The Association Between Second-hand Tobacco Smoke Exposure and Children's Cardiorespiratory Fitness, Physical Activity, Respiratory Health, and Attitudes Towards Exercise

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List of Abbreviations

3HC	Trans-3'-hydroxycotinine
6MWT	6-minute walk test
20mSRT	20-metre shuttle run test
ANOVA	Analysis of variance
AOP	Adverse outcome pathway
ATP	Adenosine triphosphate
ATS	American Thoracic Society
BMI	Body mass index
cm	Centimetre
COPD	Chronic obstructive pulmonary disease
CV	Cardiovascular
CVD	Cardiovascular disease
CO	Carbon monoxide
CO_2	Carbon dioxide
COHb	Carboxyhaemoglobin
CpG	Cytosine-phosphate-guanine
CRF	Cardiorespiratory fitness
DALY	Disability-adjusted-life-year
EIMD	English indices of multiple deprivation
EPA	Environmental protection agency
ERS	European Respiratory Society
eCO	Exhaled carbon monoxide
FCTC	Framework Convention on Tobacco Control
FeNO	Fractional exhaled nitric oxide
FER	Forced expiratory ratio
FEV_1	Forced expiratory volume in one second
FFM	Fat-free mass
FG	Focus group
Fr	Froude
FVC	Forced vital capacity
GATS	Global Adult Tobacco Survey
GATSCG	Global Adult Tobacco Survey Collaborative Group
h	Hour
Hb	Haemoglobin
HR	Heart rate
IARC	International Agency for Research on Cancer
IQR	Interquartile range
kg	Kilogram
km	Kilometre
L	Litre
LJMU	Liverpool John Moores University
LLN	Lower limit of normal
m	Metre
MHCLG	Ministry of Housing, Communities, and Local Government

MVPA	Moderate to vigorous physical activity
min	Minute(s)
MEF_{25}	Maximal expiratory flow at 25% of vital capacity left
MET	Metabolic equivalent of task
mL	Millilitre(s)
N or n	Number
NO	Nitric oxide
NS	Non-smoking household
O_2	Oxygen
ONS	Office for National Statistics
PA	Physical activity
PAH	Polycyclic aromatic hydrocarbon
PACES	Physical activity enjoyment scale
PAQ-A	Physical activity questionnaire for adolescents
PAQ-C	Physical activity questionnaire for children
PCERT	Pictorial Children's Effort Rating Table
PEF	Peak expiratory flow
PHE	Public Health England
ppb	Parts per billion
ppm	Parts per million
RER	Respiratory exchange ratio
ROC	Receiver operating characteristics
RQ	Research question
PM	Particulate matter
S	Smoking household
SD	Standard deviation
SHS	Second-hand smoke
SES	Socioeconomic status
SPSS	Statistical package for the social sciences
Tox21	Toxicological testing in the 21st century
TTC	Threshold for toxicological concern
UK	United Kingdom
US	United States
$\dot{V}CO_2$	Carbon dioxide output
$\dot{V}O_2$	Oxygen uptake
$\dot{V}O_2max$	Maximal oxygen uptake
$\dot{V}O_2peak$	Peak oxygen uptake
VPA	Vigorous intensity physical activity
WDST	Write, draw, show, tell
WHO	World Health Organization
µg	Microgram
µm	Micrometre

Abstract

Cardiorespiratory fitness (CRF) is associated with a plethora of positive health effects in both adults and children, including reduced risk of cardiovascular disease, improved body composition, and a reduction in all-cause mortality. Physical activity (PA) is a major determinant of CRF and is also associated with a range of health-related quality of life markers. Many UK children fail to meet the recommended level of PA, with an observed decline in CRF levels in children over recent decades. Childhood CRF and PA are associated with health outcomes in later life, and so research is needed to understand the factors that contribute to CRF and PA in children, to ensure children become healthy adults.

