 <upper limit of 95% CI or p<0.05*
All autoregressive estimates are significant

Table 5-22: Autoregressive and cross-lagged estimates for the relationship between mode of sports participation and SDQ scores at ages 5, 7, and 11

Sports participation

	PA4 ON PA3	PA5 ON PA4	PA4 ON SDQ3	PA5 ON SDQ4	SDQ4 ON SDQ3	SDQ5 ON SDQ4	SDQ4 on PA3	SDQ5 ON PA4
	aOR (95% CI)	aOR (95% CI)	aOR (95% CI)	aOR (95% CI)	b (p-value)	b (p-value)	b (p-value)	b (p-value)
Boys								
EM	2.089 (1.954 - 2.232)	1.793 (1.674 - 1.920)	**0.927 (0.893 - 0.962)**	**0.952 (0.916 - 0.988)**	0.526 (<0.001)	0.478 (<0.001)	**-0.087 (<0.001)**	**-0.057 (0.025)**
PE	2.079 (1.946 - 2.221)	1.773 (1.653 - 1.901)	**0.915 (0.879 - 0.951)**	**0.893 (0.855 - 0.932)**	0.531 (<0.001)	0.455 (<0.001)	**-0.053 (0.018)**	**-0.069 (0.004)**
CO	2.092 (1.957 - 2.236)	1.805 (1.685 - 1.935)	**0.937 (0.902 - 0.973)**	0.990 (0.942 - 1.041)	0.567 (<0.001)	0.527 (<0.001)	-0.033 (0.155)	-0.002 (0.914)
HY	2.099 (1.962 - 2.244)	1.803 (1.682 - 1.932)	**0.976 (0.954 - 0.998)**	**0.970 (0.945 - 0.996)**	0.652 (<0.001)	0.548 (<0.001)	-0.037 (0.176)	-0.022 (0.400)
TD	2.081 (1.946 - 2.224)	1.785 (1.665 - 1.913)	**0.971 (0.961 - 0.982)**	**0.975 (0.963 - 0.988)**	0.684 (<0.001)	0.598 (<0.001)	**-0.155 (0.021)**	-0.096 (0.153)
Girls								
EM	2.051 (1.910 - 2.203)	1.610 (1.516 - 1.710)	0.961 (0.920 - 1.004)	**0.948 (0.918 - 0.980)**	0.503 (<0.001)	0.503 (<0.001)	-0.023 (0.328)	-0.052 (0.074)
PE	2.048 (1.906 - 2.199)	1.605 (1.512 - 1.705)	**0.950 (0.903 - 0.999)**	**0.905 (0.867 - 0.945)**	0.489 (<0.001)	0.443 (<0.001)	**-0.048 (0.025)**	**-0.074 (0.001)**
CO	2.047 (1.906 - 2.197)	1.608 (1.515 - 1.708)	0.952 (0.906 - 1.001)	**0.930 (0.888 - 0.973)**	0.566 (<0.001)	0.527 (<0.001)	-0.033 (0.156)	-0.002 (0.913)
HY	2.047 (1.908 - 2.196)	1.608 (1.514 - 1.708)	**0.964 (0.937 - 0.993)**	**0.969 (0.947 - 0.991)**	0.660 (<0.001)	0.580 (<0.001)	-0.040 (0.223)	-0.014 (0.615)
TD	2.032 (1.893 - 2.181)	1.601 (1.508 - 1.701)	**0.976 (0.960 - 0.992)**	**0.971 (0.960 - 0.982)**	0.688 (<0.001)	0.608 (<0.001)	-0.001 (0.982)	**-0.157 (0.010)**

SDQ3 = SDQ at MCS3 (age 5), SDQ4 = SDQ at MCS4 (age 7), SDQ5 = SDQ at MCS5 (age 11)
PA3 = sports participation at MCS3, PA4 = sports participation at MCS4, PA5 = sports participation at MCS5
EM = emotional problems, PE = peer problems, CO = conduct problems, HY = hyperactivity, TD = total difficulties
Ordinal logistic odds ratios are presented for PA and sedentary behaviour outcomes
Unstandardised regression coefficients are presented for SDQ outcomes
*All significant cross-lagged estimates are in **bold**: estimates are significant where the lower limit of 95% CI > aOR=1.000 <upper limit of 95% CI or p<0.05*
All autoregressive estimates are significant

Table 5-23: Autoregressive and cross-lagged estimates for the relationship between weekday television viewing and SDQ scores at ages 5, 7, and 11

