ETHNIC DIFFERENCES IN PHYSICAL ACTIVITY, DIETARY INTAKE, OBESITY AND BLOOD PRESSURE AMONG YOUNG CHILDREN IN THE UK

By

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ABSTRACT

Introduction: Early-life differences in cardiovascular risk factors could contribute to ethnic differences in cardiometabolic disease in adulthood. The aim of this thesis was to investigate ethnic differences in lifestyle factors, adiposity and blood pressure among 5-6 year old children in the UK. **Methods:** Cross-sectional data on blood pressure, anthropometric measures, sociodemographics, dietary intake, ethnicity, and objectively-measured physical activity, were analysed (n=1470 consented children; 45% White British, 30% South Asian, 8% Black African/Caribbean). **Results:** Compared with White British children, South Asian children had higher, and Black African/Caribbean children had similar or lower, levels of total and central adiposity. Pakistani and Black African/Caribbean boys did more moderate-vigorous physical activity, whereas South Asian girls did less compared with their White British peers. South Asian and Black African/Caribbean children had lower or similar blood pressure compared with White British children. Sodium intake was highest among Black African children. Sugar intake was lower among all minority ethnic groups compared with White British children. **Conclusions:** The findings highlight several early-life ethnic differences which could plausibly contribute to cardiovascular health inequalities in adulthood. Early childhood might offer a key opportunity to prevent or reduce ethnic differences in cardiovascular and metabolic disease later in life.

I would like to dedicate this thesis to my grandparents,

Pauline and John Wilson.

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CONTENTS LISTING

PUBLICATIONS AND PRESENTATIONS

The four empirical chapters in this thesis are based on the following papers. The data presented in these papers are baseline measurements from the West Midlands ActiVe lifestyle and healthy Eating in School children (WAVES) study. Gemma Knowles contributed to all stages of data collection and data entry, undertook extensive data cleaning and coding, and performed all statistical analyses and written work presented in this thesis. The focussed aims of these papers were formulated by Gemma Knowles. Peymane Adab and Neil Thomas advised on data analyses and provided feedback on all written work. Where listed, the other co-authors also advised on data analysis and paper editing.

1. **Knowles G,** Pallan MJ, Lancashire ER, Thomas GN, Ekelund U, Adab P, on behalf of the WAVES study investigators. Ethnic differences in physical activity and sedentary time among young children in the UK (in submission)

2. **Knowles G,** Kelleher K, Griffin T, Pallan MJ, Thomas GN, Lancashire ER, McGee E, Cade J, Adab P, on behalf of the WAVES study investigators. Ethnic differences in nutrient dietary intake among young children in the UK (in preparation)

3. **Knowles G,** Pallan MJ, Thomas GN, Lancashire ER, Adab P, on behalf of the WAVES study investigators. Ethnic differences in body composition and fat distribution among young children in the UK (in preparation)

4. **Knowles G,** Pallan MJ, Thomas GN, Lancashire ER, Adab P, on behalf of the WAVES study investigators. Ethnic differences in blood pressure among young children in the UK (in preparation)

In addition, the following papers, presentations and conference abstracts were produced during the period of postgraduate study at the University of Birmingham.

Publications

1. **Knowles G,** Pallan MJ, Thomas GN, Barrett T, Cheng KK, Ekelund U, Adab P. Physical activity and blood pressure in primary school children: a longitudinal study. *Hypertension*. 2013; 61(1):70-5.

2. **Knowles G,** Ling FC, Thomas GN, Adab P, McManus AM. Body size perception and body size dissatisfaction among young Chinese children in Hong Kong: a cross sectional study. *Public Health Nutr*. 2014 May 20:1-8. [Epub ahead of print]

3. Ling FC, McManus AM, **Knowles G,** Masters RS, Polman RC. Do children emotionally rehearse about their body image? *J Health Psychol.* 2013 Oct 30. [Epub ahead of print] DOI: 10.1177/1359105313507965.

Revisions

1. **Knowles G,** Mellecker R, Adab P, Thomas GN, McManus AM. Validation and calibration of the wrist- and waist-worn GENEA motion sensor in children (Under revision)

2. **Knowles G,** Wing-Sze L, McManus AM, Thomas GN, Adab P, Ho SY, Lam TH. Associations between the built-environment and physical activity among Hong Kong youth (Under revision)

In preparation

1. Griffin T, Balanos G, Hemming K, Lancashire ER, **Knowles G**, Adab P. Fitness, physical activity and BMI among 5-6 year old children.

2. **Knowles G**, Pallan MJ, Thomas GN, Lancashire ER, Adab P. Ethnic differences in body image among UK primary school children: the WAVES study.

Conference Presentations

1. **Knowles G,** Pallan MJ, Lancashire ER, Thomas GN, Ekelund U, Adab P, on behalf of the WAVES study investigators. Ethnic differences in physical activity and sedentary time among UK primary school children. **European Congress for Obesity 2014, Sofia, Bulgaria (Oral)**

2. **Knowles G,** Ling FC, Thomas GN, Adab P, McManus AM. Body size dissatisfaction among young Chinese children in Hong Kong: a cross-sectional study. **European Congress for Obesity 2013, Liverpool, UK**

3. **Knowles G,** Mellecker R, Adab P, Thomas GN, McManus AM. Validation and calibration of the wrist- and waist-worn GENEA motion sensor in children. **ISBNPA 2013, Ghent, Belgium**

4. **Knowles G**, Wing-Sze L, McManus AM, Thomas GN, Adab P, Ho SY, Lam TH. Associations between the built-environment and physical activity among Hong Kong youth. **Society for Behavioural Medicine 2013 San Francisco, US**

Invited talks

1. **Knowles G**, Pallan MJ, Thomas GN, Barrett T, Cheng KK, Ekelund U, Adab P. Physical activity and blood pressure in primary school children: a longitudinal study. An Najah University, Palestine (December 2012)

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LIST OF ABBREVIATIONS

ACC – Accelerometry

BIA – Bio-impedance Analysis

BF% - Body Fat percentage

BMI – Body Mass Index

BMIz – Body Mass Index z-score

BP – Blood Pressure

CADET – Child and Diet Evaluation Tool

CBIS – Children's Body Image Scale

CHASE – Child Heart and health Study in England

CHD – Coronary Heart Disease

CI – Confidence Interval

CPM – Counts per Minute

CVD – Cardiovascular Disease

DASH - Determinants of Adolescent Social well-being and Health

DBP – Diastolic Blood Pressure

DXA - Dual-energy X-ray Absorptiometry

ECG – Electrocardiograph

FFM – Fat-Free Mass

FM – Fat Mass

HR – Heart Rate

HSE – Health Survey for England

IMD – Index of Multiple Deprivation

LPA – Light Intensity Physical Activity

MCS – Millennium Cohort Study

MPA – Moderate Intensity Physical Activity

MRC – Medical Research Council

MUFA – Monounsaturated Fatty Acids

MVPA – Moderate-to-Vigorous Intensity Physical Activity

NCMP – National Child Measurement Programme

NDNS – National Diet and Nutrition Survey

OW/OB – Overweight/Obese

PA – Physical Activity

PAEE – Physical Activity Energy Expenditure

PUFA – Polyunsaturated Fatty Acids

SCAT - Subcutaneous Adipose Tissue

SES – Socioeconomic Status

ST – Sedentary Time

SBP – Systolic Blood Pressure

T2DM – Type 2 Diabetes Mellitus

UK – United Kingdom

VAT – Visceral Adipose Tissue

VPA – Vigorous-intensity Physical Activity

US – United States

UW/NW – Underweight/Normal Weight

WAVES - West Midlands ActiVe lifestyle and healthy Eating in School children study

WC – Waist Circumference

WCz – Waist Circumference Z-score

WHtR – Waist-to-Height Ratio

WHO – World Health Organisation

CHAPTER 1

INTRODUCTION

1.1 Overview of thesis

Previous research has demonstrated considerable ethnic differences in cardiovascular and metabolic risk among adults in the UK. Despite being observed for over three decades, these disparities remain unexplained. Recent research has started to explore potential early-life determinants of these health inequalities. The evidence suggests that ethnic differences in cardiovascular and metabolic risk factors are evident by late childhood or adolescence, and often mirror the disease patterns observed in adults. Many of these risk factors are known to track into adulthood, and are independently associated with future cardiovascular health, so it is plausible that these early ethnic differences could contribute to explaining future health inequalities. The reasons for these differences, and the age at which they emerge, are unknown. Very few studies have investigated whether ethnic differences in cardiovascular and metabolic risk factors are evident among children under the age of 10 years in the UK. Such information could contribute to explaining the health inequalities observed in late childhood, adolescence and adulthood, and might help to shape the design and timing of interventions to reduce, prevent or delay future inequalities. Thus, this thesis aims to explore variations in lifestyle and physiological risk factors among a sample of 5-6 year old children in the West Midlands who have undergone baseline measurements for an ongoing large-scale intervention study. Chapter One presents the existing evidence for ethnic differences in cardiovascular disease (CVD) and associated risk factors in older age groups, the rationale for the work presented in this thesis, and an overview of the research setting. Chapters Two, Three, Four and Five comprise four papers describing the empirical studies undertaken for this work. Chapter Six summarises the main findings of this thesis, the implications and overall limitations, and suggestions for future research.

1.2 Ethnicity

1.2.1 Defining ethnicity

Ethnicity is a complex concept based on several fluid constructs which may change over time and in different contexts.[1-3] Numerous definitions have been proposed and debated; despite variations in the exact wording, the majority of proposed definitions share the concepts of self-identity, common culture and other factors such as language, religion, and ancestry.[1,2] For example, in referring to the measurement of ethnicity in the UK Census, Bulmer defined 'ethnic group' as:

> '…a collectivity within a larger population having real or putative common ancestry, memories of a shared past, and a cultural focus upon one or more symbolic elements which define the group's identity, such as kinship, religion, language, shared territory, nationality or physical appearance. Members of an ethnic group are conscious of belonging to an ethnic group'.[4]

Within the epidemiology literature on ethnicity and health, ethnicity has been defined as:

> '…the social group a person belongs to, and either identifies with or is identified with by others, as a result of a mix of cultural and other factors including language, diet, religion, ancestry and physical features traditionally associated with race'.[1]

Despite various examples of their interchangeable use in the literature,[5] ethnicity and race - the latter traditionally defined based on physical characteristics[1] - are not synonymous, although the two concepts often overlap.[1,3,6,7]

1.2.2 Measuring ethnicity

Due to its fluid, subjective, and multidimensional nature, ethnicity is inherently difficult to measure.[1,2,8,9] Previous studies have used a range of different methods to measure and categorise ethnicity, including place of birth, parents/grandparents' place of birth, and surname analysis.[10-14] Although often strongly inter-related, these markers are not synonymous with the concept of ethnicity in its entirety,[1,3,13,14] particularly in the context of globalisation, migration, inter-ethnic marriages/relationships, and within-country divisions; for example the 1947 partition of India into India and East and West Pakistan, and, in 1971, the partition of East and West Pakistan, now Pakistan and Bangladesh, respectively. Others have classified ethnic group based on the subjective assessment of the researcher, often focussing on the physical appearance of the participant, but large discrepancies between researcher- and participant-defined ethnicity have been reported.[15]

Although many have acknowledged the benefits of including multiple measures (i.e. including religion, place of birth, language, etc.) to capture its multidimensional nature,[8,16] self-definition has been referred to as the 'gold standard'[15] and is, for many in health research, the current preferred method of assessing ethnicity.[1,13,15,17-23] Indeed, self-definition has, in the last few decades, been adopted in many large-scale national surveys, including the UK census,[2] the UK School Census,[17] the Health Survey for England (HSE),[24,25] and other multi-ethnic population-based studies, such as the Newcastle Heart Project[26] and the Millennium Cohort Study.[27] In the UK, classification of self-defined ethnicity is often based on the categories used in the Census.[2,8,20] It is generally assumed that children under the age of 10-11 years are unable to reliably define their ethnicity so it is recommended that, in such cases, parent(s)/carer(s) define the ethnicity of the child.[17 28]

1.2.3 Describing and defining ethnic groups

There are inconsistencies in the literature regarding the definitions of, and terminology used to describe, specific ethnic groups,[1] and many authors have called for greater transparency and consistency in this regard.[1,3,29-31] This thesis focuses on the White British, Indian, Pakistani, Bangladeshi, Black African, and Black Caribbean populations in the UK. Throughout this thesis, Indian, Pakistani and Bangladeshi are collectively referred to as 'South Asian', and Black African and Black Caribbean are collectively referred to as 'Black African/Caribbean'. Consistent with the definitions proposed by Bhopal et al,[1] it is assumed that: White British refers to those of European ancestry who identify themselves as British; Indian, Pakistani and Bangladeshi refer to those with ancestral origins in the Indian subcontinent who identify as Indian, Pakistani, or Bangladeshi, respectively; Black African refers to those with ancestral origins in Africa who identify as Black African; and Black Caribbean refers to those with African ancestral origins whose family settled in the Caribbean before migrating to the UK and identify as Black Caribbean.[1] Although many previous studies have combined South Asian subgroups and Black African/Caribbean subgroups in health research, there is strong evidence demonstrating the heterogeneous nature of such groups.[26] Thus, in the empirical chapters of this thesis, the ethnic subgroups (Indian, Pakistani, and Bangladeshi, and Black African and Black Caribbean) are considered separately (and the term 'ethnic subgroups' refers to these five groups, unless specified otherwise). In the UK context, the term 'minority ethnic group' refers to those of non-White European or non-White British ethnicity.[1]

Throughout this thesis, when referring to the findings of previous studies, the terminology used in the original publications (i.e. the terminology chosen by the original authors) has been adopted, unless the original authors specified the exact ethnic profile of the study sample. For example, if a study describes an 'Asian' population and the authors provide no further information on the ethnicity of those included in the 'Asian' group, this thesis will adopt the same label when discussing their findings. However, if the authors refer to an 'Asian' population and specifically state that this group consists only of people of South Asian, Indian, Pakistani and/or Bangladeshi ethnicity, then the latter will be adopted when discussing their findings.

1.2.4 Ethnic profile of the UK population

The UK population is becoming increasingly ethnically-diverse.[32,32] In the most recent UK Census (2011), 87% (55 million) of people living in the UK described themselves as belonging to the White ethnic group (including White British, White Other, and White Irish), a decrease from 92% in 2001.[32] Among the non-White population, 2.3% identified as Indian, 1.9% Pakistani, 0.7% Bangladeshi, 3% Black (including Black Other and Black British), 2% 'Mixed' and 2% 'Other'. Based on current trajectories, the UK is predicted to become the most ethnically-diverse of all European and North American countries by approximately 2050.[33,34] If current trends continue, it is anticipated that the non-White population could outnumber the White population by 2070,[34] and among 0-4 year olds this could occur by 2056.[34] Indeed, over a quarter of children currently in state-funded primary schools in England are categorised as belonging to a minority ethnic group.[35]

1.2.5 Ethnic profile of the West Midlands population

The data underpinning chapters Two, Three, Four and Five were collected in the West Midlands region of the UK (see Section 1.7). The West Midlands region is ranked 2nd in the UK, behind London, for the proportion of the population who describe themselves as belonging to a non-White ethnic group.[32] In 2011, the ethnic distribution of the West Midlands population was 79.2% White British, 3.9% Indian, 4.1% Pakistani, 0.9% Bangladeshi, 1.1% Black African, and 1.5% Black Caribbean.[36,37,38] The ethnic distribution of the West Midlands Metropolitan County (consisting of Birmingham, Coventry, Dudley, Sandwell, Solihull, Walsall and Wolverhampton) was 66% White British, 6.8% Indian, 7.3% Pakistani, 1.8% Bangladeshi, 2.0% Black African, and 2.9% Black Caribbean.[38] Birmingham, located in the West Midlands, is the second biggest city in the UK. It is also one of the most multi-ethnic cities[38] with 53.1% White British, 6.0% Indian, 13.5% Pakistani, 3.0% Bangladeshi, 2.8% Black African, and 4.4% Black Caribbean.[38] The region thus provides an excellent setting for ethnicity and health research.

1.3 Ethnic differences in cardiovascular disease among adults in the UK

1.3.1 Coronary heart disease and stroke mortality

Coronary heart disease (CHD) and stroke are the global leading causes of death.[39] Despite declines in recent decades, CHD and stroke mortality collectively accounted for 1 in 4 deaths among the UK general population in 2009.[40] However, striking ethnic differences in CHD and stroke mortality are evident among UK adults.[41-49] Compared with White European adults (or the general population) in the UK, CHD mortality is 40-200% higher among UK South Asian adults[41,43-46,49,50] but 20-50% lower among UK Black African/Caribbean adults (20-30% lower among Black African/Caribbean women and approximately 50% lower among Black African/Caribbean men).[41,43,46,51] In contrast, stroke mortality is higher among both South Asian and Black African/Caribbean adults.[41,46,48,52]

It has previously been suggested that ethnic differences in CHD and stroke mortality among UK adults might be due to inequitable cardiovascular (CV) health care access and provision across ethnic groups.[53] However, a recent systematic review demonstrated that the increased risk of CHD mortality among UK South Asian adults is driven by higher incidence of CHD, as opposed to increased risk of mortality after diagnosis.[54] Similarly, there is evidence to suggest that the higher stroke mortality among Black African/Caribbean adults is due to higher stroke incidence, not post-stroke prognosis, as post-stroke survival is similar or better among Black African/Caribbeans compared with White Europeans.[52] These data suggest that efforts to reduce ethnic differences in CHD and stroke mortality should focus on primary prevention, in other words tackling the underlying causes of CHD and stroke, rather than secondary prevention.[54]

1.3.2 Cardiovascular disease risk factors

The INTERHEART study, a large-scale (n=30,000), case-control study spanning 52 countries and all inhabited continents, has shown that the major modifiable risk factors for CVD, including type 2 diabetes mellitus (T2DM), central obesity, smoking, physical inactivity, dietary intake, hypertension, insulin resistance, psychosocial factors and dyslipidaemia, are universally applicable across all populations and both sexes.[55] Collectively, these modifiable risk factors accounted for approximately 90% of the population attributable risk of myocardial infarction in each country, including those in the Indian subcontinent.[55] Similarly, a recent systematic review demonstrated the consistency of these conventional CVD risk factors among Black and White adults.[56]

Numerous studies have demonstrated ethnic differences in these modifiable CVD risk factors among UK adults, some, but not all, of which mirror the disparities in CHD and stroke mortality. For example, compared with White Europeans or the general population, South Asian adults have higher levels of insulin resistance,[47,57,58] fasting plasma glucose,[57] HbA1c,[59] fasting insulin and triglyceride concentrations[47,57,60,26] lower HDL-cholesterol,[47,57,59,60,26] higher risks of T2DM,[47,59,60,26,61-65]central obesity,[47,59,60,26,66-68] and metabolic syndrome,[47,66] along with lower levels of self-reported physical activity (PA).[69] Black African/Caribbean adults have higher levels of insulin resistance,[58,70] impaired glucose tolerance and higher fasting insulin,[71] higher systolic and diastolic blood pressure (SBP and DBP)[51,72] and increased risk of hypertension[51,61,66,70] and T2DM.[51,60,61,64] However, they also have a relatively ‘cardioprotective’ lipid profile (i.e. lower small-dense LDL- and VLDL-cholesterol, lower triglyceride concentrations, and higher HDL-cholesterol),[58,70,71] and, at least among men, less central obesity.[71,73] Thus, it has been hypothesised that central obesity and insulin resistance, along with low levels of PA, were likely to underlie the higher CHD and stroke mortality risk among South Asian adults.[74,42] Among Black African/Caribbean adults, it has been proposed that higher BP, T2DM and insulin resistance were likely to explain the higher stroke mortality, and the relatively cardioprotective lipid profile likely to explain their lower CHD mortality.[58,62,75-77]

To date, however, cross-sectional[51,60,74,] and case-control[57] studies, and, more recently, a large-scale longitudinal study[47] have been unable to fully explain the ethnic disparities in CHD and stroke mortality based on these conventional risk factors when measured in adulthood. For example, in the longitudinal Southall and Brent RE-visited (SABRE) study, the higher risk of CHD mortality among South Asian men persisted after adjustment for age, socioeconomic status (SES), hypertension, metabolic syndrome, glucose regulation, T2DM, insulin resistance, blood pressure, self-reported PA, smoking and lipid profile (measured approximately 20 years earlier at the age of 40-65 years).[47] In fact, when adjusted for these risk factors, the difference in CHD mortality almost doubled, from 60% to 114% higher risk among South Asians. Insulin resistance and central obesity largely explained the two-to-three-fold higher risk of T2DM among South Asian and Black African/Caribbean women in the SABRE study, but the differences among men remained unexplained.[64] The reasons for the higher insulin resistance and central obesity among South Asian and Black African/Caribbean women are unclear.[64] ‘Cardio-protective’ lipid profiles seem to contribute to, but do not fully explain, the lower CHD mortality among Black African/Caribbean adults.[77] Similarly, their higher BP and hyperglycaemia contribute to, but do not fully explain, their higher risk of stroke.[51] In the ARIC study in the US, stroke incidence remained 38% higher among Black Americans compared with White Americans after adjustment for conventional CVD risk factors.[78]

Several recent reviews have attempted to summarise the evidence regarding possible reasons for ethnic differences in CHD, stroke, insulin resistance and T2DM.[9,75,76,79-89] As summarised by Bhopal,[80] an article published in the Lancet in 2010 identified 23 potential contributors to the higher T2DM risk in Asian populations.[81] Numerous hypotheses have been proposed to explain the susceptibility of South Asian populations to metabolic abnormalities, for example the soldier-to-diplomat,[90] adipose tissue compartment overflow,[91] variable selection,[92] and mitochondrial efficiency[93] hypotheses. Nevertheless, all of these reviews have concluded that more research is needed to fully understand the underlying reasons for the ethnicity-related cardiovascular health inequalities.

1.3.3 Heterogeneity among ethnic subgroups

Importantly, South Asian and Black African/Caribbean subgroups, namely, Indian, Pakistani, Bangladeshi, Black African and Black Caribbean, are not homogenous in their cardiovascular risk profiles.[43,44,85,26,94-96]Among South Asians, Bangladeshi and Pakistani adults generally have more adverse CV health profiles than Indian adults.[26] For example, compared with the general population of England and Wales in 2001-2003, age-standardised CHD mortality was 75% and 62% higher among Bangladeshi and Pakistani men, respectively, and only 31% higher among Indian men.[44] In the Newcastle Heart Project, the prevalence of T2DM was 27% and 22% among Bangladeshi and Pakistani men compared with 15% among Indian men, and Bangladeshi and Pakistani adults were more likely to have a high waist-to-hip ratio. [26] Similar patterns were observed among women. Bangladeshi adults also had significantly higher LDL-cholesterol, serum triglycerides and fasting blood glucose concentrations, and lower HDL-cholesterol than Pakistani and Indian adults.[26] In the same study, however, high BP, hypertension and BMI-based obesity were least prevalent among Bangladeshi adults.[26] Among Black African/Caribbean adults, stroke mortality was 60% higher among men from the West Indies compared with the general population, but over

130% higher among men from West Africa.[41] However, while the previously reported lower CHD risk among Black African/Caribbean adults in the UK has persisted among Black Africans, there is some evidence to suggest that that the historically lower CHD mortality among Black Caribbean women is diminishing.[43,44] Such differences are likely to have been masked in the many studies in which these subgroups were combined.

The underlying reasons for these disparities are unknown. In the Newcastle Heart Project, income, education, self-reported standard of living, and occupational social class were higher among Indians compared with Pakistani and Bangladeshi adults.[26] Self-reported PA and fruit and vegetable intake were lower among Bangladeshi adults compared with Indian adults. [26] In another study, Indian adults were more likely to achieve the recommended levels of PA (based on self-report) compared with Bangladeshi and Pakistani adults.[95] Migration histories and religious beliefs also differ between subgroups, contributing to differences in environmental exposure and lifestyle behaviours. For example, Bangladeshi and Black African populations are more likely to have migrated to the UK more recently than their Indian, Pakistani and Black Caribbean counterparts.[9,26,97] In the 2011 Census, over 90% of Pakistani and Bangladeshi respondents were Muslim, whereas just under half of Indians were Hindu, and Black African/Caribbean were more likely to be Christian.[84,97] These differences could plausibly contribute to explaining the subgroup differences in CV health.

The potential impact of migration histories and religious beliefs on CVD risk is thought to be complex and multidirectional.[9,98,99] The process of migration, and events leading up to migration, can be stressful and, in some cases, traumatic.[100,101] Post-migration, some individuals/groups experience social isolation, a lack of social/cultural support networks, unemployment, and/or discrimination in the host country.[98,101] For these individuals, CVD risk could be increased by factors such as psychological stress,[101] which has been associated with increased risk of CVD.[102,103] As highlighted in a recent systematic review,[104] lack of social and cultural support in the host country could also influence health behaviours, such as PA, among migrants.

In terms of the potential impact of religious beliefs on CV health, research on the contextual influences on health behaviours among minority ethnic groups has highlighted lack of time because of religious commitments as a barrier to PA among some groups.[105] It is also possible that religious dietary laws, such as periods of prolonged fasting, could contribute to CV health. Prolonged periods of fasting for religious reasons have been associated improvements in body composition among SA Muslims,[106,107] but the long term effects of prolonged fasting on cardio-metabolic health are unknown as the current evidence-base is limited to studies with a very short follow-up.[106,107] These limited studies suggest that changes in body composition and metabolic profiles are transient.[106,107] A growing body of research suggests that repeated periods of weight loss followed by weight gain may lead to metabolic dysfunction and higher levels of body fat in the long-term,[108,109] so further research is required to investigate the long-term impact of prolonged periods of fasting for religious reasons on metabolism and metabolic health outcomes.

1.3.4 The importance of understanding early-life determinants of cardiovascular health inequalities

In the SABRE study, almost half of CHD deaths among South Asians occurred in those with T2DM at baseline, compared with 13% among White Europeans.[47] This suggests that South Asians might be more sensitive to the effects of T2DM on cardiovascular health. Interestingly, however, adjusting for T2DM and insulin resistance, among other factors listed above, did not explain the differences in CHD mortality.[47] Consequently, the authors postulated that the duration of exposure to insulin resistance and T2DM might better explain the differences in CHD and stroke risk among South Asian adults.[47] This hypothesis has not yet been fully explored, but is supported by evidence that South Asian adults develop CHD and T2DM at a younger age,[41,55,74,83,100] and that duration of T2DM is an independent predictor of CHD risk and CHD mortality.[111] Indeed, there is evidence to suggest that the younger average age of myocardial infarction (MI) among South Asians compared with White Europeans is largely explained by the earlier emergence of CVD risk factors.[110] Likewise, the duration of exposure to high BP is a strong, independent predictor of future risk of CVD events.[112-114] Black African/Caribbean adults develop hypertension and stroke at a younger age than White European adults,[51,115] so the same theory could also help to explain the differences in stroke and CHD risk among Black African/Caribbeans.

These observations highlight the importance of understanding the origins of the CV health inequalities across ethnic groups. It is well established that the atherosclerotic process begins in childhood,[116] and many modifiable CVD risk factors have been shown to track from childhood into adulthood, for example, BP,[117,118] PA and dietary habits,[119-121] lipid profile,[118] and obesity/adiposity,[118,122,123] and independently predict cardiovascular risk in adulthood.[124] For example, in the Young Finns Study, BP, fasting glucose and total cholesterol in childhood were collectively predictive of CV risk in adulthood, independent of changes in these parameters between childhood and adulthood.[125] Thus it is plausible that ethnic differences in CV risk factors in childhood could contribute to explaining the ethnic differences in CV health in adulthood.

1.4 Ethnic differences in CVD risk factors among children and adolescents in the UK

1.4.1 Previous and ongoing studies

Recently, two large studies have specifically examined differences in CV health and associated risk factors among South Asian, Black African/Caribbean and White British children and adolescents in the UK. The Child Heart And Health Study in England (CHASE) is a cross-sectional investigation of risk factors for CVD and T2DM among 9-10 year old White European, South Asian (Indian, Pakistani, Bangladeshi), and Black African/Caribbean children in London, Birmingham and Leicester which took place between 2004 and 2008 (http://www.chasestudy.ac.uk/). Overall, 5887 children took part in the main study, and approximately 2000 and 1000 children participated in sub-studies which involved more intensive measures. [126-132] The Determinants of Adolescent Social well-being and Health (DASH) study is a longitudinal study of the biological and social determinants of health among White European, South Asian (Indian, Pakistani and Bangladeshi) and Black African/Caribbean children in London (http://dash.sphsu.mrc.ac.uk/). The DASH cohort were 11-13 years old at baseline (n=6643, 2002/03) and have been followed-up at age 14-16 years (n=4779, 2005/06).[133] The DASH team also recently undertook a feasibility study to determine the best way to follow these children from school into early adulthood (n>650 at age 21-23 years, 2012-2014).

Recently, two bi-ethnic birth cohort studies were also established in the UK, one in Bradford[10] and one in Manchester,[134,135] both with the potential to explore prenatal and early-life differences between White European and Pakistani infants. The Born in Bradford (BiB) study (http://www.borninbradford.nhs.uk) collected data on 13,773 mother-offspring pairs between 2007 and 2011.[10] Half of the participants were South Asian, and 90% of these were from the Kashmir region of Pakistan. Approximately 1000 children from the BiB study participated in a sub-study investigating prenatal and early-life determinants of obesity and have been followed-up to the age of 4 years. The Manchester Children's Growth and Vascular Health study followed White European and South Asian, over 90% of whom were Pakistani, infants from birth to 3 years between 2002 and 2005.[134,135] A total of 215 infants (138 European and 77 South Asian[136] underwent measurements at birth and at one or more time-points (3, 6, 12, 24 and 36 months). The 1999 and 2004 ethnic minority-boosted HSEs[25,24] and the National Child Measurement Programme (NCMP) (http://www.hscic.gov.uk/ncmp) have also contributed to the evidence-base regarding ethnic differences in obesity prevalence among children in the UK/England, but both are limited by the use of BMI-based definitions of obesity which may be inappropriate for ethnic group comparisons[130,137,138] (see Chapter Four).

1.4.2 Evidence for early emergence of ethnic differences in CV risk factors

Collectively, the CHASE and DASH studies have contributed to a growing body of evidence which shows that ethnic differences in physiological and behavioural CV risk factors are apparent from late childhood or adolescence, and some, but not all, of these differences mirror the disease patterns observed in adults. For example, by the age of 10 years, South Asian children have elevated fasting insulin, HbA1c, C-reactive protein (CRP), triglyceride concentrations,[128] and body fat,[130] and lower HDL-cholesterol[127,128] compared with White European children. They are also less physically active[126] and have higher dietary energy and total fat intakes.[131] Black African/Caribbean children of the same age have higher HbA1c,[128] greater carotid intima-media thickness,[139] and elevated fasting insulin and CRP,[128] but lower LDL-cholesterol[127] and triglyceride concentrations[128,139] and higher HDL-cholesterol[128] compared with White European children. They also spend more time in vigorous-intensity physical activity (VPA)[126] and have lower dietary fat intake.[127] The higher SBP and DBP observed among Black African/Caribbean adults was evident among adolescents[143] but not among 9-10 year old children.[142] In contrast, the higher DBP often reported among South Asian adults was evident among 9-10 year old children in the CHASE study[142] but not among adolescents in the DASH study.[133] Consistent with the adult literature, the CHASE study has also demonstrated considerable heterogeneity among South Asian and Black African/Caribbean subgroups in late childhood. For example, the differences in fasting insulin, triglyceride concentrations, HDL-cholesterol and fat mass between South Asian and

White British children were significantly larger among Bangladeshi children than among Indian and Pakistani children,[128] as were the differences in dietary fat and energy intake.[131] Among Black African/Caribbeans, Black African children had lower total cholesterol and triglyceride concentrations[127] compared with White European children, which is consistent with the lower CHD risk among Black African/Caribbean adults. Black Caribbeans, on the other hand, had similar lipid profiles to White European children,[127] suggesting a possible shift away from historically 'cardioprotective' lipid profiles among UK-born Black Caribbean children.

Collectively, these findings show that ethnic differences in CVD risk factors are evident from late childhood or adolescence. Many of these variations mirror the chronic disease patterns observed in adults, so early intervention to reduce ethnic differences in CV risk factors during childhood may offer a good opportunity to reduce health inequalities later in life. However, to date, very few studies have explored ethnic differences in CV risk factors among children younger than 10 years of age, so the age at which these differences emerge is unknown. Indeed, the few limited studies of younger age groups have produced inconsistent results and have focussed, primarily, on the Pakistani community. For example, the BiB study demonstrated differences in early growth and cord leptin, a marker of adiposity, between White British and Pakistani infants during the first year of life[135,140] suggesting that the greater adiposity among Pakistanis might be evident from birth. However, in the Manchester birth cohort, differences in central adiposity, based on skinfold thickness, between Pakistani and White European infants at the age of 12 months were only evident among girls, not boys.[135] There were also no significant differences in fasting insulin, HDL-cholesterol,[136] and inflammatory factors including CRP,[134] by the age of 2-3 years. In contrast with observations in older age-groups, studies have also reported lower energy intake among 12 month old Pakistani infants compared with White British infants,[141] no differences in energy intake between 1-to-3 year old South Asian children compared with the (age-matched) general population,[142] and no significant differences in DXA-measured body fat percentage between South Asian and White British children under the age of 15 years.[143]

There is a distinct lack of data on ethnic differences in CV risk factors among young children, particularly between the ages of 3-to-9 years of age and among non-Pakistani minority ethnic groups. Such information could contribute to explaining the ethnic differences in CV health reported among older children, adolescents and adults, and could help to inform the design and timing of early interventions to reduce, prevent or delay these inequalities.

1.5 Summary

Unexplained ethnic differences in CVD and associated risk factors are evident among adults in the UK. A growing body of evidence suggests that these differences, including variations in body composition, fat distribution, physical activity, blood pressure, and dietary intake, emerge by late childhood or during adolescence. In general, these mirror the disease patterns observed in adults so could plausibly be implicated in the development of health inequalities later in life. Indeed, these modifiable risk factors are known to track into adulthood and predict future cardiovascular health. However, very few studies have examined ethnic differences in CV risk factors among children younger than 10 years of age, so it is unknown if such patterns are evident from a younger age. Such information could contribute to explaining ethnic differences in chronic disease risk later in life and help to shape the design and timing of early interventions to reduce future CV health inequalities.

1.6 Aims and objectives

Thus, the overall aim of this thesis is to investigate differences in lifestyle and physiological CV risk factors among 5-6 year old Indian, Pakistani, Bangladeshi, Black African, Black Caribbean and White British children in the UK.

The specific objectives of this thesis are to examine ethnic differences in:

1. Physical activity and sedentary time
2. Dietary nutrient intake
3. Systolic and diastolic blood pressure
4. Body composition and fat distribution

These important modifiable CV risk factors[55] are known to track from childhood into adulthood,[117-123] and have been associated with ethnic differences in CV and metabolic disease risk among adults.[47,51,64,60,68,144,145]

To achieve these objectives, cross-sectional baseline data from a childhood obesity prevention trial (the West Midlands ActiVe lifestyle and healthy Eating in School children (WAVES) study) were analysed. Detailed overviews of the relevant definitions, concepts, background literature and methodology are provided within the relevant chapters so are not discussed further in Chapter One. Chapter Two and Chapter Three investigate ethnic differences in lifestyle factors, namely physical activity, sedentary time, and dietary nutrient intake. Chapter Four and Chapter Five explore ethnic differences in physiological risk factors, specifically, body composition, fat distribution and blood pressure. Chapter One concludes with an overview of the research setting, the WAVES study.

1.7 The WAVES study

1.7.1 Overview

The WAVES study is a cluster-randomised controlled trial to assess the clinical- and cost-effectiveness of an intervention to prevent obesity among 6-7 year old children in the West Midlands. The intervention was a multicomponent, school- and community-based package of activities, targeting children and their families, designed to promote physical activity and encourage healthy eating and, thus, help children to maintain a healthy weight.

1.7.2 Funding and ethics approval

The WAVES study is funded by a grant from the National Institute for Health Research Health Technology Assessment programme. The study was approved by the National Research Ethics Service Committee West Midlands, The Black Country (10/H1202/69, 25/11/2010; ISRCTN: 97000586).

1.7.3 Sampling and participants

The sampling frame included all state-maintained primary schools within a 35 mile radius of the University of Birmingham (n=980). Information on ethnic mix, school size and the proportion of children receiving free school meals were obtained from the Local Education Authority. All schools were stratified by the proportion of White British, South Asian and Black African/Caribbean pupils and the top two quintiles in each stratum were identified. A weighted random sample of 200 of these schools was selected, whereby those with a high proportion of South Asian or Black African/Caribbean children had twice the chance of being selected. Chosen schools were randomly ordered within each ethnic stratum and sequentially invited to participate. Before each batch of invitations were sent out, response bias checks were undertaken to test for any differences in ethnic mix, proportion of children receiving free school meals, or school size between those who agreed to participate and those who declined. No significant differences were observed so recruitment proceeded until the target sample size of 54 schools was achieved. Written parental consent was sought for all Year 1 children (5-6 years) within each participating school.

Overall, 55.5% of children participating in the WAVES study lived in areas ranked in the most socially disadvantaged quintile of all areas in the UK; 30%, 52%, 89%, 85%, 75% and 75% of White British, Indian, Pakistani, Bangladeshi, Black African, and Black Caribbean children, respectively. The average index of multiple deprivation (IMD) score (an area-level marker of deprivation; described in detail in Section 2.3.7) for each ethnic group was 27, 36, 46, 49, 53, and 48, respectively, with higher scores indicating higher levels of deprivation in the area of residence. Although difficult to compare directly with other studies, the WAVES cohort is likely more socially disadvantaged compared with other similar studies of UK children. In a study of 469 9-11 year old (primarily White British) children in the South West of England, mean IMD score was 20.5 among boys and 19.8 among girls,[146] slightly lower (i.e. more affluent) than among White British children in the WAVES cohort, and considerably lower than the minority ethnic groups in WAVES. Similarly, in a subset of participants from the EarlyBird study,[147] average IMD score was lower (21 for boys and 22.6 for girls) than the IMD score of the WAVES cohort overall, and considerably lower than among the minority ethnic groups in WAVES.

Other UK studies of pre-adolescent children, however, have used alternative markers of SES, including parental occupation,[148,149] parental education,[148,150-152] car/house ownership,[150] and parental income,[153] so the SES of the WAVES cohort relative to these studies is unclear. For example, in the Southampton Women’s Survey (97% White British), a third of mothers in the cohort were educated to degree level or higher.[151] In ALSPAC (96% White British), 55% of parents were educated to A-level or degree level.[148] In the CHASE study, in which SES was defined based on parental occupation, 27% of parents were had ‘Managerial and Professional’ occupations (the highest occupational class), 14% were in the second highest category (Intermediate), 27% were classified in the Routine and Manual category, and 17% were economically inactive [149] A considerably higher proportion of South Asian parents were 'socioeconomically inactive' compared with White British and Black African Caribbean parents among whom higher proportions had Managerial and Professional occupations. This might suggest that the Black African/Caribbean participants in WAVES were more socially disadvantaged than those in the CHASE study, but this is unknown because the markers of SES are not directly comparable across studies (see Section 6.3.7 for further discussion of the complexities of measuring and defining SES).

1.7.4 WAVES study timeline

The WAVES study was conducted in two phases; half of the schools became involved in the 2010/2011 school year and the other half became involved in the 2011/2012 school year. For phase 1 schools, pupil and parent recruitment was carried out between January and April 2011 (Year 1, age 5-6 years) and baseline measurements were undertaken between April and July 2011. At the end of the measurement period, 50% of phase 1 schools were randomly allocated to receive the intervention and the remaining schools were allocated to the control group. The intervention was implemented throughout the 2011/2012 academic year (Year 2, age 6-7 years), and follow-up measures were undertaken between September and December 2012, January to April 2014, and September to December 2014. Phase 2 schools followed the same process but began a year later, so their baseline measurements were undertaken between April and July 2012. The measurements and procedures are described in detail in the relevant chapters.

1.8 Review of available methods

A range of methods are available for measuring PA and ST,[154-157] dietary intake,[159-165] and body composition[166-168] among adults and children. This section reviews these methods, describes their strengths and limitations, particularly for application in paediatric populations, and explains the rationale for the methods used in the WAVES study.

1.8.1 Measuring physical activity and sedentary time

PA/ST can be measured by subjective and objective methods.[154] Objective methods use equipment to measure physical movement and/or physiological exertion in response to PA (Section 1.8.1.1). Subjective methods rely on self-report, proxy parental report, or researcher-reported estimates of PA (Section 1.8.1.2).