The health effects of active smoking are well-known, with approximately 16% of total deaths in the UK attributed to smoking. The health effects of second-hand smoke (SHS) are also well-researched, with SHS responsible for 1.2 million deaths worldwide, and a significant proportion of the worldwide burden of disease. However, less is understood regarding the impact of SHS exposure on CRF, and there is a distinct gap in the literature concerning the effect of SHS exposure on CRF in children. In addition, little is known about the impact of household smoking and SHS on children's attitudes, beliefs, and perceptions of PA, fitness, and exercise. Accordingly, the overarching aim of this thesis was to use a mixed-methods approach to, quantitatively and qualitatively, explore the association between SHS exposure and CRF, PA, and respiratory health in children, and children's attitudes to PA, fitness, and exercise.

The aim of Study 1 was to use quantitative methods to explore the association between SHS exposure (as measured by the number of cigarettes smoked per household per day), and CRF, PA, PA enjoyment, and respiratory markers in children. Children in years 5 and 6 from four Merseyside primary schools participated in the study (n=104), including 38 children from smoking households. The study utilised quantitative surveys to determine household smoking habits and children's PA and PA enjoyment, and laboratory-based methods to assess children's $\dot{V}O_{2peak}$, spirometry, exhaled gases (carbon monoxide and nitric oxide), and anthropometrics. Linear regression was used to predict absolute ($mL{\cdot}min^{-1}$) and allometrically scaled ($mL{\cdot}kg^{-0.53}{\cdot}min^{-1}$) $\dot{V}O_{2peak}$ from SHS exposure, adjusting for sex, age, mass (absolute $\dot{V}O_{2peak}$ only), stature, maturation, PA, and deprivation. SHS exposure was found to be negatively associated with allometrically

scaled $\dot{V}O_{2peak}$ (B = -3.8, p = 0.030) but not absolute $\dot{V}O_{2peak}$ (B = 17.4, p = 0.091), although both the absolute and allometrically scaled $\dot{V}O_{2peak}$ regression models were statistically significant (p < 0.001) and explained 70.0% and 29.9% of the variance, respectively. Linear regression showed SHS exposure not to be a statistically significant predictor of PA, PA enjoyment, or respiratory measures in either the adjusted or unadjusted models. Results indicate that SHS exposure is associated with reduced CRF, but not PA, PA enjoyment or respiratory measures in children. This is the first study to examine the association between SHS and children's CRF using direct measurement of $\dot{V}O_{2peak}$.

Study 2 utilised creative focus groups with a sub-cohort of the larger sample (n=38), including 16 children from smoking households. The study aimed to explore children's reasons for being physically active, children's attitudes towards PA, fitness, and exercise, the perceived barriers and facilitators to PA, and children's self-perceptions of fitness and physical ability, and how these differ for children from smoking and non-smoking households. The findings support the main hypothesised mediators of PA in children including self-efficacy, enjoyment, perceived benefit, and social support. Less than a quarter of children were aware of the PA guidelines, and whilst all children agreed fitness was important to them, there were differences in children's reasons for *why* fitness was important. For example, children from non-smoking households believed fitness was important for health and performance, whereas children from smoking households were concerned with the negative physiological consequences of being unfit, such as 'getting out of breath'. Variances emerged between important barriers (sedentary behaviours including screen time, psychological factors, the environment) and facilitators (opportunities for PA, significant others, psychological factors) for children from smoking and non-smoking households. The majority of children perceived their own fitness to be high, but children from smoking households rated running as more difficult than children from non-smoking households. This study is unique in the sense that it provides a voice to children from smoking households, and is also the first to explore and compare the perceptions of PA and fitness for children from non-smoking and smoking households.

A series of case studies were used to draw together the complementary data from Study 1 and Study 2 using a mixed-methods case study approach. Cases were purposively selected based on sex, household smoking habits, child CRF, and PA data, to reflect the varied and contrasting circumstances of the participating children and their families. The case studies shed light on the individual differences and heterogeneity of the sample, as well as highlighting extreme examples, and cases that contradict the general trend. Exploration of the six unique cases has identified behaviours, perceptions, and circumstances that may be contributing to the individual's health outcomes including CRF, respiratory health, and health-promoting behaviour such as PA participation and enjoyment.