Television

	PA4 ON PA3	PA5 ON PA4	PA4 ON SDQ3	PA5 ON SDQ4	SDQ4 ON SDQ3	SDQ5 ON SDQ4	SDQ4 on PA3	SDQ5 ON PA4
	aOR (95% CI)	aOR (95% CI)	aOR (95% CI)	aOR (95% CI)	b (p-value)	b (p-value)	b (p-value)	b (p-value)
Boys								
EM	2.817 (2.461 - 3.224)	2.323 (2.011 - 2.683)	**0.927 (0.891 - 0.965)**	1.003 (0.964 - 1.043)	0.528 (<0.001)	0.480 (<0.001)	-0.079 (0.066)	-0.061 (0.197)
PE	2.817 (2.462 - 3.224)	2.320 (2.011 - 2.676)	0.959 (0.920 - 1.000)	0.987 (0.941 - 1.036)	0.531 (<0.001)	0.459 (<0.001)	**-0.117 (0.002)**	**-0.104 (0.006)**
CO	2.799 (2.446 - 3.202)	2.314 (2.006 - 2.671)	**0.920 (0.878 - 0.964)**	0.960 (0.915 - 1.008)	0.565 (<0.001)	0.526 (<0.001)	**-0.127 (<0.001)**	-0.046 (0.247)
HY	2.817 (2.459 - 3.226)	2.322 (2.012 - 2.680)	**0.958 (0.931 - 0.985)**	1.000 (0.972 - 1.029)	0.659 (<0.001)	0.581 (<0.001)	**-0.156 (0.001)**	0.042 (0.391)
TD	2.795 (2.442 - 3.200)	2.316 (2.005 - 2.674)	**0.969 (0.956 - 0.982)**	0.995 (0.982 - 1.009)	0.683 (<0.001)	0.599 (<0.001)	**-0.408 (<0.001)**	-0.123 (0.314)
Girls								
EM	2.970 (2.596 - 3.398)	2.542 (2.207 - 2.929)	**0.928 (0.882 - 0.976)**	0.979 (0.966 - 1.112)	0.504 (<0.001)	0.504 (<0.001)	-0.015 (0.736)	-0.039 (0.457)
PE	2.979 (2.604 - 3.408)	2.530 (2.198 - 2.912)	0.959 (0.911 - 1.010)	**0.934 (0.889 - 0.982)**	0.492 (<0.001)	0.446 (<0.001)	-0.019 (0.575)	-0.043 (0.257)
CO	2.955 (2.584 - 3.380)	2.543 (2.207 - 2.930)	**0.894 (0.843 - 0.947)**	0.965 (0.966 - 1.112)	0.537 (<0.001)	0.519 (<0.001)	**-0.081 (0.004)**	-0.050 (0.174)
HY	2.972 (2.598 - 3.400)	2.526 (2.191 - 2.913)	0.973 (0.943 - 1.004)	0.968 (0.965 - 1.112)	0.652 (<0.001)	0.549 (<0.001)	-0.080 (0.101)	0.004 (0.924)
TD	2.948 (2.576 - 3.372)	2.515 (2.183 - 2.898)	**0.968 (0.951 - 0.986)**	0.980 (0.966 - 1.112)	0.687 (<0.001)	0.610 (<0.001)	-0.138 (0.148)	-0.055 (0.653)

SDQ3 = SDQ at MCS3 (age 5), SDQ4 = SDQ at MCS4 (age 7), SDQ5 = SDQ at MCS5 (age 11)
PA3 = television at MCS3, PA4 = television at MCS4, PA5 = television at MCS5
EM = emotional problems, PE = peer problems, CO = conduct problems, HY = hyperactivity, TD = total difficulties
Ordinal logistic odds ratios are presented for PA and sedentary behaviour outcomes
Unstandardised regression coefficients are presented for SDQ outcomes
*All significant cross-lagged estimates are in **bold**: estimates are significant where the lower limit of 95% CI > aOR=1.000 <upper limit of 95% CI or p<0.05*
All autoregressive estimates are significant

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Table 5-24: Autoregressive and cross-lagged estimates for the relationship between weekday electronic gaming and SDQ scores at ages 5, 7, and 11