1.8.1.1 Objective methods

1.8.1.1.1 The 'Gold standard'

Calorimetry is a highly accurate and reliable measure of PA energy expenditure, but is only suitable for lab-based, not free-living, studies because of the non-portable, expensive equipment required.[169,170] Doubly labelled water (DLW) is considered the gold standard method of measuring of free-living PA.[157,158,171] DLW requires participants to ingest a specified dose of water, labelled with two non-radioactive (i.e. stable) isotopes.[172] The participant provides biological samples (urine, saliva or blood) prior to ingestion, post-ingestion after a period of equilibration, and each day for the duration of the monitoring period (often about 10 days).[172] The deuterium (^{2}H) is eliminated as water and the ^{18}O is eliminated as water and carbon dioxide, so the difference between the two elimination rates is a measure of CO_2 production, a marker of energy expenditure.[172] Basal metabolic rate (estimated, or measured by calorimetry) and diet induced thermogenesis (assumed to be 10% of energy expenditure) are subtracted from energy expenditure to give PA energy expenditure. [158,172]

As a measure of total energy expenditure, DLW is highly accurate,[172-175] and reliable.[172,176,177] The main sources of error in DLW estimates of PA are: ingestion of an incorrect dose; error in laboratory techniques; inaccurate recording of results; and inaccurate estimation of basal metabolic rate.[155] DLW is safe and suitable for all age groups and can be used on large numbers of participants in epidemiological studies. The main burden for participants is the provision of daily biological samples throughout the measurement period. DLW is more expensive than most other measures of free-living PA, incurring costs for the isotopes, collection and storage of biological samples, and laboratory analyses and equipment.[169,172] The main limitations of DLW as a measure of PA the high costs and inability to capture information on PA subdomains such as intensity, frequency and duration.[169]

1.8.1.1.2 Pedometers

Pedometers measure the number of steps that an individual takes within a specified time period. They are very easy to use, small and lightweight, non-invasive, little burden to participants, one of the cheapest available objective methods for measuring PA, and produce simple, easy-to-interpret data (steps/day) which are comparable across studies and relatively reliable (intra-class coefficients of approximately 0.6-0.7 across multiple days[178])[155,179-182] Thus, in practical terms, pedometry is very convenient for large-scale studies.

However, pedometers cannot measure the intensity, duration or frequency of PA bouts,[180,181] are unable to detect non-step-based activities, such as cycling, swimming, and upper-body movement,[157,183] and give inaccurate step counts at slow (<2mph) walking speeds.[184] Differentiation of ST from non-wear-time requires the participant to complete a diary of times when the device was not worn, increasing participant burden,[185] and many pedometers lack the capacity to store daily output in their memory and instead rely on participants recording the data at the end of each day and resetting it for the following day.[185] This introduces risk of bias and error through participants forgetting to record, or consciously/subconsciously misreporting, number of steps.[186] Moreover, unsealed pedometers are not tamper-proof, so participants are able to hit the reset button and can deliberately increase the recorded number of steps by shaking the device, producing invalid data.[183]

It is also unclear how many days, and hours per day, of pedometer data are required for valid representation of habitual PA.[181,185] The Hawthorne Effect, whereby participants modify their behaviour because they are aware that they are being monitored,[187] is, to varying extents, a potential problem for all objective methods of measuring PA.[181,185] However, it is particularly pertinent to pedometry because many devices allow participants to see their output in real-time (i.e. they have access to continuous feedback about the number of steps they have taken[185]) and research suggests that wearing a pedometer might increase participants' PA.[188]

Because of these limitations, pedometer-estimates of total PA are less accurate compared with accelerometer estimates of PA,[180] and a recent review highlighted the lack of evidence regarding validity and reliability of pedometer estimates of PA in children under the age of 6 years.[185] Overall, pedometers provide accurate and reliable assessment of step count among adolescents and children aged 6 years and above,[185] but converting the output to PAEE is difficult,[180] so it is recommended that pedometers be used only to measure step-based PA, not total PA.[180,182,185]

1.8.1.1.3 Accelerometers

Accelerometers are motion sensors which detect movement in one or more plane(s). A range of devices are available.[180,189] Most are worn on a belt at the hip, waist, chest or wrist. Some devices measure movement in one plane (uni-axial devices), while others detect movement in two (bi-axial devices) or three (tri-axial devices) planes. Uni-axial devices provide the simplest, easiest-to-process, output, but are unable to detect movement in other planes and are, therefore, generally thought to provide less valid estimates of PA than multi-axial devices,[155] although several studies in children have reported little difference in PA estimates between uni-axial and tri-axial devices.[190,191]

Accelerometer models that have been validated against DLW as a measure of free-living PA are currently considered one of the most effective field-based options for measuring PA,[158] balancing cost (accelerometry is cheaper than DLW) with accuracy and reliability (accelerometry is superior to pedometers and subjective methods[180]). Accelerometers are not subject to recall bias and provide objective, standardised data which captures frequency, duration and intensity of PA.[180,189] They are highly portable and easy to use in the field. The greater precision of accelerometers, compared with pedometers and subjective methods, also improves statistical power for a given sample size.[180]

One of the main limitations of accelerometry is inability to detect non-ambulatory activities (e.g. rowing and cycling) or changes in intensity due to gradient or load.[192-194] Water-based activities might also go undetected as many devices are not waterproof. Also, for the safety of participants, ethics committees sometimes impose restrictions on the wearing of accelerometers during contact sports.[155] Another key issue in estimating PA from accelerometry is the lack of consensus regarding which accelerometer thresholds or regression equations should be used to convert accelerometer output to PAEE or time spent in different PA intensities.[181,182,195-197] Detection of non-wear time is also difficult with accelerometry as low counts can be reflective of either ST or non-wear time.[198,199] There is also some dispute in the literature regarding the duration of PA monitoring required for the data to be sufficiently representative of habitual PA,[198,200] and the epoch length required for optimal accuracy.[197] Longer epochs (e.g. sampling at one minute intervals) generally permit a longer duration monitoring period as battery life and memory are preserved, but shorter epochs (e.g. sampling at 5-10 second intervals) tend to give more accurate estimates of PA, particularly among children.[197] The data processing stage can also be quite time consuming, and the logistics of using accelerometers in large scale studies can also be relatively labour intensive compared with some methods; all devices have to be charged, set-up, delivered to participants, collected/returned, and the data downloaded and processed.[155]

1.8.1.1.4 Heart rate monitoring

Heart rate monitors are generally worn on a belt across the chest and assess the physiological response to PA by measuring heart rate within a specified time period. The main advantages of heart rate monitors are that they are easy to use, suitable for all age groups, can be used to measure free-living PA, are particularly effective at measuring high intensity PA, are relatively cheap compared with DLW and some accelerometers, and produce simple output that is easy to interpret.[158,181,201,202] The main limitations of heart rate monitors are the requirement for individual-level calibration of the association between heart rate and energy expenditure,[171,202] which is often impractical for large scale studies, and inability to differentiate between different sources of increases in heart rate (e.g. increases in heart rate due to emotional stimuli or pain versus increases due to PA).[203,204] As such, 'noise' is a greater source of measurement error for heart rate monitors than for accelerometers.[203] Moreover, there is a time-lag between the onset of PA and the associated increase in heart rate, and, similarly, there is a delay in heart rate returning back to resting levels after PA.[154,155] This time-lag can reduce accuracy of PA estimates if intervals between PA bouts are not long enough to allow heart rate to return to resting, or near-resting, levels, and is therefore problematic for studies of children whose PA is characterised by frequent, short bouts of PA.[155] It is also a limitation if study participants differ significantly in their levels of cardiorespiratory fitness[155] because fitness level influences the speed at which heart rate returns to resting levels after exercise.[204] Finally, many devices are not waterproof and therefore unable to measure water-based activities.

1.8.1.1.5 Combined motion sensing and heart rate monitoring

In recent years, technological and computing advances have contributed to the development of methods which combine both heart rate monitoring and motion sensing.[202] This approach is thought to improve accuracy and reliability of PA estimates by overcoming the limitations of using heart rate monitoring or accelerometry alone.[205-207] For example, heart rate data provides more accurate estimates for higher intensities of PA and exercise on a gradient (e.g. uphill walking),[202] whereas accelerometry is more accurate at lower intensities.[201,202] The Actiheart monitor is an example of a combined heart rate monitor and motion sensor which has been validated and calibrated in adults and youth.[190,191,205,207] However, to optimise accuracy of PA estimates, such devices require calibration at the individual level.[202] For example, the Actiheart monitor has a built-in step-test function for this purpose.[202] The Actiheart is waterproof, extremely lightweight (6 grams), and, unlike pedometers, the output cannot be tampered with. Thus, although more expensive than a standard accelerometer, pedometer or heart rate monitor, the Actiheart is a particularly attractive option for estimating free-living PA/ST in children.[155]

1.8.1.2 Subjective methods

1.8.1.2.1 Activity diaries

Assessing PA/ST using activity diaries requires the participant(s) to keep a diary/log of all activities that they undertake within a specified time period, recording information about the duration, frequency and intensity of all PA. Activity diaries benefit from minimal reliance on memory (participants record their activities prospectively), and a recent review concluded that self-reported activity diaries have moderate validity and reliability for assessment of PA among adolescents and adults.[208] For example, activity diaries used in the UK NDNS performed well against DLW estimates of PA among adolescents.[209] Children under the age of 11 years generally lack the cognitive and literacy skills required to accurately, and in sufficient detail, record activities, so parental involvement is recommended. However, parents are unable to accurately record activities performed by the child in their absence.[155,208,209] Among all age groups, the validity of activity diaries depends on the level of compliance of the participant(s) over the specified period of time.[209] Asking participants to complete the diary frequently, at short time intervals, increases the accuracy of the recorded information, but also increases the burden for participants and thus increases risk of collecting incomplete information.[155,181,209] Moreover, converting the recorded information into PA energy expenditure or METs[210,211] can be difficult and is somewhat subjective and based on the researcher's interpretation of the recorded information.[154,155,181,212]

1.8.1.2.2 Direct observation

Unlike the majority of other methods of assessing PA, direct observation provides contextual information about an individual's PA, which can be useful in tailoring PA interventions and understanding wider influences on PA.[155] However, direct observation can be intrusive and participants might modify their behaviours as a result of being observed.[187] It is also labour-intensive and therefore quite expensive and inappropriate for large scale studies. Another challenge in accurately estimating PA from direct observation is the subjective nature of the classification of activity intensity (or assigning of METs) by the researcher(s).[210-212] It is also possible that participants might modify their behaviour as a result of being observed,[187] thus reducing the validity of PA estimates. To date, direct observation has not been validated against DLW, primarily because observation periods are too short in comparison to the duration of PA monitoring by DLW.[158]

1.8.1.2.3 Questionnaires and interviews

PA questionnaires generally ask participants to indicate the frequency and duration of time spent in different intensity categories (e.g. light, moderate, vigorous) during a specified time period. Longer questionnaires tend to request additional detail about the types of activities performed, the duration and frequency of each activity, and, to ascertain intensity, the physiological responses that the participant experiences during each activity (e.g. perspiration rate, breathing rate, heart rate).[213,214] The recorded information is usually converted to estimates of PA energy expenditure based on published estimates of energy costs for different types of activities.[210,211]

The main limitations of questionnaire-based estimates of PA are low reliability and validity,[155, 158,213,215-218] errors in assigning METs to reported activities,[155] social desirability bias,[219] recall error and recall bias because data is collected retrospectively,[181,220] and potential misinterpretation or misunderstanding of questions by participants. Questionnaires and interviews that ask the participant to recall PA for a short, recent time period (e.g. the last 7 days) are less subject to recall error than those that ask for 'usual' or 'habitual' PA, but may be less representative of habitual PA as habitual activities that haven't been conducted in the recent, short time period will not be recorded.[155,181] Nevertheless, questionnaires remain widely used because of their low cost, ease of administration and interpretation of data, and the opportunity to assess large numbers of individuals in a relatively short time period.

1.8.1.2.4 Assessment of physical activity and sedentary time in the WAVES study

Physical activity is a secondary outcome in the WAVES study but an important factor in evaluating the effectiveness of the intervention in improving health behaviours. Thus, consideration of available methods for measuring PA and ST in the WAVES cohort took into account the need for an accurate, reliable method which is acceptable to young children, parents and teachers, and allows large numbers of children to be measured in a relatively short period of time.

Gold standard methods were not feasible for this study. DLW is too costly, involves complex analytical procedures, and is less acceptable to parents and teachers because of the need to collect biological samples at each data collection period. Calorimetry is impractical for field-based research, and direct observation on up to 1500 children at all four time-points over the study period was not within the capacity of the research team because of time constraints and the limited number of researchers available. Questionnaires and interviews were feasible in terms of time and cost, but do not provide sufficient detail regarding the frequency, intensity and duration of activities, particularly for this young age group in which PA patterns are very unstructured and spontaneous. Furthermore, participating parents were to be invited to complete questionnaires on socio-demographics and home/family environment, as well as a home-based dietary assessment for the child, so the addition of another questionnaire was undesirable because of the high participant burden and, as a consequence, potentially low response rates.

Pedometers were not deemed suitable because they can be tampered with and are unable to collect information on duration, frequency and intensity of PA and non-step-based PA. Accelerometry and heart rate monitoring were considered the best options because of their validity, reliability, acceptability and low burden to participants and, because of the aforementioned limitations of either method alone, a combination of the two methods was selected (the Actiheart monitor). As described above, combining accelerometry and heart rate monitoring can improve the accuracy of PA estimates and overcome the limitations associated with each of these methods alone. The Actiheart is attached by electrodes onto the chest, rather than worn on a belt, and can be worn can be worn at all times of the day (it is waterproof and can be worn during sleeping hours), so has the potential to increase compliance and wear-time. Full methodology, including processing and analyses of these data, is described and critiqued in Chapter 2.

1.8.2 Dietary intake assessment

1.8.2.1 Gold standard methods

Accurate measurement of dietary intake is extremely difficult, cannot be done without error,[165,221] and there is currently no consensus regarding the most accurate and reliable method of assessing dietary intake among children and adolescents.[159,164,165] DLW is considered the gold standard measure of energy intake,[162,222,223] but accurate measurement of energy intake does not necessarily translate into accurate measurement of specific nutrients or foods within the diet.[165,224] There are no true gold standard methods for measuring dietary nutrient intake.[165]

1.8.2.2 Doubly labelled water

As described in detail in Section 1.8.1.1.1, DLW is a highly accurate measure of energy expenditure.[172] In dietary surveys, DLW is used as a measure of energy *intake* based on the assumption that energy intake is equal to energy expenditure in conditions of weight stability.[160,172] The main advantages and disadvantages of DLW have already been discussed (Section 1.8.1.1.1). Other limitations, specific to dietary intake assessment, include the need for repeated measures of body weight over the monitoring period to test the assumption of weight stability, and inability to capture information about participants' eating patterns, nutrient intakes, and types of foods eaten.[165] One of the main strengths of DLW as a measure of energy intake is that, unlike subjective methods, it does not rely on participants' recall of past behaviours so is not subject to recall error or social desirability bias, the latter of which has been observed in children as young as 9 years.[225]

1.8.2.3 Biomarkers

Recent research has explored the use of biomarkers as objective, and potential gold standard, measures of dietary intake in adults[226,227] and youth.[228] For example, plasma antioxidants[226] such as carotenoids[228,229] have been used as markers of fruit and vegetable intake[228] and urinary nitrogen excretion has been used as a marker of protein intake.[230] Biomarkers are independent of the major sources of error in self-reported methods (e.g. recall bias, social desirability bias, etc).[165,227] However, at present, biomarkers are only available for a small number of nutrients and are often only sensitive enough to discriminate between high and low intakes.[231] Carotenoids are relatively accurate indicators of fruit and veg intake,[232] but are invasive and therefore not suitable for young children. Other limitations of biomarkers as measures of dietary intake include complex, costly and time consuming analytical procedures, participant burden associated with multiple biological sample collections, and the influence of non-dietary factors, such as PA, genetics and environmental factors, on biomarker concentrations.[165,227]

1.8.2.4 Diet history/recall interviews

Diet recall interviews are structured interviews which ask participants to provide information on all foods eaten within a specified time period, ranging from 24 hours to several years.[160-162,164,165] A key advantage of recall interviews compared with food diaries and FFQs is that participants do not require literacy and numeracy skills to take part.[165] However, for children under the age of about 10 years, dietary recall interviews can be too complex and difficult to comprehend, particularly if the recall period is longer than 24 hours,[233] so parent involvement is generally recommended.[234,235] Compared with DLW, dietary recall interviews generally overestimate energy intake among 3-12 year old children.[162] but among adolescents aged 15-

18 years provide the most accurate estimate of energy intake compared with other subjective methods.[162,236]

The main limitations of recall interviews are recall bias, recall error and social desirability bias.[220, 237] To reduce subjective interpretation of answers, interviewers should follow standardised procedures and, if possible, more than one interviewer should be present.[238] Recall interviews can collect detailed information on estimated portion sizes, cooking and food preparation methods used and types of foods consumed,[164] but are time consuming for participants and labour intensive for researchers, both in terms of data collection and data processing and analysis.[165]

1.8.2.5 24-hour multiple pass recall

The 24-hour multiple pass recall method uses an iterative, multiple-stage approach, designed to help trigger participants' memory of food consumed in the previous 24 hours.[239] The stages vary slightly between studies[131,240-242] but, in general, the participant is first asked to produce a quick list of all foods consumed with the previous 24 hours. Then the interviewer goes through the list with the participant to obtain detailed information about each item. This stage often includes prompts to orientate the participant through the day and help them to remember any items consumed that were not on the initial list. Finally, the participant is encouraged to use photographs, food models, or household measures to estimate the portion size of each item consumed.[131,239] A recent review of dietary assessment methods that have been validated against DLW concluded that 24-hour multiple pass recall over at least 3 days, including weekend days and weekdays, with a parent as a proxy reporter, is the most accurate measure of energy intake among children aged 4-11 years,[165] but validity decreases with age.[165]

1.8.2.6 Food frequency questionnaires

Food frequency questionnaires (FFQs) ask participants to indicate the frequency of consumption, within a specified time frame, of each food item from a pre-specified list of foods.[242,243] FFQs can be self-administered, interviewer-led, or, for children, completed by a parent. Limitations of FFQs include recall error and recall bias, social desirability bias, and inability to collect detailed information on portion sizes and cooking methods.[242,243] FFQs are limited by the use of standardised portion size estimates, standardised recipes for combination foods/dishes, and pre-specified list of foods which might not include all foods consumed by the participant.[160,165,242,243] Another potential issue with FFQs is that participants may misclassify food items if they are unsure which food group/type an item belongs to. Self-administered FFQs also require a level of literacy and cognitive capacity from respondents.[155]

In general, FFQs overestimate energy intake compared with DLW,[162] and give higher estimates of energy and nutrient intake compared with food diaries and recall interviews.[165] Among children, overestimation of dietary intake by FFQs is often attributed to the use of adult portion sizes when converting the recorded data into energy and nutrient intake.[162] Among both adults and children, FFQs also produce highly variable and unreliable estimates at the individual level.[162,242,243] In general, FFQs can be useful in ranking dietary intake in large studies, but are less informative for quantification of intake at the individual level.[165] Nevertheless, FFQs offer a quicker, cheaper, less labour intensive, and less burdensome alternative to DLW, biomarkers, food diaries and recall interviews.[242,243]

1.8.2.7 Food diaries

Weighed food diaries require participants to weigh and record all foods consumed within a specified time period. Some authors have described 7-day weighed food diaries as a ‘gold standard' method.[162] but research suggests that weighed food diaries generally underestimate energy intake compared with DLW,[162,159] especially among pre-adolescent children.[162,159] Nevertheless, of the available self-reported measures of dietary intake, weighed food diaries provide the most accurate self/parental-report estimate of energy intake for children aged 0.5-4 years.[162] Other advantages of this method are the prospective collection of data (which reduces reliance on memory of past intake), and the potential to collect detailed information on nutrient intakes, portion sizes, recipes and cooking methods.[159,160,165]

Limitations of weighed food diaries include high participant and researcher burden, misreporting of intake by the individual (e.g. because of social desirability bias[244] or errors in recording the information), the level of numeracy and literacy skills required of participants, and the need for all participants to have access to accurate and calibrated weighing scales. Furthermore, participants may forget to weigh all food items before consumption, or may not have access to scales at the time of eating, particularly if food is purchased and eaten on-the-go.[165] Young children (<9-11 years old) generally have limited ability to keep an accurate weighed food diary, so parent involvement is recommended for this age group.[162,165,234,235] Additionally, intensive and burdensome methods such as weighed food diaries may lead to participation bias.[165,231] Those who adhere to the study protocols (parents and/or children) are likely to be most highly motivated and interested in the research, and might also have higher literacy and numeracy skills, and these groups may differ in their dietary intake compared with those who do not/are unable to, comply with the research protocols.[165,231,245] It is also possible that participants might change their dietary patterns during the monitoring period, for example by choosing healthier foods, or foods that are easy or convenient to weigh.[164]

A variation of the weighed food diary is the semi-weighed food diary, but these are generally less accurate and reliable than weighed food diaries, and have many of the same limitations.[162,164,165] Estimated food diaries (i.e. non-weighed) are less burdensome for participants than weighed and semi-weighed food diaries, but provide less accurate information because they are subject to recall bias and social desirability bias,[164,244] and are based on estimated portion size which is often inaccurate,[230,246] particularly among children.[246,248] Both validity and reliability of portion size estimates improve with age[248] and with the use of aids, such as portion size photographs, even in children as young as four years.[249,250] As with all dietary intake assessment methods, inaccurate estimates of habitual intake can arise if the monitoring period is not representative of typical intake;[251] intake might differ on week days compared with weekends, or in school holidays compared with term time.

1.8.2.8 Direct observation

The main strengths and limitations of direct observation in relation to PA assessment have been described above (Section 1.8.1.2.2) and are also applicable in dietary assessment. The main benefit of direct observation in dietary assessment is that it provides information about the context of participants' dietary intake, gathering detailed information about eating patterns, the types of foods consumed, cooking methods, food processing/preparation methods, and time and location of consumption.[159,160,164,165] As discussed above, a key consideration for direct observation is that participants might modify their behaviour while being observed.[187] However, some research suggests that this effect is negligible among young children when using direct observation for dietary assessment.[252]

1.8.2.9 Food purchasing surveys

Another method used in dietary surveys is food purchasing inventories, whereby all foods purchased by the participant(s)/household within a specific time period are recorded.[253] The main limitation of this method is that not all food items purchased will be consumed within the specified time period, and, when assessed at the household-level, not all members of the household will consume all of the food items purchased.[254] The main advantage of this method is that the data can be collected quickly and easily through collection of receipts.[253] A variation of this method has been used in primary school children,[255] whereby children's food purchases at school were recorded, but this approach excludes children who take packed lunch to school, and does not provide information about dietary intake outside of school.

1.8.2.10 Dietary assessment in the WAVES study

The WAVES study required a dietary assessment method which is quick and easy to administer (allowing up to 1500 children to be assessed within a three month period), low cost, and suitable for children as young as five years. DLW was considered unfeasible because of the high costs of storing and analysing biological samples, the need for repeated anthropometric measurements within each data collection period, and inability to estimate nutrient intake or food types consumed. Direct observation was considered too labour intensive and time consuming for the number of children to be assessed in the short time period. Biomarkers would not have provided sufficient information for all nutrients and food types consumed, and were also considered inappropriate, and likely unacceptable to parents, because of the need for invasive biological samples.

Weighed and estimated food diaries would likely result in very low response and compliance rates because of the high burden on parents and the need for detailed, written information to be recorded. This was a particular concern because of the ethnic and socio-economic diversity of the cohort. As discussed above, children under the age of eight years generally lack the literacy, numeracy, and cognitive skills required to accurately estimate their dietary intake,[160] so proxy parental report was preferable to child-reported intake. As such, 24-hour recall interviews, or 24-hour multiple pass recall, with the child alone were not appropriate (all assessments took place during school time so parents were not present), and response rates would likely have been low if parents were required to visit the school to complete a recall interview on behalf of their child. Phone-based dietary recall interviews were beyond the capacity of the research team because of the amount of time needed for each interview.

Thus, parent-completed FFQs were considered the most suitable method for dietary intake assessment for the WAVES study because they are very quick and easy to complete, very low cost, easy to analyse, and acceptable to parents. One of the main limitations of parental-report dietary intake is that parents are unable to accurately report intake during periods of the day when they are not with the child (e.g. during school time). The Child and Diet Assessment Tool (CADET) is one of very few tools designed for children under the age of 8 years[256] and is designed to be completed by the researcher during the school day, and by parent(s) before and after school,[257] thus overcoming the issue of parental absence during the school day. The CADET is specifically designed for the rapid assessment of dietary intake in large numbers of children, and thus permitted whole classes of children to be assessed within one day.

1.8.2.11 Dietary assessment methods used in previous studies of minority ethnic groups in the UK

Previous studies of minority ethnic groups in the UK have used a range of methods for assessing dietary intake, including 24 hour recall interviews,[258-261] 24 hour multiple pass recall,[131] 7-day household inventory,[262,253] FFQs,[263-269] weighed food diaries,[258-260,270,271] non-weighed food diaries,[265,267] and combinations of these.[131,258-160,267] One study simply asked participants (Black African/Caribbean adults) to list the foods they most frequently consumed over the last two weeks.[272] Some of these studies reported using tools and/or methods that had been developed specifically for the ethnic groups of interest,[263,264,268,273] or tried to adapt existing tools to the study population.[266] Others used tools/methods developed for the general or White British population, with no adaptations,[162] or did not provide enough information to inform the reader which specific tool was used, so it is unclear how/for whom the tool was developed.[260,267] As discussed already, there are no true gold standard methods for dietary assessment,[162,165] so the validity and reliability of these methods within each ethnic group is unknown. Many of these above studies reported using strategies to improve the validity and reliability of the dietary assessment tools in the study population. For example, nutrient analysis software were supplemented with foods and dishes commonly consumed by the ethnic group(s) of interest,[131,262,264,266,268,270] bilingual/multilingual interviewers/researchers were used,[253,261,267,270] and questionnaires were translated.[262] Others used two or more methods, concurrently, to assess dietary intake and assessed agreement between the two methods in an attempt to generate data to support the validity of the method,[131,260,264,267,274] although these studies did not report ethnic-specific levels of agreement. For example, in the CHASE study, which used 24 hour multiple pass dietary recall, a subset (n~500 children) also completed a 7 day weighed food diary. The authors reported that the two methods were 'positively correlated', but did not report the level of agreement within each ethnic group.[131] Moreover, as discussed above, this approach does not provide any information about the accuracy of the method(s).

Sharma et al (1996) developed three ethnic-specific FFQs, one for Black African/Caribbean, one for White European and one for South Asian adults in the UK, based on a list of foods recorded by participants from each ethnic group in a 3-day food diary.[273,275,276] The FFQs were then compared with 4-day food diaries and 24 hour recalls.[273,275] For, Black African/Caribbean participants (n~40) correlations of 0.55 and 0.50 were observed, respectively[273,264,275] and good group-level, but not individual-level, agreement between methods.[264.275] Level of agreement between methods for South Asian and White British groups has, to my knowledge, not been published. These ethnic-specific FFQs have since been used for ethnic group comparisons in the UK,[264,268] and in a comparative study of Black African/Caribbean communities in the UK and Cameroon.[273]

Sevak *et al* designed an interviewer-administered FFQ for assessing dietary intake among South Asian women in the UK,[277] primarily for the purpose of evaluating the role of diet in breast cancer risk. They compared the FFQ with monthly, telephone-based, 24-hour recall interviews.[277] Correlations between the two methods were generally low-to-moderate for most micronutrients (ranging from 0.18 for vitamin A to 0.69 for vitamin D), and moderate for most macronutrients (ranging from 0.39 for carbohydrates to 0.60 for saturated fat).[277] But, again, agreement between the two methods does not indicate validity or reliability of their FFQ. Kassam-Khamis *et al* also developed an interviewer-administered FFQ for SAs in the UK and reported moderate reliability when participants repeated the FFQ about 3 months later (≥70% of participants were categorised in the same tertile at time one and time two for most macronutrients),[274] but the small sample size (n=14) limits generalisability of these findings. The same study also compared the FFQ data with 7-day weighed food diaries in 11 South Asian women and reported correlation coefficients ranging from 0.05 for fibre to 0.40 for carbohydrate.[274] At present, there are no ethnic-specific dietary assessment methods for UK children.

1.8.3 Body composition

A wide range of techniques, several of which are suitable for paediatric populations, are available for the assessment of body composition (i.e. distinguishing fat-mass and fat-free mass).[166-168] These techniques vary in accuracy, reliability, complexity, ease-of-use, financial costs, time demands, and suitability for different situations and populations.[166-168] Selecting the 'best' body composition assessment method(s) for epidemiological research is, for the most part, a trade-off between logistical considerations, financial constraints, and accuracy and reliability.

1.8.3.1 'Gold standard' methods

Theoretically, the only true 'gold standard' and direct method of assessing body composition is cadaver analysis.[278] All other methods involve indirect estimation of body composition based on certain assumptions, and are therefore subject to methodological error at the data collection stage, and error in the assumptions used to estimate body composition parameters from the raw data.[166]

1.8.3.2 Multi-compartment models

Most body composition assessment methods are based on the concept of the body as two chemically-distinct compartments, fat-mass and fat-free mass.[167,168,278] Isotope dilution (a measure of total body water, see Section 1.8.3.3), and densitometry (a measure of body density, see Section 1.8.3.4) are methods commonly used in two-compartment models.[279] These methods provide highly accurate estimates of body density and total body water.[279] respectively. However, estimation of fat mass is less accurate because the calculations assume constant densities and hydration of FM and FFM,[167] and yet FFM composition varies within and between individuals.[279] The three compartment model improves body composition estimates by further dividing fat free mass into total body water and fat-free dry mass.[279] Four compartment models, which further divide fat-free dry mass into proteins and minerals.[279] are considered the 'gold standard' method of assessing body composition in living humans, with excellent reliability and an estimated accuracy of +/-1%.[279,280]

1.8.3.3 Isotope dilution

Based on early observations showing that 73% of fat-free mass (FFM) is water, and stored triglyceride (fat) does not contain water,[281] accurate measurement of total body water (TBW) can be used to estimate fat-free mass and, in turn, fat mass, with a good level of accuracy.[167,279] Water labelled with a non-radioactive stable isotope is ingested in known quantities and, following a period of equilibration, the isotope concentration is measured in a single or multiple biological sample(s) (urine, saliva or blood) and used to calculate total body water.[279,282] Isotope dilution is quick and easy to administer, safe and acceptable in all age groups, easily performed in field studies, and provides accurate information on body composition at both group-level and individual-level.[279,282] The main disadvantages are the high costs of the isotopes and analytical procedures, the delay in obtaining the results, and error due to variation in hydration of fat-free-mass, particularly in young children.[166]

1.8.3.4 Densitometry

Densitometry is the assessment of body density (body mass divided by body volume) using techniques such as underwater weighing and air displacement plethysmography which measure body volume.[283] Hydrodensitometry involves submerging the participant underwater and measuring the amount of water displaced by the participant.[166] For air displacement plethysmography, participants are asked to sit inside a measurement chamber (an air displacement plethysmograph, or Bod Pod) and the amount of air displaced by the body is measured.[283,284] Hydrodensitometry is generally unacceptable among young children, but air displacement plethysmography is suitable for children as young as 4 years[166] and provides more accurate body composition compared with hydrodensitometry among children.[283,285] A limitation of densitometry is that, particularly among children, fat free mass density varies slightly based on its composition.[283] In validation studies using four-compartment criterion methods, hydrodensitometry and air displacement plethysmography tend to underestimate body fat percentage by approximately 2%.[283]

1.8.3.5 Dual-energy x-ray absorptiometry

Dual-energy x-ray absorptiometry (DXA) provides highly accurate measurements of bone mineral density,[166,286] and valid estimates of body fat percentage.[287-289] DXA has been validated against a multicompartment reference method among children and adolescents;[288] the mean difference between the two methods was 1%.[288] Studies suggest that DXA produces highly reliable estimates of fat mass and fat-free mass in repeated measures among children.[290] DXA body fat percentage reference data have been developed for 8-18 year old children and adolescents in the US, based on NHANES data on almost 9000 children,[291] so comparisons can be made with the general population. The limitations of DXA include the expensive, non-portable equipment, the need for specialist training for use of the equipment and interpretation of the output,[286] and increasing error with increasing levels of body fat.[288] Specifically, DXA overestimates higher levels of body fat but underestimates lower levels of body fat.[288] The radiation exposure is extremely low, far below the levels deemed harmful to humans,[166] so DXA is considered safe for all age groups,[286,287] but, nonetheless, might be intimidating for young children and requires them to lie still throughout the measurement.

1.8.3.6 Magnetic resonance imaging and computed tomography

Magnetic resonance imaging (MRI) and computed tomography (CT) are non-invasive, accurate measures of regional and total adipose tissue mass.[292,293] A key advantage of MRI and CT imaging is their ability to differentiate and accurately quantify total, subcutaneous and visceral adipose tissue, as well as bone, skeletal muscle and organs.[292,293] These imaging techniques are also capable of accurately identifying and quantifying ectopic fat depots stored in and around muscles and organs (e.g. around the heart and liver).[293] In repeated measures, CT and MRI provide reliable estimates of subcutaneous and visceral adipose tissue (coefficient of variation ~2%).[294-296] CT is generally quicker to perform than MRI, but emits higher levels of radiation.[293] Both MRI and CT imaging are expensive to perform and are limited to lab-based research because the imaging equipment is large and not easily moved. Use of the equipment and interpretation of the output also require specialist training and knowledge.[293] Moreover, MRI and CT imaging can be somewhat intimidating, especially for young children, and requires the subject to be still for a prolonged period of time.

1.8.3.7 Anthropometric measurements

A range of anthropometric indices have been used to indirectly estimate human body composition. These include measures of relative weight-for-height (e.g. the body mass index (BMI, kg/m^2), ponderal index (kg/m^3), and weight-to-height ratio,[297]), bodily circumferences (e.g. waist circumference and waist-to-hip circumference ratio),[298] and skinfold thickness.[166] These parameters can be self-reported by the participant, or objectively measured. All of these measurements are low cost, quick and easy to perform, highly available/accessible, require little specialist training, equipment or knowledge, are portable for fieldwork, and are acceptable for all age groups. For many of these anthropometric indices, reference data have been developed to facilitate comparison of values with the general population.[299,300] The most widely used anthropometric measurements are BMI, waist circumference and skinfold measurements.

1.8.3.8 Body mass index

The body mass index (BMI, kg/m^2) is a measure of relative weight-for-height and the most commonly used measure of overweight/obesity among adults and children.[297,301] Among adults, height remains relatively stable over time so any within-individual changes in BMI largely reflect changes in body weight. Thus, in adults, definitions of overweight and obesity are based on static BMI values which are applicable across sexes and age groups.[301] In contrast, height and weight change substantially throughout childhood and rates of growth vary by age, maturation and sex, so a single cut-off to define weight status among children is inappropriate.[302] Thus, for children and adolescents, BMI is converted to age- and sex-specific standard deviation scores based on a (national or international) reference population, and arbitrary cut-offs are used to define weight status (e.g. the 85th percentile for overweight and the 95th percentile for obesity.[299,300]

The main limitation of BMI is its inability to distinguish between fat-mass and fat-free mass.[303,304] Indeed, research suggests a prediction error of approximately 5-7% in estimating body fat percentage from BMI.[168] However, despite its inability to differentiate fat-mass and fat-free mass, and lower accuracy in detecting fat mass compared with skinfolds,[305] several studies have shown that children with a BMI above the 95th percentile for their age and sex are likely to be 'overfat',[306-310] and a BMI above the 95th percentile is as strongly associated with indicators of cardio-metabolic health, as are skinfolds above the 95th percentile.[308]

1.8.3.8 Waist circumference

A large body of evidence among adults suggests that central adiposity is a stronger predictor of cardio-metabolic health than is total adiposity.[311,312] Similarly, it appears that central fat is a strong, independent predictor of cardio-metabolic health among children.[311,313-315] Such findings are thought to be due to the accumulation of visceral adipose tissue in and around the organs.[316,317] Accurate measurement of central adiposity, particularly VAT, is limited to expensive techniques such as MRI and CT imaging,[293] but waist circumference is widely used as a surrogate marker of central adiposity in both adults and children.[311-318]

Waist circumference is a quick, easy, low-cost, non-invasive anthropometric measure, which can be easily used in the field, is acceptable for all groups and is associated with numerous markers of cardio-metabolic health in both adults and children.[311] Waist circumference varies with age, maturation and sex among children[319] so, as with BMI, children's crude waist circumference measurements are converted to standard deviation scores and compared with population-based reference data such as those developed for UK children.[319] Waist circumference is unable to differentiate between different fat depots, but validation studies using MRI or CT as the criterion method suggest that waist circumference is strongly associated with visceral adipose tissue among children.[168]

1.8.3.9 Skinfolds

Skinfold thickness measurements at various bodily sites have been widely used as a measure of body fat.[320] Skinfold measurements are quick and easy to perform, incur very few costs, require little specialist training, use portable equipment, and are acceptable across all age groups. Unlike other anthropometric measurements such as BMI, skinfold thickness measurements assess adiposity, not relative body dimensions. Indeed, the error in predicted body fat percentage from skinfolds is significantly lower than the error in predicted body fat percentage from BMI.[305,321,322] Moreover, skinfold measurements at multiple sites can facilitate characterisation of (subcutaneous) body fat distribution.[166,168,323] One of the main limitations of skinfold measurement is that they only provide information on the amount of subcutaneous fat, not visceral fat or fat-free mass.[323,324] Additionally, although the measurement technique is quite simple, skinfolds data are subject to substantial intra- and inter-observer variation.[166] Thorough training and adherence to standardised protocols can reduce this source of variation, but it cannot be prevented entirely. Other limitations include lack of consensus regarding which regression equations should be used to calculate body fat percentage from the raw data.[323,324]

1.8.3.10 Bio-impedance

When considered in relation to anthropometric measurements, bio-impedance analysis (BIA) is the only simple, predictive technique which estimates fat-free mass components of body composition.[166] BIA is based on the concept that different bodily tissues have different levels of electrical conductivity because of variations in water content. Fat-mass has low water content so is relatively resistant to electrical currents, whereas, fat-free mass has high water content, so is relatively conductive.[166,167,325] Thus, by applying an electrical current to the body and measuring the impedance (obstruction) by the body, TBW content can be estimated based on regression equations for the relationship between height^2/impedance and TBW.[167,326] As already discussed, TBW makes up approximately 73.2% of FFM in conditions of normal hydration, so, by estimating TBW from BIA, FFM can also be estimated.[279] FFM can be deducted from total body weight to give total fat mass, and, in turn, body fat percentage can be estimated.

BIA is quick and easy to perform, relatively cheap, acceptable in all age groups and suitable for fieldwork.[327] BIA estimates of body fat percentage are highly reliable, with intra-class correlation coefficients generally above 0.8 for repeated measurements[327] and minimal inter- and intra-observer variability.[327] However, accurate estimation of body composition parameters from BIA is dependent on the availability of validated, population specific equations.[130,325,327] A further limitation of BIA is that it assumes constant hydration of the fat-free mass components of the body.[279] Body composition estimates by BIA can also be influenced by factors such as dehydration, food consumption, temperature, and moderate-to-high intensity exercise shortly before BIA.[328,329]

1.8.3.11 Body composition assessment in the WAVES study

The WAVES study is investigating the effectiveness of an intervention to prevent obesity among young children. Thus, accurate indicators of body composition were highly important for this research. However, the selected methods also needed to be low cost, non-invasive, acceptable for use in young children, and feasible within the school environment. As such, techniques such as densitometry, MRI, CT imaging and DXA were unsuitable for the WAVES study because of the time, money and specialist equipment/training required, and the very limited portability of such equipment. Isotope dilution methods are acceptable for this age group, feasible for most school-based research, allow large numbers of children to be assessed in a relatively short period of time, and give relatively accurate and reliable results, but the costs of equipment and analyses was too high for this study. Self-reported and parent-reported estimates of weight status are low-cost, non-invasive, and quick and easy to obtain, but lack the validity and reliability required for a study in which body composition is a primary outcome.

The above methods were, therefore, deemed unsuitable or unfeasible for the WAVES study. Instead, a range of anthropometric measurements (namely, BMI z-score, skinfold thickness at five sites (bicep, tricep, subscapular, suprailiac and thigh) and waist circumference) and bio-impedance analysis were selected for inclusion in the battery of measurements in the WAVES study (described and critiqued in Chapter 4). All of these measurements are quick and easy to perform, non-invasive, require little specialist training and/or equipment, are acceptable for young children, allow large numbers of children to be measured in a short time-frame, and are easily undertaken in schools. BMI z-score is extremely quick and easy to measure, is highly reliable, has very low intra- and inter-observer variation, enables comparison with UK public health policy definitions of weight status and population-level obesity surveillance and prevalence data, and is the most commonly used indicator of weight status worldwide so facilitates comparison with the vast majority of similar epidemiological studies. Skinfold measurements and waist circumference add important information on total adiposity, central adiposity and fat distribution, which BMI alone is unable to provide. BIA provides a highly reliable measure of body composition, including information on fat-mass, fat-free mass, and components of fat-free mass, which BMI, skinfolds and waist circumference are unable to measure. As discussed above, the accuracy of BIA estimates of body composition are dependent on the availability of validated population-specific equations, so the absolute accuracy of BIA-estimates of body composition in this study might lack precision but are highly reliable and therefore facilitate intra-individual comparisons over the duration of this longitudinal study. The main limitations of the chosen battery of measurements are the lack of information on different fat depots, and the lack of a gold standard reference method, without which population-specific BIA equations cannot be developed for this study.