This thesis makes an original contribution to the body of research concerning children's health, fitness, and PA, in relation to household smoking and SHS exposure. The studies included have provided an original and unique insight into the physical and psychological impacts of household tobacco smoking on children. Further research is now needed to explore in-depth, the behaviours, exposures, psychological factors, and possible mechanisms that contribute to the findings in this research.

Declaration

I declare that no portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

Thesis Outputs

Conference communications from thesis

Parnell, M., Gee, I., Foweather, L., Whyte, G., Knowles, Z., Dickinson, J. The Impact of Environmental Tobacco Smoke Exposure on Children's Cardiorespiratory Fitness. A Pilot Study. Air Pollution 2019 (Wessex Institute). Aveiro, Portugal (June 2019). Oral presentation.

Parnell, M., Gee, I., Foweather, L., Whyte, G., Knowles, Z., Dickinson, J. The Impact of Environmental Tobacco Smoke Exposure on Children's Cardiorespiratory Fitness. UK and Ireland Exposure Science Meeting in Edinburgh by the Institute of Occupational Medicine. Edinburgh, UK (April 2019). Oral presentation.

Parnell, M., Gee, I., Foweather, L., Whyte, G. The Effect of Second-hand Tobacco Smoke on Children's Fitness. Liverpool John Moores University PhD Symposium. Liverpool, UK (July 2018). Poster presentation. Runner up for best poster presentation.

Parnell, M., Gee, I., Foweather, L., Whyte, G. The Effect of Second-hand Tobacco Smoke on Children's Fitness. Institute for Health Research Conference. Liverpool, UK (May 2018). Oral presentation.

Parnell, M. The Impact of Second-hand Smoke Exposure on Children's Exercise Performance: A Future Project. Liverpool John Moores University Physical Activity Exchange Symposium. Liverpool, UK (January 2017). Oral presentation.

Peer reviewed thesis publications

Parnell, M., Gee, I., Foweather, L., Whyte, G., Knowles, Z., & Dickinson, J. (2019). The impact of environmental tobacco smoke exposure on cardiorespiratory fitness in children: A pilot study. *International Journal of Environmental Impacts: Management, Mitigation and Recovery*, *2*(3), 240–248.

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Dedication

I would like to dedicate this PhD thesis to the memory of both my Great Nana Bobbie and Uncle Ian, who both sadly passed away during my PhD journey. I think they would be very proud.

Chapter 1

Introduction

1.1. The Research Problem

Cardiovascular disease (CVD) is the leading cause of mortality and morbidity worldwide (Joseph et al., 2017), of which low cardiorespiratory fitness (Ekblom-Bak et al., 2019), low physical activity (Loprinzi & Joyner, 2017), and tobacco smoke exposure (Digiacomo et al., 2019) are major risk factors. Children can develop risk factors for CVD from a young age (Fobian, Elliott, & Louie, 2018) and rates of hypertension (Ostchega et al., 2009), obesity (Garrido-Miguel et al., 2019), and type 2 diabetes (Forouhi & Wareham, 2019) have been increasing in children over recent decades, whilst cardiorespiratory fitness is in decline in high and upper-middle-income countries (Tomkinson, Lang, & Tremblay, 2019).

Cardiorespiratory fitness (CRF) is a health-related component of physical fitness defined as the ability of the circulatory, respiratory, and muscular systems to supply oxygen during sustained physical activity (Lee et al., 2010). CRF is positively associated with a plethora of health effects in both adults and children, including reduced risk of CVD (Castro-Piñero et al., 2017), reduced adiposity, reduced blood pressure (Bailey et al., 2012), and a reduction in all-cause mortality (Imboden et al., 2019). As a result, CRF in childhood is a cornerstone in the prevention of multiple lifestyle diseases (Elbe et al., 2017). CRF is determined by a number of modifiable and non-modifiable factors including sex, age, maturation, body composition, genetics, physical activity (PA), socioeconomic status, and environmental exposures. Modifiable determinants, namely PA, are often the focus of interventions and strategies to improve CRF.