Electronic games

	PA4 ON PA3	**PA5 ON PA4**	**PA4 ON SDQ3**	**PA5 ON SDQ4**	**SDQ4 ON SDQ3**	**SDQ5 ON SDQ4**	**SDQ4 on PA3**	**SDQ5 ON PA4**
	aOR (95% CI)	aOR (95% CI)	aOR (95% CI)	aOR (95% CI)	b (p-value)	b (p-value)	b (p-value)	b (p-value)
Boys								
EM	1.877 (1.726 - 2.041)	1.730 (1.561 - 1.918)	0.979 (0.938 - 1.022)	1.007 (0.857 - 1.012)	0.529 (<0.001)	0.481 (<0.001)	-0.016 (0.643)	-0.010 (0.783)
PE	1.875 (1.725 - 2.039)	1.729 (1.560 - 1.916)	**0.954 (0.913 - 0.996)**	0.994 (0.955 - 1.035)	0.568 (<0.001)	0.527 (<0.001)	-0.004 (0.892)	0.010 (0.735)
CO	1.869 (1.720 - 2.032)	1.730 (1.561 - 1.917)	**0.950 (0.912 - 0.990)**	0.970 (0.857 - 1.012)	0.568 (<0.001)	0.527 (<0.001)	-0.004 (0.892)	0.010 (0.735)
HY	1.875 (1.724 - 2.038)	1.731 (1.562 - 1.917)	0.999 (0.972 - 1.027)	0.972 (0.857 - 1.012)	0.661 (<0.001)	0.581 (<0.001)	-0.021 (0.601)	-0.007 (0.867)
TD	1.875 (1.724 - 2.038)	1.728 (1.560 - 1.915)	0.988 (0.974 - 1.002)	0.992 (0.857 - 1.012)	0.686 (<0.001)	0.600 (<0.001)	-0.089 (0.250)	0.013 (0.892)
Girls								
EM	1.823 (1.659 - 2.003)	1.359 (1.240 - 1.489)	0.988 (0.943 - 1.035)	**0.991 (0.849 - 0.963)**	0.504 (<0.001)	0.505 (<0.001)	0.010 (0.751)	-0.073 (0.086)
PE	1.822 (1.659 - 2.000)	1.359 (1.240 - 1.489)	0.983 (0.929 - 1.039)	0.971 (0.928 - 1.015)	0.492 (<0.001)	0.447 (<0.001)	-0.018 (0.525)	0.001 (0.979)
CO	1.823 (1.661 - 2.000)	1.352 (1.233 - 1.483)	0.959 (0.913 - 1.008)	**0.934 (0.849 - 0.963)**	0.540 (<0.001)	0.519 (<0.001)	-0.046 (0.102)	-0.065 (0.055)
HY	1.823 (1.660 - 2.002)	1.352 (1.232 - 1.483)	0.980 (0.949 - 1.012)	**0.943 (0.848 - 0.962)**	0.653 (<0.001)	0.548 (<0.001)	0.010 (0.807)	-0.025 (0.547)
TD	1.824 (1.661 - 2.004)	1.353 (1.234 - 1.483)	0.988 (0.971 - 1.005)	**0.976 (0.848 - 0.962)**	0.688 (<0.001)	0.610 (<0.001)	-0.067 (0.442)	-0.152 (0.163)

SDQ3 = SDQ at MCS3 (age 5), SDQ4 = SDQ at MCS4 (age 7), SDQ5 = SDQ at MCS5 (age 11)
PA3 = electronic games at MCS3, PA4 = electronic games at MCS4, PA5 = electronic games at MCS5
EM = emotional problems, PE = peer problems, CO = conduct problems, HY = hyperactivity, TD = total difficulties
Ordinal logistic odds ratios are presented for PA and sedentary behaviour outcomes
Unstandardised regression coefficients are presented for SDQ outcomes
All significant cross-lagged estimates are in ***bold****: estimates are significant where the lower limit of 95% CI > aOR=1.000 <upper limit of 95% CI or p<0.05*
All autoregressive estimates are significant

6 Discussion

This thesis set out to examine the relationship between PA, sedentary time, and mental health in children. The aims of this thesis were to:

1. To investigate whether objectively-measured sedentary time and PA at age 7 are predictive of mental health outcomes at age 11;
2. To investigate the effects of environmental characteristics in the relationship between objectively-measured total PA and sedentary time at age 7 and mental health, and to explore the role of area-level factors;
3. To investigate whether reported measures of PA and sedentary screen time at two measured time points are predictive of mental health outcomes at subsequent times point; and whether there is evidence for reverse causation or bidirectionality of the association.

At the conclusion of each of the analysis chapters, the chapter-specific findings, strengths and limitations, and recommendations for future research were presented (see sections 3.4, 4.6, and 5.5). This final chapter will discuss the broader findings of the work as a whole. First, I will present a summary of the results, followed by a discussion of the main contributions of this thesis, the implications for policy and future research, and the strengths and limitations of the work as a whole.

6.1 Summary of results

The literature review in chapter 1 examined the evidence for the association between PA/sedentary behaviour and mental health in children. A range of correlates of activity and mental health were explored and important factors identified, although the degree to which these factors were considered in studies was inconsistent. The majority of studies found evidence that higher levels of PA are associated with better mental health outcomes, although the results for sedentary behaviour were less conclusive. The predominance of cross-sectional studies meant that the direction of the association could not be inferred. The emerging picture from this field or research is that the relationship between PA/sedentary behaviour and mental health is not unequivocal; in particular, associations vary by the characteristics of the activity and mental health outcomes captured by the measures used. A conceptual framework that considers how the dimensions of PA/sedentary behaviour might operate on mental health, in the presence of potential confounders of the relationship was proposed.

In the chapters 3, 4, and 5, the relationship between PA, sedentary behaviour, and mental health was explored using the MCS, a cohort of children in the UK. Data on 6,153 children aged 7 were available for the accelerometry-based analyses and 11,604 at ages 5, 7, and 11 for the reported activity analyses. Consistent mental health measures in the form of the SDQ were available at all sweeps allowing both cross-sectional and longitudinal analyses to be conducted.