1.9 References

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CHAPTER 2

ETHNIC DIFFERENCES IN PHYSICAL ACTIVITY AND SEDENTARY TIME AMONG YOUNG CHILDREN IN THE UK

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2.1 Abstract

Background: Ethnic differences in physical activity (PA) are evident among adults in the UK and contribute to cardiovascular health inequalities. Similar ethnic differences in PA were recently reported among 9-10 year old children. Whether these differences are evident among younger children is unclear. **Aim:** To investigate ethnic differences in the amount and patterns of objectively-measured PA among 5-6 year old children in the UK. **Methods:** Cross-sectional PA and ethnicity data were available for 1045 children (52% male, 46% White British, 31% South Asian, 7% Black African/Caribbean). Adjusted multilevel regression models explored ethnic-differences in weekday, weekend, non-school-time and school-time PA and sedentary time (ST). **Results:** Compared with White British girls, Pakistani girls did less moderate-vigorous PA (MVPA) in school-time (-12.9min/day (95% CI: -20.1, -5.7)) and non-school-time on weekdays (-11.5min/day (-20.5, -2.6)), and were 51% less likely to accumulate 60min/day MVPA on weekdays (OR: 0.49 (0.26, 0.92)). Compared with White British boys, Pakistani boys were less sedentary and did more light PA (LPA) and MVPA at the weekend (ST: -56.4min/day (-90.3, -22.5); LPA: +33.0min/day (9.2, 56.8); MVPA: +23.3min/day (4.0, 42.7)) and in non-school-time on weekdays (ST: -43.7min/day (-61.8, -25.6); LPA: +32.8min/day (20.0, 45.7); MVPA: +11.2min/day (0.9, 21.4)). Black African girls were significantly less active (LPA:-42.6min/day (-80.3, -5.0)) and more sedentary (+65.3min/day (14.2, 116.4)) at the weekend compared with their White British peers, as were Black Caribbean boys (ST: +97.6min/day (3.2, 191.9); LPA:-79.7min/day (-146.7, -12.6)). **Conclusions:** This data highlights important ethnic subgroup differences in physical activity and inactivity among young UK children across different times of the week. Increasing MVPA among Pakistani girls is a public health priority.

2.2 Introduction

Physical activity (PA) is defined as, "any bodily movement produced by skeletal muscles that requires energy expenditure".[1] The cardiovascular and metabolic health benefits of regular PA are widely-reported in adults [2-5] and children.[6,7] For example, research has demonstrated strong, dose-response associations between higher levels of moderate-to-vigorous intensity PA (MVPA) and lower risk of cardiovascular disease (CVD), type 2 diabetes (T2DM), coronary heart disease (CHD), stroke, hypertension, cardiovascular (CV)-mortality, and all-cause-mortality among adults.[2,3,5,8-13] Similarly, higher levels of MVPA during childhood and adolescence are associated with improved lipid profiles, less insulin resistance, lower blood pressure, and reduced risk of metabolic syndrome.[6,7,14] A growing body of research has also demonstrated inverse associations between sedentary time (ST) and cardiometabolic health, independent of MVPA, in both adults[4,15-18] and children.[19,20] Indeed, physical inactivity is thought to be the fourth leading cause of mortality worldwide.[21]

Based on these health benefits, current UK guidelines recommend that adults aged 19-64 years should do at least 150 min/week MVPA, accumulated over the week in bouts of at least 10 minutes, or 75 min/week vigorous intensity PA (VPA).[22] It is advised that children and adolescents aged 5-18 years should do at least 60 minutes of MVPA every day of the week, with VPA incorporated on at least 3 days per week.[22] However, self-report and objectively-measured PA data suggest that a large proportion of the UK population do not reach these recommended levels of activity.[23,24] For example, self-report PA data from the 2008 Health Survey for England (HSE) suggest that only 39% of men and 29% of women do the recommended 150 min/week MVPA.[23] Objectively-measured PA data from the same HSE, however, suggest that only 6% of men and 4% of women meet the recommended PA levels.[23]

Among children aged 2-15 years, HSE self-report PA data suggest that 32% of boys and 24% of girls do 60min/day MVPA.[23] Objectively-measured PA data gave similar estimates (33% of boys and 21% of girls).[23] In age-stratified analyses, 51% and 34% of 4-10 year old boys and girls did the recommended levels of PA, compared with 7% of boys and no girls in the 11-15 year old age group.[23] There are no specific guidelines for sedentary time; the current advice is to minimise prolonged periods of sedentariness.[22]

Ethnic differences in PA have been reported among UK adults[25-28] and contribute to the unexplained ethnic differences in T2DM, stroke, and CHD mortality.[28-34] Self-reported MVPA appears to be particularly low among South Asian adults, especially women, compared with White Europeans or the general UK population.[25;26;35;36] In the 2004 HSE, Indian, Pakistani and Bangladeshi men and women were less likely, whereas Black Caribbean men and women were more likely, to meet the recommended levels of MVPA compared with the general population, based on self-report PA.[28] Bangladeshi men and women were least active. Based on these self-report HSE data, it has been estimated that low levels of MVPA among South Asian women account for over 20% of their excess CHD mortality.[35]

Considering the substantial health benefits of regular PA, and the strong tracking of PA from childhood into adulthood,[2,6] it is plausible that ethnic differences in PA during childhood could contribute to ethnic inequalities in stroke, hypertension, T2DM and CHD in adulthood.[29-34] However, the few available UK studies on ethnic differences in PA among children and adolescents have produced some conflicting results and have primarily been based on subjective measures of PA.[37] Subjective measures of PA may be inappropriate for ethnic comparisons[26] and generally provide less valid estimates of children's PA than do objective measures.[38,39]

In the CHASE study, objectively-measured MVPA was 6 min/day lower among 9-10 year old South Asian girls compared with White European girls.[40] A similar, but less marked and non-significant, trend was observed for South Asian boys (mean difference: -4 min/day (95% CI: -8, 0)). They also reported higher levels VPA among Black African/Caribbean boys and girls compared with White Europeans.[40]. In contrast, others have reported lower MVPA among Black African/Caribbean adolescent girls compared with their White counterparts, but no differences between Black and White adolescent boys.[41] Self-report PA data from the 2004 HSE suggests that 2-15 year old Pakistani boys are equally as likely as the general population to do the recommended 60 min/day MVPA.[42] In the same study, Bangladeshi and Indian boys, and Indian, Pakistani, Bangladeshi and Black African, but not Black Caribbean, girls were less likely to do 60 min/day MVPA compared with the general population.[42] The Millennium Cohort Study (MCS) reported lower objectively-measured total PA and MVPA among 7-8 year old Indian, but not Pakistani, Bangladeshi or Black children, compared with White children.[24] A smaller proportion of Bangladeshi children in the MCS did 60 min/day MVPA (32%) compared with White (51%) and Black (52%) children, although this difference was not significant.[24]

No study has yet explored ethnic differences in objectively-measured PA among UK children younger than 7 years, and none have segmented PA across the week. Such information would be of value in the development of effective, tailored interventions to increase PA in ethnically-diverse groups of children. Thus, the aim of this study was to explore ethnic differences in objectively-measured PA and sedentary time (ST), segmented across the week, and within and outside of the school day, in a large, ethnically-diverse cohort of 5-6 year old children in the UK. It was hypothesised that South Asian children would be less active and more sedentary than White British children, whereas White British and Black African/Caribbean children would be similarly active.

2.3 Participants and Methods

2.3.1 Study design

Cross-sectional baseline data from a UK childhood obesity prevention trial, the West Midlands ActiVe lifestyle and healthy Eating in School children (WAVES) study, were analysed.

2.3.2 Sampling and participants

The sampling frame included all state-maintained primary schools within a 35 mile radius of the University of Birmingham (n=980). Information on ethnic mix, school size and the proportion of children receiving free school meals were obtained from the Local Education Authority. All schools were stratified by the proportion of White British, South Asian and Black African/Caribbean pupils and the top 2 quintiles in each stratum were identified. A weighted random sample of 200 of these schools was selected and those with a high proportion of South Asian or Black African/Caribbean children had twice the chance of being selected. Chosen schools were randomly ordered within each ethnic stratum and sequentially invited to participate. Before each batch of invitations was sent out, response bias checks were undertaken to test for any differences in ethnic mix, proportion of children receiving free school meals, or school size between those who agreed to participate and those who declined. No significant differences were observed so recruitment proceeded until the target sample size of 54 schools was achieved. Written parental consent was sought for all Year 1 children (5-6 years, n=2462 eligible children) within each participating school.

2.3.3 Consent and ethical approval

Written parental consent was obtained for all participants (n=1372, 55.7% of eligible children). Verbal assent was sought from each child on the day of measurement. The study was approved by the National Research Ethics Service Committee West Midlands, The Black Country (10/H1202/69, 25/11/2010; ISRCTN: 97000586).

2.3.4 Measurement setting

At baseline, all consented children underwent a series of measurements, including anthropometric, dietary, PA, and psychological assessments, which took place within the school. All measurements were performed by trained researchers, following standardised protocols and using validated instruments. Parents were also invited to complete a questionnaire about sociodemographic characteristics and family habits. Data on each child's date of birth, ethnicity, and residential postcode were obtained from schools.

2.3.5 Ethnicity

Child ethnicity was defined by the parent(s), from a list of 18 options as used in the 2001 Census,[43] either through completion of the baseline questionnaire, or through school data. For this analysis, these data were categorised as White British (excluding Irish and Gypsy/Irish traveller), South Asian (Indian, Pakistani and Bangladeshi), Black African/Caribbean (Black African and Black Caribbean), or 'other' (including mixed ethnicity).

2.3.6 Physical activity measurement

Children were fitted with a waterproof, combined movement sensor and heart rate monitor (Actiheart, Cambridge Neurotechnology Ltd, Papworth, UK), which they were asked to wear continuously for 5 days. The Actiheart has excellent technical validity and reliability[44] and has been validated in children as young as 3 years.[45,46,47] The monitor was set to record acceleration and heart rate in 30-second epochs. All monitors were fitted on Wednesday, Thursday or Friday to include weekend days in the recording period.

Methods for deriving PA energy expenditure (PAEE) from combined heart rate and accelerometry data are still being developed for young children so only accelerometry data are used in this analysis. The accelerometer-only output has been validated as a measure of PAEE in children aged 3-6 years.[46,47] Accelerometry data were processed using a custom-designed program developed by the MRC Epidemiology Unit at Cambridge University. To facilitate comparison of accelerometry output between different accelerometer brands, the output from the Actiheart monitor, counts, was converted to the SI unit m/sec^2, using a conversion factor of 0.003.[44] For the main analysis, data recorded during sleeping hours (defined as 11pm until 6am[48,49]) and during non-wear time (defined as 90 consecutive minutes of zero acceleration and non-physiological heart rate data[50]) were removed. Only days on which at least 10 hours of data were recorded were included in the analysis as this provides a valid indication of habitual PA.[51] Duration of time (min/day) spent sedentary ($\leq$0.075m/s^2), and in light PA (LPA; >0.075m/s^2 and $\leq$1.75m/s^2), moderate PA (MPA; >1.75m/s^2 and $\leq$5.0m/s^2) and vigorous PA (VPA; >5.0m/s^2) were calculated.

2.3.7 Other measurements

Height was measured in duplicate to the nearest 0.1cm with a portable stadiometer (Leicester height measure, UK). Weight was measured to the nearest 0.1kg using Tanita bio-impedance scales (Tanita SC-331S, Japan). Body mass index (BMI) was calculated (kg/m^2) and converted to standard deviation scores (BMI z-score) based on age- and sex-specific UK reference data.[52] Skinfold thickness was measured at four sites (bicep, tricep, subscapular, and suprailiac) using Holtain calipers. Each site was measured twice and the average of the two readings was used. If readings differed by more than 0.4mm a third, and, if necessary, fourth reading was taken. The average of the two closest readings was used. The sum of the four sites was used as an indicator of adiposity. The child's residential postcode was converted to

English Index of Multiple Deprivation (IMD) scores, an indicator of area-level deprivation,[53] using specialised software (http://geoconvert.mimas.ac.uk/). The IMD ranks over 32,000 neighbourhoods in England based on their relative level of deprivation; information on 38 indicators across seven domains (education, employment, income, living environment, health, crime, and access to services) is combined to produce an overall IMD score with higher scores indicating higher levels of deprivation. IMD was categorised into quintiles based on rank within all areas of England.

2.3.8 Statistical analyses

All analyses were performed in STATA 10.1. Multilevel regression models adjusted for clustering at the school level were used to assess ethnic differences in sociodemographic, anthropometric and physical activity variables (dependent variables), with ethnicity as the independent variable in all models. Models adjusted for clustering, but no other confounders, are henceforth referred to as ‘unadjusted’ models. The unadjusted PA models were further adjusted for age, SES (continuous IMD score), month of measurement, and wear-time (as fixed effects). For each PA outcome variable (ST, total PA (acceleration divided by wear-time), LPA, MVPA, and VPA), separate models are presented for weekday, weekend, school-time (9am-3pm Monday-Friday), non-school-time (weekdays only) and the overall daily average. White British children were the reference group in all comparisons. Odds ratios (ORs) for ethnic differences in achieving the current PA guidelines (60min/day MVPA)[22] were derived from multilevel logistic regression models, adjusted as above. Sex-ethnicity interactions were significant in all models, so sex-stratified results are presented. All residuals were checked for normality. 95% confidence intervals (95% CI) are presented for all ethnic comparisons.

2.3.9 Sensitivity analyses

To test the robustness of the data, all analyses were repeated as follows: 1) Analyses included only days on which 24 consecutive hours of PA data was recorded (n=941 children remaining); 2) Analyses were restricted to children for whom at least 3 days of ≥10hr/day PA data was available (n=815 children remaining). For weekend- and weekday-specific models, analyses were restricted to children with 2 days of ≥10hr/day for weekday-only and weekend-only models (n=919 and 876 children, respectively)); 3) The definitions of waking hours were changed to 6am-10pm and 6am-9pm; 4) Models were further adjusted for BMIz and, separately, adiposity (sum of four skinfolds), to see if these attenuated any of the ethnic differences in PA.

2.4 Results

2.4.1 Participant characteristics

Ethnicity and valid PA data were available for 1045 children (76.2% of those with parental consent to wear an Actiheart; 5-6 years, 52% boys, 46% White British, 31% South Asian, 7% Black African/Caribbean). Those excluded from the analysis (n=327) either left the school or withdrew from the study (n=14), were absent from school or declined to wear an Actiheart (n=128), did not provide valid Actiheart data (n=178), or did not have their ethnicity recorded (n=7). Compared with those included in the analysis, excluded children were more socially disadvantaged ($p<0.001$), but were similar in terms of sex, age, ethnicity, BMIz and weight status.

Among included boys (Table 2.1), BMIz was lowest for Indian (-0.30 (95% CI: -0.63, 0.04)) and highest among Black African (0.98 (95% CI: 0.52, 1.44)) and Black Caribbean (0.70 (95% CI: -0.26, 1.65)) boys. Among girls, BMIz was lowest among Bangladeshi (-1.27 (95% CI: -2.04, -0.49)) and Indian (-0.31 (95% CI: -0.64, 0.02)) girls and highest among Black

African (0.31 (95% CI: -0.14, 0.77)) and Black Caribbean (0.61 (95% CI: -0.09, 1.30)) girls.

Among both boys and girls, White British and Indian children were less socially

Table 2.1. Participant characteristics by ethnicity among boys (top) and girls (bottom).

	White British (241 boys, 237 girls)	South Asian (170 boys, 153 girls)	Indian (58 boys, 45 girls)	Pakistani (95 boys, 100 girls)	Bangladeshi (17 boys, 8 girls)	Black African/ Caribbean (37 boys, 34 girls)	Black African (30 boys, 24 girls)	Black Caribbean (7 boys, 10 girls)
	Mean (95% CI)	**Mean (95% CI)**	**Mean (95% CI)**	**Mean (95% CI)**	**Mean (95% CI)**	**Mean (95% CI)**	**Mean (95% CI)**	**Mean (95% CI)**
BOYS								
Age (yrs)	6.28 (6.24, 6.33)	6.31 (6.26, 6.36)	6.30 (6.22, 6.38)	6.33 (6.27, 6.40)	6.21 (6.06, 6.36)	6.33 (6.23, 6.43)	6.31 (6.20, 6.42)	6.42 (6.19, 6.64)
Height (cm)	118 (118, 119)	120 (119, 120)	120 (118, 121)	120 (118, 121)	118 (115, 121)	123 (121, 124)	122 (120, 124)	123 (119, 127)
Weight (kg)	22.5 (22.0, 23.0)	22.8 (22.1, 23.4)	22.3 (21.2, 23.4)	23.0 (22.2, 23.9)	23.0 (21.0, 25.1)	25.9 (24.5, 27.2)	25.9 (24.4, 27.4)	25.6 (22.4, 28.7)
BMI z-scoreŦ	0.20 (0.03, 0.38)	-0.05 (-0.26, 0.15)	-0.30 (-0.63, 0.04)	0.05 (-0.22, 0.32)	0.22 (-0.40, 0.84)	0.93 (0.51, 1.35)	0.98 (0.52, 1.44)	0.70 (-0.26, 1.65)
SES (%)¶								
Higher SES	40.9 (34.8, 47.3)	14.7 (10.1, 20.9)	29.3 (19.1, 42.2)	6.3 (2.9, 13.4)	11.8 (3.0, 36.8)	5.4 (1.4, 19.2)	6.7 (1.7, 23.1)	0.0 (0.0, 0.0)
Lower SES	59.1 (52.7, 65.2)	85.3 (79.1, 89.9)	70.7 (57.8, 80.9)	93.7 (86.6, 97.1)	88.2 (63.2, 97.0)	94.6 (80.8, 98.6)	93.3 (76.9, 98.3)	100 (100, 100)
GIRLS								
Age (yrs)	6.28 (6.24, 6.32)	6.26 (6.21, 6.32)	6.22 (6.13, 6.31)	6.26 (6.20, 6.33)	6.52 (6.32, 6.72)	6.36 (6.26, 6.46)	6.38 (6.26, 6.50)	6.31 (6.12, 6.49)
Height (cm)	118 (117, 118)	117 (116, 118)	117 (115, 119)	117 (116, 118)	116 (113, 120)	122 (120, 123)	122 (119, 124)	122 (118, 125)
Weight (kg)	22.2 (21.7, 22.8)	21.9 (21.1, 22.6)	21.0 (19.7, 22.3)	22.5 (21.7, 23.4)	18.8 (15.8, 21.8)	24.7 (23.2, 26.2)	24.5 (22.7, 26.2)	25.2 (22.5, 27.9)
BMI z-scoreŦ	0.17 (0.02, 0.33)	-0.03 (-0.22, 0.16)	-0.31 (-0.64, 0.02)	0.21 (-0.02, 0.44)	-1.27 (-2.0, -0.49)	0.40 (0.01, 0.79)	0.31 (-0.1, 0.77)	0.61 (-0.09, 1.30)
SES (%)¶								
Higher SES	47.0 (40.6, 53.4)	15.0 (10.2, 21.6)	35.6 (23.1, 50.4)	7.0 (3.4, 14.0)	100 (100, 100)	20.6 (10.1, 37.3)	25.0 (11.7, 45.6)	10.0 (1.4, 46.7)
Lower SES	53.0 (46.6, 59.4)	85.0 (78.4, 89.8)	64.4 (49.6, 76.9)	93.0 (86.0, 96.6)	0.0 (0.0, 0.0)	62.7 (89.9, 0.0)	75.0 (54.4, 88.3)	90.0 (53.3, 98.6)

Means (continuous variables) and percentages (categorical variables), with 95% CIs, were obtained from multilevel regression models adjusted for clustering at the school level. White British children were the reference group in all comparisons. ŦBMI z-score is based on age- and sex-specific UK reference data.[52] ¶Socioeconomic status (SES) based on Index of Multiple Deprivation. Lower SES = the two most socially disadvantaged quintiles; Higher SES = the three less socially disadvantaged quintiles. To avoid over-adjustment, SES was not adjusted for clustering as both school and IMD are associated with the child's postcode/area of residence (percentages and 95% CIs were obtained from standard unadjusted regression models). IMD: index of multiple deprivation; SES: socioeconomic status; BMI: body mass index.

disadvantaged compared with Pakistani, Bangladeshi, Black African and Black Caribbean children ($p<0.001$).

2.4.2 Unadjusted physical activity and sedentary time by sex and ethnicity

There were no significant ethnic differences in average monitor wear-time (942 min/day). In models adjusted only for clustering but no other covariates, boys did significantly more MVPA than girls on both weekdays (mean difference: 14.9 min/day (95% CI: 7.9, 21.8)) and weekend days (mean difference: 12.6 min/day (95% CI: 4.6, 20.7). This pattern was consistent among White British, Indian, Pakistani and Black African children. Both boys (Table 2.2) and girls (Table 2.3) were more likely to accumulate 60 min/day MVPA on weekdays (73% of boys, 59% of girls) than on weekend days (57% of boys, 44% of girls, $p<0.001$). This pattern was consistent across all ethnic groups.

Among boys, the proportion of children doing 60 min/day MVPA was lowest among Black Caribbeans (61% (95% CI: 21, 88)) and highest among Black Africans (77% (95% CI: 58, 89)). Time spent in sedentary activities was lowest among Pakistani boys (391 min/day (95% CI: 372, 409)) and highest among Black Caribbean boys (433 min/day (95% CI: 354, 511)). Among boys, all ethnic groups were more sedentary at the weekend than on weekdays, with weekend ST ranging from 411 min/day (95% CI: 383, 440) among Pakistani boys to 596 min/day (95% CI: 498, 695) among Black Caribbean boys. Across all ethnic groups, the average time spent in MVPA during school-time was approximately 44-54 min/day for boys.

Among girls, the proportion of children doing 60 min/day MVPA was lowest among Indian (36% (95% CI: 22, 54)) and Pakistani (45% (95% CI: 33, 58)) girls and highest among Black African (65% (95% CI: 41, 83)) and ‘other’ ethnicity (71% (95% CI: 59, 82)) girls.

Table 2.2. Total PA and time spent in ST, LPA and MVPA by ethnicity among boys.

	White British	**South Asian**	**Indian**	**Pakistani**	**Bangladeshi**	**Black African/ Caribbean**	**Black African**	**Black Caribbean**
Average across all days								
Total PA (m/s^2)	0.48 (0.44, 0.51)	**0.54 (0.50, 0.58)**	0.53 (0.47, 0.60)	**0.56 (0.51, 0.62)**	0.46 (0.34, 0.57)	0.55 (0.47, 0.63)	0.55 (0.47, 0.64)	0.55 (0.38, 0.73)
ST (min/day)	431 (416, 447)	**391 (372, 409)**	409 (380, 438)	**372 (349, 396)**	430 (377, 482)	423 (388, 458)	421 (382, 460)	433 (354, 511)
LPA (min/day)	424 (413, 434)	**448 (436, 461)**	**447 (427, 467)**	**451 (435, 467)**	439 (404, 475)	428 (404, 452)	429 (403, 456)	422 (368, 476)
MVPA (min/day)	85 (76, 93)	**97 (88, 107)**	95 (80, 110)	**102 (90, 114)**	79.7 (53, 107)	103 (85, 121)	103 (83, 123)	105 (64, 145)
≥60min/day MVPA (%)	72 (65, 78)	72 (64, 79)	74 (60, 84)	72 (62, 81)	66 (41, 85)	74 (57, 86)	77 (58, 89)	61 (25, 88)
Weekdays								
Total PA (m/s^2)	0.51 (0.47, 0.55)	0.56 (0.51, 0.61)	0.56 (0.48, 0.63)	0.57 (0.51, 0.64)	0.51 (0.37, 0.64)	0.59 (0.50, 0.68)	0.59 (0.49, 0.69)	0.62 (0.42, 0.82)
ST (min/day)	405 (388, 421)	**374 (355, 393)**	392 (363, 422)	**359 (334, 383)**	393 (339, 447)	397 (361, 433)	405 (365, 445)	365 (284, 446)
LPA (min/day)	418 (405, 431)	**444 (429, 460)**	437 (415, 460)	**450 (431, 469)**	440 (400, 479)	397 (361, 433)	418 (389, 448)	456 (397, 515)
MVPA (min/day)	89 (80, 98)	100 (89, 110)	100 (84, 116)	101 (88, 115)	89 (60, 119)	**111 (92, 131)**	110 (88, 132)	116 (72, 161)
≥60min/day MVPA (%)	73 (65, 79)	74 (66, 82)	76 (62, 86)	74 (63, 83)	68 (41, 86)	90 (75, 96)	90 (73, 97)	87 (43.5, 98)
Weekend days								
Total PA (m/s^2)	0.44 (0.40, 0.48)	0.49 (0.44, 0.53)	0.47 (0.40, 0.54)	**0.52 (0.46, 0.58)**	0.36 (0.24, 0.49)	0.47 (0.37, 0.56)	0.50 (0.40, 0.61)	0.34 (0.14, 0.54)
ST (min/day)	476 (458, 494)	**433 (412, 454)**	447 (413, 480)	**411 (383, 440)**	495 (434, 557)	481 (436, 527)	450 (399, 501)	**596 (498, 695)**
LPA (min/day)	439 (426, 451)	455 (440, 469)	461 (437, 485)	454 (435, 474)	432 (389, 475)	435 (403, 467)	455 (419, 491)	**362 (292, 431)**
MVPA (min/day)	81 (71, 91)	91 (79, 103)	85 (67, 103)	**101 (85, 116)**	62 (29, 95)	88 (64, 112)	95 (67, 122)	65 (13, 117)
≥60min/day MVPA (%)	57 (50, 65)	59 (50, 67)	59 (45, 72)	63 (51, 73)	38 (18, 64)	52 (34, 70)	57 (36, 76)	36 (9, 76)
Non-school-time on weekdays								
Total PA (m/s^2)	0.43 (0.39, 0.46)	**0.50 (0.45, 0.54)**	0.47 (0.40, 0.54)	**0.53 (0.47, 0.58)**	0.42 (0.30, 0.55)	0.50 (0.41, 0.58)	0.48 (0.39, 0.57)	0.57 (0.38, 0.76)
ST (min/day)	299 (288, 310)	**267 (254, 281)**	287 (267, 308)	**252 (235, 269)**	288 (250, 326)	291 (266, 317)	297 (269, 326)	267 (210, 325)
LPA (min/day)	243 (235, 251)	**269 (260, 278)**	**259 (245, 274)**	**275 (263, 287)**	264 (238, 290)	253 (236, 271)	252 (232, 272)	258 (219, 298)
MVPA (min/day)	46 (40, 51)	**56 (50, 62)**	54 (44, 64)	**59 (50, 67)**	47 (28, 65)	59 (46, 71)	56 (43, 70)	68 (40, 96)
School-time (9am-3pm Mon-Fri)								
Total PA (m/s^2)	0.66 (0.60, 0.72)	0.68 (0.61, 0.75)	0.71 (0.61, 0.81)	0.66 (0.57, 0.74)	0.65 (0.48, 0.82)	0.76 (0.64, 0.88)	0.76 (0.64, 0.89)	0.74 (0.48, 0.99)
ST (min/day)	105 (97, 113)	106 (97, 116)	105 (92, 119)	107 (96, 118)	106 (84, 129)	106 (90, 121)	108 (91, 125)	97 (63, 131)
LPA (min/day)	175 (167, 182)	177 (168, 186)	179 (167, 191)	175 (165, 186)	176 (156, 197)	172 (158, 186)	166 (151, 182)	197 (167, 227)
MVPA (min/day)	44 (39, 49)	44 (38, 50)	46 (38, 54)	43 (36, 50)	42 (28, 56)	52.8 (43, 62)	53 (43, 64)	51 (30, 72)

School-time is defined as 9am-3pm Monday to Friday. Non-school-time is defined as weekdays excluding 9am-3pm. PA data is only included if at least 10hr of data was recorded during waking hours (6am-11pm). Total PA (m/s^2) is calculated as average acceleration divided by wear time for that specific period of time. Bold font indicates $p<0.05$ for difference with White British boys.

Table 2.3. Total PA and time spent in ST, LPA and MVPA by ethnicity among girls.

	White British	South Asian	Indian	Pakistani	Bangladeshi	Black African/ Caribbean	Black African	Black Caribbean
Average across all days								
Total PA (m/s^2)	0.45 (0.41, 0.48)	0.41 (0.37, 0.45)	0.41 (0.35, 0.48)	0.40 (0.35, 0.45)	0.48 (0.34, 0.63)	0.45 (0.37, 0.52)	0.42 (0.33, 0.50)	0.51 (0.38, 0.64)
ST (min/day)	436 (419, 452)	425 (406, 443)	418 (388, 448)	432 (409, 455)	390 (324, 455)	440 (406, 474)	451 (410, 491)	414 (354, 473)
LPA (min/day)	431 (420, 442)	**456 (443, 469)**	436 (414, 458)	**463 (447, 479)**	**482 (432, 531)**	448 (423, 473)	436 (406, 466)	**479 (434, 524)**
MVPA (min/day)	77 (69, 85)	66 (57, 75)	65 (50, 81)	64 (53, 76)	86 (52, 121)	76 (58, 94)	70 (49, 91)	91 (60, 123)
≥60min/day MVPA (%)	56 (47, 65)	43 (33, 54)	36 (22, 54)	45 (33, 58)	60 (24, 88)	60 (40, 77)	65 (41, 83)	50 (20, 79)
Weekdays								
Total PA (m/s^2)	0.46 (0.43, 0.50)	0.42 (0.38, 0.47)	0.44 (0.37, 0.51)	0.41 (0.35, 0.46)	0.50 (0.35, 0.66)	0.50 (0.43, 0.58)	0.48 (0.38, 0.57)	0.57 (0.43, 0.71)
ST (min/day)	418 (400, 435)	408 (388, 427)	400 (369, 431)	415 (392, 439)	374 (307, 440)	396 (361, 431)	403 (362, 444)	379 (319, 440)
LPA (min/day)	422 (408, 435)	**449 (434, 464)**	432 (408, 457)	**455 (436, 474)**	472 (418, 526)	**456 (428, 483)**	445 (412, 478)	**480 (432, 529)**
MVPA (min/day)	80 (71, 88)	68 (58, 78)	70 (54, 87)	**65 (52, 77)**	89 (53, 126)	88 (69, 107)	81 (58, 103)	105 (72, 138)
≥60min/day MVPA (%)	59 (50, 67)	48 (38, 58)	48 (32, 64)	47 (35, 59)	60 (24, 88)	73 (54, 86)	73 (51, 88)	72.7 (38, 91.9)
Weekend days								
Total PA (m/s^2)	0.42 (0.38, 0.45)	0.39 (0.34, 0.43)	0.38 (0.30, 0.45)	0.38 (0.33, 0.44)	0.46 (0.29, 0.63)	0.35 (0.27, 0.44)	**0.31 (0.21, 0.41)**	0.44 (0.30, 0.59)
ST (min/day)	471 (453, 490)	466 (444, 488)	471 (431, 510)	469 (442, 496)	427 (343, 511)	512 (471, 553)	**536 (486, 586)**	459 (387, 530)
LPA (min/day)	450 (437, 463)	467 (451, 483)	440 (411, 469)	**475 (456, 494)**	505 (441, 568)	426 (396, 457)	**404 (367, 441)**	476 (423, 530)
MVPA (min/day)	73 (63, 82)	64 (53, 75)	62 (42, 82)	62 (49, 76)	86 (43, 129)	58 (37, 79)	50 (25, 76)	75 (38, 111)
≥60min/day MVPA (%)	48 (40, 57)	39 (30, 49)	40 (24, 57)	37 (26, 49)	57 (22, 86)	37 (21, 56)	31 (15, 54)	50 (21, 79)
Non-school-time on weekdays								
Total PA (m/s^2)	0.40 (0.37, 0.44)	0.38 (0.34, 0.42)	0.39 (0.33, 0.46)	0.37 (0.32, 0.42)	0.43 (0.29, 0.57)	0.38 (0.34, 0.42)	0.41 (0.32, 0.50)	0.52 (0.39, 0.66)
ST (min/day)	306 (294, 318)	290 (276, 304)	289 (268, 311)	292 (275, 309)	274 (228, 321)	293 (269, 317)	301 (272, 330)	276 (233, 318)
LPA (min/day)	245 (236, 253)	**267 (258, 277)**	251 (235, 267)	**273 (261, 284)**	**287 (251, 323)**	**265 (247, 283)**	256 (235, 278)	**287 (255, 320)**
MVPA (min/day)	43 (38, 49)	38 (31, 44)	38 (28, 48)	36 (29, 44)	48 (26, 70)	48 (37, 60)	42 (29, 56)	61 (42, 81)
School-time (9am-3pm Mon-Fri)								
Total PA (m/s^2)	0.58 (0.52, 0.63)	**0.50 (0.44, 0.56)**	0.53 (0.44, 0.63)	**0.47 (0.40, 0.54)**	0.64 (0.44, 0.85)	0.62 (0.51, 0.73)	0.61 (0.48, 0.73)	0.65 (0.47, 0.84)
ST (min/day)	112 (104, 119)	118 (109, 127)	111 (97, 125)	123 (113, 134)	99 (69, 129)	103 (87, 119)	102 (84, 121)	104 (76, 131)
LPA (min/day)	177 (169, 184)	184 (175, 192)	183 (171, 196)	184 (174, 194)	185 (159, 212)	188 (174, 203)	188 (171, 205)	190 (166, 215)
MVPA (min/day)	37 (33, 41)	**30 (25, 35)**	32 (24, 40)	**28 (22, 34)**	40 (23, 58)	40 (31, 49)	38 (27, 49)	44 (28, 60)

School-time is defined as 9am-3pm Monday to Friday. Non-school-time is defined as weekdays excluding 9am-3pm. PA data is only included if at least 10hr of data was recorded during waking hours (6am-11pm). Total PA (m/s^2) is calculated as average acceleration divided by wear time for that specific period of time. Bold font indicates p<0.05 for difference with White British girls.

Bangladeshi girls did the highest amount of LPA (482 min/day (95% CI: 432, 531)) overall. Among girls, all ethnic groups were more sedentary at the weekend than on weekdays, with weekend ST ranging from 374 min/day (95% CI: 307, 440) among Bangladeshi girls to 536 min/day (95% CI: 486, 586) among Black African girls. Across all ethnic groups, the average time spent in MVPA during school-time was approximately 28-40 min/day for girls.

2.4.3 Adjusted ethnic differences in physical activity and sedentary time among boys

Hereafter, White British children are the reference group in all comparisons, unless stated otherwise. After adjusting for age, SES, month of measurement, wear-time, and school (Table 2.4 and Figure 2.1), Pakistani boys were significantly less sedentary (-50 min/day (95% CI: -77, -24)) and more active (adjusted mean difference in total PA: 0.08 (95% CI: 0.01, 0.14); LPA: 35 min/day (95% CI: 17, 53) ; MVPA: 16 min/day (95% CI: 0.4, 31)) compared with White British boys. These differences were mainly driven by PA outside of school time, not during school time. A similar pattern was also seen among Indian boys, but these differences were not significant. There was also some evidence to suggest that Black African/Caribbean boys did more MVPA than White British boys (adjusted mean difference: 17.6 min/day (95% CI: -2.5, 37.6), p=0.087). This pattern was reflected in both Black African and Black Caribbean boys and was driven by higher MVPA on weekdays, not on weekend days. Black African boys did more VPA overall (adjusted mean difference: 3.7 min/day (95% CI: 0.1, 7.2)), mainly due to higher VPA during school-time (adjusted mean difference: 2.9 min/day (95% CI: 0.3, 5.4); data not shown)). Conversely, Black Caribbean boys were more sedentary and did less LPA at the weekend. There were no significant ethnic differences the odds of accumulating 60 min/day MVPA among boys.

2.4.4 Adjusted ethnic differences in physical activity and sedentary time among girls

Compared with White British girls, after adjusting for age, SES, month of measurement, wear-time, and school, total PA was lower among Pakistani girls (Table 2.5) who did less MVPA (Figure 2.1), particularly on weekdays. There was also some evidence for lower VPA among Pakistani girls (-2.4 min/day (-5.1, 0.3), p=0.085). There were, however, no significant differences in ST between White British and Pakistani girls, and Pakistani girls did more LPA (28.5 min/day (95% CI: 9.8, 47.1)), particularly during non-school-time. Similar patterns were also seen for Indian girls (less MVPA but more LPA and similar ST compared with White British girls), but these differences were not significant. Bangladeshi girls accumulated more LPA overall, mainly due to higher LPA during non-school-time, but did not differ significantly from White British girls in terms of ST, total PA, or MVPA. Black African girls did less LPA and were more sedentary on weekend days. Black Caribbean girls were less sedentary during non-school-time and there was evidence to suggest that they did more LPA. Pakistani girls were 51% less likely to accumulate 60 min/day MVPA on weekdays (OR: 0.49 (95% CI: 26.4, 92.4)), but there were no significant differences on weekend days or among other ethnic minority groups across the week.

2.4.5 Sensitivity analyses

In general, the size and direction of the differences remained very similar across all sensitivity analyses. Ethnic differences in LPA and ST were slightly larger in the 24-hr models than in the main analysis, but the overall findings remained unchanged, and further adjustment for BMI z-score or adiposity did not explain any of the ethnic differences (data not shown).

Table 2.4. Adjusted ethnic differences in physical activity and sedentary time among boys (White British as the reference category).

	White British	**South Asian**	**South Asian subgroups**			**Black African/ Caribbean**	**Black African/Caribbean subgroups**	
			Indian	**Pakistani**	**Bangladeshi**		**Black African**	**Black Caribbean**
	Adjusted mean (95% CI)	**Adjusted mean difference (95%CI)**	**Adjusted mean difference (95%CI)**	**Adjusted mean difference (95%CI)**	**Adjusted mean difference (95%CI)**	**Adjusted mean difference (95%CI)**	**Adjusted mean difference (95%CI)**	**Adjusted mean difference (95%CI)**
Average across all days								
Total PA (m/s^2)	0.48 (0.44, 0.51)	**0.06 (0.01, 0.12)**	0.06 (-0.01, 0.13)	**0.08 (0.01, 0.14)**	-0.01 (-0.13, 0.11)	0.08 (-0.01, 0.17)	0.08 (-0.01, 0.17)	0.08 (-0.10, 0.26)
ST (min/day)	433 (418, 448)	**-37.7 (-59.8, -15.7)**	-27.8 (-56.8, 1.3)	**-50.4 (-76.9, -23.9)**	-8.0 (-57.8, 41.7)	-16.5 (-51.5, 18.5)	-18.9 (-57.1, 19.4)	-11.8 (-84.3, 60.8)
LPA (min/day)	423 (414, 433)	**26.4 (11.8, 41.0)**	18.4 (-1.1, 37.9)	**34.9 (17.1, 52.6)**	12.5 (-21.1, 46.1)	-0.3 (-24.0, 23.5)	2.0 (-24.0, 28.0)	-6.1 (-55.5, 43.2)
MVPA (min/day)	85 (77, 94)	11.8 (-0.9, 24.5)	10.2 (-6.5, 26.8)	**15.7 (0.4, 30.9)**	-4.1 (-32.7, 24.4)	17.6 (-2.5, 37.6)	17.7 (-4.3, 39.7)	18.4 (-23.2, 60.1)
Weekdays only								
Total PA (m/s^2)	0.51 (0.47, 0.55)	0.05 (-0.01, 0.11)	0.06 (-0.03, 0.14)	0.06 (-0.02, 0.13)	0.00 (-0.14, 0.14)	0.09 (-0.01, 0.18)	0.08 (-0.03, 0.19)	0.12 (-0.09, 0.32)
ST (min/day)	408 (392, 424)	**-31.4 (-54.4, -8.3)**	-20.0 (-50.1, 10.1)	**-42.5 (-70.2, -14.9)**	-15.6 (-67.0, 35.9)	-16.0 (-52.1, 20.1)	-8.3 (-47.7, 31.2)	-53.2 (-127.9, 21.5)
LPA (min/day)	421 (410, 431)	**23.8 (8.1, 39.4)**	12.0 (-8.6, 32.5)	**33.7 (15.0, 52.5)**	16.8 (-18.5, 52.1)	-2.7 (-27.6, 22.2)	-8.8 (-35.9, 18.4)	27.2 (-24.4, 78.7)
MVPA (min/day)	91 (81, 100)	8.3 (-5.5, 22.1)	9.5 (-8.8, 27.7)	8.9 (-7.7, 25.5)	-1.1 (-32.4, 30.1)	19.0 (-3.0, 41.0)	17.8 (-6.4, 41.9)	24.3 (-21.5, 70.0)
Weekend days only								
Total PA (m/s^2)	0.44 (0.40, 0.48)	0.05 (-0.01, 0.11)	0.04 (-0.04, 0.12)	**0.09 (0.01, 0.16)**	-0.06 (-0.20, 0.07)	0.04 (-0.07, 0.14)	0.08 (-0.04, 0.19)	-0.09 (-0.30, 0.12)
ST (min/day)	478 (460, 495)	**-37.5 (-65.2, -9.8)**	-29.5 (-65.3, 6.2)	**-56.4 (-90.3, -22.5)**	16.9 (-44.4, 78.3)	-7.4 (-55.1, 40.2)	-38.4 (-90.8, 13.9)	**97.6 (3.2, 191.9)**
LPA (min/day)	435 (422, 447)	**25.5 (6.2, 44.8)**	24.1 (-1.2, 49.3)	**33.0 (9.2, 56.8)**	-0.1 (-43.5, 43.2)	0.9 (-32.8, 34.7)	23.6 (-13.5, 60.8)	**-79.7 (-147, -12.6)**
MVPA (min/day)	80 (70, 90)	11.8 (-3.9, 27.6)	5.2 (-15.1, 25.6)	**23.3 (4.0, 42.7)**	-16.3 (-51.2, 18.5)	7.5 (-19.4, 34.3)	15.6 (-14.1, 45.2)	-16.7 (-70.1, 36.8)
Non-school-time on weekdays								
Total PA (m/s^2)	0.42 (0.39, 0.46)	**0.07 (0.01, 0.13)**	0.06 (-0.02, 0.13)	**0.09 (0.02, 0.16)**	0.01 (-0.12, 0.14)	0.07 (-0.02, 0.16)	0.06 (-0.04, 0.16)	0.14 (-0.05, 0.33)
ST (min/day)	301 (291, 311)	**-31.4 (-46.5, -16.4)**	-18.1 (-38.0, 1.7)	**-43.7 (-61.8, -25.6)**	-17.7 (-51.7, 16.3)	-13.5 (-37.6, 10.6)	-10.3 (-36.6, 15.9)	-33.0 (-82.7, 16.8)
LPA (min/day)	245 (238, 252)	**23.0 (12.4, 33.7)**	11.2 (-3.0, 25.4)	**32.8 (20.0, 45.7)**	16.6 (-7.8, 41.0)	2.8 (-14.6, 20.1)	1.8 (-17.1, 20.7)	11.8 (-24.1, 47.7)
MVPA (min/day)	46 (41, 52)	**9.0 (0.5, 17.6)**	7.9 (-3.4, 19.2)	**11.2 (0.9, 21.4)**	1.2 (-18.3, 20.7)	11.0 (-2.8, 24.7)	8.9 (-6.2, 24.0)	20.3 (-8.3, 48.9)
School-time (9am-3pm Mon-Fri)								
Total PA (m/s^2)	0.67 (0.61, 0.73)	0.01 (-0.07, 0.09)	0.04 (-0.06, 0.15)	-0.01 (-0.11, 0.08)	-0.02 (-0.19, 0.16)	0.09 (-0.03, 0.22)	0.10 (-0.04, 0.23)	0.07 (-0.19, 0.32)
ST (min/day)	106 (98, 115)	0.7 (-10.1, 11.4)	-1.1 (-14.9, 12.6)	2.0 (-10.8, 14.9)	1.5 (-21.9, 24.8)	-1.6 (-17.8, 14.6)	1.9 (-15.8, 19.6)	-15.1 (-48.7, 18.4)
LPA (min/day)	177 (171, 182)	0.8 (-7.2, 8.8)	1.0 (-9.3, 11.3)	0.5 (-9.1, 10.0)	1.4 (-16.2, 19.1)	-5.3 (-17.6, 7.1)	-9.5 (-22.9, 4.0)	12.1 (-13.5, 37.6)
MVPA (min/day)	45 (40, 50)	-1.2 (-7.9, 5.5)	0.6 (-8.1, 9.3)	-2.5 (-10.5, 5.6)	-2.6 (-17.4, 12.2)	7.2 (-3.1, 17.5)	8.1 (-3.2, 19.4)	2.8 (-18.6, 24.2)

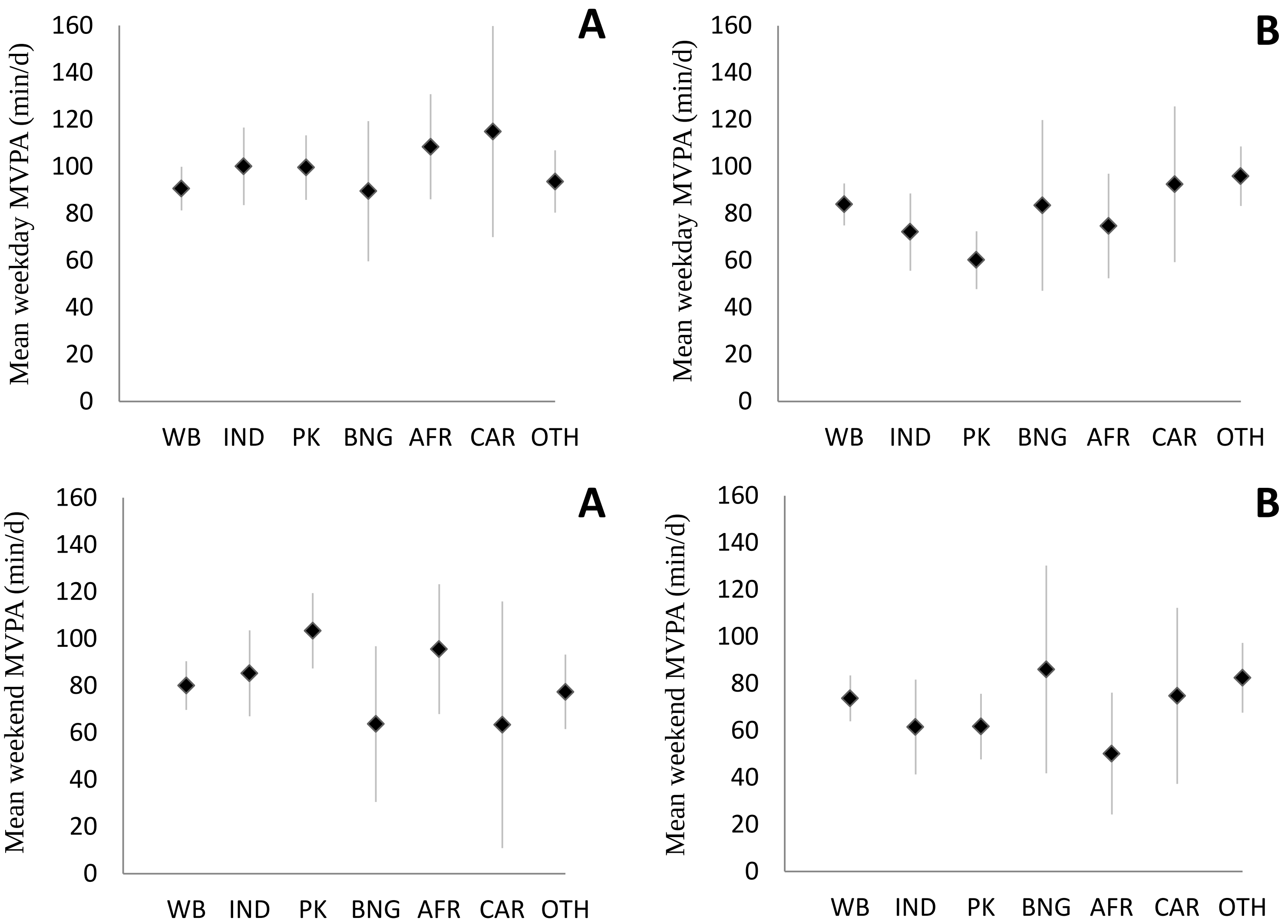
Values for White British boys, the reference category, are adjusted means. For all other ethnic groups, values are adjusted mean differences when compared with White British boys. All values are adjusted for age, SES (continuous IMD score), month of measurement, wear-time, and school (random effect). PA – physical activity; ST – sedentary time; LPA – light physical activity; MVPA – moderate-to-vigorous physical activity.

Table 2.5. Adjusted ethnic differences in physical activity and sedentary time among girls (White British as the reference category).

	White British	South Asian	South Asian subgroups			Black African/ Caribbean	Black African/Caribbean subgroups	
			Indian	Pakistani	Bangladeshi		Black African	Black Caribbean
	Adjusted mean (95% CI)	**Adjusted mean difference (95%CI)**	**Adjusted mean difference (95%CI)**	**Adjusted mean difference (95%CI)**	**Adjusted mean difference (95%CI)**	**Adjusted mean difference (95%CI)**	**Adjusted mean difference (95%CI)**	**Adjusted mean difference (95%CI)**
Average across all days								
Total PA (m/s^2)	0.46 (0.42, 0.50)	**-0.06 (-0.11, -0.01)**	-0.05 (-0.12, 0.03)	**-0.07 (-0.13, -0.01)**	0.01 (-0.14, 0.16)	-0.03 (-0.11, 0.05)	-0.06 (-0.15, 0.04)	0.03 (-0.11, 0.16)
ST (min/day)	432 (415, 448)	-5.7 (-27.7, 16.3)	0.3 (-29.9, 30.5)	-5.2 (-31.1, 20.8)	-49.6 (-113.2, 13.9)	-0.3 (-36.0, 35.3)	13.4 (-27.4, 54.2)	-36.3 (-95.2, 22.7)
LPA (min/day)	429 (418, 440)	**25.2 (9.3, 41.0)**	16.2 (-6.0, 38.5)	**28.5 (9.8, 47.1)**	**49.2 (1.6, 96.8)**	7.3 (-18.8, 33.5)	-0.7 (-30.8, 29.3)	31.4 (-12.4, 75.2)
MVPA (min/day)	80 (72, 89)	**-16.2 (-28.3, -4.2)**	-13.2 (-30.1, 3.6)	**-19.7 (-33.9, -5.5)**	1.6 (-34.2, 37.5)	-10.2 (-30.0, 9.7)	-15.6 (-38.3, 7.1)	1.8 (-31.3, 34.9)
Weekdays only								
Total PA (m/s^2)	0.48 (0.44, 0.52)	**-0.06 (-0.12, -0.01)**	-0.03 (-0.11, 0.04)	**-0.09 (-0.15, -0.02)**	0.00 (-0.16, 0.16)	0.00 (-0.09, 0.09)	-0.02 (-0.12, 0.08)	0.05 (-0.09, 0.20)
ST (min/day)	415 (397, 432)	-6.0 (-29.0, 16.9)	-5.4 (-36.6, 25.8)	-2.5 (-29.5, 24.4)	-45.2 (-109.9, 19.6)	-24.4 (-60.9, 12.1)	-13.9 (-55.7, 28.0)	-50.1 (-110.3, 10.2)
LPA (min/day)	420 (408, 432)	**27.4 (10.2, 44.5)**	20.4 (-3.4, 44.2)	**29.8 (9.6, 49.9)**	48.0 (-2.1, 98.0)	24.9 (-2.9, 52.7)	20.0 (-11.8, 51.9)	39.7 (-6.5, 85.9)
MVPA (min/day)	84 (75, 93)	**-18.1 (-30.8, -5.4)**	-11.7 (-29.4, 5.9)	**-23.7 (-38.6, -8.8)**	-0.4 (-37.6, 36.7)	-3.3 (-23.9, 17.3)	-9.2 (-32.8, 14.4)	8.6 (-25.8, 42.9)
Weekend days only								
Total PA (m/s^2)	0.42 (0.38, 0.46)	-0.04 (-0.10, 0.02)	-0.05 (-0.14, 0.03)	-0.04 (-0.11, 0.03)	0.05 (-0.13, 0.22)	-0.07 (-0.16, 0.03)	**-0.11 (-0.22, 0.00)**	0.03 (-0.13, 0.18)
ST (min/day)	470 (451, 488)	-4.0 (-31.7, 23.6)	16.1 (-24.2, 56.3)	-8.9 (-40.8, 23.0)	-62.0 (-144.8, 20.8)	39.3 (-4.9, 83.5)	**65.3 (14.2, 116.4)**	-25.7 (-97.1, 45.6)
LPA (min/day)	449 (436, 462)	15.9 (-4.3, 36.1)	-2.6 (-32.3, 27.1)	22.9 (-0.3, 46.2)	49.6 (-12.0, 111.2)	-24.4 (-57.0, 8.3)	**-42.6 (-80.3, -5.0)**	22.6 (-30.2, 75.5)
MVPA (min/day)	74 (64, 84)	-10.7 (-25.7, 4.3)	-12.2 (-34.2, 9.8)	-12.0 (-29.3, 5.4)	12.3 (-33.0, 57.7)	-16.0 (-40.1, 8.0)	-23.5 (-51.4, 4.4)	1.1 (-37.9, 40.1)
Non-school-time on weekdays								
Total PA (m/s^2)	0.42 (0.38, 0.45)	-0.04 (-0.09, 0.01)	-0.02 (-0.09, 0.05)	-0.06 (-0.12, 0.00)	0.00 (-0.15, 0.14)	0.01 (-0.08, 0.09)	-0.03 (-0.12, 0.07)	0.08 (-0.06, 0.21)
ST (min/day)	303 (291, 314)	-10.4 (-25.4, 4.7)	-3.9 (-24.4, 16.6)	-12.1 (-29.7, 5.5)	-34.9 (-77.5, 7.7)	-14.7 (-38.7, 9.2)	-4.9 (-32.3, 22.6)	**-41.1 (-80.7, -1.6)**
LPA (min/day)	244 (236, 252)	**21.3 (10.1, 32.6)**	12.2 (-3.7, 28.0)	**25.5 (12.3, 38.7)**	**36.8 (3.2, 70.4)**	12.9 (-5.6, 31.4)	8.0 (-13.3, 29.2)	28.8 (-2.1, 59.8)
MVPA (min/day)	74 (64, 84)	**-9.1 (-16.8, -1.4)**	-6.2 (-16.9, 4.4)	**-11.5 (-20.5, -2.6)**	-1.5 (-23.9, 20.8)	-2.0 (-14.4, 10.4)	-6.8 (-21.1, 7.4)	8.6 (-12.1, 29.2)
School-time (9am-3pm Mon-Fri)								
Total PA (m/s^2)	0.60 (0.54, 0.65)	**-0.10 (-0.18, -0.03)**	-0.06 (-0.16, 0.04)	**-0.14 (-0.23, -0.05)**	0.03 (-0.19, 0.24)	0.00 (-0.12, 0.12)	-0.01 (-0.15, 0.13)	0.02 (-0.18, 0.21)
ST (min/day)	112 (104, 120)	5.3 (-5.5, 16.1)	0.2 (-14.4, 14.9)	10.4 (-2.3, 23.2)	-11.0 (-41.5, 19.6)	-9.6 (-26.8, 7.6)	-8.9 (-28.6, 10.8)	-9.5 (-37.8, 18.9)
LPA (min/day)	178 (172, 184)	5.2 (-3.2, 13.5)	7.2 (-4.3, 18.8)	3.2 (-6.6, 13.1)	11.3 (-13.0, 35.6)	10.7 (-2.8, 24.2)	10.9 (-4.6, 26.4)	9.5 (-12.9, 31.9)
MVPA (min/day)	39 (34, 43)	**-9.8 (-15.9, -3.7)**	-6.5 (-15.0, 1.9)	**-12.9 (-20.1, -5.7)**	0.9 (-16.9, 18.6)	-1.2 (-11.0, 8.7)	-2.2 (-13.5, 9.1)	0.3 (-16.0, 16.7)

Values for White British girls, the reference category, are adjusted means. For all other ethnic groups, values are adjusted mean differences when compared with White British girls. All values are adjusted for age, SES (continuous IMD score), month of measurement, wear-time, and school (random effect). PA – physical activity; ST – sedentary time; LPA – light physical activity; MVPA – moderate-to-vigorous physical activity.

Figure 2.1. Mean MVPA (min/day) on weekdays (top) and weekend days (bottom) by sex and ethnic group. A=boys, B=girls. Values adjusted for age, SES, month of measurement, wear-time, and school (random effect). Error bars indicate 95% CI. WB=White British, IND=Indian, PK=Pakistani, BNG=Bangladeshi, AFR=Black African, CAR=Black Caribbean, OTH=other.



2.5 Discussion

2.5.1 Main findings

This study is the first to report ethnic differences in objectively-measured physical activity and sedentary time, segmented across the week, and within and outside of school time, among 5-6 year old boys and girls in the UK. Compared with White British boys, Pakistani boys did 16 min/day more MVPA, 50 min/day less ST, and 35 min/day more LPA. These differences were mainly driven by activities outside of school-time. Similar patterns were observed between Indian and White British boys. Compared with White British boys, Black African boys did 4 min/day more VPA overall and there was evidence to suggest that Black African and Black Caribbean boys did 18 min/day more MVPA. Compared with White British girls, Pakistani girls did 20 min/day less MVPA overall, and this was mainly driven by lower levels of MVPA on weekdays. However, Pakistani and White British girls spent similar amounts of time in sedentary activities, and Pakistani girls did 29 min/day more LPA. Similar patterns were observed for Indian girls compared with White British girls. Across all ethnic groups, boys and girls were significantly more active on weekdays than on weekend days.

2.5.2 Strengths and limitations

The main strengths of this study are the objective, validated measure of PA[45,46,47] and the large, ethnically-diverse cohort, which permitted sex-stratified analyses across ethnic subgroups. Importantly, this allowed exploration of differences in sex and ethnic subgroups that may have been missed in other studies. The analyses maximised use of available data by including all children with at least 1 day of >10hr PA, as done recently by others.[40] The results were consistent when 1 or 3 days[51,54] of >10hr Actiheart data were included, and when various sensitivity analyses were undertaken. This study has also, for the first time, considered ethnic differences in PA within specific time periods, which could help to shape interventions and develop hypotheses to explain the differences.

This study also has several limitations to consider. Uniaxial accelerometers detect movement in the vertical plane only, and may therefore underestimate PA energy expenditure during activities such as cycling and other non-ambulatory activities.[47] Nevertheless, uniaxial accelerometry remains a more accurate measure of PA among children compared with self-report measures and pedometry,[39,38] and output from uniaxial and triaxial accelerometers are generally quite similar in young children.[45,47,55] The use of 30-second epochs for PA recording is a potential limitation of this study. Children's PA is generally characterised by short, sporadic bursts of activity which are often less than 10 seconds in duration.[56] Thus, when averaged over the 30-seconds, PA intensity, particularly moderate- and vigorous-intensity bouts of activity, may have been underestimated due to the inclusion of low- and high-intensity PA within the same epoch.[56,57] However, although this may have had an impact on the absolute estimates of time spent in each PA intensity across all groups, it is unlikely to have significantly influenced the relative differences between ethnic groups, which were the main focus of this study.

Furthermore, there is dispute in the literature regarding which thresholds should be used to define PA intensity from accelerometry.[58,57,59] To facilitate future comparisons between different accelerometer brands, the intensity thresholds used in the present study are expressed in SI units (m/s^2); MVPA was defined as >1.75 m/s^2, which is approximately equal to walking at 4.1km/h, and VPA was defined as $>5.0 m/s^2$, which is equal to jogging/running at 7.2 km/h.[44] This study may also have been underpowered to detect differences in PA and ST for some ethnic groups due to small subgroup sizes in sex-stratified analyses. Larger studies are required to confirm these findings, particularly for Bangladeshi and Black Caribbean children. There were also no available data on other potential sources of heterogeneity, such as acculturation, duration of time in the UK, religion, and socio-economic differences within and between ethnic groups. These factors are thought to influence health behaviours and attitudes[60,61] so such data might reveal variations within ethnic subgroups, or identify potential reasons for variations between groups.

2.5.3 Comparison with other studies

Several UK studies have reported lower self-reported PA among South Asian children compared with White British children,[26,28,27,62] but only two large-scale studies have explored ethnic differences in objectively-measured PA among children.[40,24] In the CHASE study, 9-10 year old South Asian boys and girls did 4 and 6 min/day less MVPA, respectively, compared with White British children, but the difference was not significant among boys (mean difference: -4 min/day (95% CI: -8, 0)). South Asian subgroup analyses were not presented but the authors stated that the differences were consistent across subgroups.[40] Our findings are consistent with their observations for girls, although the difference was more marked in the present study, but are in contrast with our findings for boys. It is possible that the age difference between cohorts may explain some of this discrepancy, but longitudinal studies with objective measures of PA are required to explore this further.

Objective PA data from the Millennium Cohort Study suggests that 7-8 year old Indian children are significantly more sedentary, less active, and do 8 min/day less MVPA compared with White British children, but there were no differences in MVPA or ST between White British and Pakistani, Bangladeshi or Black African/Caribbean children.[24] These data were not stratified by sex, and were adjusted only for season of measurement, no other potential confounders, so direct comparison with the findings for boys and girls in the present study is difficult. In adjusted analyses, presented for adherence to PA recommendations only[22], Bangladeshi children were least likely to accumulate 60 min/day MVPA (33% compared with

40%, 45%, 51% and 52% of Indian, Pakistani, White and Black children, respectively), but this difference was not significant.[24] It is possible that the combining of sexes, and the averaging of PA over the week, might have masked important ethnic differences in PA in the MCS. The age difference between the WAVES and MCS cohorts might also contribute to the inconsistent findings. Further research is needed to better understand these differences in this age group and to identify the age at which ethnic differences in PA emerge, as this will shape future intervention strategies.

Two previous studies have reported similar levels of PA among Pakistani and White British children,[42,24] but this study is the first to observe higher levels of PA, including MVPA, among Pakistani (and possibly Indian) boys. In the 2004 HSE, the proportion of 2-15 year old Pakistani boys who reported doing 60 min/day MVPA was no different to that of the general population.[42] The MCS found no significant differences in MVPA between 7-8 year old Pakistani and White British children, respectively.[24] Ethnic subgroup analyses were not presented for the CHASE data, so it is unclear if Pakistani and White British boys did similar amounts of MVPA.[40] Other studies comparing South Asian sand White European children have focussed only on girls.[63] These cross-sectional observations might indicate that early childhood provides a key opportunity to prevent the emergence of relatively low levels of PA among South Asian boys compared with their White British peers. Longitudinal studies of objectively-measured PA are needed to explore this period of childhood in more detail. Alternatively, it is also possible that methodological differences in PA measurement, and the combining of sex- and ethnic-subgroups, could account for some of the discrepant findings between studies.

Few studies have explored differences in PA between Black African/Caribbean and White British children[24,27,40,41] and findings have been inconsistent. In a longitudinal study of self-report PA among adolescents in the UK, Black adolescents were more sedentary than White children, and Black girls, but not boys, did less MVPA.[41] The CHASE study and the MCS reported no differences in total PA, ST or MVPA between 9-10 and 7-8 year old White and Black children in the UK, respectively,[24,40] but the latter did not separate sexes or Black African/Caribbean subgroups. The higher levels of VPA among Black African boys in this study is consistent with the higher levels of VPA among Black African/Caribbean children in the CHASE study.[40] The present study observed no significant Black-White differences in ST when averaged across the week, which is consistent with Owen et al.[40] but suggests Black-White differences in ST on weekend days, which may have been missed in previous studies when weekend and weekday PA is combined.[24,40,41]

The results of this study are consistent with two previous studies in which primary school children across all ethnic groups were less active at the weekend than on weekdays.[40,64] Similarly, weekend PA was considerably lower than weekday PA among a large (n=2064), primarily White British sample of 10 year old children in Norfolk, UK.[65] Longitudinal data from the SPEEDY study also showed that age-related declines in PA are steeper for weekend PA than weekday PA.[65] These data suggest that, irrespective of sex or ethnicity, efforts to increase PA may benefit from targeting weekend days, particularly by reducing the high amounts of time spent in sedentary activities. Moreover, the finding that school-time contributes little to ethnic differences in PA is consistent with patterns observed in a small study of 8-9 year old children in Coventry (UK).[66] Another small study reported lower PA among Pakistani girls during school recess, compared with White British girls;[63] whether the lower school-time MVPA among Pakistani girls in the present study is due to break-time activity could not be explored in our study and should be investigated further.

Consistent with the present findings of sex-differences in PA across all ethnic groups, lower levels of MVPA were reported among 10 year old girls compared with boys in the SPEEDY study,[65] and among 5 year old girls compared with boys in the EarlyBird Study.[67] In the latter, 42% of boys and only 11% of girls did at least 60 min/day MVPA.[67] A much smaller sex difference was observed among 4 year old children (n~400) in the Southampton Women's Survey, primarily because of relatively high levels of MVPA among girls (89 min/day and 82 min/day for boys and girls, respectively).[68] The levels of PA observed in the Southampton study were very similar to estimates presented here for White British children in the WAVES study (85 min/day and 77 min/day MVPA for boys and girls, respectively). Such observations might suggest that the transition into primary school plays a role in the divergence of PA between boys and girls, but longitudinal data are required to explore this.

As expected (it is well known that PA declines with age during late adulthood and adolescence[65]), the WAVES cohort were more active than slightly older children in ALSPAC,[69] the Earlybird study[70] and Action 3:30.[71] In ALSPAC, 12 year old primarily White British children (N=4150) did about 20 min/day MVPA (boys=26 min/day, girls=16 min/day) as measured by accelerometry.[69] In Action 3:30 (n=469 9-11 year old children, primarily White British), boys did 69 min/day MVPA on weekdays, with 14 minutes of this being afterschool PA,[71] considerably less than average weekday (89 min/day) and afterschool (46 min/day) MVPA among White British boys in the WAVES study. In the same study, girls did 53 min/day MVPA on weekdays, with 12 minutes of this being afterschool PA,[71] compared with 80 min/day and 43 min/day MVPA among White British girls in WAVES. In contrast, however, and unexpected because of the age difference, 10 year old boys and girls in the SPEEDY cohort did about 10 min/day more MVPA (boys: 84 min/day; girls: 66 min/day) than 5-6 year old boys and girls in the WAVES study.[65] Similarly, compared with 11-12 year old White British boys and girls in the PEACH study, White British boys in the WAVES study did almost the same amount of MVPA per day, and girls in the WAVES study did less MVPA per day, despite the age difference.[72] These inconsistent observations might reflect methodological differences between studies (e.g. the very low levels of MVPA in the

ALSPAC study may be due to the high accelerometer cut-points used to define MVPA),[69] differences in participant characteristics (e.g. obesity prevalence in the SPEEDY study was approximately 5%, compared with 12% in the WAVES cohort),[65] or limitations of some studies (e.g. the sample size was small for the PEACH study (n=84) and thus perhaps not representative of the general population).[72]

2.6 Implications

Objectively-measured PA has been associated with improved cardiometabolic profiles in children and adolescents aged 5-18 years[73,74] and the benefits appear to be similar for White European, South Asian and Black African/Caribbean children. [73] PA tracks from childhood into adulthood,[75] and ethnic differences in CVD originate in childhood.[76,77] Thus, in the context of these results, low MVPA among Pakistani girls could contribute to a higher risk of T2DM and CHD in adulthood, whereas the higher VPA among Black African boys, and higher MVPA among Black African and Black Caribbean boys, could contribute to their lower CHD risk in adulthood.[29,30-32,34] Prospective cohort studies are required to explore this further. The low levels of MVPA among South Asian girls at this young age are of particular concern as PA declines with age,[78-82] and the relatively low levels of PA among South Asian women have been estimated to account for more than 20% of their excess risk of CHD mortality.[35] Moreover, emerging data suggests that South Asian adults may need to do considerably more MVPA than their White European counterparts to get the same cardiometabolic health improvements.[83,84] Whether this applies to younger age groups is unknown and should be explored further. The cross-sectional CHASE data suggest comparable cardiometabolic profiles at a given level of PA across ethnic groups, [73] but data in adults suggests that South Asian adults might need to do as much as 266 min/week MVPA to gain the same health benefits as White European adults who do 150 min/week MVPA.[84]

2.7 Conclusions

These data highlight important weekend/weekday and school-time/non-school-time differences in PA across sex and ethnic subgroups. Understanding these patterns will help shape future interventions, which, based on these findings, should prioritise attempts to increase MVPA among South Asian, particularly Pakistani, girls, and increase weekend PA among all ethnic groups. When considered in relation to previous studies, these data might also suggest a need to reduce declines in PA among Pakistani boys during childhood.

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CHAPTER 3

ETHNIC DIFFERENCES IN DIETARY NUTRIENT INTAKE AMONG YOUNG CHILDREN IN THE UK

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3.1 Abstract

Introduction: Dietary intake tracks from childhood into adulthood and is associated with cardiovascular and metabolic health. Thus, ethnic differences in dietary intake during childhood could contribute to explaining ethnicity-related health inequalities later in life. **Objective:** To explore ethnic differences in dietary nutrient intake among 5-6 year old children in the UK. **Methods:** Cross-sectional data on dietary intake (24-hour food-frequency tick-list) and parental-report ethnicity were available for 1175 children participating in the WAVES study (51% male; 47% White British, 30% South Asian, 7% Black African/Caribbean). Multilevel regression models explored ethnic differences in dietary nutrient intake adjusted for clustering and potential confounders. **Results:** Body-weight-adjusted energy intake was lower among Black Caribbean children compared with White British children (adjusted mean difference: -12.6kcal/kg (95% CI: -22.6, -2.6)). The proportion of energy derived from sugar was lower among all minority ethnic groups compared with White British children. The proportion of energy obtained from polyunsaturated fat was higher among Pakistani (0.4 (95% CI: 0.2, 0.7)) and Bangladeshi (0.7 (95% CI: 0.3, 1.2)) children. When comparing the most socially disadvantaged groups, saturated (1.05 (95% CI: 0.19, 1.90) and monounsaturated (0.7 (95% CI: 0.1, 1.3)) fat intake were higher, as a percentage of energy intake, among Black African compared with White British children. There was also some evidence for higher sodium intake among Black African children compared with White British children. Across all ethnic groups, saturated fat, carbohydrate, sugar and sodium intake exceeded the current guidelines, whereas polyunsaturated and monounsaturated fat and fibre intake were below recommended levels. **Conclusion:** Ethnic differences in dietary intake are evident among young children in the UK, some of which mirror previously reported health inequalities among adults. The findings suggest that, to achieve the current dietary guidelines for this age group, reductions in

saturated fat, sugar and sodium intake, and increases in fibre, polyunsaturated and monounsaturated fat intake are needed across all ethnic groups.

3.2 Introduction

Unexplained ethnic differences in cardiovascular and metabolic risk are evident among adults in the UK.[1-8] Compared with White European adults, South Asian adults in the UK have increased risk of type 2 diabetes (T2DM), central obesity, stroke and coronary heart disease (CHD),[1,5,9-14] whereas Black African/Caribbean adults in the UK experience higher risk of stroke, T2DM and hypertension, but a lower risk of CHD. [1-4,7,8] A growing body of evidence suggests that ethnic differences in biological cardiovascular risk factors are apparent in childhood or adolescence and generally mirror the health inequalities observed among adults. [15-19] Thus, it is plausible that early-life differences in lifestyle factors could contribute to future health inequalities.

Dietary intake is an important, modifiable risk factor for cardiovascular and metabolic disease.[20-28] For example, high added sugar intake is positively associated with dyslipidaemia,[29,30] cardiovascular-mortality,[23] and obesity.[31] Dietary fibre intake is implicated in satiety control[24] and reduces the risk of obesity,[25,32] CHD,[26,33-35] T2DM[28] and cardiovascular- and all-cause mortality.[27] Excess energy intake and energy dense foods are associated with increased risk of obesity[22] and elevated fasting plasma glucose and insulin resistance.[36] Trans-fats are associated with increased risk of CHD.[37,38] Although there is some conflicting evidence,[38] polyunsaturated and monounsaturated fatty acids (PUFA and MUFA, respectively) are thought to be cardio-protective[39] and may be inversely associated with blood pressure.[40,41] Conversely, sodium intake is positively associated with blood pressure.[42]

Ethnic differences in dietary nutrient intake have been reported among adults in the UK. Studies have consistently reported lower fat intake,[43-52] particularly saturated fat, [43,47-54] and higher carbohydrate intake[43,49,50;51;53] among Black African/Caribbean adults in the UK compared with White British adults or the UK general population. The authors have postulated that this may contribute to explaining the favourable lipid profile and lower CHD risk observed among Black African/Caribbeans. There is some evidence however, that total and saturated fat intake among younger, British-born Black African/Caribbean adults are converging towards that of the general population of the UK.[49] Findings for UK South Asian adults are less consistent and differences between South Asian subgroups are evident.[45,46] The majority of studies have reported lower total fat intake, [45,48,55,56] lower saturated fat intake, [45,48,53,55-57] higher PUFA intake[55-58] and higher fibre intake[55] among South Asian adults compared with White British adults or the general population. However, others have reported higher total and saturated fat intake among South Asian adults in Scotland.[58] Higher fat intake and lower fibre intake among Pakistani[59] and Bangladeshi,[45] but lower fat intake[43,45,46] and higher fibre intake[45] among Indian adults in the UK have been reported compared with the general population. Lower sugar[48,55] and higher starch[55] and carbohydrate intake[53] have also been reported among South Asian adults compared with White British adults.

Recently, ethnic differences in nutrient intake were reported among 9-10 year old UK children in the CHASE study (n>2000).[60] Some of these differences mirrored the ethnic differences in nutrient intake and CVD risk observed in adults; for example, lower total and saturated fat intake among Black African/Caribbean children, higher PUFA intake among Pakistani and Bangladeshi children and lower sugar intake among all South Asian and Black African/Caribbean subgroups.[60] Childhood dietary patterns are known to track into adulthood,[61] so it is plausible that these early-life differences in nutrient intake could contribute to future health inequalities.

However, very little is known about ethnic differences in dietary nutrient intake among younger children in the UK. The population-representative National Diet and Nutrition

Survey (NDNS) provides the most extensive data on dietary intake among British children,[62] but no ethnic comparisons have been undertaken. In terms of dietary factors, the 1999 and 2004 Health Surveys for England (HSE) only reported on fruit and vegetable and alcohol intake among children.[45,46] Other studies have been undertaken in Europe[63] and the US,[63-67] where dietary intake and ethnic mix differ from those of British children. One UK-based study has explored differences in dietary intake between 12 month old Pakistani and White European infants in Bradford,[68] but there is a distinct lack of data on other minority ethnic groups and children under the age of 10 years. These data could help to shape the timing and design of interventions in ethnically-diverse communities and highlight early-life dietary factors that might contribute to future health inequalities. Thus, the aim of this study was to explore differences in dietary nutrient intake among 5-6 year old White British, Indian, Pakistani, Bangladeshi, Black African and Black Caribbean children in the UK.

3.3 Methods

3.3.1 Study design

Cross-sectional analyses of baseline data from a UK childhood obesity prevention trial (the West Midlands ActiVe lifestyle and healthy Eating in School children study) were undertaken.

3.3.2 Sampling and participants

The sampling frame included all state-maintained primary schools within a 35 mile radius of the University of Birmingham (n=980). Information on ethnic mix, school size and the proportion of children receiving free school meals were obtained from the Local Education Authority. All schools were stratified by the proportion of White British, South Asian and Black African/Caribbean pupils and the top 2 quintiles in each stratum were identified. A weighted random sample of 200 of these schools was selected and those with a high proportion of South Asian or Black African/Caribbean children had twice the chance of being selected. Chosen schools were randomly ordered within each ethnic stratum and sequentially invited to participate. Before each batch of invitations were sent out, response bias checks were undertaken to test for any differences in ethnic mix, proportion of children receiving free school meals, or school size between those who agreed to participate and those who declined. No significant differences were observed so recruitment proceeded until the target sample size of 54 schools was achieved. Written parental consent was sought for all Year 1 children (5-6 years, n=2462 eligible children) within each participating school.

3.3.3 Consent and ethical approval

Written parental consent was obtained for all participants (n=1372, 55.7% of those eligible) and verbal child assent was sought on the day of measurement. The study was approved by the National Research Ethics Service Committee West Midlands, The Black Country (10/H1202/69, 25/11/2010; ISRCTN: 97000586).

3.3.4 Measurement setting

At baseline, all consented children underwent a series of assessments (including anthropometric, dietary, physical activity, and psychological measures) undertaken by trained researchers, following standardised protocols and using validated instruments. Parents were also invited to complete a questionnaire about sociodemographic characteristics and family habits. Data on each child's date of birth, ethnicity, and residential postcode were obtained from schools.

3.3.5 Ethnicity

Child ethnicity was defined by the parent(s), from a list of 18 options,[69] either through completion of the baseline questionnaire, or through school data. For the present analyses, these data were categorised as White British, Indian, Pakistani Bangladeshi, Black African, Black Caribbean, and ‘other’ (including mixed ethnicity).

3.3.6 Dietary assessment

Dietary nutrient intake was measured using the Child and Diet Evaluation Tool (CADET), a 24-hour food-frequency tick-list developed for the rapid assessment of dietary intake among 3-7 year old children.[70] The CADET has been validated against a 24-hour semi-weighed food diary in this age group, with correlations between methods ranging from 0.4 to 0.7 for all nutrients, and 0.4 to 0.9 for specific food items.[70] The procedure for using the CADET has been explained in detail elsewhere.[70] Briefly, trained researchers observed and recorded all food consumption for each participating child throughout the school day. At the end of the day children were provided with a food frequency tick-list and a DVD, which explained how to complete the tick-list, to take home to parents. Parents were asked to record the child’s food intake from the end of the school day until the start of the following school day. The parent-completed tick-lists were returned to the researcher at the start of the following school day to be checked for completion. If the researcher found that a diary was incomplete, or had been completed incorrectly, a one-to-one dietary recall was performed with the child. All completed tick-lists were sent to the Nutrition Epidemiology Group at the University of Leeds to be coded. All tick-lists were processed using the Diet And Nutrition Tool for Evaluation (DANTE), an electronic food diary analysis programme.[70] Portion size estimates were based on the age- and sex-specific mean portion sizes recorded in the NDNS.[71] The DANTE database calculates nutrient intake based on McCance and Widdowson’s *The Composition of Foods*,[72] 6th edition, and *The Composition of Foods 1985: Immigrant Foods*.[73]

3.3.7 Identification of possible over- and under-reporters of energy intake

Potential over- and under-reporters of energy intake were identified using a previously published,[74] widely-used[60,75-78] method which has been described in detail elsewhere.[79] Basal metabolic rate (BMR) was estimated using age-and sex-specific equations:[80]

$$\text{Male BMR (kcal/day)} = 19.6 \text{ x weight (kg)} + 130.3 \text{ x height (m)} + 414.9$$

$$\text{Female BMR (kcal/day)} = 16.97 \text{ x weight (kg)} + 161.8 \text{ x height (m)} + 371.2$$

Reported energy intake (rEI) was expressed as a multiple of BMR (rEI:BMR). Upper and lower limits for rEI:BMR were calculated using the equations of Goldberg *et al*,[74] which take into account within-subject variability in PAL, BMR and rEI:[74,79]

$$\text{Lower cut-off} = \text{PAL x exp}\left[s.d._{min} \text{ x } \left(\frac{S}{100}\right)/\sqrt{\text{n}}\right]$$

$$\text{Upper cut-off} = \text{PAL x exp}\left[s.d._{max} \text{ x } \left(\frac{S}{100}\right)/\sqrt{\text{n}}\right]$$

where

$$S = \sqrt{\frac{\text{CV}_{\text{wEI}}^2}{d} + \text{CV}_{w\text{BMR}}^2 + \text{CV}_{\text{tPA}}^2}$$

where PAL is the estimated physical activity level (based on age- and sex-specific estimates:[81] PAL=1.45 for boys<6yr, 1.55 for boys≥6yr, 1.45 for girls<6yr, 1.50 for girls≥6yr), $s.d._{max}$ is -1.96 (for the lower cut off), and $s.d._{min}$ is +1.96 (for the upper cut-off), and n is the number of subjects (set at 1 in the present study as estimates are made at the individual level rather than the group level). *S* is the Index of Variability, where CV_{wEI} is the co-efficient of variation in rEI,[82] d is the number of days of dietary assessment, CV_{wBMR} is the coefficient of variation for the precision of estimated compared with measured BMR,[79] and CV_{PA} is the total variation in PAL.[79] This method was initially developed in adults but has since been adapted for children[75,79] using age-specific equations for calculating BMR,[80] PAL,[81] and the Index of Variability,[79],[82] as used in our study. Thus, the cut-offs for 'plausible' rEI:BMR in our study were: boys <6yrs: 0.74 to 2.85, boys ≥6yrs: 0.92 to 2.61, girls <6yrs: 0.78 to 2.69, girls ≥6yrs: 0.93 to 2.42, which are very similar to those used by others.[76] Those with a rEI:BMR greater than the upper cut-off were defined as over-reporters, and those with a rEI:BMR smaller than the lower cut-off were defined as under-reporters. Those between the upper and lower cut-offs were defined as plausible reporters. Applying these cut-offs to our data excluded 13 under-reporters (1.1%), 68 over-reporters (5.8%), and 24 children (2%) for whom BMR could not be estimated due to missing height and/or weight data, leaving 1070 'plausible reporters' (93%).