In single-level accelerometer-measured models, peer problems at age 11 were significantly better in children who engaged in more objectively measured light PA at age 7 and worse for children who were more sedentary in fully adjusted models. Increases in MVPA were also associated with reduced peer problems in boys only. Conversely, increases in light PA and MVPA was associated with more hyperactive symptoms, while sedentary time was associated with fewer hyperactive symptoms. For boys, increased MVPA was also associated with more conduct problems.

The direction and statistical significance of these associations persisted in the multilevel models, which additionally adjusted for neighbourhood characteristics and accounted for ward level variance. Accounting for the clustering at ward level in multilevel models highlighted the importance of context: between-ward variance accounted for a 4.5-12.4% of the total variance in SDQ scores after adjusting for multiple confounders. However, there was no evidence that green space confounded or moderated the association between PA, sedentary behaviour, and mental health.

In the three-wave cross-lagged models, the relationship between different types of parent-reported active and sedentary behaviours were explored. Increased frequency of sports participation at waves 1 and 2 was associated with reduced peer problems at subsequent waves in boys and girls. Sports participation in preceding waves was also associated with reduced emotional problems at both time points in boys, and total difficulties at age 11 in girls. Active commuting, however, showed no significant relationships with mental health outcomes for either boys or girls. The detrimental effect on hyperactivity in children with more objectively-measured light PA and MVPA (and MVPA on conduct problems in boys) was not observed with sports participation or mode of school commute.

Less reported TV viewing at earlier sweeps was associated with fewer peer problems in boys at both ages 7 and 11; however, this was not observed for girls. In boys, greater TV exposure at age 5 was associated with more hyperactive symptoms, conduct problems, and total difficulties at age 7. This differs from the finding that increased objectively-measured sedentary time reduced hyperactivity and conduct problems. Greater TV exposure at age 5 predicted more conduct problems at age 7 in girls. Effects of TV time at age 7 on SDQ scores at age 11 were restricted to peer problems in boys, indicating that mental health outcomes might be more susceptible to TV exposure at younger ages. Console and PC gaming was not predictive of SDQ scores at either time point.

The effects of mental health outcomes on active and sedentary behaviours were also explored. Higher scores in all SDQ subscales were found to be predictive of lower sport at waves 2 and 3. Except for peer problems, higher SDQ scores at age 5 were also found to be predictive of increased TV viewing at age 7. These relationships did not participate at the subsequent wave, however, and only peer problems were found to be predictive of TV viewing at the wave 3. Peer and conduct problems in boys at age 5 were predictive of increased electronic gaming at age 7, but not at the following wave. Higher externalising problems in girls at age 7 predicted increased electronic gaming at age 11. An unexpected finding was that that, for girls, higher SDQ scores (peer problems at age 5; emotional problems, hyperactivity, and total difficulties at age 7) and were also predictive of a higher likelihood of active commuting subsequent waves. In the other direction, boys with higher conduct problems (age 5) and emotional problems (age 7) were less likely to actively commute.

6.2 Main contributions of this study

In section 1.7.1, I proposed a conceptual framework, suggesting the possible mechanisms (i.e. psychosocial, neurobiological, and behavioural) through which PA and sedentary behaviour affect mental health, adjusting for a range of proximal and distal correlates of both exposure and outcome. Building on the framework built on the PA model proposed by Lubans et al., multiple dimensions of PA and sedentary behaviour were considered: intensity, duration, type, and frequency. These were examined as distinct constructs: reported and objective measures of PA (or sedentary behaviour) were not assumed to be equivalent, nor were PA and sedentary behaviour assumed to be functional opposites. Different aspects of mental health functioning were also modelled separately to explore whether effects of activity were domain-specific. The possibility of reverse causality was also included. This conceptual framework served as a model for my analyses, through which several important findings were highlighted.

First, this thesis demonstrated that objective and reported activity measures represent distinct dimensions of activity that can have different impacts on mental health. In cross-sectional analyses, accelerometer-measured sedentary behaviour and PA were not correlated or very weakly correlated with reported measures. This was supported by the longitudinal results, which showed that associations were not consistent for sedentary behaviours across SDQ subscales. For example, increased objectively-measured sedentary time and TV viewing were predictive of peer problems, but electronic gaming was not. Furthermore, sedentary behaviour did not consistently affect mental health in the same direction: children who accumulated more accelerometer-measured sedentary time were less hyperactive, whereas greater TV exposure resulted in more hyperactive symptoms. Evidence that the dimensions of active behaviour affect mental health differently were also observed. For example, MVPA (boys only), light PA, and sports participation were associated with reduced peer problems; however, active commuting was not found to be predictive of any SDQ outcomes. Active commuting may not fully capture the processes through which PA can affect mental health, and there could be greater variability in the intensity and duration of the commute compared with playing sports.

Second, this study found that increases in both objectively-measured PA and sports participation were associated with a reduction in peer problems, indicating that this relationship might operate through psychosocial mechanisms. The association between sports participation and a range of psychosocial correlates, such as social anxiety, shyness, self-concept, and social skills, have been widely reported in a number of studies (Bowker, 2006; Dimech & Seiler, 2011; Donaldson & Ronan, 2006; Ferron et al., 1999; Findlay & Coplan, 2008; L. J. Griffiths et al., 2010; Howie et al., 2010). This study supports these findings and further strengthens the evidence by demonstrating improvements to mental health via peer relationships using longitudinal data and multiple PA measures.

Third, the relationship between PA/sedentary behaviour and mental health outcomes were different for boys and girls, demonstrating that the mechanisms through which PA and sedentary behaviour operate on mental health could be moderated by gender. For example, higher levels of MVPA were not associated with any SDQ outcomes in girls, and gender-specific associations were found with screen time activities, where boys' mental health was affected by TV viewing to a greater extent than girls. The timing of the observed associations also differed for boys and girls: girls with poor mental health at age 7 were more likely to engage in sedentary screen behaviours at age 11, which was not observed for boys.

Finally, this study also explored the possibility that mental health could have an impact on children's active and sedentary behaviours. Although the analyses were conducted with the reported measures of activity only, the multiple associations found across the three points in time indicate that certain domains of mental health can have an effect on children's activity levels. Few studies have explored the relationship in this direction and only one used measures of sedentary behaviour in addition to PA (see (L. Griffiths et al., 2016; Stavrakakis et al., 2012)), thus, most of these findings have not been replicated. The finding that hyperactivity was consistently predictive of lower likelihood of sports participation may be indicative of a behavioural mechanism at work, whereby children who are hyperactive may not have the have the ability to focus or follow rules (Johnson & Rosen, 2000; H. Lee et al., 2014). This mechanism might help explain why higher levels of MVPA and light PA were predictive of hyperactivity in the accelerometer models: children whose hyperactive symptoms preclude their participation in sports may be engaging in behaviours that are symptomatic of hyperactivity (i.e. fidgeting, restlessness) that are recorded as PA.

6.3 Implications for research and policy

Differentiating between PA and sedentary behaviour dimensions has important implications for future research, particularly where the effects of screen time are concerned. In the literature, the effects of screen time as a type of sedentary behaviour are often conflated with overall sedentariness, and the different types of screen time (e.g. TV and electronic games) are categorised into a single exposure, potentially leading to null or equivocal results (Gentile et al., 2009; Hammond et al., 2014; Liu, Wu, & Yao, 2016; Parkes et al., 2013; Przybylski & Weinstein, 2017). As the availability of screen technology increases, identifying different types of screen time uses, and how best these can be captured, will also become increasingly important to understanding any pathways to mental health outcomes. The relationship between different types of screen time and mental health may also change as children grow older so these pathways may not be static. For example, the children in this study may have been too young for online interaction via social media platforms but older children could be exposed to online abuse and cyber-bullying, particularly girls (Booker, Kelly, & Sacker, 2018; Keeffe & Clarke-Pearson, 2011; Marcheselli et al., 2018). Currently, the UK has no published guidelines on recommended screen time limits for children as a result of the conflicting evidence; however, screen time limits for certain uses, in line with guidance from other countries (i.e. <2 hours per day in Canada and Australia) are unlikely to cause harm. National guidelines that are based around specific screen time uses and technologies may help to isolate problematic behaviours (i.e. excessive TV viewing), and prevent deleterious mental health effects. Policymakers should develop guidance that is responsive to the rapidly changing technological landscape, as consensus may not be reached before the mental health and development of young children are impacted.

The finding that increasing overall activity volume and sports participation can improve mental health, particularly via social and peer relationships, could be used to improve existing guidance on PA levels in children. Recommendations currently suggest that children engage in at least 60 minutes of MVPA over the course of a day and vigorous weight-bearing activities incorporated at least three days a week (Department of Health et al., 2011). The guidelines address the importance of the intensity and duration of activity for health outcomes, and examples of structured activities (i.e. taught/coached activity that promotes skill learning and development, sport and dance) and unstructured activities (i.e. active travel, indoor or outdoor play) are provided, but the type of activity vis-à-vis promotion of social skills and psychosocial development is not considered.