3.3.8 Other measures

Children attended the session in light clothing and removed shoes and socks before undergoing height and weight measurement. Height was measured in duplicate (to the nearest 0.1cm) using a portable stadiometer (Leicester height measure, UK). The average of the two values was used in the analysis. If readings differed by more than 0.4cm, a third reading was taken and the average of the two closest values was used. Weight was measured to the nearest 0.1kg using Tanita bio-impedance scales (Tanita SC-331S, Japan). Body mass index (BMI) was calculated (kg/m^2), and weight status (underweight/normal weight and overweight/obese) was defined according to age- and sex-specific UK reference data, using the 85th percentile as the cut-off for overweight/obese.[83] The child's residential postcode was converted to Index of Multiple Deprivation (IMD) scores, an indicator of area-level deprivation,[69] using specialised software (http://geoconvert.mimas.ac.uk/). Higher scores indicate greater deprivation. Physical activity (PA) was measured using a validated, waterproof accelerometer (Actiheart, Cambridge Neurotechnology Ltd, Papworth, UK).[84,85] Average acceleration throughout the day was used as an indicator of total PA. Time spent in moderate-to-vigorous PA (MVPA, min/day) was defined as periods of acceleration greater than 1.75m/sec^2 (approximately equal to walking at 4.1km/h).

3.3.9 Statistical analyses

All analyses were performed in STATA version 10.1 (Statacorp LP, College Station, TX, USA). Multilevel linear regression models explored ethnic differences in dietary nutrient variables (XTMIXED command). Each nutrient variable was entered as the dependent variable in separate models. School was fitted as a random effect in all models to account for clustering at the school level. Models were also adjusted for age, sex, socioeconomic status (SES, based on Index of Multiple Deprivation), and month of measurement as fixed effects. Interactions between sex and ethnicity were tested in each model and sex-stratified models were explored if a significant interaction term was observed. All model residuals were checked for normality. Protein, fat and carbohydrate intakes were considered as both absolute values (total intake in grams) and as percentages of total energy (%EI, 1g carbohydrate = 16 kJ; 1g protein = 17kJ; 1g fat = 37kJ)[72,86,87] to facilitate comparison with current UK[88] and international[22] dietary guidelines. Mean differences or adjusted means (with 95% confidence intervals) are reported for all ethnic group comparisons.

3.3.10 Sensitivity analyses

All analyses were repeated under the following conditions: 1. Only ‘plausible reporters’ of energy intake were included[74] (n=1061); 2. Children who underwent the dietary recall interview were excluded (n= 331 excluded, 28.2%); 3. Analyses were further adjusted for physical activity (n=953) and, separately, body weight; 4. Only those in the two most socially disadvantaged quintiles were included (n=828).

3.4 Results

3.4.1 Participant characteristics

Dietary and ethnicity data were available for 1175 children (86% of those consented; 47.2% White British, 29.7% South Asian (Indian, Pakistani or Bangladeshi), 7.3% Black African/Caribbean; Table 3.1). Those excluded from the analysis (n=197), were either absent on the day of measurement or did not return the CADET (n=167), were excluded due to an underlying medical condition and associated dietary modifications (n=2), did not provide valid dietary data (n=18, based on a pragmatic cut-off of ≥50 ticks in a 24-hour period), were unable to complete the dietary recall interview (n=2), or their ethnic origin was unknown (n=8). Compared with those included in the analysis, excluded children were similar in terms of age, sex, BMI z-score and weight status but were of a lower SES ($p<0.001$) and more likely to be of Pakistani origin ($p<0.05$).

Compared with White British children, Black African and Black Caribbean children were taller and heavier, and were more likely to be overweight/obese (Table 3.1). SES was higher among White British and Indian children compared with all other ethnic groups. Compared with White children (13.9%), a greater proportion South Asian (41.6%) and Black African/Caribbean (46.5%) children underwent dietary recall interviews ($p<0.001$), and this was consistent across all subgroups. The prevalence of under-reporting was 0.2, 1.0, 2.3, 3.1, 1.7 and 0.0% for White British, Indian, Pakistani, Black African and Black Caribbean children, respectively, and the corresponding figure for over-reporters were 4.1, 6.9, 7.9, 3.1, 8.6 and 7.1%, respectively ($p=0.09$).

3.4.2 Comparison of average nutrient intakes with current dietary guidelines

Across all ethnic groups, carbohydrate, saturated fat and sodium intake exceeded recommended levels (50% and ≤11% of energy intake and <1200mg/day, respectively,[88,89] whereas fibre, PUFA and MUFA intake were below the recommended levels (≥18g/day and 6.5% and 13% of energy intake, respectively[88] (Table 3.2). Only Black African and Black Caribbean children met the recommended 15% of energy intake from protein.

3.4.3 Differences between White British and South Asian children

Henceforth, all comparisons are with the White British group, unless stated otherwise. Absolute energy intake was lower among Bangladeshi children (adjusted mean difference: -246kcal (95% CI: -423, -69)), but this difference was no longer evident after adjustment for body weight (Table 3.3). There were no significant differences in total fat intake between White British and South Asian children, but the proportion of energy from PUFA was higher among Pakistani (+0.4 (95% CI: 0.2, 0.7)) and Bangladeshi children (+0.7 (95% CI: 0.3, 1.2)).

The proportion of energy obtained from carbohydrates was significantly lower among Pakistani (-1.2 (95% CI: -2.3, -0.1)) and Bangladeshi (-2.8 (95% CI: -5.0, -0.6)) children. Among all South Asian subgroups, a smaller proportion of energy intake came from sugars (Indian: -2.0 (95% CI: -3.4, -0.6); Pakistani: -3.4 (95% CI: -4.6, -2.2); Bangladeshi: -5.3 (-7.6, -2.9)), and a larger proportion came from starch (Indian: +1.7 (95% CI: 0.6, 2.7); Pakistani: +2.4 (95% CI: 1.5, 3.3); Bangladeshi: +2.7 (95% CI: 0.9, 4.5)). The proportion of energy obtained from protein was higher among Pakistani (+1.0 (95% CI: 0.5, 1.5)) and Bangladeshi (+3.2 (95% CI: 2.1, 4.2)) children. Fibre intake was lower among Bangladeshi children (-2.1 grams (95% CI: -3.7, -0.5)) and this difference persisted with adjustment for body weight or energy intake.

The observed differences between White British and South Asian children were not materially affected by adjustment for PA or when comparing the most socially disadvantaged groups.

Table 3.1. Participants' sociodemographic and physical characteristics by ethnicity.

	White British (n=555)	Indian (n=102)	Pakistani (n=215)	Bangladeshi (n=32)	Black African (n=58)	Black Caribbean (n=28)	Other (n=185)
	Mean (95% CI)	**Mean (95% CI)**	**Mean (95% CI)**	**Mean (95% CI)**	**Mean (95% CI)**	**Mean (95% CI)**	**Mean (95% CI)**
Sex (%)							
Male	51.4 (46.6, 56.3)	52.0 (41.8, 62.1)	43.3 (36.2, 50.7)	70.5 (51.9, 84.1)	52.8 (39.4, 65.9)	45.8 (28.2, 64.4)	55.4 (47.8, 62.9)
Female	48.6 (43.7, 53.4)	48.0 (37.9, 58.2)	56.7 (49.3, 63.8)	29.5 (15.9, 48.1)	47.2 (34.1, 60.6)	54.2 (35.6, 71.8)	44.6 (37.1, 52.2)
Age (years)	6.28 (6.25, 6.32)	6.27 (6.20, 6.33)	6.29 (6.24, 6.34)	6.32 (6.21, 6.43)	6.35 (6.27, 6.43)	6.25 (6.13, 6.37)	6.23 (6.18, 6.28)
Height (m)	118 (117, 118)	118 (117, 119)	118 (117, 119)	118 (116, 120)	122 (121, 124)	121 (119, 123)	119 (118, 120)
Weight (kg)	22.4 (22.0, 22.8)	21.6 (20.7, 22.4)	22.6 (21.9, 23.2)	21.8 (20.2, 23.3)	25.3 (24.2, 26.4)	25.5 (23.8, 27.1)	23.2 (22.5, 23.8)
BMI z-score[Ŧ]	0.22 (0.12, 0.32)	-0.32 (-0.55, -0.08)	0.07 (-0.09, 0.24)	-0.29 (-0.72, 0.14)	0.67 (0.36, 0.98)	0.75 (0.29, 1.21)	0.27 (0.10, 0.44)
Weight status[Ŧ] (%)							
UW/NW	80.1 (76.5, 83.3)	86.1 (77.9, 91.6)	77.0 (70.8, 82.2)	83.3 (65.7, 92.9)	60.3 (47.3, 72.0)	65.4 (45.7, 80.9)	75.5 (68.8, 81.2)
OW/OB	19.9 (16.7, 23.5)	13.9 (8.4, 22.1)	23.0 (17.8, 29.2)	16.7 (7.1, 34.3)	39.7 (28.0, 52.7)	34.6 (19.1, 54.3)	24.5 (18.8, 31.2)
Socioeconomic status[¶] (%)							
Lower SES	55.5 (51.3, 59.6)	66.7 (57.0, 75.1)	94.4 (90.4, 96.8)	93.8 (78.2, 98.4)	87.9 (76.8, 94.1)	92.9 (75.5, 98.2)	86.5 (80.8, 90.7)
Higher SES	44.5 (40.4, 48.7)	33.3 (24.9, 43.0)	5.6 (3.2, 9.6)	6.3 (1.6, 21.8)	12.1 (5.9, 23.2)	7.1 (1.8, 24.5)	13.5 (9.3, 19.2)

Values are adjusted means (95% CI) for continuous variables and percentages (95% CI) for categorical variables obtained from multilevel regression models adjusted for clustering at the school level. White British children were the reference group in all comparisons. [Ŧ]BMI z-score is based on age- and sex-specific UK reference data.[83] Overweight/obese was defined as ≥85th percentile. [¶]Socioeconomic status not adjusted for clustering as both school and Index of Multiple Deprivation (IMD) are associated with the child’s postcode/area of residence. Lower SES = the two most socially disadvantaged quintiles of IMD. Higher SES = the three least socially disadvantaged quintiles of IMD. UW/NW: underweight/normal weight; OW/OB: overweight/obese; SES: socioeconomic status; BMI: body mass index.

Results were also generally similar when child-recall dietary data were excluded from the analyses; the exception (data not shown) was higher total fat intake, as a percentage of energy, among Pakistani children (+1.5 (95% CI: 0.3, 2.7)) compared with White British children, which was not evident in the main analysis. When over- and under- reporters were excluded form analyses, energy intake was significantly lower among all South Asian subgroups compared with White British children, but again these differences were attenuated by adjustment for body weight. Sodium intake was significantly lower among Pakistani (-177.5mg (95% CI: -293.3, -61.6)) and Bangladeshi children (-238.9mg (95% CI: -467.3, -10.6); data not shown) when over- and under-reporters were excluded.

3.4.4 Differences between White British and Black African/Caribbean children

Absolute energy intake did not differ significantly between Black African/Caribbean and White British children (Table 3.3). However, when adjusted for body weight, energy intake was significantly lower among Black Caribbean children (-12.6kcal/kg (95% CI: -22.6, -2.6)). In sex-stratified models ($p<0.05$ for sex-interaction), the difference in absolute energy intake was only significant among Black Caribbean boys (-15.7kcal/kgbw (95% CI: -29.5, -1.8)), not girls (-9.95kcal/kg (95% CI: -24.33, 4.42), data not shown). There were no significant differences in the proportion of energy obtained from fats. The proportion of energy obtained from carbohydrates was significantly lower among Black African/Caribbean children (-1.83 (95% CI: -3.28, -0.39), and this was driven by proportionally lower sugar intake (Black African: -3.5 (95% CI: -5.0, -1.9); Black Caribbean: -3.74 (95% CI: -6.2, -1.2)). The percentage of energy derived from starch was higher among Black Africans (+1.7 (95% CI: 0.3, 3.1)). Both Black African (+1.6 (95% CI: 0.8, 2.4)) and Black Caribbean (+2.9 (95% CI: 1.7, 4.0)) children consumed a greater proportion of energy from protein. These differences were slightly larger among girls than among boys ($p<0.05$ for sex-interaction). There were no

Table 3.2. Adjusted mean nutrient intake by ethnic group (with 95% confidence intervals).

	White British (n=555) Mean (95% CI)	Indian (n=102) Mean (95% CI)	Pakistani (n=215) Mean (95% CI)	Bangladeshi (n=32) Mean (95% CI)	Black African (n=58) Mean (95% CI)	Black Caribbean (n=28) Mean (95% CI)	Other (n=185) Mean (95% CI)
Energy (kJ)	7213 (7003, 7422)	7118 (6714, 7523)	6990 (6682, 7297)	**6176 (5463, 6889)Ŧ**	7511 (6973, 8048)	6858 (6092, 7623)	7178 (6872, 7483)
Energy (kJ/kgbw)	330 (319, 342)	339 (317, 360)	319 (303, 336)	296 (258, 335)	307 (279, 336)	**278 (237, 318)***	319 (303, 336)
Energy (kcal)	1713 (1663, 1763)	1690 (1594, 1787)	1660 (1587, 1733)	**1467 (1297, 1637)Ŧ**	1784 (1656, 1912)	1628 (1445, 1810)	1705 (1632, 1778)
Energy (kcal/kgbw)	78.5 (75.8, 81.1)	80.5 (75.3, 85.6)	75.8 (71.9, 79.7)	70.3 (61.2, 79.5)	72.9 (66.2, 79.7)	**65.9 (56.2, 75.6)***	75.8 (72.0, 79.7)
Total fats (g)	62.2 (59.6, 64.7)	62.5 (57.8, 67.2)	61.6 (58.0, 65.3)	54.2 (46.0, 62.4)	66.3 (60.1, 72.5)	58.1 (49.3, 66.9)	64.6 (61.1, 68.2)
Total fats (%EI)	31.7 (31.1, 32.3)	31.8 (30.7, 32.9)	32.0 (31.2, 32.9)	31.4 (29.5, 33.2)	31.9 (30.5, 33.3)	30.9 (28.9, 32.8)	**32.8 (31.9, 33.6)***
MUFA (g)	17.8 (17.0, 18.5)	17.1 (15.7, 18.5)	17.4 (16.3, 18.5)	16.5 (13.9, 19.0)	19.7 (17.8, 21.6)	17.1 (14.3, 19.8)	18.5 (17.4, 19.6)
MUFA (%EI)	9.07 (8.85, 9.28)	8.70 (8.30, 9.10)	9.00 (8.69, 9.31)	9.65 (8.95, 10.35)	9.46 (8.93, 9.99)	9.03 (8.28, 9.77)	9.36 (9.05, 9.66)
PUFA (g)	7.50 (7.10, 7.89)	7.62 (6.87, 8.38)	**8.34 (7.76, 8.92)***	7.83 (6.50, 9.17)	8.23 (7.22, 9.24)	6.93 (5.50, 8.36)	**8.37 (7.80, 8.94)***
PUFA (%EI)	3.84 (3.70, 3.99)	3.90 (3.64, 4.16)	**4.29 (4.08, 4.49)ǂ**	**4.57 (4.12, 5.03)Ŧ**	3.95 (3.61, 4.30)	3.76 (3.27, 4.24)	**4.21 (4.01, 4.41)Ŧ**
Saturated fat (g)	23.0 (22.0, 23.9)	22.4 (20.6, 24.2)	21.6 (20.2, 23.0)	**19.4 (16.2, 22.6)***	25.4 (23.0, 27.8)	21.5 (18.1, 25.0)	23.6 (22.2, 24.9)
Saturated fat (%EI)	11.7 (11.4, 12.0)	11.4 (10.8, 11.9)	11.3 (10.8, 11.7)	11.4 (10.4, 12.4)	12.1 (11.4, 12.9)	11.3 (10.3, 12.4)	12.0 (11.6, 12.4)
Carbohydrate (g)	249 (242, 256)	242 (229, 255)	**234 (224, 244)***	**200 (177, 223)ǂ**	249 (231, 266)	228 (203, 253)	238 (228, 248)
Carbohydrate (%EI)	55.4 (54.8, 56.1)	55.0 (53.8, 56.2)	**54.2 (53.3, 55.1)***	**52.7 (50.5, 54.8)***	**53.6 (52.0, 55.2)***	53.5 (51.2, 55.7)	**53.6 (52.7, 54.5)Ŧ**
Sugars (g)	138 (134, 143)	**126 (118, 135)***	**119 (112, 125)ǂ**	**98 (83, 113)ǂ**	**126 (114, 137)***	**116 (100, 132)Ŧ**	**126 (119, 133)Ŧ**
Sugars (%EI)	30.8 (30.0, 31.5)	**28.8 (27.5, 30.1)Ŧ**	**27.3 (26.3, 28.4)ǂ**	**25.5 (23.2, 27.8)ǂ**	**27.2 (25.5, 29.0)ǂ**	**27.0 (24.6, 29.5)Ŧ**	**28.4 (27.4, 29.4)ǂ**
Starch (g)	108 (104, 112)	114 (107, 121)	114 (108, 119)	102 (89, 114)	**120 (111, 129)***	108 (95, 122)	110 (105, 115)
Starch (%EI)	24.1 (23.6, 24.6)	**25.8 (24.8, 26.7)Ŧ**	**26.5 (25.7, 27.2)ǂ**	**26.8 (25.0, 28.5)Ŧ**	**25.8 (24.5, 27.1)***	25.5 (23.6, 27.4)	24.7 (24.0, 25.5)
Protein (g)	54.6 (52.7, 56.5)	55.5 (51.6, 59.4)	57.4 (54.5, 60.3)	57.7 (50.7, 64.6)	**63.3 (58.1, 68.5)Ŧ**	**62.5 (55.0, 70.0)***	57.9 (55.0, 60.8)
Protein (%EI)	12.9 (12.6, 13.2)	13.3 (12.7, 13.9)	**13.9 (13.5, 14.3)ǂ**	**16.1 (15.1, 17.1)ǂ**	**14.5 (13.7, 15.3)ǂ**	**15.8 (14.7, 16.9)ǂ**	**13.7 (13.3, 14.2)Ŧ**
Fibre (g)	11.0 (10.5, 11.5)	11.0 (10.1, 11.9)	10.9 (10.2, 11.6)	**8.9 (7.4, 10.4)***	11.0 (9.8, 12.2)	10.3 (8.7, 12.0)	10.9 (10.3, 11.6)
Sodium (mg)	2193 (2105, 2281)	2197 (2040, 2353)	2065 (1941, 2188)	1984 (1715, 2253)	2376 (2171, 2581)	2196 (1909, 2483)	2214 (2094, 2334)

Means and 95% CIs derived from multilevel linear regression models adjusted for age, sex, month of measurement, SES (IMD as a continuous variable) and clustering. All comparisons are with the White British group: *$p<0.05$, Ŧ$p<0.01$, ǂ$p<0.001$. %EI: percentage of energy intake; g: grams; PUFA: polyunsaturated fatty acids; MUFA: monounsaturated fatty acids; kcal: kilocalorie; kgbw: per kilogram of body weight; kJ: kilojoule; CI: confidence interval.

Table 3.3 Adjusted mean differences (and 95%CIs) in dietary nutrient intake compared with White British children.

	Indian (n=102)		Pakistani (n=215)		Bangladeshi (n=32)		Black African (n=58)		Black Caribbean (n=28)	
	Mean difference (95% CI)	**p**	**Mean difference (95% CI)**	**p**	**Mean difference (95% CI)**	**p**	**Mean difference (95% CI)**	**p**	**Mean difference (95% CI)**	**p**
Energy (kJ)	-94 (-530, 342)	0.672	-223 (-592, 146)	0.236	**-1037 (-1779, -294)**	**0.006**	298 (-274, 870)	0.308	-355 (-1144, 434)	0.378
Energy (kJ/kgbw)	8.3 (-14.9, 31.5)	0.482	-11.2 (-30.9, 8.4)	0.264	-34.3 (-74.4, 5.8)	0.095	-23.3 (-53.8, 7.2)	0.134	**-52.8 (-94.9, -10.8)**	**0.014**
Energy (kcal)	-22 (-126, 81)	0.672	-53 (-141, 35)	0.240	**-246 (-423, -69)**	**0.006**	71 (-65, 207)	0.307	-85 (-273, 103)	0.374
Energy (kcal/kgbw)	2.0 (-3.5, 7.5)	0.483	-2.6 (-7.3, 2.0)	0.268	-8.1 (-17.7, 1.4)	0.095	-5.5 (-12.8, 1.7)	0.135	**-12.6 (-22.6, -2.6)**	**0.014**
Total fats (g)	0.3 (-4.7, 5.4)	0.894	-0.5 (-4.8, 3.8)	0.812	-7.9 (-16.5, 0.6)	0.069	4.1 (-2.4, 10.7)	0.217	-4.1 (-13.1, 5.0)	0.378
Total fats (%EI)	0.1 (-1.0, 1.3)	0.832	0.3 (-0.6, 1.3)	0.507	-0.3 (-2.2, 1.6)	0.739	0.3 (-1.2, 1.7)	0.735	-0.8 (-2.8, 1.2)	0.433
MUFA (g)	-0.7 (-2.2, 0.9)	0.391	-0.4 (-1.7, 0.9)	0.557	-1.3 (-3.9, 1.4)	0.339	1.9 (-0.1, 4.0)	0.062	-0.7 (-3.5, 2.1)	0.619
MUFA (%EI)	-0.4 (-0.8, 0.1)	0.091	-0.1 (-0.4, 0.3)	0.736	0.6 (-0.1, 1.3)	0.115	0.4 (-0.2, 1.0)	0.164	0.0 (-0.8, 0.7)	0.919
PUFA (g)	0.13 (-0.69, 0.94)	0.759	**0.84 (0.15, 1.53)**	**0.017**	0.34 (-1.05, 1.72)	0.635	0.73 (-0.34, 1.80)	0.179	-0.57 (-2.04, 0.91)	0.451
PUFA (%EI)	0.1 (-0.2, 0.3)	0.688	**0.4 (0.2, 0.7)**	**<0.001**	**0.7 (0.3, 1.2)**	**0.002**	0.1 (-0.3, 0.5)	0.546	-0.1 (-0.6, 0.4)	0.746
Saturated fat (g)	-0.5 (-2.5, 1.4)	0.591	-1.4 (-3.0, 0.3)	0.104	**-3.5 (-6.9, -0.2)**	**0.038**	2.4 (-0.1, 5.0)	0.063	-1.4 (-5.0, 2.1)	0.435
Saturated fat (%EI)	-0.30 (-0.90, 0.29)	0.319	-0.44 (-0.94, 0.07)	0.090	-0.31 (-1.32, 0.70)	0.547	0.45 (-0.33, 1.23)	0.258	-0.38 (-1.46, 0.70)	0.489
Carbohydrate (g)	-7.3 (-21.5, 6.9)	0.312	**-15.4 (-27.5, -3.4)**	**0.012**	**-49.3 (-73.5, -25.1)**	**<0.001**	-0.6 (-19.2, 18.1)	0.950	-21.0 (-46.7, 4.7)	0.110
Carbohydrate (%EI)	-0.4 (-1.7, 0.9)	0.526	**-1.2 (-2.3, -0.1)**	**0.030**	**-2.8 (-5.0, -0.6)**	**0.013**	**-1.9 (-3.6, -0.2)**	**0.030**	-2.0 (-4.3, 0.4)	0.098
Sugars (g)	**-12.1 (-21.4, -2.9)**	**0.010**	**-19.7 (-27.6, -11.8)**	**<0.001**	**-40.7 (-56.3, -25.1)**	**<0.001**	**-12.6 (-24.7, -0.6)**	**0.040**	**-22.6 (-39.2, -6.1)**	**0.007**
Sugars (%EI)	**-2.0 (-3.4, -0.6)**	**0.006**	**-3.4 (-4.6, -2.2)**	**<0.001**	**-5.3 (-7.6, -2.9)**	**<0.001**	**-3.5 (-5.3, -1.7)**	**<0.001**	**-3.7 (-6.2, -1.2)**	**0.003**
Starch (g)	5.7 (-1.8, 13.2)	0.136	5.5 (-0.9, 11.9)	0.093	-6.6 (-19.3, 6.2)	0.315	**11.8 (2.0, 21.7)**	**0.019**	0.4 (-13.2, 13.9)	0.957
Starch (%EI)	**1.7 (0.6, 2.7)**	**0.002**	**2.4 (1.5, 3.3)**	**<0.001**	**2.7 (0.9, 4.5)**	**0.004**	**1.7 (0.3, 3.1)**	**0.017**	1.4 (-0.5, 3.4)	0.142
Protein (g)	0.9 (-3.3, 5.2)	0.669	2.8 (-0.7, 6.4)	0.115	3.1 (-4.1, 10.4)	0.399	**8.7 (3.1, 14.3)**	**0.002**	**7.9 (0.2, 15.7)**	**0.045**
Protein (%EI)	0.4 (-0.3, 1.0)	0.260	**1.0 (0.5, 1.5)**	**<0.001**	**3.2 (2.1, 4.2)**	**<0.001**	**1.6 (0.8, 2.4)**	**<0.001**	**2.9 (1.7, 4.0)**	**<0.001**
Fibre (g)	0.0 (-1.0, 0.9)	0.978	-0.1 (-0.9, 0.7)	0.872	**-2.1 (-3.7, -0.5)**	**0.010**	0.0 (-1.2, 1.2)	0.985	-0.7 (-2.4, 1.0)	0.429
Sodium (mg)	0.00 (-0.16, 0.17)	0.968	-0.13 (-0.27, 0.01)	0.077	-0.21 (-0.49, 0.07)	0.140	0.18 (-0.03, 0.40)	0.095	0.00 (-0.29, 0.30)	0.985

Adjusted mean differences obtained from multilevel linear regression models adjusted for age, sex, SES (IMD as a continuous variable), month of measurement, and school (random effect). White British children as the reference group in all ethnic comparisons. Negative values indicate lower intake compared with White British children. Positive values indicate higher intake compared with White British children. Abbreviations: CI, confidence interval; MUFA, monounsaturated fat; PUFA, polyunsaturated fat; g, grams; %EI, expressed as a percentage of energy intake; kgbw: per kilogram of body weight.

significant differences in fibre intake between White British and Black African/Caribbean children.

Adjustment for PA, exclusion of over- and under-reporters, and exclusion of child-recall data generally gave very similar results in terms of direction and size of the observed differences between White British and Black African/Caribbean children. When comparing those in the most socially-disadvantaged quintiles, however, the energy obtained from monounsaturated (+0.7 (95% CI: 0.1, 1.3)) and saturated fat (+1.05 (95% CI: 0.19, 1.90)) was higher among Black African children compared with White British children. There was a trend towards higher sodium intake among Black African children in the main analysis, (+182.9mg (95% CI: -31.8, 397.6) (p=0.09)) and this was significant in all sensitivity analyses (+200 to +300mg, p<0.05 for all).

3.5 Discussion

3.5.1 Main findings

This is the first large-scale study to report ethnic differences in dietary nutrient intake among young South Asian, Black African/Caribbean and White British children in the UK. These findings suggest that, to meet the current dietary guidelines,[88] reductions in saturated fat, sugar, and sodium intake, and increases in MUFA, PUFA and fibre intake are needed across all ethnic groups at this age. Carbohydrate and sugar intake were particularly high among White British children, whereas sodium intake was particularly high among Black African children. PUFA intake was higher among Pakistani and Bangladeshi children, whereas, when comparing the most socially disadvantaged children, Black Africans consumed more saturated fat and MUFA compared with White British children. Energy and fibre intake were lower among Bangladeshi children compared with white British children, but the former was explained by their lower body weight. Body-weight-adjusted energy intake was lower among Black Caribbean children.

3.5.2 Strengths and limitations

This study benefits from a large, ethnically-diverse sample of young children, which enabled ethnic subgroup comparisons which have not been reported previously in this age group. All measurements were undertaken by trained researchers, following standardised protocols, and using validated tools,[70] and analyses were adjusted for several potential confounders. The robustness of the data was demonstrated in a series of sensitivity analyses, including the exclusion of potential under- and over-reporters of energy intake.

This study does, however, have several limitations which should be considered when interpreting the results. First of all, although the CADET has been validated in this age group,[70] the validation study was limited by the use of a non-gold-standard reference method (semi-weighed food diaries). Moreover, the validity and reliability of the CADET were tested among 180 children (100 boys, 80 girls), primarily White British, from six state primary schools in North England.[70] The authors state that the study population was multi-ethnic (9% of boys and 1% of girls were from households of Indian or Pakistani origin), but, in absolute terms, this validation study included very small numbers of children from non-White British households. Specifically, two children (both boys) were from households of Indian origin, eight (seven boys, one girl) were from Pakistani households, and five (two boys, three girls), were from Black Caribbean households, compared with 173 (83 boys, 90 girls) from White British households. [70] Thus the true validity and reliability of the CADET as a measure of dietary intake within and between ethnic groups are unknown. Ethnic-specific FFQs supplemented with face-to-face interviews can optimize data quality when conducting dietary assessments in minority ethnic groups[90] but this was not feasible in the present study due to time constraints. The CADET offers a quick and easy method for assessing dietary intake in this age group and includes a variety of 'international' foods for which nutrient composition and energy content can be estimated .[72,73] The portion size estimates used in this study were based on the age- and sex-specific mean portion sizes recorded in the NDNS.[71] However, for some food items, these NDNS estimates were based on small numbers of children and may therefore be inaccurate or unrepresentative of the wider population in this age group. The CADET is also unable to measure half portions. Thus, if, for example, a child eats just over half of a food item, it would be classed as a full portion and thus overestimate intake, and vice versa.

Additionally, dietary intake was only assessed for a single 24-hour period on a school day, so our data might not be representative of non-school days, especially among minority ethnic groups who tend to consume a more 'traditional' diet on weekend days.[91] It is anticipated, however, that this would result in underestimation, rather than overestimation, of the observed ethnic differences, as dietary patterns would therefore be more similar across ethnic groups on weekdays than on weekend days. A greater proportion of Bangladeshi, Pakistani and Black African/Caribbean children returned unfinished or incorrectly completed food-frequency tick-lists. For Pakistani and Bangladeshi parents this might reflect lack of understanding of the task among parents whose first language is not English. However, language barriers are unlikely to explain the low response rates among Black Caribbean parents, who are most likely fluent in English. Within the questionnaire that was sent home to parents in the WAVES study, one question asked the parent(s) to indicate their native language and any other languages spoken at home. Unfortunately, however, questionnaire response rates were very low among minority ethnic groups, so it is unknown if low literacy levels are the explanation. Alternatively, previous research has shown that response rates for written-questionnaires are poor among low SES groups of any ethnicity.[92-95] Thus, the lower response/completion rates among Pakistani, Bangladeshi, Black African and Black Caribbean parents compared with White British and Indian parents in the present study might simply reflect differences in SES between these groups. Nevertheless, all returned diaries were checked for quality and completeness immediately after the 24-hour assessment period, clarification of any potential mistakes or misreporting of food intake were sought from children, and the results were generally consistent when these data were excluded from analyses.

The method of identifying potential under- and over-reporters of energy intake also has several limitations, as described in detail elsewhere.[79] Arguably the most pertinent limitation for our study is that the equations for estimating energy expenditure, and thus used to identify potential under- and over- reporters, do not take into account potential ethnic variations in PA,[96] BMR[97] and fat-free mass,[19] a strong predictor or BMR.[98] Objective measurement of energy expenditure would improve the sensitivity of this method in future studies,[99] but is often impractical in large-scale surveys of young children.

The overall response rate was moderate, but did not differ significantly by ethnic group. Although the overall sample size was large, this study may have been underpowered to detect differences in the smaller ethnic subgroups so these findings require confirmation in future studies. This data suggest that ethnic differences in dietary nutrient intake were independent of SES, a correlate of dietary intake,[100,101] which is consistent with findings in a similar age-group. [60,102] However, it should be noted that the indicator of SES used in this study was based on residential area, not individual-level factors, and the lack of variation in SES within some minority ethnic groups makes it difficult to generalise the findings to those living in more socially advantaged areas. Isolating the effects of ethnicity and SES on dietary intake, and other health behaviours, is difficult. In an attempt to address this to some extent, sensitivity analyses were performed, comparing only the most socially disadvantaged children in the study, and broadly similar findings to those in the main analysis were observed.

Despite these potential limitations, the validity of these data is supported by several observations: 1. Average energy intake was lower among girls compared with boys (adjusted mean difference: -143kcal/day (95% CI: -197, -89)), as expected,[78,86,103] and this was consistent across all ethnic groups; 2. Reported energy intake (1621 and 1758 kcal/day for girls and boys, respectively) was broadly similar to previous recommendations for this age group (1545 and 1715 kcal/day for 4-6 year old girls and boys, respectively,[86] although slightly higher than more recent recommendations for 6 year old boys and girls (1482 and 1577 kcal/day, respectively[103]); 3.The overall contributions of total fats (32%), saturated fat (12%), protein (14%) and carbohydrates (55%) to total energy intake in this study are very similar to those reported among 4-10 year old children in the most recent NDNS (33%, 13%, 14% and 52%, respectively, based on 4-day food diaries),[62] as was total fibre intake (10.9g vs. 11.1g); and 4. Many of these results are consistent with those of previous studies (for example, lower sugar and higher starch intakes among South Asians,[48,55] higher PUFA in Pakistanis and Bangladeshis,[55-58] high sodium intake Black African/Caribbeans,[104] and high saturated fat, sugar and sodium intake among all groups.[62]

Detailed breakdowns of different sugars and fats, for instance, non-milk extrinsic sugars (NMES), omega-3 and omega-6 PUFA, and trans-fatty acids, were not available for this study. These are known to differ in their associations with CV health[38,105] so such information could therefore provide greater insight into the potential contribution of ethnic differences in dietary intake to current and future health inequalities, and improve knowledge of compliance with dietary guidelines across ethnic groups. Religious beliefs,[56,106-110] acculturation and duration of time in the UK,[109,110] migrant generation status,[49,58,91,111-114] and region of birth in the country of origin[106,107,110,114,115] are known to influence dietary behaviours and differ within and between ethnic groups in the UK.[113] These sources of variation could help to explain the ethnic differences observed in this study, and might reveal variations in dietary behaviours within ethnic groups. Unfortunately these data were not available for this study but should be explored in future research.

Nutrient-based analyses are important as they facilitate comparison with recommended intakes[86,89,105] and therefore help to highlight potential areas of concern. However, food-based analyses of dietary data can provide important additional information to facilitate the development of targeted interventions and dietary guidelines.[116-118] For example, this Chapter reports high sugar intake among all ethnic groups, but these data do not offer any information about the main sources of sugar intake within each ethnic group (or, indeed, key sources of sugar intake that are common to all groups). A food-based analysis of these dietary data would provide this information and thus facilitate the development of tailored dietary interventions which could, for instance, recommend low-sugar alternatives, or adaptations to commonly used recipes, for the main sources of sugar intake within the diet. A recent example of the utility of food-based analyses comes from research on the role of sugar sweetened beverages (SSBs) in the development of obesity.[119-121] Food-based analysis of NDNS data suggests that SSBs make up 6% of energy intake among 4-18 year olds in the UK[122] and recent research has shown that SSBs are strongly associated with weight gain.[119-121] Emerging data suggests that replacing SSBs with non-caloric alternatives can reduce weight gain in children,[123] so reducing SSB consumption is increasingly emphasised in the fight against childhood obesity.[124,125] Food-based analyses of these data should be pursued in future work.

3.5.3 Comparison with other studies

After adjustment for body weight, there were no differences in energy intake between White British and South Asian children. This is consistent with previous reports for Indian children[60] but in contrast to the higher energy intake observed among 9-10 year old Bangladeshi and Pakistani children in the CHASE study[60] and South Asian adults in Glasgow.[58] These discrepancies could be explained by methodological variations in dietary assessment, for example, the CHASE study used 24-hour dietary recall interviews. Alternatively, they might reflect the age difference between the cohorts. The latter is supported by recent cross-sectional studies showing lower energy intake among 12 month old Pakistani infants compared with White British infants.[68] Likewise, lower energy intake among 1-3 year old, but higher energy intake among 4-11 year old, South Asian children compared with the age-matched general population, have been reported.[126] High energy intake has been associated with elevated fasting plasma glucose and insulin resistance in children[36] and both of these CV markers are elevated among South Asian children by the age of 10 years.[15,17] Although there are no published longitudinal studies of dietary intake among UK children from different ethnic groups, these cross-sectional observations, considered together, might indicate a need for early intervention to prevent excessive increases in energy intake among Bangladeshi and Pakistani children during early childhood. Longitudinal studies are needed to confirm this.

The lower sugar and higher starch intake among South Asian children in this study is consistent with observations among adults[48,55] and 9-10yr old children in the CHASE study.[60] Compared with White British children in our study, the proportion of energy derived from sugars was approximately 2, 4 and 5 percentage points lower among Indian/Pakistani, Black African/Caribbean, and Bangladeshi children, respectively, mirroring the patterns observed in CHASE.[60] Current UK dietary guidelines recommend that no more than 10% of total energy intake should come from non-milk extrinsic sugars (NMES),[88] although this may be revised downward to 5% [105] in line with proposed changes to the WHO recommendations.[127]

Unfortunately, we were unable to differentiate NMES and intrinsic or milk sugars in our study, and there are currently no official guidelines for total sugar intake. However, to put these data into context, the current GDA for total sugar intake among adults is 90g per day;[128] with the exception of Bangladeshi children, among whom sugar intake was lowest (98g) but still exceeded the GDA, absolute sugar intake for all other ethnic groups was approximately 30-50% above the GDA. This is consistent with the most recent NDNS in which total sugar intake was high in all age-groups and NMES consumption among 4-10 year old children was 50% above the RDV at 14.7% of energy intake.[62] These data highlight the need to reduce sugar consumption among young children across all ethnic groups.

Consistent with findings from the NDNS[62] and the Family Food Survey (FFS),[47] fibre intake was below the recommended 18g/day[88] in all ethnic groups. Furthermore, consistent with the CHASE data,[60] fibre intake was particularly low among Bangladeshi children. Fibre intake is associated with appetite regulation and glycaemic control[24,28] so lower intake among Bangladeshi children could plausibly contribute to their elevated risk of T2DM and central obesity. The higher PUFA intake among Pakistani and Bangladeshi children in our study is also consistent with several previous studies in adults[55-58] and children.[129,60] Among all groups, however, PUFA intake was lower than the recommended 6.5% of energy intake per day, with most groups obtaining <4% of energy from PUFA. There was also some evidence (p=0.09) for lower saturated fat intake among Pakistani children, which mirrors the findings of a small study of 10-12 year old Pakistani children in London.[129] However, it is notable that saturated fat intake exceeded the recommended levels in all groups in our study, as observed in the NDNS.[62]

Previous studies have consistently reported lower total fat and SFA intake among Black African/Caribbean adults[43,47-52,54] and children[60] in the UK compared with their White British peers. In the CHASE study, lower SFA intake explained the lower total and LDL-cholesterol among Black African, but not Black Caribbean, children.[130] In contrast to these findings, no Black-White differences in fat intake were observed in the main analysis in the present study. When comparing the most socially disadvantaged children, MUFA and SFA intake were higher among Black African children. Explanations for this are unclear. Methodological, geographical and sociodemographic differences between study populations may explain the inconsistent findings. Alternatively, it is possible that White British children in this study reported lower SFA and MUFA than in other studies, as opposed to higher reported intakes among Black African/Caribbean children. That said, the estimates for White British children in this study are very similar to those reported among primarily White British groups of similar age children in ALSPAC[78] and the NDNS.[62] An alternative explanation is that our findings, for fat and carbohydrate intake among Black African/Caribbeans, reflect shifting dietary patterns across generations. Total and saturated fat intake is thought to increase following migration to the UK[109] and second generation Black African/Caribbean migrants tend to consume more fat and saturated fat than Caribbean-born migrants in the UK and their counterparts in the country of origin.[49,110,109] For example, lower saturated fat and higher carbohydrate intake was observed among Caribbean-born migrants (mean age 56yrs) living in Manchester, compared with the general population, but, in the same study, younger (25-34 year old) Black-Caribbean adults reported nutrient intakes very similar to those of the general population.[49] This apparent shift in dietary patterns among younger Black African/Caribbean migrants is also reflected in recent suggestions that the historically lower CHD risk and cardio-protective lipid profiles of Black Caribbeans in the UK may be diminishing.[3,130]

Although differences in macronutrient intake were the main focus of this study, we also explored differences in sodium intake, a strong, population-based, predictor of blood pressure (BP),[42] to see if these mirrored the ethnic differences in BP observed among UK adults. Consistent with those patterns, the data suggest that sodium intake is considerably higher among Black African children compared with White British children. The data also suggest that levels may be lower among Pakistani children, and markedly lower among Bangladeshi children, although this was only evident after exclusion of over- and under-reporters and this study was underpowered to detect this as a significant difference. Among all groups, average sodium intake exceeded the 1200mg/day (3g/day salt intake) recommended maximum intake for 4-6 year old children,[88,89] and Black African children consumed twice this amount. These findings are consistent with the high sodium intake reported among 4-10 year old children in the NDNS,[62] the lower sodium intake reported among South Asian compared with White British adults in Glasgow,[58] and the high sodium intake (3231mg/day, 8.1g of salt) reported among Black African/Caribbean adults in Coventry.[104] In the 2004 HSE, Black African/Caribbean adults were also more likely than the general population to add salt to their food while cooking.[46] These observations support early intervention to reduce dietary sodium intake among all groups, but particularly among Black African children. Longitudinal studies are required to explore the prospective contribution of dietary sodium intake to future health inequalities.

3.6 Implications

Longitudinal data shows that dietary patterns are established in early childhood, track into adulthood, and are associated with CV risk markers in adulthood,[61,131] It is possible, therefore, that ethnic differences in dietary intake in childhood contribute to health inequalities in adolescence and adulthood. For example, the particularly high sodium intake among Black African children in our study could contribute to their higher BP in adolescence[18] and higher risk of stroke and hypertension in adulthood.[132] Likewise, the lower sugar intake, and lower weight-adjusted energy intake among Black Caribbean children, could contribute to their lower body fat percentage,[14,19,134] and lower risk of CHD.[12]

When considering the findings for South Asian children, however, it is more difficult to postulate how some of these observations might translate into future health inequalities as the nutrient composition of their diets were more closely aligned to current dietary guidelines than those of White British children. As discussed above, our data might indicate the need for early intervention to prevent the development of less favourable dietary intake among South Asian children, but longitudinal studies are needed to confirm this. It is also possible that dietary factors play little role in explaining the higher rates of CHD and T2DM among South Asians.[57] Indeed, dietary nutrient intake did not explain the higher serum triglycerides and lower HDL-cholesterol among South Asian children in the cross-sectional CHASE study.[130] Other factors, such as prenatal programming, low birth weight and subsequent 'catch up' growth, elevated body fat and central fat distribution, lower cardiorespiratory fitness and insulin resistance[134,135] might be more strongly associated with future health inequalities. Genetic factors might also increase susceptibility of Asian populations to the effects of diet on CV risk factors,[136,137] although this is yet to be confirmed. Longitudinal studies are needed to explore these hypotheses. Future work should also try to address the methodological limitations associated with dietary assessment in multi-ethnic groups, as described above.

3.7 Conclusions

Ethnic differences in dietary intake are evident among young children in the UK, some of which are consistent with ethnic differences in health inequalities in adulthood while others suggest potential changes compared with patterns observed in older generations. These findings highlight the need to reduce saturated fat, sugar and sodium intake, and increase fibre, PUFA and MUFA intake among all ethnic groups to achieve the current dietary guidelines. Prospective studies are needed to assess the long-term contribution of ethnic differences in dietary intake in childhood to differences in chronic disease risk in adulthood.

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CHAPTER 4

ETHNIC DIFFERENCES IN BODY COMPOSITION AND FAT DISTRIBUTION AMONG YOUNG CHILDREN IN THE UK

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4.1 Abstract

Background: Ethnic differences in body composition and fat distribution contribute to differences in cardiometabolic disease among adults. It is unclear if similar patterns are observed among young children in the UK. We explored ethnic differences in a range of anthropometric measures and bioimpedance among 5-6 year old children in the UK.

Methods: Cross-sectional baseline data from a childhood obesity prevention trial were analysed. Anthropometric measures (BMI, waist circumference (WC) and skinfold measurements), bioimpedance data, and parent-reported ethnicity were available for 1384 children (45% White British, 30% South Asian (Indian, Pakistani, Bangladeshi), 8% Black African/Caribbean, 17% Other/Mixed). All physical measures were performed by trained researchers following standardised protocols. Multilevel regression models assessed ethnic differences in body composition measures adjusted for clustering and potential confounders.

Results: Compared with White British children of a given BMI z-score, Indian, Pakistani and Bangladeshi children had similar WC and waist-to-height ratio (WHtR) but higher body fat percentage, elevated fat mass and larger trunk, limb and total skinfold thickness. Indian and Pakistani children also had significantly less fat-free mass. Compared with White British children of the same BMI z-score, Black African/Caribbean children had smaller WC and WHtR. Limb, trunk and total skinfold thickness were similar between White British and Black African children, but were generally lower among Black Caribbean children.

Conclusion: Ethnic differences in body composition and fat distribution are evident from a young age. Compared with White British children of a given BMI z-score, adiposity is higher among South Asian children and lower or similar among Black African/Caribbean children.

4.2 Introduction

Obesity is defined as abnormal or excessive fat accumulation that may impair health.[1] Body mass index (BMI), a measure of relative weight-for-height (kg/m^2), is the most commonly used method of measuring obesity. At the population-level, BMI is a useful marker of obesity (BMI≥30kg/m^2) and is positively associated with future cardiovascular disease (CVD) morbidity and mortality among adults.[2-5] For example, a recent, large-scale, international study suggests that, above a BMI of 20 kg/m^2, every 5 kg/m^2 increase is associated with a 27% increased risk coronary heart disease (CHD) and 18% increased risk of stroke.[2] The World Health Organization estimates that overweight and obesity account for approximately 3.4 million (8%) deaths in high income countries, and 44% and 23% of type 2 diabetes (T2DM) and CHD, worldwide.[6]

Global obesity prevalence has almost doubled over the last three decades.[7] In 2008, over 200 million men and almost 300 million women over the age of 20 years (11%) were obese.[8] Recent estimates from the 2012 Health Survey for England (HSE) suggest that 24% of men and 25% of women in England are obese, an increase from 13% and 16% in 1993.[9] The most recent data from the National Child Measurement Programme (NCMP) show that, in England, approximately 23% of boys and 21% of girls aged 4-5 years are overweight/obese, and 10% and 9% are obese.[10] Estimated prevalence is considerably higher among older children; approximately 35% of boys and 32% of girls aged 10-11 years are overweight/obese, and 20% and 17% are obese.[10]

There is evidence to suggest that ethnic differences in cardiometabolic disease develop during childhood.[11,12] For example, by the age of 10 years, markers of insulin resistance are elevated among South Asian and, less markedly so, Black African/Caribbean children compared with White European children.[11,12] Childhood obesity tracks from childhood into adulthood.[13-15]

and is associated with impaired cardiometabolic profile during childhood[16] and increased risk of CVD in adulthood.[17,18] Thus, early-life ethnic differences in obesity are likely to contribute to future cardiovascular and metabolic health inequalities.

Several large-scale UK studies have compared childhood obesity prevalence (based on BMI standard deviation scores[19]) across ethnic groups.[20-26] These data consistently indicate higher levels of obesity among Black African/Caribbean children compared with White British children.[10,20-22,24,25] In contrast, findings for South Asian children are inconsistent,[26] with studies reporting lower,[22] higher,[20] or similar[21,25] obesity prevalence compared with White British children. Some have also highlighted ethnic subgroup differences in obesity.[10,24] For example, at the age of 4-5 years, obesity prevalence (based on BMI) is higher among Black Africans compared with other Black subgroups,[10] and lower among Indian compared with Pakistani and Bangladeshi children.[10]

However, these estimates are based on BMI which is a measure of relative weight-for-height[27,28] and is unable to differentiate fat-mass (FM) and fat-free mass (FFM), or provide any indication of fat distribution.[29,30] In adults, central adiposity, often measured by waist circumference (WC), waist-to-hip ratio (WHR) or waist-to-height ratio (WHtR),[31] is a strong predictor of cardiometabolic disease and mortality, independent of general obesity.[31-39] Body composition and fat distribution differ by ethnicity among UK adults,[40-43] so, although BMI may be useful as a population-level marker of obesity and CVD risk,[29] it appears to be inappropriate for ethnic group comparisons.[44,45-47]

When adiposity-specific measures (for example, skinfold thickness, computerised tomography, magnetic resonance imaging), or markers of central adiposity (e.g. WHtR, WHR, WC), are employed, UK South Asians generally have higher levels of body fat and central adiposity [21,40-43,48] compared with White European adults of the same BMI.

Conversely, Black African/Caribbean adults, particularly men,[20,21] tend to have similar or lower levels of total and central adiposity compared with White Europeans.[40] Similar patterns have also been observed in the US [44,49] and Canada.[50,51] Importantly, research has shown that these differences contribute to explaining ethnic inequalities in cardiometabolic disease in adults.[52,53]

Recently, a few large-scale studies have explored ethnic differences in body composition among UK children and adolescents using measures other than BMI.[54-56] In the largest of these, South Asian children aged 9-10 years had lower BMI but elevated central and total adiposity (based on skinfold thickness and fat-mass from bio-impedance analysis) compared with White British children. Conversely, Black African/Caribbean children had higher BMI but, after adjusting for differences in stature, similar or lower levels of adiposity (based on fat-mass and skinfolds, respectively).[54] A smaller study (n=129) also reported higher body fat percentage (BF%) among 14-17 year old South Asian adolescents using dual-energy x-ray absorptiometry (DXA).[56] Only one large-scale UK study has explored ethnic differences in body composition among younger children.[55] Compared with White British children aged 5-18 years, BF% measured by DXA was significantly lower among Black African/Caribbean children as young as 5 years, but differences between South Asian and White British children were only evident among children aged ≥15 years. [55] It is possible, however, that differences were not detected among younger children due to small numbers in age-stratified subgroups.

Thus, the aim of this study was to investigate ethnic differences in body composition and fat distribution, using a range of different adiposity measures, in a large sample of 5-6 year old children in the UK. It was hypothesised that South Asian children (all subgroups) would have higher levels of adiposity and Black African/Caribbean children lower levels of adiposity, compared with White British children.

4.3 Participants and Methods

4.3.1 Study design

Cross-sectional baseline data from a UK childhood obesity prevention trial (the West Midlands ActiVe lifestyle and healthy Eating in School children (WAVES) study) were analysed.

4.3.2 Sampling and participants

The sampling frame included all state-maintained primary schools within a 35 mile radius of the University of Birmingham (n=980). Information on ethnic mix, school size and the proportion of children receiving free school meals were obtained from the Local Education Authority. All schools were stratified by the proportion of White British, South Asian and Black African/Caribbean pupils and the top 2 quintiles in each stratum were identified. A weighted random sample of 200 of these schools was selected and those with a high proportion of South Asian or Black African/Caribbean children had twice the chance of being selected. Chosen schools were randomly ordered within each ethnic stratum and sequentially invited to participate. Before each batch of invitations were sent out, response bias checks were undertaken to test for any differences in ethnic mix, proportion of children receiving free school meals, or school size between those who agreed to participate and those who declined. No significant differences were observed so recruitment proceeded until the target sample size of 54 schools was achieved. Written parental consent was sought for all Year 1 children (5-6 years, n=2462 eligible children) within each participating school.

4.3.3 Consent and ethical approval

Written parental consent and verbal child assent were obtained for all participants (n=1470, 59.7%). The study was approved by the National Research Ethics Service Committee West Midlands, The Black Country (10/H1202/69, 25/11/2010; ISRCTN: 97000586).

4.3.4 Anthropometric measurements

All measurements were undertaken by trained researchers, following standardised protocols. The performance of each researcher was reviewed before and during the measurement period. Children were measured barefoot and in light clothing. Height was measured twice, to the nearest 0.1cm, with a portable stadiometer (Leicester height measure, UK). Weight (to the nearest 0.1kg) and leg-to-leg impedance were measured with Tanita bioimpedance scales (Tanita SC-331S, Japan). BMI was calculated (kg/m^2) and converted into standard deviation scores (BMI z-score (BMIz)) based on the UK 1990 growth reference data.[19] Overweight/obesity was defined as BMIz $\geq 85^{th}$ centile.[19] FFM was derived from bioimpedance analysis (BIA) using the manufacturer's equations. FM was calculated by subtracting FFM from total body weight. BF% was obtained by dividing FM by total body weight. Waist circumference was measured to the nearest 0.1cm, at the mid-point between the lowest rib and the iliac crest, with a flexible, non-stretch tape measure. Two measurements were taken and the average was used in the analyses. If the first two measurements differed by more than 0.4cm, a third reading was taken and the average of the two closest readings was used. Waist-to-height ratio (WHtR) was calculated. Skinfold thickness (triceps, biceps, subscapular, suprailliac and thigh) were measured on the child's non-dominant side using Holtain skinfold calipers, which were calibrated before each measurement period. Each site was measured twice and the average was calculated. If the two measurements differed by more than 0.4mm, a third reading was taken and the average of the two closest readings was used. The sum of four skinfolds (triceps, biceps, subscapular and suprailliac) was used as an indicator of overall adiposity. Trunk (subscapular and suprailliac), arm (triceps and biceps), thigh, and the ratio of trunk-to-arm skinfolds, were used as indicators of fat distribution.

4.3.5 Ethnicity and socioeconomic status

Child ethnicity was defined by the parent(s) (from a list of 18 options[57]), either through completion of the baseline questionnaire, or through school data, and categorised as White British, Indian, Pakistani, Bangladeshi, Black African, Black Caribbean, or 'other' (including mixed). The child's residential postcode was converted to Index of Multiple Deprivation (IMD) scores,[58] an indicator of area-level deprivation, using specialised software (http://geoconvert.mimas.ac.uk/). These were categorised into quintiles based on their rank within all areas in England.

4.3.6 Statistical analyses

All analyses were performed in STATA version 10.1. Multilevel linear regression models were developed to explore ethnic differences in the different adiposity measures, adjusting for clustering and potential confounders. Model 1 was adjusted for researcher and school, both as random effects. Model 2 was further adjusted for age, sex and socioeconomic status (SES) (continuous IMD variable), all as fixed effects. Model 3 was further adjusted for height. Model 4 was further adjusted for BMI-z-score. Models were also further adjusted for total physical activity (PA) and moderate-to-vigorous PA (MVPA) (see section 2.3.6 for methodology) to see if these explained any of the ethnic differences in the adiposity measures. Interactions between sex and ethnicity and, independently, SES and ethnicity, were assessed in all models. All residuals were checked for normality and 95% confidence intervals are presented for all comparisons.

4.3.7 Sensitivity analyses

Analyses were also repeated with only children in the two lowest SES quintiles included in the analyses, and with different BIA equations used to derive FFM.[59]

4.4 Results

4.4.1 Participant characteristics

Of the 1470 consented children, ethnic origin was unknown for 16 children and a further 70 children were either absent on the day of measurement or declined physical measurements, so 1384 children (94%) were included in the analysis (52% boys; 45% White British, 30% South Asian, 8% Black African/Caribbean). Compared with those included in the analysis, children who declined or were absent for measurements, or did not provide consent to participate, were more likely to be in the lowest IMD quintile ($p<0.001$ for both). Those who declined skinfold and/or WC measurements (148, 201 and 327 children missing arm, trunk and thigh skinfolds data, respectively, and 110 children missing WC data) were also more likely to be female ($p=0.014$), overweight/obese (based on BMI –z-score; $p<0.001$), and of South Asian or Black African/Caribbean ethnicity ($p<0.01$ for all subgroups).

Black African and Black Caribbean children were, on average, 2-4 cm taller and 3 kg heavier than White British and South Asian children, and had higher BMI z-scores ($p<0.001$; Table 4.1). Overweight/obesity prevalence (based on BMIz) was highest among Black African (35.4%) and Black Caribbean (34.4%) children, and lowest among Indian (12.7%) children ($p<0.001$) who also had the lowest BMIz-score ($p<0.001$). Compared with White British (56.0%) and Indian (70.3%) children, a larger proportion of Pakistani (94.3%), Bangladeshi (92.7%), Black African (89.9%), and Black Caribbean (94.0%) children were ranked in the two most socially disadvantaged quintiles based on IMD ($p<0.001$).

Table 4.1. Participant characteristics by ethnic group (mean and 95% CI, unless specified).

	White British (n=624)	Indian (n=118)	Pakistani (n=262)	Bangladeshi (n=41)	Black African (n=79)	Black Caribbean (n=33)	Other (n=227)
Boys (%)	51.4 (46.7, 56.1)	52.6 (42.9, 62.1)	47.1 (40.2, 54.0)	60.9 (44.5, 75.2)	53.5 (41.8, 64.9)	51.0 (34.0, 67.8)	54.0 (47.0, 60.8)
Age (years)	6.28 (6.25, 6.31)	6.27 (6.21, 6.33)	6.31 (6.26, 6.35)	6.35 (6.25, 6.45)	6.31 (6.24, 6.39)	6.23 (6.12, 6.33)	6.24 (6.20, 6.29)
Height (cm)	118 (117, 118)	119 (118, 120)	118 (118, 119)	117 (116, 119)	122 (121, 123)	120 (118, 122)	119 (118, 120)
Weight (kg)	22.4 (22.0, 22.7)	21.8 (21.0, 22.6)	22.8 (22.3, 23.4)	21.7 (20.3, 23.1)	25.1 (24.1, 26.1)	25.1 (23.5, 26.6)	23.1 (22.6, 23.7)
BMI z-score*	0.22 (0.12, 0.32)	-0.27 (-0.49, -0.04)	0.13 (-0.02, 0.29)	-0.20 (-0.58, 0.18)	0.62 (0.35, 0.89)	0.72 (0.30, 1.15)	0.26 (0.10, 0.42)
Weight status* (%)							
UW/NW	80.3 (77.0, 83.2)	87.3 (80.0, 92.2)	76.5 (71.0, 81.3)	82.5 (67.6, 91.4)	64.6 (53.5, 74.3)	65.6 (47.9, 79.8)	75.3 (69.3, 80.5)
OW/OB	19.7 (16.8, 23.0)	12.7 (7.8, 20.0)	23.5 (18.7, 29.0)	17.5 (8.6, 32.4)	35.4 (25.7, 46.5)	34.4 (20.2, 52.1)	24.7 (19.5, 30.7)
Socioeconomic status (%)[Ŧ]							
Lower SES	56.0 (52.1, 59.9)	70.3 (61.5, 77.9)	94.3 (90.7, 96.5)	92.7 (79.6, 97.6)	89.9 (81.0, 94.9)	93.9 (78.8, 98.5)	88.1 (83.2, 91.7)
Higher SES	44.0 (40.1, 47.9)	29.7 (22.1, 38.5)	5.7 (3.5, 9.3)	7.3 (2.4, 20.4)	10.1 (5.1, 19.0)	6.1 (1.5, 21.2)	11.9 (8.3, 16.8)

*BMI was calculated (kg/m^2) and converted into standard deviation scores (BMI z-score) using the UK 1990 growth reference charts.[19] The 85th centile was used as the cut-off for overweight/obese. [Ŧ]Socioeconomic status (SES) based on Index of Multiple Deprivation: lower SES = the two most socially disadvantaged quintiles; higher SES = the three least socially disadvantaged quintiles. UW/NW – underweight/normal weight; OW/OB – overweight/obese; SES – socioeconomic status.

4.4.2 Adjusted ethnic differences in body composition measurements

4.4.2.1 Body mass index, waist circumference and waist-to-height ratio

After adjustment for age, sex, SES, school, researcher, and height (Table 4.2), BMIz-score was significantly lower among Indian, Pakistani and Bangladeshi children compared with White British children. WC, WCz and WHtR were also significantly smaller among Indian and Bangladeshi children. In models 1 and 2, BMIz was higher among Black African and Black Caribbean children, and WC was higher among Black African children compared with White British children, but these differences were no longer evident when models were adjusted for height. There were no Black-White differences in WHtR.

4.4.2.2 Bioimpedance analysis

In height-adjusted models (Table 4.3, Model 3), FFM was lower among Indian, Pakistani and Bangladeshi children compared with White British children, and BF% and FM were higher among Pakistani children. Before adjustment for height, BF%, FFM and FM were significantly higher among Black African and Black Caribbean children compared with white British children. Adjustment for height explained the higher BF% among Black Caribbean but not Black African children.

4.4.2.3 Skinfold thickness

Compared with White British children, sum of four skinfolds, trunk skinfolds and trunk-to-arm skinfold ratio were significantly larger among Pakistani children in all models (Table 4.4). Arm and thigh skinfolds were also significantly larger among Pakistani children but were attenuated slightly when adjusted for height. Trunk-to-arm skinfold ratio was also significantly higher among Indian children and thigh skinfold thickness significantly smaller among Bangladeshi children when compared with White British children. After adjustment for height, there were no significant differences in skinfold thickness between Black African/Caribbean and White British children.

4.4.2.4 Adjusted ethnic differences in adiposity at a given BMI z-score

Compared with White British children of the same BMIz (Figure 1), Indian, Pakistani and Bangladeshi children had higher BF%, more FM, and larger, trunk, arm and sum of four skinfolds. Indian and Pakistani children also had significantly less FFM and larger thigh skinfold thickness. There were no significant differences in WC, WCz or WHtR between White British and South Asian children. Compared with White British children of the same BMIz, Black African and Black Caribbean children had smaller WC WCz and WHtR. Black Caribbean children also had smaller arm, thigh, and sum of four skinfolds, and a trend towards smaller trunk skinfolds. There were no significant differences in skinfold thickness between White British and Black African children. However, based on BIA, Black African children had more FM, higher BF% and less FFM compared with White British children, but these did not differ between Black Caribbean and White British children.

4.4.3 Sex-stratified analyses

The ethnic differences observed in this study were very similar for girls and boys. Compared with White British girls of the same BMIz, South Asian girls (subgroups combined) had a higher WC (0.55cm (0.00, 1.10), p=0.050), but this was not evident among boys. The larger trunk-to-arm skinfold ratio among South Asian children (all subgroups) compared with White British children was also more pronounced (approximately twice as large) among girls than among boys.

Table 4.2. Adjusted ethnic differences in BMIz, waist circumference and waist-to-height ratio (White British children as the reference group in all comparisons).

	Model 1		Model 2		Model 3	
	Adjusted mean difference (95% CI)	**p**	**Adjusted mean difference (95% CI)**	**p**	**Adjusted mean difference (95% CI)**	**p**
BMI z-score						
White British (adjusted mean)	0.22 (0.12, 0.32)		0.24 (0.14, 0.35)		0.31 (0.21, 0.41)	
Indian	**-0.48 (-0.73, -0.24)**	**<0.001**	**-0.52 (-0.76, -0.28)**	**<0.001**	**-0.61 (-0.84, -0.38)**	**<0.001**
Pakistani	-0.08 (-0.27, 0.10)	0.365	-0.13 (-0.33, 0.06)	0.187	**-0.19 (-0.38, -0.01)**	**0.040**
Bangladeshi	**-0.42 (-0.81, -0.03)**	**0.035**	**-0.49 (-0.89, -0.09)**	**0.017**	**-0.45 (-0.82, -0.07)**	**0.020**
Black African	**0.40 (0.11, 0.69)**	**0.006**	**0.33 (0.03, 0.64)**	**0.032**	-0.02 (-0.31, 0.27)	0.876
Black Caribbean	**0.51 (0.07, 0.94)**	**0.022**	**0.45 (0.01, 0.89)**	**0.045**	0.18 (-0.23, 0.60)	0.392
Other/mixed	0.04 (-0.15, 0.23)	0.674	0.00 (-0.20, 0.20)	0.985	-0.14 (-0.32, 0.05)	0.153
WC (cm)						
White British (adjusted mean)	55.9 (55.2, 56.5)		55.9 (55.2, 56.6)		56.3 (55.7, 56.9)	
Indian	**-1.27 (-2.54, 0.00)**	**0.050**	-1.28 (-2.57, 0.01)	**0.052**	**-1.74 (-2.88, -0.61)**	**0.003**
Pakistani	0.24 (-0.74, 1.22)	0.633	0.15 (-0.91, 1.21)	0.782	-0.34 (-1.30, 0.62)	0.486
Bangladeshi	-2.14 (-4.33, 0.04)	0.055	**-2.32 (-4.56, -0.08)**	**0.042**	**-2.13 (-4.12, -0.13)**	**0.036**
Black African	**1.75 (0.19, 3.30)**	**0.028**	**1.66 (0.03, 3.30)**	**0.046**	-0.91 (-2.38, 0.55)	0.221
Black Caribbean	1.83 (-0.55, 4.22)	0.132	1.88 (-0.54, 4.30)	0.128	-0.04 (-2.17, 2.09)	0.974
Other/mixed	0.38 (-0.62, 1.39)	0.456	0.43 (-0.63, 1.49)	0.429	-0.53 (-1.46, 0.41)	0.272
WC z-score						
White British (adjusted mean)	0.76 (0.61, 0.91)		0.76 (0.61, 0.91)		0.85 (0.72, 0.98)	
Indian	**-0.37 (-0.63, -0.11)**	**0.005**	**-0.37 (-0.63, -0.11)**	**0.006**	**-0.46 (-0.69, -0.23)**	**<0.001**
Pakistani	-0.08 (-0.28, 0.13)	0.455	-0.09 (-0.30, 0.13)	0.443	-0.18 (-0.38, 0.01)	0.066
Bangladeshi	**-0.69 (-1.14, -0.25)**	**0.002**	**-0.70 (-1.15, -0.24)**	**0.003**	**-0.63 (-1.03, -0.24)**	**0.002**
Black African	**0.32 (0.01, 0.64)**	**0.044**	0.32 (-0.01, 0.65)	0.057	-0.23 (-0.52, 0.06)	0.117
Black Caribbean	0.26 (-0.22, 0.74)	0.287	0.26 (-0.23, 0.75)	0.296	-0.15 (-0.57, 0.28)	0.501
Other/mixed	0.02 (-0.19, 0.22)	0.857	0.02 (-0.19, 0.24)	0.853	-0.18 (-0.37, 0.01)	0.058
WHtR						
White British (adjusted mean)	0.47 (0.47, 0.48)		0.47 (0.47, 0.48)		0.48 (0.47, 0.48)	
Indian	**-0.01 (-0.02, 0.00)**	**0.007**	**-0.01 (-0.02, 0.00)**	**0.004**	**-0.01 (-0.02, -0.01)**	**0.002**
Pakistani	0.00 (-0.01, 0.01)	0.827	0.00 (-0.01, 0.01)	0.548	0.00 (-0.01, 0.00)	0.427
Bangladeshi	**-0.02 (-0.03, 0.00)**	**0.028**	**-0.02 (-0.04, 0.00)**	**0.027**	**-0.02 (-0.04, 0.00)**	**0.026**
Black African	0.00 (-0.01, 0.01)	0.710	0.00 (-0.02, 0.01)	0.551	-0.01 (-0.02, 0.00)	0.201
Black Caribbean	0.00 (-0.01, 0.02)	0.594	0.00 (-0.02, 0.02)	0.777	0.00 (-0.02, 0.02)	0.944
Other/mixed	0.00 (-0.01, 0.01)	0.757	0.00 (-0.01, 0.00)	0.452	0.00 (-0.01, 0.00)	0.252

Adjusted mean differences derived from multilevel mixed-effects regression models. White British children as the reference group in all comparisons (adjusted mean presented for White British children only). Model 1: adjusted for school and researcher as random effects. Model 2: further adjusted for age, sex and socioeconomic status. Model 3: further adjusted for height. Model 4: further adjusted for BMI z-score. BMI = body mass index; WC = waist circumference; WCz = waist circumference z-score; WHtR = waist-to-height ratio.

Table 4.3. Adjusted ethnic differences in bio-impedance analysis (White British children as the reference group in all comparisons).

	Model 1		Model 2		Model 3	
	Adjusted mean difference (95% CI)	**p**	**Adjusted mean difference (95% CI)**	**p**	**Adjusted mean difference (95% CI)**	**p**
BF%						
White British (adjusted mean)	20.4 (20.0, 20.8)		20.6 (20.1, 21.0)		20.8 (20.4, 21.2)	
Indian	0.54 (-0.50, 1.59)	0.310	0.41 (-0.64, 1.45)	0.445	0.15 (-0.86, 1.17)	0.768
Pakistani	**1.66 (0.89, 2.44)**	**<0.001**	**1.35 (0.51, 2.18)**	**0.002**	**1.14 (0.33, 1.95)**	**0.006**
Bangladeshi	-0.19 (-1.85, 1.48)	0.827	-0.29 (-1.99, 1.40)	0.733	-0.15 (-1.78, 1.49)	0.860
Black African	**3.26 (2.03, 4.48)**	**<0.001**	**2.90 (1.61, 4.19)**	**<0.001**	**1.72 (0.45, 2.98)**	**0.008**
Black Caribbean	**2.41 (0.57, 4.26)**	**0.010**	**2.07 (0.21, 3.93)**	**0.029**	1.17 (-0.64, 2.98)	0.204
Other/mixed	0.59 (-0.22, 1.39)	0.153	0.34 (-0.51, 1.18)	0.436	-0.13 (-0.95, 0.69)	0.748
FFM (kg)						
White British (adjusted mean)	17.7 (17.5, 17.9)		17.6 (17.4, 17.8)		18.0 (17.8, 18.1)	
Indian	**-0.67 (-1.20, -0.15)**	**0.012**	**-0.60 (-1.10, -0.10)**	**0.019**	**-0.99 (-1.28, -0.69)**	**<0.001**
Pakistani	-0.21 (-0.61, 0.19)	0.302	-0.14 (-0.54, 0.26)	0.502	**-0.45 (-0.69, -0.21)**	**<0.001**
Bangladeshi	-0.55 (-1.38, 0.28)	0.197	-0.70 (-1.51, 0.11)	0.091	**-0.49 (-0.97, -0.01)**	**0.043**
Black African	**1.10 (0.48, 1.71)**	**<0.001**	**1.15 (0.53, 1.77)**	**<0.001**	**-0.61 (-0.98, -0.24)**	**0.001**
Black Caribbean	**1.33 (0.42, 2.25)**	**0.004**	**1.52 (0.63, 2.41)**	**0.001**	0.19 (-0.33, 0.72)	0.468
Other/mixed	**0.45 (0.05, 0.86)**	**0.028**	**0.61 (0.20, 1.01)**	**0.003**	-0.09 (-0.33, 0.15)	0.472
FM (kg)						
White British (adjusted mean)	4.67 (4.48, 4.86)		4.71 (4.50, 4.91)		4.88 (4.69, 5.06)	
Indian	0.01 (-0.45, 0.48)	0.954	-0.01 (-0.48, 0.46)	0.967	-0.21 (-0.63, 0.21)	0.332
Pakistani	**0.57 (0.22, 0.91)**	**0.001**	**0.49 (0.11, 0.87)**	**0.011**	**0.33 (0.00, 0.67)**	**0.053**
Bangladeshi	-0.03 (-0.77, 0.70)	0.926	-0.13 (-0.89, 0.63)	0.740	-0.02 (-0.69, 0.66)	0.957
Black African	**1.52 (0.97, 2.07)**	**<0.001**	**1.44 (0.86, 2.02)**	**<0.001**	0.51 (-0.02, 1.03)	0.059
Black Caribbean	**1.43 (0.61, 2.25)**	**0.001**	**1.38 (0.55, 2.22)**	**<0.001**	0.69 (-0.05, 1.44)	0.068
Other/mixed	**0.42 (0.06, 0.78)**	**0.021**	**0.38 (0.00, 0.76)**	**0.048**	0.02 (-0.31, 0.36)	0.886

Adjusted mean differences derived from multilevel mixed-effects regression models. White British children as the reference group in all comparisons. *Adjusted means presented for White British children only. Model 1: adjusted for school and researcher as random effects. Model 2: further adjusted for age, sex and socioeconomic status. Model 3: further adjusted for height. Model 4: further adjusted for BMI z-score. BF% = body fat percentage; FM = fat mass; FFM = fat-free mass.

Table 4.4. Adjusted ethnic differences in skinfold thickness (White British children as the reference group in all comparisons).

	Model 1		Model 2		Model 3	
	Adjusted mean difference (95% CI)	**p**	**Adjusted mean difference (95% CI)**	**p**	**Adjusted mean difference (95% CI)**	**p**
Sum of four skinfolds (mm)						
White British (adjusted mean)	31.4 (28.4, 34.5)		31.7 (28.6, 34.8)		32.3 (29.2, 35.4)	
Indian	1.08 (-2.09, 4.25)	0.504	0.71 (-2.41, 3.83)	0.656	0.31 (-2.66, 3.29)	0.837
Pakistani	**5.85 (3.37, 8.32)**	**<0.001**	**5.08 (2.53, 7.64)**	**<0.001**	**4.53 (2.08, 6.97)**	**<0.001**
Bangladeshi	-0.73 (-6.17, 4.71)	0.793	-0.58 (-5.98, 4.82)	0.833	-0.24 (-5.46, 4.97)	0.927
Black African	**4.27 (0.40, 8.14)**	**0.031**	**4.17 (0.26, 8.08)**	**0.037**	0.64 (-3.14, 4.41)	0.741
Black Caribbean	1.99 (-3.68, 7.67)	0.492	1.72 (-3.90, 7.33)	0.549	-1.21 (-6.58, 4.16)	0.659
Other/mixed	1.45 (-1.02, 3.91)	0.251	1.24 (-1.28, 3.75)	0.336	0.03 (-2.38, 2.43)	0.982
Sum of trunk skinfolds (mm)						
White British (adjusted mean)	13. 8 (12.0, 15.5)		14.0 (12.2, 15.7)		14.3 (12.6, 16.0)	
Indian	1.12 (-0.68, 2.92)	0.224	0.91 (-0.87, 2.70)	0.317	0.64 (-1.06, 2.34)	0.461
Pakistani	**4.23 (2.85, 5.62)**	**<0.001**	**3.77 (2.31, 5.22)**	**<0.001**	**3.42 (2.03, 4.81)**	**<0.001**
Bangladeshi	0.48 (-2.62, 3.59)	0.760	0.48 (-2.63, 3.58)	0.764	0.59 (-2.40, 3.59)	0.698
Black African	**2.70 (0.49, 4.90)**	**0.017**	**2.55 (0.29, 4.80)**	**0.027**	0.44 (-1.72, 2.61)	0.688
Black Caribbean	2.10 (-1.15, 5.35)	0.206	1.88 (-1.36, 5.12)	0.256	0.14 (-2.95, 3.22)	0.931
Other/mixed	**1.42 (0.02, 2.82)**	**0.047**	1.25 (-0.19, 2.70)	0.090	0.52 (-0.86, 1.90)	0.461
Sum of arm skinfolds (mm)						
White British (adjusted mean)	18.2 (16.3, 20.2)		18.3 (16.4, 20.3)		18.7 (16.7, 20.6)	
Indian	0.36 (-1.10, 1.81)	0.631	0.19 (-1.24, 1.62)	0.795	-0.07 (-1.43, 1.30)	0.926
Pakistani	**1.79 (0.61, 2.97)**	**0.003**	**1.37 (0.16, 2.57)**	**0.026**	1.11 (-0.05, 2.27)	0.061
Bangladeshi	0.03 (-2.46, 2.51)	0.983	0.13 (-2.33, 2.58)	0.919	0.26 (-2.12, 2.64)	0.832
Black African	1.69 (-0.09, 3.48)	0.063	1.57 (-0.22, 3.36)	0.086	0.05 (-1.69, 1.79)	0.954
Black Caribbean	-0.09 (-2.72, 2.53)	0.945	-0.32 (-2.90, 2.26)	0.808	-1.58 (-4.06, 0.90)	0.213
Other/mixed	-0.05 (-1.21, 1.11)	0.936	-0.17 (-1.34, 1.00)	0.779	-0.68 (-1.80, 0.45)	0.237
Trunk to arm skinfolds ratio						
White British (adjusted mean)	0.77 (0.71, 0.83)		0.78 (0.72, 0.84)		0.78 (0.72, 0.84)	
Indian	**0.07 (0.03, 0.11)**	**0.002**	**0.07 (0.02, 0.11)**	**0.003**	**0.06 (0.02, 0.10)**	**0.004**
Pakistani	**0.12 (0.09, 0.16)**	**<0.001**	**0.12 (0.08, 0.15)**	**<0.001**	**0.11 (0.07, 0.15)**	**<0.001**
Bangladeshi	0.05 (-0.03, 0.12)	0.232	0.04 (-0.04, 0.11)	0.318	0.04 (-0.04, 0.11)	0.323
Black African	**0.07 (0.02, 0.12)**	**0.008**	**0.06 (0.01, 0.12)**	**0.019**	0.03 (-0.03, 0.08)	0.317
Black Caribbean	**0.11 (0.03, 0.18)**	**0.007**	**0.10 (0.02, 0.18)**	**0.010**	0.07 (0.00, 0.15)	0.060
Other/mixed	**0.07 (0.03, 0.10)**	**<0.001**	**0.06 (0.03, 0.10)**	**<0.001**	**0.05 (0.02, 0.09)**	**0.003**
Thigh skinfold (mm)						
White British (adjusted mean)	14.9 (13.4, 16.3)		14.9 (13.5, 16.4)		15.1 (13.7, 16.6)	
Indian	0.24 (-0.97, 1.46)	0.696	0.21 (-0.98, 1.39)	0.733	-0.03 (-1.16, 1.10)	0.955
Pakistani	**1.30 (0.32, 2.28)**	**0.009**	**1.03 (0.02, 2.03)**	**0.045**	0.89 (-0.07, 1.85)	0.069
Bangladeshi	**-2.07 (-4.13, 0.00)**	**0.050**	**-2.03 (-4.05, 0.00)**	**0.049**	**-2.03 (-3.99, -0.08)**	**0.042**
Black African	0.54 (-1.07, 2.15)	0.509	0.70 (-0.90, 2.29)	0.393	-0.75 (-2.29, 0.79)	0.339
Black Caribbean	-0.08 (-2.16, 2.01)	0.943	-0.24 (-2.27, 1.80)	0.821	-1.27 (-3.21, 0.68)	0.202
Other/mixed	-0.38 (-1.37, 0.61)	0.450	-0.40 (-1.40, 0.59)	0.428	-0.71 (-1.66, 0.24)	0.141

Adjusted mean differences derived from multilevel mixed-effects regression models. White British children as the reference group in all comparisons (adjusted mean presented for White British children only). Model 1: adjusted for school and researcher as random effects. Model 2: further adjusted for age, sex and socioeconomic status. Model 3: further adjusted for height. Model 4: further adjusted for BMI z-score.