Additional guidance from the UK Chief Medical Officer (CMO) suggests that at least 30 minutes of MVPA should be during the school day and 30 minutes outside of school (Public Health England, 2020); however, in a recent report from 2018-19 identified that only 40% of children aged 7-11 take part in 30+ minutes of activity a day at school (Sport England, 2019). There is no statutory requirement to provide specific amounts of time for physical education (PE) in schools in the UK, although the Department for Education *Healthy Schools Rating Scheme* awards schools that offer 2+ hours a week a Silver/Gold standard (Department of Health, 2019) and a recent Ofsted report on PE in children aged 5-16 found that the majority of schools visited offered at least 2 hours of PE a week (Ofsted, 2013). Nonetheless, consistent with the CMO's guidance recommending 30+ minutes a day in school, statutory requirements could be put in place to offer 2.5 hours in-school PE per week to ensure children meet the minimum recommendations, with an emphasis on activities that promote teamwork, collaboration, and inclusion. Outside of school, children may not have the same opportunities to participate in social PA or organised sports. Access to extracurricular activities might be limited to families who have the financial resources and time available, and some areas may lack the programmes and infrastructure for adequate provision. Schools are uniquely positioned in that they can provide instruction, encourage participation, and offer an environment where children can engage in the social dimensions of PA with their peers, through PE lessons available to all children. Future intervention studies to examine the role of activity in school settings on mental health outcomes would help to support broader policy initiatives.

The observed differences between boys and girls highlight the need for targeted approaches to increase PA and limit sedentary behaviours. Girls in particular are independently at risk for lower PA and worse mental health outcomes. According to a report on participants aged 2-15 years of age from the Health Survey for England, differences in formal PA[4] frequency and

[4] (Formal PA included any organised team sport, running or athletics, all types of swimming, gymnastics, weight training, aerobics and tennis. 'Informal activities include cycling (excluding to/from school), dancing, skating, trampolining, hopscotch, active play, skipping rope, and housework and gardening.')

duration between boys and girls can be observed as early as ages 2-4 and gender differences widen as children grow older (Scholes, 2016). Sport is important to boys' sense of self-concept, identity, and self-efficacy, because of the expectation that boys should be interested in sport and the value placed in their athletic ability (Lagerberg, 2005; Women in Sport, 2017). Early engagement in PA is important as it increases motor proficiency and, reciprocally, motor proficiency is associated with increased opportunities for PA (Jaakkola & Washington, 2013; Peyre et al., 2019). Given the lower levels of PA in girls in the MCS, there could be a corresponding decline in motor skills and reduced breadth of activities available to girls; thus, MVPA in girls may not be sport-based, or similarly beneficial, and mental health benefits not obtained. Furthermore, in a study of children 8-10 years old, motor skills were related to a greater perception of self-adequacy in boys only, demonstrating that the pathways from PA, via motor skills, to mental health may differ but are more likely socio-culturally driven than biological (Linda S. Pagani et al., 2013; Wrotniak, Epstein, Dorn, Jones, & Kondilis, 2006). Establishing healthy PA behaviours in early childhood may improve the likelihood of an active lifestyle in adulthood and interventions to mitigate long-term, gender-based risk should be a priority for policy makers.

In November 2018, a report by the ONS revealed that girls aged 11 to 16 were more likely to have an emotional disorder than boys (10.9% compared to 7.1%). At ages 17 to 19, the likelihood of emotional disorder in boys remained the same (7.9%), however, that of girls doubled to 22.4%, with 5.6% identifying with body dysmorphic disorder (Marcheselli et al., 2018). One in four girls aged 11-14 years old were unhappy the way their body looked, increasing to 1 in 3 by ages 14-16 (Women in Sport, 2017). Girls aged 11-16 cite dissatisfaction with body image, low confidence and ability, self-consciousness, and pressures of school work as barriers to PA uptake, with fewer girls than boys feel that PA is an important part of or relevant to their lives (Women in Sport, 2017).

Political and athletic governing bodies have power to effect a change in culture by eliminating gender pay gaps in sporting events, increasing exposure and creating positive role models for girls. For example, in 2017, the Norwegian Football Association announced both men and women teams would receive equal pay for playing international football in order to improve standards and reward performance in the women's team (Wrack, 2017). In California, the State Lands Commission made equal pay a condition of being granted a permit to lease the public lands for a major surfing tournament in August 2018, prompting prize equity across all tournaments (California State Lands Commission, 2018). Major tennis tournaments that offer equal prizes for both men's and women's finals have seen viewership numbers of the women's finals surpass those of the men's in the last decade (Badenhausen, 2018; BBC News, 2016; Levitt, 2018) .

Normalising the presence and participation of women at the highest level of sport, and providing girls with the opportunity to play sport and engage in PA at young ages would allow them to develop the confidence and skills to participate, and for PA to become an integral part of girls' lives. Targeted programmes to increase opportunities for young girls to increase PA are a start, but a more holistic approach is needed to address the close association with perceptions of body image in girls to create positive population level changes. Removing the focus on PA as merely cosmetic, banning the proliferation of unrealistic standards of body image in the media, and instilling enjoyment in PA, will help girls improve PA uptake and their health, both mental and physical, as they grow up. Further research to explore how enjoyment, body image, and expectations affect activity levels would help to determine the barriers to PA and sports participation in girls, and identify the pathways to improving their mental health.

Finally, the effects of mental health on the active and sedentary behaviours of children is a relatively underdeveloped area of research and future studies should systematically explore the mechanisms through which this might occur. Adult studies have suggested that low energy levels and motivation, anhedonia, and psychomotor retardation as potential barriers to PA resulting from mental health dysfunction (Goodwin, 2003; Pinto Pereira, Geoffroy, & Power, 2014). A better understanding of the mechanisms underpinning these relationships in children will be necessary for designing effective interventions or policy, as efforts to increase PA may not be effective for children who are suffering from mental health disorder, nor will they necessarily have the same effects on outcomes.

The prevalence of mental health disorder in young people aged 5-15 increased from 9.7% to 11.2% between 1999 and 2017, with rates rising to 16.9% by ages 17-19 (Sadler et al., 2018). A report by the Education Policy Institute in 2018 found that a quarter of children in England referred for specialist mental health services were not accepted into treatment, and that alternative support services for those unable to access specialist treatment had been decommissioned since 2010 (Crenna-Jennings & Hutchinson, 2018). Long waiting times for treatment provision (average 56 days) and significant regional variation in waiting times (median 82 days in Cambridgeshire and 182 days in West London) were reported (Crenna-Jennings & Hutchinson, 2018). Poor mental health in childhood predicts greater likelihood of mental health and psychiatric disorder in adulthood, as well as negative educational, occupational, and physical health outcomes (Kim-Cohen et al., 2003; Richards & Huppert, 2011; Stevens, 2018). Given the evidence for the reciprocal nature of this relationship, ignoring the impact of mental health on active behaviours risks perpetuating a negative feedback cycle. The consequences of poor mental health could extend to physical outcomes of ill-health (i.e. obesity, hypertension, diabetes, and increased cancer risk) via low PA levels (S. Biddle et al., 2000; S. Biddle & Mutrie, 2008).

6.4 Strengths and limitations

The strengths and limitations of the methods and data used in the specific chapters have been discussed in sections 3.4.3, 4.6.2, and 5.5.5. The overarching strengths and limitations of the work as a whole will be discussed in the following sections.

As highlighted in the previous section describing the main contributions, this study was the first to demonstrate longitudinal associations between PA, sedentary behaviour, and mental health outcomes in children using a large sample and multiple measures that captured a number of dimensions of activity. This was made possible through the use of Millennium Cohort Study data, which is a nationally-representative, prospective cohort study. The Strengths and Difficulties Questionnaire is a widely-used, validated tool used to screen for mental health and behavioural problems in the general population. The SDQ was used to assess children's mental health and was available at all sweeps in the datasets used throughout this thesis. A wide range of factors were included in analyses to account for differences in child, family, and environmental characteristics. Weights were available to account for sampling probability and cohort attrition, and item missingness was addressed using multiple imputation and FIML estimation techniques. As a result, more robust estimates could be obtained, and data from a greater number of children could be analysed, than if complete case analysis was used. This study was also the first to consider bidirectionality using cohort data from three time points, and to use sedentary screen time measures in addition to active measures.

There were, however, several limitations to the data, methodology, and scope of this thesis. First, the data did not capture factors related to PA and sedentary behaviours that may moderate or confound the associations observed. For example, children who enjoy PA and whose parental encourage active behaviours are more likely to engage in PA (Lagerberg, 2005; Scholes, 2016; Women in Sport, 2017), and this might impact their mental health differently to children who have negative views of activity and whose parents are less involved. Similarly, parental supervision of sedentary screen time, particularly TV viewing, might limit negative effects on mental health by limiting potentially harmful content

(Bickham & Rich, 2006; Christakis & Zimmerman, 2007). Questions on perceptions of PA and parental attitudes towards these activities were not included in the MCS interviews, however.

Second, although a range of active and sedentary behaviours were captured, they may not be an accurate representation of the activity undertaken. Parents may have over-reported or misremembered sports participation and under-reported screen time, for example. While accelerometers may be ‘objective’ in recording activity, participating in the accelerometer study may have led the children to behave differently in their activity. The study might have excluded more or less active children who failed to meet recorded wear time minimums either because of not wanting to have inactivity recorded or not wanting the device to hinder their activity. Children who are more prone to mental health disorder might have limited their wear time due to self-consciousness, fear of being bullied or other socio-emotional issues.

Third, accelerometer data were not available at additional sweeps so comparison with the reported measures could only be conducted at age 7. Although the reported and objective measures of PA (and sedentary behaviour) were not strongly correlated, this relationship might change at later time points. The activity of young children is often unstructured and sporadic in nature, and becomes more structured and volitional as they grow older (S. J. Biddle & Asare, 2011), and activity recorded by accelerometers may become more closely aligned with reported measures. For example, sports participation and MVPA were very weakly correlated in boys, but may become more strongly correlated if the majority of MVPA took place during sport. Therefore, the relationships observed in these analyses may not remain consistent and the dimensions of activity captured by certain measures may change.