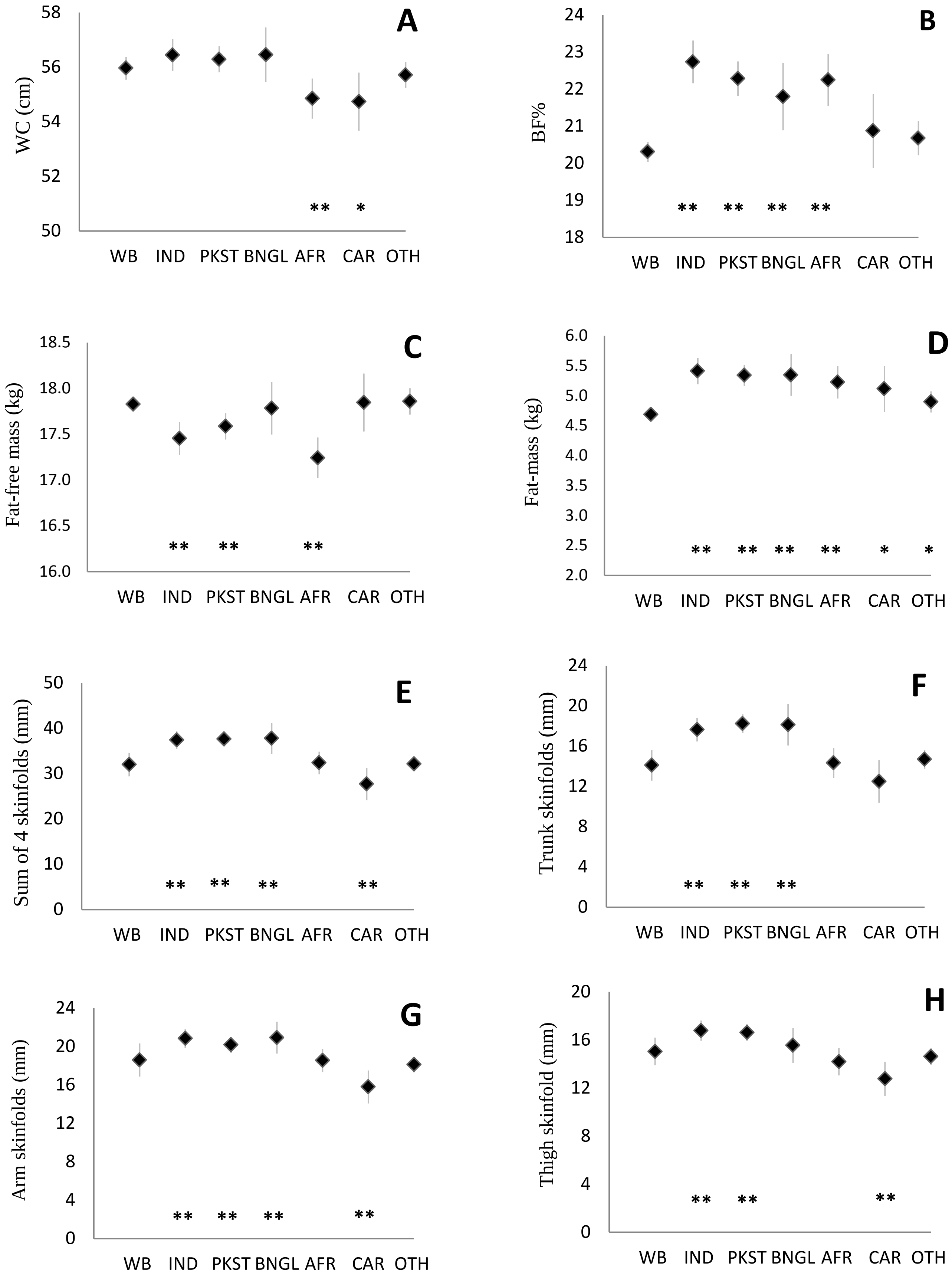

Figure 4.1. Adjusted mean waist circumference and body fat measures at a given BMI z-score. A - waist circumference; B – body fat percentage; C – fat-free mass; D – fat-mass; E – sum of four skinfolds; F – trunk skinfolds; G – arm skinfolds; H – thigh skinfold. Adjusted means derived from multilevel regression models adjusted for age, sex, SES, height and BMI z-score (fixed effects) and school and observer (random effects). Error bars represent 95% confidence intervals. Asterisks denote significant difference compared with White British children (**p<0.001, *p<0.05). Abbreviations: WB – White British; IND –Indian; PKST – Pakistani; BNGL – Bangladeshi; AFR – Black African; CAR – Black Caribbean; OTH – other/mixed.

4.4 Sensitivity analyses

When different equations were used to derive FFM (and, therefore, FM and BF%) from BIA,[59] the differences in BF%, FFM and FM between South Asian and Black African/Caribbean children were approximately 10-20% larger. Restricting analyses to only those in the two most socially disadvantaged SES quintiles did not materially affect the results. Further adjustment for total PA or MVPA did not explain any of the ethnic differences.

4.5 Discussion

4.5.1 Main findings

This is the first large-scale study to report ethnic differences in body composition and fat distribution, using a range of different measures, among young children in the UK. BMIz is higher among Black African and Black Caribbean children, and lower among South Asian children compared with White British children. However, at a given BMIz, Indian, Pakistani and Bangladeshi children have higher levels of total and central adiposity, and less FFM, compared with White British children, whereas Black African/Caribbean children have similar or lower levels of total and central adiposity.

4.5.2 Strengths and limitations

The main limitation of our study is the lack of a ‘gold standard’ measure of body composition (e.g. the four-compartment model[30,60,61]). Such intensive measures may be intimidating for children and are impractical for large-scale studies due to time constraints, financial costs, and the need for extra space and special equipment.[30] We have, however, presented data on a range of objective adiposity measures, including indicators of fat distribution, in a large, ethnically-diverse sample of young children, and were able to explore ethnic subgroup comparisons that have not been investigated previously in this age group. All measurements were performed by trained researchers, following standardised procedures, and we were able to adjust for several potential confounders. The response rate for our study was relatively high and comparable with others,[54] but acknowledge some response bias as those who declined skinfold or waist circumference measurement were more socially disadvantaged, more likely to be overweight/obese, and, for some measurements, more likely to be South Asian or Black African/Caribbean. However, we anticipate that this would have led to underestimation, rather than overestimation, of the ethnic differences in our study. Our study lacked data on several factors that might contribute to explaining the observed differences (such as migrant generation status, birth weight, prenatal factors, physical fitness, and parental body composition), and we were also unable to differentiate between visceral and subcutaneous adipose tissue (SCAT) which are independently and differently associated with cardiometabolic risk[52,62] and would therefore provide more insight regarding the potential influence of the observed differences on future health inequalities. These are important areas for future research.

4.5.3 Comparison with other studies

This is the first large-scale study to report higher levels of total and central adiposity, and lower FFM, among South Asian children as young as 5 years compared with White British children of the same BMIz. There was some heterogeneity between the South Asian subgroups, with lower BMIz among Indian and Bangladeshi compared with Pakistani children, but at a given BMIz, all groups were more adipose (based on BIA and skinfolds) compared with White British children. This is consistent with observations in adults, [40,42,43] adolescents,[56] and older children[54] in the UK, and studies in Europe,[63] Canada[50,51] and the US.[49] A study of 5-18 year old children in the UK reported higher BF% (measured by DXA) among South Asian children ≥15 years old, but not among younger children, however their study was limited by small numbers of children in age-stratified groups.[55] In support of our findings, West *et al* reported higher cord leptin levels (a proxy for adiposity) and similar skinfold thickness among UK Pakistani infants compared with White British infants, despite lower body weight among the Pakistani group.[64,65] Similarly, a small study (n=60) of UK infants reported lower FFM, measured by air-displacement plethysmography, among South Asian infants compared with White British infants.[66]

Consistent with population-wide obesity prevalence data for 4-5 year old children in the UK,[10] our data suggests that overweight/obesity prevalence is highest among Black African/Caribbean groups when based on BMI. However, as reflected in our study, Black African/Caribbean children seem to have similar or lower adiposity levels compared with White British children after adjusting for their greater height,[54] thus it seems that BMI overestimates adiposity among Black African/Caribbean children. Interestingly, our data also indicate some differences between the Black African and Black Caribbean subgroups. In general, Black Caribbean children had lower, whereas Black African children had similar, adiposity levels compared with White British children (based on skinfolds data). These findings are based on relatively small numbers of children in the two subgroups and need to be confirmed in larger studies, but the pattern is consistent with the lower plasma glucose levels[11] and smaller skinfold thickness[54] among 9-10yr Black Caribbean (compared with Black African) children in the CHASE study. Despite evidence for similar or relatively lower adiposity levels among Black African/Caribbean children[54,55]and adults[40] this group experiences unexplained higher levels of T2DM, hypertension and stroke than the general population,[41,20,21,73,74,75] so cardiometabolic health promotion and prevention of excess adiposity among Black African/Caribbean children remains a priority.

The ethnic differences observed in our study were generally very similar for boys and girls, which is consistent with a similar study of 9-10 year old UK children.[54] The data do, however, suggest that the tendency towards central adiposity among South Asians is more pronounced among girls than among boys (waist circumference was higher among South Asian girls, but not boys, compared with White British girls). This is in line with reports of more pronounced South Asian-White differences in central obesity among women than among men,[48,52] and the greater prevalence of T2DM and central obesity among indigenous Pakistani women compared with men.[76,77] Sex-differences may become more pronounced during or after puberty when increases in body fat differ between boys and girls,[55,70,78] but longitudinal studies are needed to explore this further.

4.6 Implications

Childhood obesity is associated with impaired cardiometabolic profile in childhood[16,79] and higher risk of CVD in adulthood.[17,18] Thus, ethnic differences in body composition and fat distribution in infancy,[64-66] and childhood could contribute to ethnic differences in cardiometabolic risk in adulthood. Longitudinal studies are urgently needed to explore this hypothesis. Accurate identification of those with excess adiposity is essential to facilitate early intervention to reduce, prevent, or delay the detrimental effects on cardiovascular and metabolic health. South Asians are particularly susceptible to the adverse metabolic effects of excess adiposity,[52,69] and experience higher levels cardiometabolic disease at a younger age compared with White Europeans,[21,73,80-82] so early lifestyle intervention may be particularly important among this group.

Previous research suggest that, at a given BF%, BMI is approximately 1.3 to 1.7 kg/m^2 lower among Asian adults compared with White Europeans.[45] As a result, lower BMI cut-offs are recommended for defining overweight (23-27.5kg/m^2) and obesity ($\geq$27.5kg/m^2) among Asian adults,[45] and an even lower cut-off for obesity ($\geq$25kg/m^2) has been adopted in India.[67] Among 9-10 year old children, BMI was 0.7kg/m^2 lower among UK South Asians at a given

BF%.[54] The need for ethnic-specific BMI cut-offs for children has been debated,[68] but no consensus has been reached due to insufficient evidence for increased health risks at a lower BMI among South Asian children (although cross-sectional evidence does suggest that South Asian children develop insulin resistance at a lower BMI compared with White Europeans[12,56,69]). Nevertheless, a substantial body of international evidence, including ours, demonstrates that BMI is unsuitable for comparisons of weight status or adiposity across ethnic groups among children.[49,54,63,70-72] These findings emphasize the need to incorporate specific measures of adiposity, not just measures of relative weight, in studies of ethnically-diverse groups of children.

Among Black African/Caribbean children in this study, the discrepancy between BIA estimates of body composition (which indicated higher levels of adiposity) compared with skinfold measures and WC (both indicating lower total and central adiposity) suggests that ethnic–specific leg-to-leg BIA equations are needed for this age group. BIA is a quick and easy measurement to undertake in large scale studies, even with children, and provides highly reliable estimates of FFM, BF% and FM.[83] However, the accuracy of BIA is low to moderate in children unless validated, population-specific equations are used.[83] Ethnic-specific arm-to-leg BIA equations have recently been developed for 8-11 year old UK South Asian, Black African/Caribbean and White British children and demonstrate excellent validity when compared with deuterium dilution,[84] but, as far as we are aware, none exist for younger children. This should be addressed in future research.

4.7 Conclusion

Ethnic differences in body composition and body fat distribution are evident from a young age. Compared with White British children of a given BMI z-score, adiposity is higher among South Asian children and lower or similar among Black African/Caribbean children.

Longitudinal studies are needed to assess the contribution of ethnic differences in body composition and fat distribution in childhood to health inequalities in adulthood.

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CHAPTER 5

ETHNIC DIFFERENCES IN BLOOD PRESSURE AMONG YOUNG CHILDREN IN THE UK

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5.1 Abstract

Introduction: Ethnic differences in blood pressure are evident among adults in the UK and contribute to ethnic differences in cardiovascular disease. It is unclear if similar blood pressure patterns exist among young children. **Objective:** To explore ethnic differences in blood pressure among 5-6 year old children in the UK. **Methods:** Baseline, cross-sectional blood pressure and ethnicity data were available for 1297 children (52% boys, 45% White British, 31% South Asian, 8% Black African/Caribbean) participating in an obesity prevention trial. Ethnic differences in systolic and diastolic blood pressure (SBP and DBP), and risk of prehypertension/hypertension, were assessed using multilevel regression models adjusted for clustering and potential confounders. **Results:** With the exception of a near-significant lower adiposity-adjusted SBP among Pakistani boys (adjusted mean difference: -2.23mmHg (95% CI: -4.65, 0.18), p=0.070), there was little evidence for ethnic differences in blood pressure among boys. Compared with White British girls, SBP was significantly lower among South Asian girls (fully adjusted model: -2.63mmHg (-4.68, -0.58)) and this was observed among Indian, Pakistani and Bangladeshi girls. Adiposity-adjusted DBP was lower among Indian girls (-2.66mmHg (-5.25, -0.08)) and remained borderline-significant after adjustment for SES (-2.51mmHg (5.10, 0.08), p=0.057). SBP was also lower among Black African/Caribbean girls compared with White British girls (-3.11mmHg (-6.26, 0.05), p=0.054). This difference was attenuated slightly with adjustment for adiposity (-2.93mmHg (6.22, 0.37), p=0.082) and attenuated further when adjusted for SES (-2.22mmHg (-5.62, 1.18)). The ethnic differences in blood pressure among girls were slightly smaller, but still apparent, when comparing only the most socioeconomically disadvantaged groups. There were no ethnic differences in the odds of prehypertension/hypertension among boys or girls. **Conclusion:** Ethnic differences in blood pressure are evident among 5-6 year old girls in the UK, but do not mirror the patters observed among adults. South Asian and Black

African/Caribbean girls have lower SBP compared with White British girls and Indian girls have lower DBP.

5.2 Introduction

High blood pressure is a major risk factor for coronary heart disease (CHD), stroke, and cardiovascular disease (CVD) mortality.[1-8] It has been estimated that high blood pressure is responsible for over 9 million deaths per year, worldwide,[2] and accounts for 45% and 51% of CHD and stroke mortality, respectively.[3] Among adults, persistent high blood pressure, or hypertension, is defined as systolic blood pressure (SBP) greater than or equal to 140mmHg, and/or diastolic blood pressure (DBP) greater than or equal to 90mmHg.[9,10] Nevertheless, studies have demonstrated a positive, dose-response association between higher blood pressure and increased risk of CHD and stroke from as low as 115/75mmHg.[1,5,7] For example, among adults, every 2mmHg increase in SBP above this level is associated with a 7% higher risk of CHD mortality and 10% higher risk of stroke mortality.[10] Every 20mmHg increase in SBP, or 10mmHg increase in DBP, doubles the risk of CHD and stroke mortality.[7]

Despite modest declines in global population-level blood pressure over the past three decades,[11] approximately 40% of the adult population (≥25 years of age) had high blood pressure in 2008.[12] In high income countries, the prevalence of high blood pressure was 35%, and among men and women in East and West Africa it was 46%.[11,13] In the UK, the estimated prevalence of hypertension among adults is approximately 30%;[14,15] 29% among women and 31.5% among men.[16,17]

Ethnic differences in mean blood pressure and hypertension prevalence have been reported among adults in the UK.[18,19] The vast majority of UK studies have reported considerably higher mean SBP and DBP, and greater hypertension prevalence, among Black African/Caribbean adults compared with White European adults or the general adult population.[18] Importantly, recent research suggests that this higher blood pressure contributes to the higher risk of stroke among Black African/Caribbeans.[20] The evidence for Black-White differences in BP among younger adults, however, is less consistent, with some reporting similar or lower BP among Black African/Caribbeans aged <40 years[21] or <30 years of age,[22] but higher BP among older Black African/Caribbeans.[21,22]

The evidence for blood pressure differences between White European and South Asian adults is less consistent.[19] A systematic review of studies published before 2002 highlighted these inconsistencies, but, overall, concluded that UK South Asian adults tend to have higher DBP and lower SBP compared with their White European peers.[23] In general, hypertension was also more prevalent among South Asian men compared with White European men.[19] This review also highlighted considerable heterogeneity in blood pressure between South Asian subgroups. Specifically, among South Asians, Bangladeshi adults had the lowest blood pressure, followed by Pakistani and then Indian adults.[19,24,25] Similar patterns have since been reported in the 2004 Health Survey for England (HSE).[26]

It is unclear if these differences are evident from an early age or develop over time as a result of environmental influences. A systematic review of cross-sectional studies published prior to 2003 found little variation in blood pressure by ethnicity among UK children.[27] More recently, a few large-scale studies have explored whether ethnic differences in blood pressure are apparent during late childhood and adolescence,[28-31] but results have been inconsistent. A longitudinal study suggests that adult blood pressure patterns are not apparent at age 11-13 years but emerge among Black African/Caribbeans by the age of 14-16 years.[30] Conversely, other cross-sectional studies have observed adult patterns of blood pressure among younger South Asian but not Black African/Caribbean children.[28,31] Methodological variations, age differences, lack of adjustment for socioeconomic status (SES),[29,31,32] and grouping of heterogeneous sex and ethnic subgroups[32] may contribute to these inconsistencies.

At present, very little is known about blood pressure patterns among children under the age of 9-10 years across different ethnic groups. High blood pressure tracks from childhood into adulthood[33] and starts the process of cardiovascular end organ damage.[34-36] Research has shown that the duration of exposure to high blood pressure is a strong predictor of future cardiovascular health.[37-40] Thus, understanding the origins of ethnic variations in blood pressure could contribute to explaining the ethnic differences in stroke and CHD risk in adulthood,[41-47] which are currently not fully understood,[48] and could help to inform the timing of interventions.

5.3 Aims and Objectives

The aim of this study was to explore ethnic differences in blood pressure among 5-6 year old White British, South Asian (Indian, Pakistani and Bangladeshi) and Black African/Caribbean children in the UK.

5.4 Method

5.4.1 Study design

Cross-sectional baseline data from a UK childhood obesity prevention trial (the West Midlands ActiVe lifestyle and healthy Eating in School children (WAVES) study) were analysed.

5.4.2 Sampling and participants

The sampling frame included all state-maintained primary schools within a 35-mile radius of the University of Birmingham (n=980). Information on ethnic mix, school size and the proportion of children receiving free school meals were obtained from the Local Education Authority. All schools were stratified by the proportion of White British, South Asian and Black African/Caribbean pupils and the top 2 quintiles in each stratum were identified. A weighted random sample of 200 of these schools was selected and those with a high proportion of South Asian or Black African/Caribbean children had twice the chance of being selected. Chosen schools were randomly ordered within each ethnic stratum and sequentially invited to participate. Before each batch of invitations were sent out, response bias checks were undertaken to test for any differences in ethnic mix, proportion of children receiving free school meals, or school size between those who agreed to participate and those who declined. No significant differences were observed so recruitment proceeded until the target sample size of 54 schools was achieved. Written parental consent was sought for all Year 1 children (5-6 years, n=2462 eligible children) within each participating school.

5.4.3 Consent and ethical approval

Written parental consent and verbal child assent were obtained for all measurements (n=1470, 59.7%). The study was approved by the National Research Ethics Service Committee West Midlands, The Black Country (10/H1202/69, 25/11/2010; ISRCTN: 97000586).

5.4.4 Measurement setting

At baseline, all consented children underwent a series of assessments, including anthropometric, dietary, physical activity, and psychological measures, taken by trained researchers, following standardised protocols and using validated instruments. Parents were also invited to complete a questionnaire about sociodemographic characteristics and family habits. Data on each child’s date of birth, ethnicity, and residential postcode were obtained from schools.

5.4.5 Ethnicity

Child ethnicity was defined by the parent(s), from a list of 18 options,[49] either through completion of the baseline questionnaire, or through school data. For this analysis, the data were categorised as White British, South Asian (Indian, Pakistani and Bangladeshi subgroups), and Black African/Caribbean (Black African and Black Caribbean subgroups), or 'other' (including mixed ethnicity).

5.4.6 Blood pressure

Blood pressure was measured using clinically validated, automated, oscillometric blood pressure monitors (BpTRU BPM-100, British Columbia, Canada)[50] which were calibrated at the start of the study. After 3 minutes seated-rest, two readings were taken, using the appropriate cuff-size used for each child, with a 3 minute rest-interval between each. Measurements were taken in the seated position, on the right arm, with the arm resting at chest height, and children were asked to remain still and silent throughout. The average of the two readings was used in the analysis. If the monitor displayed an error reading, or if the value was outside of the normal range the child's age and sex, a third measurement was taken and the average of the two closest readings was used. Blood pressure readings which were more than 20mmHg above the 99.6th percentile of the UK age- and sex-specific blood pressure reference data[51] were excluded as implausible readings. Children for whom only one blood pressure reading was available (n=163) were included in the main analysis but excluded in a sensitivity analysis.

Prehypertension (SBP and/or DBP $\geq 90^{th}$ percentile and $<95^{th}$ percentile) and hypertension (SBP and/or DBP $\geq 95^{th}$ percentile) were defined based on the US age-, height- and sex-specific normative blood pressure data for children.[52] The US reference data,[52] rather than UK reference data,[51] were used to define prehypertension/hypertension because the former are recommended by the European and British Hypertension Societies for clinical diagnosis of paediatric hypertension,[53] are most commonly used in the literature, including UK studies,[28-30] and are height-specific, unlike the UK reference data. Height is associated with blood pressure,[52] as observed in the present data, and ethnic differences in height are apparent among UK children.[54] Identification of implausible readings (>20mmHg above the 99.6th percentile) were based on of the UK reference data as this gave a slightly higher cut-off and thus reduced the risk of excluding genuinely high blood pressure readings.

5.4.7 Other measurements

Children were measured barefoot and in light clothing. Height was measured in duplicate, to the nearest 0.1cm, with a portable stadiometer (Leicester height measure, UK). The average of the two readings was used in this analysis. If the readings differed by more than 0.4cm, a third reading was taken and the average of the two closest readings was used. Body weight was measured to the nearest 0.1kg with Tanita bio-impedance scales (Tanita SC-331S, Japan). Body mass index (BMI) was calculated (kg/m^2) and converted to standard deviation scores (BMI z-scores). Weight status (underweight/normal weight and overweight/obese) was classified according to age- and sex-specific UK reference data using the 85th percentile as the cut-off for overweight/obese.[55] Skinfold thickness was measured at four sites, biceps, triceps, suprailliac and subscapular, with Holtain calipers. The sum of the four was used as an indicator of adiposity. The child's residential postcode was converted to Index of Multiple Deprivation (IMD) scores, an indicator of area-level deprivation,[29] using specialised software (http://geoconvert.mimas.ac.uk/). These were categorised into quintiles based on their rank within all areas in England.[56] Dietary sodium intake was assessed by 24-hour food frequency tick-list, the Child and Diet Evaluation Tool.[57] Physical activity was measured using a validated, waterproof accelerometer (Actiheart, Cambridge Neurotechnology Ltd, Papworth, UK).[58,59] Total PA was calculated as average acceleration throughout the day. Time spent in moderate-to-vigorous PA (MVPA, min/day) was defined as periods of acceleration greater than 1.75m/sec^2 (approximately equal to walking at 4.1km/h). The state of the child during blood pressure measurement (relaxed/nervous, still/restless, silent/not silent), and whether or not he/she had exercised in the last 30 minutes, were recorded. Ambient air temperature was measured with a digital thermometer.

5.4.8 Statistical analysis

All analyses were performed in STATA version 10.1. All continuous variables approximated a normal distribution. Multilevel linear regression models were used to assess ethnic differences in SBP and DBP with school fitted as a random effect to account for clustering at the school level. Models adjusted for clustering but no other covariates, henceforth referred to as 'unadjusted' models, were used to assess differences in participant characteristics and blood pressure variables by ethnicity, and between those included and excluded from the analyses. The models were then adjusted for potential confounders. Model 1 was adjusted for age, height, state of the child (relaxed/nervous, still/restless, silent/not silent), exercise in the previous 30 minutes (yes/no), room temperature, month of measurement (fixed effects), and school (random effect). Model 2 was further adjusted for the sum of four skinfolds as a measure of adiposity. Model 3 was further adjusted for SES (continuous IMD variable). Although the focus of this study was to describe ethnic differences in blood pressure rather than explain them (if any), models were also further adjusted for objectively-measured total physical activity and, separately, moderate-to-vigorous (PA), and sodium intake, which are strongly associated with blood pressure,[60,61] to see if these factors accounted any ethnic differences.

Odds ratios for prehypertension or hypertension by ethnic group,[52] adjusted as described above, were derived from multilevel logistic regression models. Interactions between sex and ethnicity were significant in models where DBP was the dependent variable (p=0.01) and borderline-significant in models where SBP was the dependent variable (p=0.078), so sex-stratified models are presented. Interactions between SES and ethnicity were also evident in models where SBP was the outcome (p=0.029). However, due to low numbers of Pakistani, Bangladeshi, Black African and Black Caribbean children in the three most affluent SES quintiles, stratification by SES was not feasible. Instead, in an attempt to standardise SES somewhat, analyses were repeated using only children in the two most socially disadvantaged quintiles (n=951). Ninety five percent confidence intervals (95% CIs) are presented for all comparisons.

5.4.9 Sensitivity analyses

Sensitivity analyses were conducted to assess the robustness of the blood pressure data: 1. Children with only one blood pressure reading were excluded (163 children excluded); 2. Blood pressure readings were excluded if the two closest values differed by more than 10mmHg (296 children excluded); and 3. The lowest blood pressure reading was used instead of the average. Finally, analyses were also repeated with adjustment for the ratio of trunk-to-limb skinfold thickness, as an indicator of fat distribution, instead of the sum of four skinfolds, as fat distribution is strongly associated with blood pressure[62] and differs by ethnic group.[54]

5.5 Results

5.5.1 Participant characteristics

Of the 1470 children for whom consent was obtained, 1367 underwent blood pressure measurement (93% of consented children). Ethnic origin was unknown for 36, and blood pressure data were excluded as implausible readings for 34 children. Therefore 1297 children were included in the final analysis (88.2% of those with parental consent to participate; 52% males, 45% White British, 31% South Asian, 7.5% Black African/Caribbean). Compared with the 1297 included children, those excluded from the analysis (due to missing data or lack of consent) were similar in terms of age, height, weight, BMI z-score, weight status, ethnic

Table 5.1 Sociodemographic and physical characteristics of participating boys (n=637) by ethnicity.

	White British (n=286)	South Asian (n=195)	South Asian subgroups			Black African/ Caribbean (n=46)	Black African/Caribbean subgroups	
			Indian (n=52)	Pakistani (n=131)	Bangladeshi (n=12)		Black African (n=31	Black Caribbean (n=15)
Age (years)	6.29 (6.25, 6.33)	6.34 (6.29, 6.39)	6.32 (6.24, 6.40)	6.36 (6.30, 6.42)	6.28 (6.15, 6.40)	6.29 (6.20, 6.37)	6.29 (6.19, 6.39)	6.28 (6.11, 6.46)
Height (m)	118 (117, 118)	119 (118, 120)	120 (118, 121)	119 (118, 120)	117 (115, 119)	122 (120, 123)	122 (120, 124)	120 (117, 123)
Weight (kg)	22.5 (21.9, 23.0)	22.9 (22.2, 23.5)	22.6 (21.4, 23.7)	23.2 (22.3, 24.0)	22.3 (20.6, 24.1)	26.1 (24.8, 27.3)	26.0 (24.6, 27.5)	26.2 (23.6, 28.7)
BMI z-scoreŦ	0.20 (0.04, 0.36)	-0.03 (-0.22, 0.16)	-0.23 (-0.56, 0.10)	0.09 (-0.16, 0.33)	-0.04 (-0.55, 0.48)	0.92 (0.56, 1.28)	0.93 (0.51, 1.34)	0.90 (0.16, 1.64)
Weight statusŦ **(%)**								
UW/NW	79.3 (74.3, 83.6)	78.7 (72.6, 83.8)	85.7 (74.8, 92.4)	75.4 (66.9, 82.4)	76.9 (57.2, 89.2)	56.9 (43.1, 69.6)	56.4 (40.7, 70.9)	58.3 (30.8, 81.5)
OW/OB	20.7 (16.4, 25.7)	21.3 (16.2, 27.4)	14.3 (7.6, 25.2)	24.6 (17.6, 33.1)	23.1 (10.8, 42.8)	43.1 (30.4, 56.9)	43.6 (29.1, 59.3)	41.7 (18.5, 69.2)
Sum of SFs (mm)	27.4 (25.5, 29.3)	31.4 (29.1, 33.7)	29.2 (25.5, 32.8)	32.7 (29.9, 35.4)	30.7 (24.9, 36.4)	35.1 (31.3, 39.0)	35.2 (30.9, 39.5)	34.9 (27.1, 42.8)
SBP (mmHg)	96.6 (95.1, 98.1)	96.8 (95.1, 98.6)	98.0 (95.4, 100.6)	96.1 (94.0, 98.2)	97.3 (93.4, 101.2)	97.5 (94.7, 100.3)	97.1 (94.0, 100.3)	98.5 (93.1, 104.0)
DBP (mmHg)	63.6 (62.2, 64.9)	63.3 (61.7, 64.9)	64.3 (62.0, 66.7)	62.7 (60.8, 64.5)	63.4 (60.0, 66.9)	63.8 (61.4, 66.3)	63.9 (61.1, 66.7)	63.8 (59.0, 68.5)
BP statusǂ **(%)**								
Normal BP	79.7 (73.2, 85.0)	79.2 (71.2, 85.5)	74.7 (60.9, 84.9)	80.5 (70.7, 87.7)	85.2 (64.7, 94.8)	82.1 (67.6, 91.0)	81.8 (64.8, 91.7)	82.6 (49.4, 95.9)
Prehypertension	8.0 (5.2, 12.0)	9.4 (5.8, 14.8)	9.2 (4.0, 19.7)	10.6 (6.0, 18.2)	3.7 (0.5, 22.5)	9.8 (4.1, 21.6)	10.2 (3.9, 24.5)	8.3 (1.1, 41.4)
Hypertension	12.0 (8.2, 17.2)	12.1 (7.7, 18.6)	16.7 (8.9, 29.3)	9.6 (5.1, 17.2)	12.0 (3.7, 33.0)	7.3 (2.6, 18.7)	7.1 (2.2, 20.9)	8.0 (1.0, 41.8)
Socioeconomic statusƗ **(%)**								
Higher SES	39.3 (33.9, 45.1)	12.1 (7.7, 18.6)	27.0 (17.5, 39.2)	5.9 (2.8, 11.8)	7.7 (1.9, 26.1)	7.3 (2.6, 18.7)	5.1 (1.3, 18.3)	8.3 (1.2, 41.3)
Lower SES	60.7 (55.0, 66.1)	12.5 (8.7, 17.7)	73.0 (60.8, 82.5)	94.1 (88.2, 97.2)	92.3 (73.9, 98.1)	5.9 (1.9, 16.7)	94.9 (81.7, 98.7)	91.7 (58.7, 98.8)

Values are means or percentages (and 95% CIs) from multilevel linear regression models adjusted for clustering but no other covariates. ŦBMI z-score and weight status are based on the age- and sex-specific UK reference data; overweight/obese is defined as >85th centile.[55] ǂPrehypertension is defined as SBP and/or DBP ≥90th percentile and <95th percentile of the US age-, height- and sex-specific normative values for BP in children. Hypertension is defined as SBP and/or DBP ≥95th percentile.[52] ƗSocioeconomic status (SES) based on Index of Multiple Deprivation: lower SES = the two most socially disadvantaged quintiles, higher SES = the three least socially disadvantaged quintiles. BMI: body mass index. UW/NW: underweight/normal weight. OW/OB: overweight/obese. SF: skinfolds. SBP: systolic blood pressure. DBP: diastolic blood pressure. BP: blood pressure. SES: socioeconomic status.

Table 5.2. Sociodemographic and physical characteristics of participating girls (n=624) by ethnicity.

	White British (n=286)	South Asian (n=195)	South Asian subgroups			Black African/ Caribbean (n=46)	Black African/Caribbean subgroups	
			Indian (n=52)	Pakistani (n=131)	Bangladeshi (n=12)		Black African (n=31)	Black Caribbean (n=15)
Age (years)	6.27 (6.22, 6.31)	6.28 (6.23, 6.33)	6.21 (6.13, 6.30)	6.29 (6.23, 6.35)	6.41 (6.24, 6.58)	6.28 (6.19, 6.37)	6.34 (6.23, 6.46)	6.16 (6.01, 6.31)
Height (m)	117 (116, 117)	117 (116, 118)	117 (115, 118)	117 (116, 118)	116 (113, 119)	120 (119, 122)	120 (118, 122)	120 (117, 123)
Weight (kg)	22.2 (21.6, 22.7)	22.0 (21.3, 22.6)	21.1 (19.9, 22.2)	22.5 (21.8, 23.3)	20.0 (17.4, 22.5)	24.1 (22.8, 25.3)	23.9 (22.4, 25.5)	24.3 (22.1, 26.5)
BMI z-scoreŦ	0.21 (0.07, 0.35)	-0.04 (-0.20, 0.13)	-0.31 (-0.62, -0.01)	0.15 (-0.05, 0.35)	-0.78 (-1.44, -0.12)	0.32 (-0.02, 0.65)	0.25 (-0.15, 0.65)	0.44 (-0.13, 1.00)
Weight statusŦ **(%)**								
UW/NW	80.4 (75.4, 84.6)	80.8 (74.7, 85.8)	88.5 (76.6, 94.7)	76.9 (68.9, 83.4)	90.9 (56.1, 98.7)	71.7 (57.2, 82.8)	71.0 (52.9, 84.1)	73.3 (46.7, 89.6)
OW/OB	19.6 (15.4, 24.6)	19.2 (14.2, 25.3)	11.5 (5.3, 23.4)	23.1 (16.6, 31.1)	9.1 (1.3, 43.9)	28.3 (17.2, 42.8)	29.0 (15.9, 47.1)	26.7 (10.4, 53.3)
Sum of SFs (mm)	34.5 (32.0, 37.0)	37.5 (34.6, 40.3)	34.8 (30.1, 39.6)	39.6 (36.2, 43.0)	27.0 (17.0, 37.0)	34.3 (29.0, 39.6)	35.5 (29.1, 41.9)	31.9 (23.1, 40.6)
SBP (mmHg)	98.3 (96.7, 99.9)	96.3 (94.4, 98.1)	96.7 (93.9, 99.4)	96.2 (94.1, 98.4)	94.9 (89.6, 100.1)	97.0 (94.0, 100.1)	96.3 (92.6, 99.9)	98.3 (93.5, 103.1)
DBP (mmHg)	63.7 (62.5, 64.9)	62.6 (61.2, 64.0)	61.3 (59.0, 63.7)	63.0 (61.3, 64.6)	65.2 (60.6, 69.8)	64.9 (62.4, 67.4)	64.9 (61.8, 68.0)	65.1 (60.9, 69.2)
BP statusǂ **(%)**								
Normal BP	74.2 (66.5, 80.6)	77.6 (69.2, 84.2)	71.7 (55.6, 83.7)	80.5 (70.8, 87.5)	72.8 (39.6, 91.6)	76.7 (60.2, 87.8)	78.9 (58.6, 90.8)	72.5 (43.2, 90.1)
Prehypertension	12.0 (8.2, 17.1)	10.9 (6.9, 16.8)	12.8 (5.9, 25.5)	10.3 (5.8, 17.6)	8.2 (1.1, 42.1)	7.9 (2.8, 20.3)	8.8 (2.6, 25.5)	6.1 (0.8, 34.2)
Hypertension	12.7 (8.5, 18.4)	10.6 (6.6, 16.7)	13.4 (6.1, 26.8)	8.9 (4.7, 16.0)	16.7 (3.9, 49.9)	14.6 (6.5, 29.5)	11.9 (4.0, 30.1)	20.2 (6.1, 49.6)
Socioeconomic statusɫ **(%)**								
Higher SES	47.7 (41.9, 53.5)	13.3 (9.2, 18.9)	34.6 (23.0, 48.4)	5.3 (2.6, 10.8)	8.3 (1.2, 41.3)	15.2 (7.4, 28.6)	19.4 (9.0, 36.9)	6.7 (0.9, 35.2)
Lower SES	52.3 (46.5, 58.1)	86.7 (81.1, 90.8)	65.4 (51.6, 77.0)	94.7 (89.2, 97.4)	91.7 (58.7, 98.8)	84.8 (71.4, 92.6)	80.6 (63.1, 91.0)	93.3 (64.8, 99.1)

Values are means or percentages (and 95% CIs) from multilevel linear regression models adjusted for clustering but no other covariates. ŦBMI z-score and weight status are based on the age- and sex-specific UK reference data; overweight/obese is defined as $>85^{th}$ centile.[55] ǂPrehypertension is defined as SBP and/or DBP ≥90th percentile and $<95^{th}$ percentile of the US age-, height- and sex-specific normative values for BP in children. Hypertension is defined as SBP and/or DBP ≥95th percentile.[52] ɫSocioeconomic status (SES) based on Index of Multiple Deprivation: lower SES = the two most socially disadvantaged quintiles, higher SES = the 3 less socially disadvantaged quintiles. BMI: body mass index. UW/NW: underweight/normal weight. OW/OB: overweight/obese. SF: skinfolds. SBP: systolic blood pressure. DBP: diastolic blood pressure. BP: blood pressure. SES: socioeconomic status.

distribution, and sex, but excluded children were more socioeconomically disadvantaged ($p<0.001$). Among the 1297 children included in the analysis, skinfold thickness data was not available for 163 children. Compared with the 1134 children for whom both blood pressure and skinfolds data were available, these 163 children were similar to in term of age, sex, ethnicity, SES, SBP and DBP (no significant differences), but had a higher BMI z-score (mean difference: 0.30 (95% CI: 0.09, 0.50)). There was a non-significant trend towards Bangladeshi children being more likely to be missing skinfolds thickness data (OR: 1.96 (95%: 0.6, 6.0)).

In unadjusted comparisons, sum of four skinfolds thickness was higher among Pakistani boys (Table 5.1) and girls (Table 5.2) compared with White British boys and girls, and higher African/Caribbean boys compared with White British boys. SES was higher among White British children compared with all minority ethnic groups, and higher among Indian children compared with Bangladeshi, Pakistani, Black African/Caribbean and 'other' children. There were no significant ethnic differences in unadjusted SBP, DBP or prevalence of prehypertension or hypertension among boys or girls.

5.5.2 Adjusted ethnic differences in systolic and diastolic blood pressure and hypertension

There were no significant ethnic differences in adjusted SBP or DBP among boys (Table 5.3). There was, however, a trend towards lower adiposity-adjusted SBP among Pakistani boys compared with White British boys, but this did not reach significance (model 2: adjusted mean difference = -2.23mmHg (95% CI: -4.65, 0.18), p=0.070; model 3: -2.12mmHg (95% CI: -4.62, 0.37), p=0.095).

Compared with White British girls (Table 5.4), SBP was significantly lower among South Asian girls (model 1: -2.46 mmHg (95% CI: -4.48, -0.44)) and this persisted after adjustment for adiposity (model 2: -3.07 (95% CI: -5.08, -1.06)) and SES (model 3: -2.63 mmHg (95% CI: -4.68, -0.58)). This pattern was evident among girls in all South Asian subgroups, and most markedly so among Bangladeshi and then Pakistani girls. However, reflecting the subgroup sample sizes, the lower SBP was only significant among Pakistani girls (model 2: -3.23 mmHg (95% CI: -5.58, -0.88); model 3: -2.71mmHg (95% CI: -5.12, -0.31)), and was borderline-significant among Indian girls (model 2: -2.68 (95% CI: -5.50, 0.13), p=0.062; model 3: -2.40 (95% CI: -5.22, 0.41), p=0.095). DBP was significantly lower among Indian girls compared with White British girls (model 1: -2.52mmHg (95% CI: -5.01, -0.03)). This difference persisted after adjustment for adiposity (-2.66 mmHg (95% CI: -5.25, -0.08)) and remained borderline-significant after adjustment for SES (-2.51 mmHg (95% CI: -5.10, 0.08), p=0.057).

SBP was also lower among Black African/Caribbean girls compared with White British girls (model 1: B= -3.11 mmHg (95% CI: -6.26, 0.05), p=0.054). This was attenuated slightly with adjustment for adiposity (-2.93 mmHg (95% CI: -6.22, 0.37), p=0.082) and attenuated further when adjusted for SES (-2.22 mmHg (95% CI: -5.62, 1.18)). This pattern was more evident among Black African then Black Caribbean girls. There were no significant differences in odds of prehypertension or hypertension among girls or boys (data not shown).

When analyses were restricted to the two most socioeconomically-disadvantaged quintiles, the difference in SBP between South Asian and White British girls was reduced by about a third, but the direction of the difference remained consistent (model 2: -1.93 (95% CI: -4.29, 0.42), p=0.108). This pattern was consistent among Indian, Pakistani and Bangladeshi girls, and for the lower SBP among Black African/Caribbean girls and lower DBP among Indian girls. Additionally, the near-significant trend towards lower SBP among Pakistani boys in adiposity-adjusted models in the main analysis was no longer evident.