Fourth, SDQ outcomes on a continuous scale were used, rather than the defined groups of ‘close to average’, ‘slightly raised’, ‘high’, and ‘very high’ (R. Goodman, 2015). This classification is used to screen children who are likely to have a mental health disorder, corresponding to those with ‘high’ and ‘very high’ SDQ scores. Although PA, for example, might be associated with lower SDQ scores, whether this corresponds to an improvement of any clinical significance is unknown. There is an assumption in this thesis that a lower score across the range corresponds to a mental health advantage (A. Goodman & Goodman, 2009).

Fifth, the analytic samples were represented by a more advantaged sub-sample of children. Children were more likely to have completed the MCS4 PA study and to have participated at all three MCS sweeps examined in these analyses if they were white, from less deprived households, lived in two-parent families, and had degree-educated mothers. These were controlled for using non-response and non-compliance weights; however, the possibility remains that the results cannot be extrapolated to the general population, and inferences should not be made for ethnic minorities or more deprived populations.

Sixth, only maternal characteristics were included in models, which meant that the importance of paternal characteristics could not be evaluated. In the MCS, interviews conducted at home with main (usually the mother) and partner (usually the father) respondents. When the children were 9 months of age, 99.9% the natural mother of child was the main respondent. This decreased at subsequent sweeps although the vast majority of main respondents were the natural mother: 97% at MCS3, 96.6% at MCS4, and 95.2% at MCS5 (Hansen et al., 2012). At the first interview, 85% of families had both natural parents in the household, however, by age 11, only 56% of families had both natural parents in the household at all five sweeps (Platt et al., 2014). More than 25% of children in the MCS were at one point living in a lone parent household by age 11, usually the natural mother. These shifts in family composition mean that (where the main respondent was the natural mother) the partner respondent was not always the natural father and may not have been the same person from a previous sweep. To retain consistency across sweeps, when assessing parental correlates of PA, sedentary behaviour and mental health, the response of the natural mother main respondent was used. This is not to say that the role of the father is not important in children's mental health. Fathers' involvement in child care has been shown to be positively related to children's mental health and paternal depression associated with high SDQ scores (A. M. McMunn et al., 2001; Twamley, Brunton, Sutcliffe, Hinds, & Thomas, 2013). The diversity of family structures and parental roles have changed substantially in recent years and future studies should aim to capture paternal roles to reinforce their importance to children's health and development.

Finally, the analyses considered the independent effects of different dimensions of PA and sedentary behaviour on mental health outcomes, but this does not allow for a broader examination of how the combination of activity and sedentary behaviours can affect mental health—the literature suggests that PA and sedentary behaviours are not functional opposites nor do they act in isolation (Brodersen et al., 2005; Mark Hamer et al., 2009; Taveras et al., 2007). Methodological limitations prevented a holistic consideration of the sedentary and active behaviours in this thesis. With the accelerometer measures, PA and sedentary time could not be included in the same models because they comprised a proportion of a standardised day of wear time, and the collinearity between measures would have been problematic (Leite, 2014). With the parent-reported measures, initially, exploratory factor analyses (EFA) and latent class analyses (LCA) were also considered to determine to what degree sedentary and active behaviours could co-exist within a single profile, however, the reported measures showed poor correlation precluding EFA, and LCA failed to identify distinct profile constructs (results not shown).

In 2016, Canada released the *24-Hour Movement Guidelines for Children and Youth*, which considers PA, screen-time, and sleep as three distinct movement behaviours that make up at 24-hour period. Optimal health results from balancing these behaviours and meeting recommendations (>=60 minutes MVPA, <2 hours sedentary screen time, and uninterrupted sleep of 8-11 hours for 5-13 year olds) (M. S. Tremblay et al., 2016). A study on the relationship between the 24h movement guidelines and psychological well-being found that children who met all three recommendations had higher odds of happiness and lower odds of stress than children who met none, one, or two of the guidelines (E.-Y. Lee, Spence, Tremblay, & Carson, 2018).

6.5 Concluding remarks

In the UK, the prevalence of mental health disorders in children has increased in the last decade, and mental health services are becoming increasingly difficult to access. Behavioural and lifestyle changes, such as increasing PA levels and decreasing sedentary behaviours, may help alleviate some of the symptoms of poor mental health. This thesis aimed to explore how the levels of engagement in different dimensions of PA and sedentary behaviour predicted mental health outcomes. Results showed consistent associations with some forms of PA (i.e. sports, light PA, and MVPA (boys only)) and sedentary behaviours (i.e. sedentary time and TV viewing) on particular subscales of the SDQ (i.e. peer problems and hyperactivity), but other activities (i.e. active commuting and electronic gaming) were not predictive of any mental health outcomes. The differences in effects observed by activity dimension and SDQ outcome highlight the need for holistic approaches to monitoring movement in order to maximise mental health benefits.

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