Table 5.3. Ethnic differences in systolic and diastolic blood pressure among boys (White British boys as the reference group in all comparisons)

	Model 1		Model 2 (adiposity)		Model 3 (SES)	
	Adjusted mean difference (95% CI)	p	Adjusted mean difference (95% CI)	p	Adjusted mean difference (95% CI)	p
Systolic blood pressure						
White British (adjusted mean)	96.8 (95.3, 98.3)		97.3 (95.8, 98.8)		97.2 (95.6, 98.8)	
All South Asian	0.04 (-1.98, 2.06)	0.970	-1.09 (-3.18, 1.00)	0.307	-0.97 (-3.12, 1.18)	0.377
Indian	1.10 (-1.62, 3.83)	0.429	0.37 (-2.47, 3.22)	0.797	0.41 (-2.46, 3.27)	0.781
Pakistani	-0.85 (-3.23, 1.52)	0.482	-2.23 (-4.65, 0.18)	0.070	-2.12 (-4.62, 0.37)	0.095
Bangladeshi	0.91 (-3.09, 4.91)	0.656	0.19 (-4.14, 4.51)	0.933	0.35 (-4.04 , 4.74)	0.875
All Black African/Caribbean	-0.27 (-3.23, 2.68)	0.855	-1.66 (-4.68, 1.37)	0.283	-1.52 (-4.61, 1.57)	0.336
Black African	-0.69 (-4.00, 2.62)	0.683	-2.00 (-5.34, 1.35)	0.242	-1.88 (-5.31, 1.54)	0.281
Black Caribbean	0.87 (-4.55, 6.30)	0.752	-0.85 (-6.55, 4.85)	0.771	-0.80 (-6.52, 4.93)	0.785
Other/mixed	-0.29 (-2.48, 1.89)	0.792	-0.76 (-2.99, 1.47)	0.504	-0.63 (-2.93, 1.67)	0.593
Diastolic blood pressure						
White British (adjusted mean)	63.7 (62.3, 65.1)		63.9 (62.4, 65.4)		63.9 (62.4, 65.4)	
All South Asian	-0.27 (-2.11, 1.57)	0.776	-0.73 (-2.66, 1.20)	0.459	-0.73 (-2.71, 1.25)	0.472
Indian	0.75 (-1.72, 3.21)	0.553	0.66 (-1.95, 3.26)	0.622	0.64 (-1.99, 3.26)	0.635
Pakistani	-0.97 (-3.13, 1.18)	0.376	-1.63 (-3.86, 0.61)	0.153	-1.66 (-3.95, 0.64)	0.158
Bangladeshi	-0.19 (-3.80, 3.42)	0.917	-0.58 (-4.53, 3.38)	0.775	-0.60 (-4.62, 3.42)	0.769
All Black African/Caribbean	-0.12 (-2.78, 2.54)	0.931	-0.87 (-3.63, 1.89)	0.537	-0.86 (-3.68, 1.97)	0.553
Black African	-0.14 (-3.13, 2.84)	0.924	-0.78 (-3.84, 2.27)	0.616	-0.81 (-3.94, 2.32)	0.613
Black Caribbean	-0.11 (-4.99, 4.76)	0.963	-1.41 (-6.60, 3.78)	0.594	-1.43 (-6.65, 3.79)	0.591
Other/mixed	-0.46 (-2.43, 1.51)	0.649	-0.55 (-2.59, 1.50)	0.601	-0.56 (-2.66, 1.55)	0.604

Values for all non-White British ethnic groups are adjusted mean differences (and 95% CIs) from multilevel linear regression models adjusted for clustering and potential confounders. Adjusted means (and 95% CIs) are presented for White British boys, the reference group in all comparisons. Model 1 is adjusted for age, height, state of child (relaxed/nervous, still/restless, silent/not silent), exercise in the previous 30mins (yes/no), room temperature, month of measurement, and school as a random effect (n= 671). Model 2 is further adjusted for sum of four skinfolds (n=588). Model 3 is further adjusted for SES (continuous IMD score; n=584).

5.5.3 Sensitivity analyses

Excluding single blood pressure readings, using the lowest blood pressure reading, and excluding readings which differed by more 10mmHg, made little difference to the results in terms of direction and magnitude of the ethnic differences observed in the main analyses. The results also remained very similar when models were further adjusted for MVPA, total PA, and sodium intake, and when models were adjusted for the ratio of trunk-to-limb skinfolds instead of sum of four skinfolds.

Table 5.4. Ethnic differences in systolic and diastolic blood pressure among girls (White British girls are the reference group in all comparisons)

	Model 1		Model 2 (adiposity)		Model 3 (SES)	
	Adjusted mean difference (95% CI)	**p**	**Adjusted mean difference (95% CI)**	**p**	**Adjusted mean difference (95% CI)**	**p**
Systolic blood pressure						
White British (adjusted mean)	99.0 (97.4, 100.6)		98.9 (97.3, 100.4)		98.5 (96.9, 100.1)	
All South Asian	-2.46 (-4.48, -0.44)	0.017	-3.07 (-5.08, -1.06)	0.003	-2.63 (-4.68, -0.58)	0.012
Indian	-2.06 (-4.86, 0.75)	0.151	-2.68 (-5.50, 0.13)	0.062	-2.40 (-5.22, 0.41)	0.095
Pakistani	-2.55 (-4.92, -0.18)	0.035	-3.23 (-5.58, -0.88)	0.007	-2.71 (-5.12, -0.31)	0.027
Bangladeshi	-3.77 (-9.24, 1.71)	0.178	-3.72 (-9.78, 2.35)	0.230	-3.19 (-9.27, 2.88)	0.302
All Black African/Caribbean	-3.11 (-6.26, 0.05)	0.054	-2.93 (-6.22, 0.37)	0.082	-2.22 (-5.62, 1.18)	0.201
Black African	-3.45 (-7.18, 0.27)	0.069	-3.12 (-7.04, 0.79)	0.118	-2.48 (-6.46, 1.50)	0.221
Black Caribbean	-2.53 (-7.49, 2.42)	0.316	-2.64 (-7.92, 2.64)	0.327	-1.78 (-7.16, 3.59)	0.516
Other/mixed	-0.62 (-2.89, 1.64)	0.591	-1.14 (-3.43, 1.15)	0.329	-0.64 (-2.99, 1.71)	0.593
Diastolic blood pressure						
White British (adjusted mean)	64.0 (62.7, 65.3)		63.7 (62.5, 65.0)		63.6 (62.3, 64.9)	
All South Asian	-1.24 (-2.98, 0.49)	0.161	-1.48 (-3.26, 0.29)	0.102	-1.38 (-3.23, 0.46)	0.143
Indian	-2.52 (-5.01, -0.03)	0.047	-2.66 (-5.25, -0.08)	0.043	-2.51 (-5.10, 0.08)	0.057
Pakistani	-0.87 (-2.90, 1.16)	0.400	-1.21 (-3.27, 0.86)	0.251	-1.07 (-3.22, 1.09)	0.331
Bangladeshi	1.90 (-3.01, 6.81)	0.448	2.66 (-2.96, 8.28)	0.353	2.81 (-2.83, 8.45)	0.329
All Black African/Caribbean	-0.03 (-2.81, 2.75)	0.983	1.00 (-1.99, 3.99)	0.512	1.19 (-1.93, 4.31)	0.456
Black African	0.56 (-2.72, 3.83)	0.739	1.47 (-2.06, 5.00)	0.415	1.72 (-1.90, 5.35)	0.351
Black Caribbean	-0.99 (-5.42, 3.45)	0.662	0.29 (-4.60, 5.18)	0.907	0.57 (-4.43, 5.57)	0.823
Other/mixed	-0.67 (-2.67, 1.32)	0.508	-0.25 (-2.33, 1.83)	0.814	-0.06 (-2.22, 2.10)	0.955

Values for all non-White British ethnic groups are adjusted mean differences (and 95% CIs) from multilevel linear regression models adjusted for clustering and potential confounders. Adjusted means (and 95% CIs) are presented for White British girls, the reference group in all comparisons. Model 1 is adjusted for age, height, state of child (relaxed/nervous, still/restless, silent/not silent), exercise in the previous 30mins (yes/no), room temperature, month of measurement, and school as a random effect (n= 621). Model 2 is further adjusted for the sum of four skinfolds (n=539). Model 3 is further adjusted for SES (IMD as a continuous variable) (n=534).

5.6 Discussion

5.6.1 Main findings

This is the first large-scale study to explore ethnic differences in blood pressure among 5-6 year old children in the UK. With the exception of lower SBP among South Asian girls, the blood pressure patterns observed in this age group do not yet mirror the patterns observed among adults in the UK. Specifically, compared with White British girls, SBP was 2-3mmHg lower among all subgroups of South Asian girls and 3mmHg lower among Black African/Caribbean girls, and DBP was 2.5mmHg lower among Indian girls. These differences appeared to be independent of adiposity and SES. There was also some evidence to suggest that adiposity-adjusted SBP was approximately 2mmHg lower among Pakistani boys compared with White British boys.

5.6.2 Strengths and limitations

This study benefits from a large, ethnically-diverse UK sample of young children. Prior to this study, very little was known about blood pressure patterns among this young age-group. The use of validated and calibrated blood pressure monitors,[50] trained researchers and standardised protocols, and the availability of detailed information on sociodemographic factors and objective measures of adiposity and physical activity are strengths of this study. Moreover, the robustness of the blood pressure data was observed through a series of sensitivity analyses. The use of parental-report ethnicity and sex- and ethnic-subgroup analyses are also key strengths of this study.

There are, however, several limitations which should be considered when interpreting these findings. Although the overall sample size was large, the study is limited by the small numbers of children in some minority ethnic subgroups. It is possible that this study was underpowered to detect modest differences in blood pressure in these groups, especially when stratified by sex. For example, the data indicate possible subgroup differences in blood pressure among South Asian girls, but this study was likely underpowered to detect these differences as significant, particularly among Bangladeshi children. Additionally, although models were adjusted for SES, the lack of representation of Pakistani, Bangladeshi, and Black African/Caribbean children from higher SES areas makes it difficult to fully separate the effects of ethnicity and SES in our study and limits the generalizability of these findings. Area-based indicators of SES, such as that used in this study, are also limited in their ability to capture information on individual-level circumstances. Although area-based indicators of deprivation correlate well with individual SES and CV risk factors in adults,[63] and may help to contextualise the effects of living conditions,[63] using a combination of both individual and area level indicators of SES can strengthen the accuracy of SES measurement.[63]

Furthermore, although the automated blood pressure device used in our study has been validated in children as young as 3 years old,[50] validity is not synonymous with reliability; validation criteria still allow for 24% of readings to differ by more than 10 mmHg.[50,64,65] In this study, 23% of children had readings that differed by more than 10mmHg. Nevertheless, consistent results were observed when these data are included or excluded from the analysis. Measuring blood pressure at a single time-point may lead to overestimations of blood pressure[66] but repeated measures are not feasible in large scale epidemiological studies such as this, and single time-point measurement is widely-used in similar studies.[28,30,32] It is not clear if the white-coat effect differs by ethnic group.[67] The few studies on this topic have found no difference between Black and White adults but there is some evidence for a lower white-coat effect in South Asians.[67] Theoretically, this could influence the results by systematically overestimating blood pressure in White and Black African/Caribbean children but not South Asian children. Indeed, in the LOLIPOP study, there were no differences in office blood pressure between South Asian and White adults, but South Asian adults had higher 24-hr ambulatory blood pressure.[68] Ambulatory monitoring was not feasible in the WAVES study due to time constraints, but it is possible that such data could yield different results to those reported here so should be explored in future work.

Another limitation is the lack of information on migrant generation status. Some studies have suggested that third generation migrants, more so than first and second generation migrants, tend to converge towards the host population in terms of lifestyle factors, cultural values and some cardiovascular markers, including blood pressure. [27,69] Thus, it is possible that stratification by, or adjustment for, generation status may have produced different results.

5.6.3 Comparison with other studies

Unlike the patterns observed among UK adults,[18,45,70-77] this study found no evidence for higher SBP or DBP among Black African/Caribbean compared with White British children. In fact, SBP was approximately 3mmHg lower among Black African/Caribbean girls compared with White British girls. The latter is in line with the 1.6mmHg lower SBP observed among Black African/Caribbean children in the CHASE study.[28] These observations are consistent with a growing body of evidence from studies in the UK[29,30,32,78,77,22] and the US[79] which suggests that the higher SBP and DBP among Black adult populations are not established until late adolescence[30] or even early adulthood.[22,21] These data suggest that targeting interventions in childhood may present a key opportunity to reduce or prevent Black-White differences in blood pressure later in life. Further research is needed to identify the underlying causes of the higher blood pressure among older Black African/Caribbeans.[80]

After adjustment for confounders, SBP was approximately 2-3mmHg lower among South Asian girls compared with White British girls in this study. There was also some evidence for lower adiposity-adjusted SBP among Pakistani (-2.23mmHg (95% CI: -4.65, 0.18), p=0.07) boys. This is generally consistent with studies of UK adults[19,24,25,76,78,81-83] including one in

Birmingham,[78] and 9-10 year old children in the CHASE study.[28] Consistent with the current findings, the lower SBP among older South Asian children and adolescents in the CHASE and DASH studies was most evident among Pakistani children and least evident among Indian children,[28,29]

Although there are some inconsistencies in the literature,[24,81] the majority of UK studies have reported higher DBP among South Asian adults compared with White Europeans or the general population.[19,25,45,72, 75,76,78,83,84] Higher DBP has also been reported among South Asian children aged 8-11 years,[32] 9-10 years,[28] and 5-15 years,[31] compared with White European children. In contrast, the present study reports 2.5 mmHg lower DBP among 5-6 year old Indian girls, and no differences in DBP between South Asian boys or Indian and Bangladeshi girls compared with their White British counterparts. However, the general lack of differences in DBP between South Asian and White British children in the present study is largely consistent with the findings of the DASH study.[30] Although, in that study, 11-13 year old Indian girls, had higher DBP compared with White children,[29] which is in direct contrast to the lower DBP observed among Indian girls in the present study. It is possible that the present study was underpowered to detect differences in DBP when stratified by sex and ethnic subgroups. Indeed, there was a non-significant trend towards higher DBP among Bangladeshi girls compared with White British girls. Alternatively, the discrepant findings might suggest that this divergence in DBP between South Asian and White European children occurs between the ages of approximately 5 and 10 years, but longitudinal studies are required to explore this further. Direct comparison of these cross-sectional studies is limited by wide variations in methodologies and participant characteristics. For example, differences in age, blood pressure measurement, socioeconomic status, ethnicity assessment and definitions, geographical location, physical activity levels, and the relative proportions of each ethnic subgroup to overall South Asian and Black African/Caribbean samples, could contribute to the inconsistent findings.

The majority of previous studies, particularly those in adults, have combined South Asian[32,45,68,72,75-77,81,82,84-86] and Black[45,70,74,76-78,84,86,87] subgroups in their analyses. However, Bhopal *et al*,[24] and data from the HSE,[25,26,21] have demonstrated considerable variation in blood pressure and hypertension between these subgroups. In general, Bangladeshi adults have the lowest blood pressure of the South Asian subgroups, and differ most markedly from Europeans, and Indians have the highest blood pressure.[24,26] Despite the small numbers of children in some ethnic subgroups in this study, the data do indicate trends that are consistent with the subgroup differences observed in previous studies.[24,26,28] For example, the lower SBP among South Asian compared with White British girls in the present study was most marked among Bangladeshi and least marked among Indian girls. This is consistent with the patterns observed among adults in the Newcastle Heart Project[24] and the 2004 HSE.[26] Similarly, although not significant due to small subgroup sizes, the lower SBP among Black African/Caribbean girls was most marked among Black African girls and less so among Black Caribbean girls in this study. The same pattern was observed in the CHASE study.[28] These apparent subgroup variations further emphasize the importance of separating such groups in future analyses.

A recent large-scale (n=5,221) study of primarily White European 10 year old children from eight European countries (Spain, Germany, Hungary, Italy, Cyprus, Estonia, Sweden and Belgium) found that approximately 10% of participants were classified as having high blood pressure,[88] about half the observed prevalence among White British children in the WAVES study, with a yearly incidence of 121 per 1000 for pre-high blood pressure and 110 per 1000 children for high blood pressure.[88] Thus, the prevalence of prehypertension/hypertension among all groups in the present study is considerably higher than expected. Indeed, it is surprisingly high when compared data from the Health Survey for England which suggests that 30% of adults have elevated blood pressure.[89] Explanations for this observation are unclear. Obesity prevalence is higher in the WAVES cohort compared with these European countries, but this is unlikely to account for the difference. BP might be overestimated in the WAVES cohort if some children became restless during the measurement(s), and, as discussed above, the single time-point measurements can also contribute to overestimated blood pressure readings.

5.7 Implications and conclusions

As summarised in two systematic reviews, previous studies have reported higher SBP and DBP among Black African/Caribbean adults and, in general, lower SBP but higher DBP among South Asian adults.[18,19] With the exception of lower SBP among South Asian girls, the blood pressure patterns observed in this age group do not yet mirror the patterns observed among adults in the UK. High blood pressure is a strong risk factor for stroke and CHD,[8,7] and there evidence suggests that ethnic differences in blood pressure among adults contribute to ethnic differences in stroke and CHD mortality.[20,90] Growing evidence suggests that ethnic differences in blood pressure emerge in late adulthood or adolescence.[28-30,31,32] Thus, while acknowledging the limitations of this study, the findings suggest that targeting intervention efforts at this young age group could be a good opportunity to reduce inequalities in hypertension, stroke and CHD later in life. Longitudinal studies are needed to identify the exact age at which the higher SBP and DBP among Black African/Caribbeans and higher DBP among South Asians emerge, and to identify the determinants of these variations.

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CHAPTER 6

DISCUSSION

6.1 Aims and rationale

Ethnic differences in cardiovascular and metabolic disease are evident among adults in the UK,[1-7] but the underlying reasons for these differences are not fully understood. Recent studies have demonstrated that ethnic differences in cardiovascular disease (CVD) risk factors are evident by the age 10 years.[8-14] Some of these differences reflect the disease patterns observed in adults so could plausibly contribute future health inequalities. Understanding these early-life ethnic differences is essential for the design of timely and effective interventions, but very few studies have explored variations in cardiovascular risk factors among younger children from different ethnic groups. Thus, the aim of this thesis was to investigate differences in physical activity, sedentary time, dietary intake, adiposity, fat distribution, and blood pressure among 5-6 year old Indian, Pakistani, Bangladeshi, Black African, Black Caribbean and White British children in the UK. Baseline data from a cluster-RCT of a childhood obesity prevention intervention, including 56 schools and over 1400 children from across the West Midlands (UK), were analysed. It is hoped that these findings will help to shape the timing and design of interventions to reduce ethnic differences in cardiometabolic health by contributing to our understanding of the early origins of these inequalities. Chapter 7 provides an overview of the collective findings of this thesis, and discusses their implications, limitations, and directions for future research.

6.2. Summary of main findings

Collectively, the findings suggest that ethnic differences in physical activity, sedentary time, dietary intake, body composition and fat distribution are evident by the age of 5-6 years among children in the UK. Importantly, some of these differences are consistent with the cardiometabolic health inequalities that have been reported among older age groups. For example, South Asian boys and girls had higher levels of body fat and central fat distribution compared with White British girls (Section 4.4, page 185-186), and South Asian, particularly Pakistani, girls spent considerably less time in MVPA (Section 2.4.4, page 109). These findings are consistent with their higher risks of T2DM, CHD, central obesity and stroke in adulthood[2-6,15,16 17]and elevated markers of insulin resistance in late childhood.[11,18,19] Black African/Caribbean boys spent more time in MVPA and VPA (Section 2.4.3, page 108). Both Black African/Caribbean boys and girls had less central adiposity (based on waist circumference and, for Caribbean children, skinfold thickness (Section 4.4, page 185-186)) and consumed less sugar (Section 3.4.4, page 145) compared with White British children. These observations are consistent with their lower risk of CHD in adulthood[3,4,20] and lower total- and LDL-cholesterol in late childhood.[21] Conversely, the high sodium intake among Black African children at this age is consistent with elevated blood pressure during adolescence[8] and higher risk of hypertension and stroke in adulthood,[7,22-24]

Other findings, however, are less consistent with the ethnic differences in cardiometabolic profiles observed among older age groups. For example, Pakistani boys were considerably more physically active and less sedentary compared with White British boys (Section 2.4.3, page 108). A similar non-significant trend was observed for Indian boys. Sugar intake was lower among all minority ethnic groups. Energy intake and total and saturated fat intake were similar between White British and South Asian children. Blood pressure was generally lower among girls from minority ethnic groups, and similar among boys from minority ethnic groups, compared with their White British counterparts.

This work also highlighted some areas of concern which were pertinent to all six ethnic groups. For example, sugar, sodium and saturated fat intake exceeded the current dietary guidelines in all groups, whereas MUFA, PUFA and fibre intake were below the recommended levels. Additionally, with the exception of Pakistani boys, children were less active, more sedentary and less likely to achieve the recommended 60 min/day MVPA on weekend days than on weekdays.

6.3 Strengths and limitations

Strengths and limitations specific to each chapter have been discussed already, but there are also some wider limitations, relevant to all five empirical chapters, which should be taken into consideration when interpreting the overall findings of this thesis.

6.3.1 Measuring and categorising ethnicity

There are two main limitations associated with the measurement of ethnicity in the present study. Firstly, although the use of predefined response options facilitates categorisation, and thus analysis, of ethnicity data, it also comes with the limitation of potentially restricting or influencing participants' answers.[25,26] However, this issue was minimised in the present study as parents had the option to elaborate, via a free-text answer, if they felt that their child's ethnic group was not included in the list of response options.[27] Secondly, the ethnicity data were obtained from two sources: 1. via a questionnaire which was sent home to parents specifically for this study, and 2. via data obtained from the child's school. Schools are required to collect this information from parents for the School Census (https://www.gov.uk/school-census). Ultimately, both sets of information were provided by the parent(s) so it was anticipated that there would be no inconsistencies between the two. However, there were a few instances where this was not the case. For 26 (3.1%) of the 840 children for whom both sources of ethnicity data were available, the two data sources gave conflicting information about the ethnicity of the child. It is possible, therefore, that a small proportion of children were categorised into the wrong ethnic group. However, as this issue applied to a very small number of children, and there was no observed ethnic bias in these inconsistencies, it is unlikely that this limitation influenced the main findings of this thesis.

6.3.2 Heterogeneity within ethnic groups

Previous studies have demonstrated large variations in CV risk factors and mortality within broad ethnic groups, such as 'South Asian' and 'Black'.[2,6,28,29] Accordingly, this thesis specifically focussed on the main subgroups within these broader categories. Nevertheless, is likely that marked heterogeneity exists even within these comparatively narrow groups, in terms of, for example, religious beliefs, migrant generation status, experiences of racism, acculturation, socioeconomic status, education level, region of origin, and language.[6,30-33] Such differences likely influence the health beliefs and behaviours within these subgroups.[34-40] For example, religious dietary laws influence nutrient intake within and between ethnic groups.[36,38,39] Unfortunately, these data were not collected in the WAVES study so it was not possible to assess their influence on the outcomes explored in Chapters 2 to 6. Such information would likely help to refine interventions to the needs of specific subgroups so should, if possible, be explored in future studies in this age group.[34]

6.3.3 Other/mixed ethnic groups

Due to the heterogeneous nature of the 'other/mixed' ethnic group, their results were not discussed in this thesis. This limitation is common to the majority of studies in this field so extremely little is known about cardiovascular health outcomes and behaviours among children from these groups. For the present study, the 'other/mixed' group consisted of Arab, Chinese, Irish, Other White, Other Black, Other Asian, and mixed ethnicity children. These groups are growing in size in the UK.[31,41] For example, in 2001, 672,000 people in England and Wales self- identified as belonging to more than one ethnic group (i.e. "mixed" ethnicity). [41] By 2011, this number had grown to 1,224,000, an overall increase of 82%, and an annual increase of 6%.[41] It is likely that these groups differ in their cardiovascular risk profiles and health behaviours.[2,3,5,33,42] Future studies should, therefore, endeavour to understand more about their health behaviours and outcomes to ensure that these groups are not neglected when designing and targeting intervention strategies.

6.3.4 Sample size

Although the overall sample size was large, the numbers in some groups were small, especially in sex-stratified analyses. It is possible, therefore, that this study was underpowered to detect differences in the smaller groups as the precision of estimates (i.e. confidence interval width) is influenced by sample size. Throughout this thesis, a larger number of significant differences were observed between Pakistani (the largest minority ethnic group in this study) and White British children than there were for other minority ethnic groups. It is possible that Pakistani children were most different to White British children in this study, and thus more significant differences were observed. Alternatively, it could be that this study was sufficiently powered to detect differences between these two groups, but less so among others. There were instances where point estimates differed quite substantially between a smaller minority ethnic group and the White British group, but did not reach statistical significance, most likely because of low statistical power. For example, in Chapter 2, the differences in PA between Indian and White British boys largely mirrored the differences between Pakistani and White British boys but did the former did not reach statistical significance. Larger studies, with representative samples across ethnic groups, are required to confirm such observations.

The decision to present sex-stratified results for some models, but not others, was driven by formal tests for sex interactions in the associations between ethnicity and each outcome (i.e. the PA, ST, dietary intake, body composition and BP variables of interest in each chapter). If a significant sex-ethnicity interaction was observed, sex-stratified models were explored and are presented and discussed in the relevant chapter. As such, Chapters 2 and 5 present sex-stratified results, whereas Chapters 3 and 4 present results for boys and girls combined. Combining boys and girls in the analyses for Chapters 2 and 5, in which significant sex-ethnicity interactions were observed, would mask sex-specific ethnic differences in terms of both magnitude and direction of any differences. For example, in Chapter 2, the direction of the differences in PA/ST between South Asian and White British boys were in direct contrast to those observed among girls. Combining boys and girls in this analysis would therefore have masked these important observations. However, as mentioned above, stratifying these analyses by sex reduces statistical power to detect any real differences between ethnic groups because comparisons are based on smaller numbers of children within each ethnic group. As such, power to detect any real differences between ethnic groups was considerably higher in Chapters 3 and 4 than in Chapters 2 and 5. To increase power in Chapters 2 and 5, data are presented for all South Asian groups combined and both Black groups combined, as well as for each ethnic subgroup, separately.

6.3.5 Validity of the measures used for ethnic group comparisons

The measures and procedures used in the WAVES study have been validated for this, or a similar, age group.[43-46] It is important to note, however, that these validation studies were, for the most part, conducted on groups of White European children[43-46] and have not been specifically validated for inter-ethnic group comparisons or among minority ethnic groups. The extent to which this influences the results reported in this thesis is unknown. This limitation is common to many previous similar studies[47,48] because of the distinct lack of tools and measures that are validated for ethnic group comparisons, especially among children.[49-52] This is a key area for future research.

6.3.6 Explanations for the observed differences

A further limitation of this thesis is that few data were available to try to explain the observed ethnic differences. There are some instances in this thesis where analyses have been adjusted for an additional variable to see if it explained or attenuated any of the observed ethnic differences. For example, additional analyses were performed to see if variations in weight status or adiposity explained the ethnic differences in physical activity and sedentary time (Chapter 2), or if physical activity contributed to variations in body composition and fat distribution (Chapter 4). In all analyses, models were adjusted for socioeconomic status. These adjustments had very little or no influence on the main findings. However, such observations should be interpreted with caution because of the cross-sectional study design and methodological limitations associated with some of the measurement tools. For example, as discussed below, it is possible measure of SES used in this thesis did not fully account for the confounding effect of SES as area-based measures can reflect very different circumstances across ethnic groups (see section 6.3.7).[26]

6.3.7 Socioeconomic status

A major challenge in this area of research is disentangling the effects of SES and ethnicity on CV health inequalities.[26,53] Indeed, this topic is widely debated in the literature, with some suggesting that ethnic inequalities in CVD risk and associated behaviours are independent of,[3,12,24,49,54,54-56] partially explained by,[24,57,58] or largely explained by[53,59-61] variations in SES. In some cases, adjustment for SES actually increased the size of ethnic inequalities in CV health and mortality.[62] Arguably the main reasons for these discrepancies are: 1. Inconsistencies in defining, categorising, and measuring ethnicity and SES; and 2. Difficulties in effectively accounting for the confounding effects of SES.[26]

Both SES and ethnicity are challenging to measure[63-65]and methods vary quite widely in the literature[63,66-69] so comparison and interpretation of findings are difficult. The difficulty in ethnicity and health research is that each SES-related variable can represent different circumstances across ethnic groups.[6,26] For example, income may vary by ethnicity within a particular occupational class.[6,63,70] Occupational class and income may differ by ethnicity within educational attainment strata.[69] Quality of housing may differ by ethnicity among house owners.[70,71] Individual-level markers of SES may also vary by ethnic group within area-based deprivation strata.[69] Moreover, associations between markers of SES and cardiovascular health outcomes are not always consistent in strength and/or direction, within and between ethnic groups, depending on the measures used and the outcome of interest.[6,26,54,67, 76,75] This applies to both studies of adults[26,54,67,72-75,75] and children.[8,76] Thus, it is unclear which measures of SES provide the most optimal adjustment to fully account for the confounding effects of SES when modelling ethnic differences in CV risk factors.

The above issues are pertinent to the work presented in this thesis. The findings are limited by the use of a single, area-based measure of deprivation, the lack of variation in IMD within the minority ethnic groups, and the large differences in IMD between minority ethnic groups (lower SES) and the White British group (higher SES). In an attempt to standardise SES across ethnic groups, sensitivity analyses were conducted in each chapter, comparing only those in the two most socially disadvantaged quintiles. Unfortunately, the lack of variation in SES within ethnic minority groups prevented comparisons of those in the top three quintiles. In the majority of these analyses, the main findings were unchanged, and any exceptions were discussed within the relevant chapter. However, although area-based indicators of SES have, in some studies, performed relatively well as comparable markers of SES across ethnic groups,[67,69] it is unlikely that the IMD variable alone fully accounts for the confounding effects of SES.[26,53,63,77-79] Thus, although the ethnic differences presented in this thesis are, for the most part, apparently independent of SES, these observations should be interpreted with caution and require further investigation.

6.3.8 Response bias and generalizability

The overall response rate for the WAVES study was a moderate 55% overall, with consent being obtained for 1470 of a possible 2682 children. Among these, the parents of 99 children provided consent for only the less intensive measures to be undertaken. In these cases, skinfold measurements, dietary assessment, and physical activity monitoring were not included in their baseline measurements. Overall, non-participating children were more socially disadvantaged compared with participating children. Although it is possible that the findings may have changed slightly if these more socially-disadvantaged children had participated, any impact is likely to be minor as the absolute differences in IMD between participating and non-participating children were very small. Moreover, 55.5% of participating children lived in areas which ranked in the bottom, most disadvantaged quintile of all areas in England. Thus, the findings of this thesis are unlikely to be generalisable to more affluent groups or regions in the UK, among whom cardiovascular risk factors may differ compared with those in the present study. Indeed, based on NCMP data, obesity prevalence among 4-5 year old children in the West Midlands region (10%)[81] is higher than in the general population of 4-5 year olds in England(9%).[80] Obesity prevalence was even higher among children participating in the WAVES study (13%). Again this might reflect the lower SES of the WAVES cohort compared with the general population (and possibly the higher proportion of Black African/Caribbean children, who have higher average BMI, in the WAVES study). However, direct comparison is difficult because of the slight age difference between the NCMP (4-5 years) and WAVES (5-6 years) cohorts. Obesity prevalence almost doubles between the ages of 4-5 years and 10-11 years in England so slightly higher prevalence among the WAVES children would be expected.[80]

6.3.9 The comparative approach

Ethnicity and health research is usually based on a comparative approach, whereby minority ethnic groups are compared with the general population or the majority ethnic group.[82] Thus, when interpreting the findings, it should be noted that any relative differences are determined, not only by the behaviours or outcomes of the minority ethnic groups, but also by the standards set by the reference population. For example, if the reference population differs between studies, in their health behaviours and outcomes, two similar studies can come to quite different conclusions regarding differences between ethnic groups. In an attempt to facilitate comparison with previous and future studies, adjusted means (not just adjusted mean differences) have been presented for all ethnic groups in each of the empirical chapters in this study. To put the data into context, attempts have been made, where possible, to compare the characteristics of the reference population in this thesis with those in other similar studies.

6.3.10 Wider debates regarding the benefits and potential harms of ethnicity and health research

It is important, at this point, to acknowledge a wider debate regarding the importance and potential harms of ethnicity and health research.[26,49,50,59,64,65,82-87] The main arguments regarding the potential harms and overarching flaws of ethnicity and health research are that it: could be perceived as racist in its motives and/or outcomes[49,50,59,88] or may promote racial prejudice. Prejudice may arise because of the tendency to focus on the negative aspects of the health of minority ethnic groups and, thus, the burden on wider society and their inferiority to the reference (often White) population.[49,82] There is also the perspective that ethnicity is unimportant in health research as the focus should be on tackling poverty and social disadvantage to alleviate health inequalities.[53,60] Others have argued that methodological issues, such as difficulties in defining, measuring and categorising ethnicity,[34,49,59,64,83,89,90] and wide heterogeneity within groups,[5,6,82] limit the scientific validity of such data. Lack of appropriate adjustment for confounders such as SES,[26,64,82] and the use of measurement tools and norms which have, more often than not, been developed and validated in White European populations,[49-52] have also been cited as flaws in this area of research.

Given the challenges and complexities of accurately measuring ethnicity and SES, and the difficulties in isolating ethnicity as an independent CVD risk factor (see Section 6.3.7 for further discussion of this topic), there is an argument in the literature for excluding ethnicity as a variable in health research.[87] As discussed in Chapter 1, large-scale international research has demonstrated that the major modifiable CVD risk factors collectively account for over 90% of myocardial infarction in all continents across the world, irrespective of ethnicity.[91] Thus, in identifying CVD risk, there is a case for simply defining groups based on traditional CVD risk factors, not ethnicity. Wide heterogeneity in CVD risk and health behaviour patterns exists within, as well as between, ethnic groups; CVD risk is not high among all individuals within an ethnic group.[5,6,82] Thus, grouping individuals based on traditional, modifiable CVD risk factors, irrespective of SES and/or ethnicity, could help to target interventions at those most ‘at risk’ as opposed to targeting an entire ethnic group.

However, while acknowledging the limitations of ethnicity as a variable in public health research, numerous scholars have highlighted its importance.[49,50,64,82,86] Such studies contribute to our understanding of disease aetiology[49,50,64] and help to direct public health resources and interventions. For example, by identifying groups in which national health policies are proving less effective or ineffective.[64,86] Furthermore, such research informs the design of tailored treatment and prevention strategies to reduce inequalities.[86] Indeed, culturally-adapted interventions have the potential to be more effective compared with the one-size-fits-all approach[92-94] and can improve uptake and acceptability.[95] These authors have challenged the argument that ethnicity-related health inequalities are largely due to SES,[26,49] often citing examples where disease rates and health behaviours are better among minority ethnic groups compared with the general population; for example, the substantially lower CHD risk and mortality among Black African/Caribbeans,[3,96] and lower risks of some cancers among South Asians[97,98] despite comparatively low SES.

Numerous steps have been proposed to improve the quality, transparency, and consistency of ethnicity and health research.[34,99] Consistent with these suggestions, this thesis has attempted to be explicit in the methods used to measure and categorise ethnicity, and clearly defined the purpose of and rationale for the research. Moreover, the analyses focussed on pre-specified ethnic groups, and South Asian and Black African/Caribbean subgroups were separated in the analyses. Analyses were adjusted for potential confounders where possible, and the specific and broader limitations of the work have been discussed in detail.

6.4 Future research

Some specific suggestions for future research have been discussed in chapters 2 to 6 and in the previous section when discussing the limitations of this work. The most pressing areas for further investigation are discussed here.

At present, the majority of existing knowledge about early-life ethnic differences in cardiovascular risk factors comes from cross-sectional studies.[11,13,47,48,55,80,100-104] or from longitudinal studies confined to infancy[105,106] or adolescence.[8] Therefore, the extent to which these early differences contribute to health inequalities later in life remains unknown. There is an urgent need for longitudinal research, from pre-birth through to adulthood, to investigate this further. Such efforts should include sufficiently large and representative groups of children across ethnic groups, including those investigated in this thesis (the largest minority groups in the UK), but also the rapidly growing groups, such as the Chinese and Arab populations. Studies should also avoid combining broad ethnic groups such as 'White', 'South Asian', and 'Black'. For such work to yield accurate and valid conclusions, it is important that more emphasis is placed on developing measurement tools and 'norm' criteria that are valid for ethnic comparisons.

It is also important that greater efforts are made to fully account for the confounding effects of SES on ethnic differences in CV risk factors. This will improve our understanding of the determinants of ethnic-related health inequalities and help to shape interventions to reduce them. Hence, future studies should collect data on multiple markers of SES (including cumulative SES,[26,53,66,107-110] adjust analyses for the SES markers that are most comparable across ethnic groups, and ensure that the full range of SES is represented in all ethnic groups studied.

Encouragingly, recent research has started to address some of these gaps in the literature. For example, in terms of longitudinal studies, the Born in Bradford birth cohort study[106,111] offers an excellent opportunity to understand prenatal, infancy and childhood influences on future health inequalities between Pakistani and White British communities. The DASH study[8] has recently taken steps to follow a subset of South Asian, Black African/Caribbean and White British adolescents into early adulthood. In terms of developing ethnic specific measures and norms, the CHASE team have developed ethnic-specific equations for estimating FFM, and thus FM and BF%, using arm-to-leg bioimpedance analysis in 8-11 year old children.[14] Furthermore, accumulating evidence advocates the use of adiposity-specific measures, as opposed to measures of relative weight, for inter-ethnic comparisons of weight status/adiposity in children[13,112-116] (as discussed in Chapter Four, Section 4.6) and for investigating associations with CVD risk factors.

More information is needed regarding the determinants of ethnic differences in CV risk factors during early childhood, such as those observed in this thesis. Subsequently, this could help to inform tailored interventions for different ethnic groups, for example to promote MVPA among South Asian girls. Culturally adapted interventions have the potential to be more effective[92-94] and can increase uptake and acceptability[92,93] compared with one-size-fits-all approaches, but a recent systematic review[92] highlighted the distinct lack of evidence regarding the best way to adapt and deliver health-promotion interventions to minority ethnic groups in the UK.[92,95,117,118] However, the same research group has recently developed an evidence-based resource, the Tool Kit of Adaptation Approaches, which it hopes will inform and support the design, development, implementation and reporting of health behaviour change interventions in minority ethnic groups.[92]

An increasing area of interest, which has not been discussed in detail in this thesis, is that of the role of genetics, and gene-environment interactions, in ethnicity-related health inequalities.[119,120] To date, studies have generally reported little variation between ethnic groups in terms of genetic influences on CVD risk.[119-123] However, recent technological advances in the field, and larger studies, such as the London Life Sciences Prospective Population study (www.lolipopstudy.org), powered to investigate the role of genetics in ethnicity-related health inequalities, may facilitate greater understanding in this regard.

6.5 Implications and conclusions

This thesis presents the first large-scale study to explore differences in lifestyle and physiological factors among young White British, Indian, Pakistani, Bangladeshi, Black African and Black Caribbean children in the UK. The findings highlight several early-life differences which could plausibly contribute to future CV health inequalities. For instance, the markedly lower levels of MVPA among Pakistani girls, and elevated adiposity and central fat distribution among South Asian children, could contribute to their increased risks of T2DM, CHD and stroke later in life.[2,3,5,6,56,124] These observations are also likely to contribute to their early-onset insulin resistance,[11,125,126] lower HDL-cholesterol and raised triglycerides,[127] and higher DBP[12] which become evident by late childhood. The high sodium intake among Black African children could contribute to their increased risks of stroke and hypertension in adulthood[5,7,22] and elevated BP in adolescence.[8] The lower sugar intake, higher levels of VPA, and lower central adiposity among Black African/Caribbean children could contribute to their lower risk of CHD. Interestingly, in this study, ethnic differences in lifestyle factors and adiposity were already evident among this young age group, but were generally not reflected in in their blood pressure patterns. For example, South Asian girls did less MVPA and had more central adiposity than White British girls, and yet South Asian girls had lower BP. These observations suggest that early childhood might pose a good opportunity to target interventions to reduce health inequalities later in life. Moreover, when considered in relation to the findings of previous studies of older age groups,[8,47,48] contrasting observations in this thesis suggest a need to prevent, during the primary school years, excessive declines in PA among Pakistani boys and excessive increases in energy intake among South Asian children (compared with White British children). Longitudinal studies are required to confirm this.

This thesis has also highlighted some areas of concern which were pertinent to all ethnic groups. For example, all groups were generally less active and more sedentary on weekend days compared with weekdays (Chapter 2). High sugar, saturated fat and sodium intake, and low MUFA, PUFA and fibre intake (Chapter 3) were also observed in all groups. Tailored interventions may be needed to effectively address these concerns across ethnic groups.[92,93,95] Consistent with reports among adults,[128-130] adolescents,[112-116] and older children,[13] the findings also suggest that BMI is not appropriate for inter-ethnic comparisons of weight status or adiposity among young children. These studies support the use of adiposity-specific measures, or ethnic-specific BMI thresholds, when studying ethnically-diverse groups.

Longitudinal studies are needed to investigate the contribution of early-life differences in cardiovascular risk factors to health inequalities later in life, and to identify the specific age at which these differences emerge. Studies should also develop measurement tools and norms that are valid for inter-ethnic comparisons. More work is also needed to disentangle the effects of SES and ethnicity on health inequalities in childhood, and to explore the determinants of ethnic differences in lifestyle factors, body composition and fat distribution among this age-group.

6.6 References

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