Physical activity is defined as any bodily movement produced by skeletal muscles that results in substantial energy expenditure above resting (Caspersen, Powell, Christenson, 1985). PA is a major determinant of CRF (Zeiher et al., 2019), and is also associated with a range of health-related quality of life markers (Marker et al., 2018), including healthy weight status (Moore et al., 2018), improved mental health (Bélair et al., 2018) and reduced overall mortality (Mok et al., 2019). The quote by the UK Chief Medical Officers famously describes the benefit of PA to health: ''If physical activity were a drug, we would refer to it as a miracle cure, due to the great many illnesses it can prevent and help treat'' (Department of Health and Social Care, 2019). The socioecological model of

PA describes the various intrapersonal (individual), interpersonal, and community (environmental) levels that categorise the various correlates and determinants of PA (Moore et al., 2010). Some key correlates of PA in children include age, sex, maturation (Biddle et al., 2011), motor competence, perceived competence (Utesch et al., 2018), PA enjoyment (Burns, Fu, & Podlog, 2017), and self-efficacy (Dishman et al., 2005). Improving CRF and increasing PA, via their modifiable determinants, are therefore the focus of many health interventions, and keystones in public health improvement campaigns.

National (UK) and international (WHO) guidelines state that children and youth aged 5–18 years should achieve at least an average of 60 min of moderate-to-vigorous physical activity (MVPA) daily (Bull et al., 2020; Department of Health and Social Care, 2019; WHO, 2018), but less than half of all children and young people, including 51% of boys and 43% of girls, met these guidelines in England in 2019 (Sport England, 2019). Low PA in childhood is predictive of low PA in adulthood (Mäkelä et al., 2017, Telama et al., 2005) which emphasises the need for early intervention and uptake of PA by children. CRF in children and adolescents has substantially declined in high and upper-middle-income countries since the 1980s (Tomkinson, Lang, & Tremblay, 2019). In the UK, CRF (as measured by $\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)) decreased by 5.2% between the years 2000 and 2014 (Tomkinson, Lang, & Tremblay, 2019). Increasing overweight and obesity, decreasing PA, and increasing sedentary time may be responsible for the global and national decreases in fitness in children. In adults, previous research has shown that active smoking is associated with less PA (Salin et al., 2019; Rovio et al., 2018), and both active smoking and second-hand smoke exposure has been shown to be detrimental to CRF (De Borba et al. (2014). It is therefore possible that second-hand smoke exposure impacts children's PA and CRF.

Article 8 of the World Health Organisation (WHO) Framework Convention on Tobacco Control (FCTC) states that individuals have a right to a tobacco smoke-free environment (WHO FCTC, 2018). Since the WHO recommended compliance with Article 8 of FCTC (WHO, 2003), smoke-free policies have been increasingly adopted all over the world (Carreras et al., 2019). Despite this, in 2017, over 1 million deaths were attributable to second-hand smoke exposure (GBD 2017 Risk Factor Collaborators, 2018). In England, children's exposure to second-hand smoke (SHS) has substantially declined since the late

1990s (Jarvis & Feyerabend, 2015), but as smoking is still permitted in private residences, approximately one-third of children are still exposed to SHS, with the proportion considerably higher for children of low socioeconomic status (Jarvis & Feyerabend, 2015; Moore et al., 2012a).

Since the early work of Doll & Hill (1950), the health impacts of active smoking have been extensively researched, and it is now well established that first, second, and third-hand smoke pose serious health risks to all exposed (Carreras et al., 2019; Acuff et al., 2016). Approximately 83% of tobacco smoke is in an invisible and gaseous form (Gee et al., 2013) which inadvertently exposes non-smokers to the effects of tobacco smoke. The effects of second-hand smoking are substantial, rapid, and are predicted to be almost as large (up to 90%) as chronic active smoking (Barnoya & Glantz, 2005). In adults, SHS can cause coronary heart disease, stroke, and lung cancer, and exposed children can suffer from numerous health problems including severe asthma attacks, respiratory infections, ear infections, and sudden infant death syndrome (Naeem, 2015). Childhood and in-uterine exposure to SHS has been shown to be detrimental to lung function (Bird & Staines-Orozco, 2016), with asthmatic children exposed to SHS twice as likely to be hospitalised compared to asthmatic children not exposed to SHS (Wang et al., 2015).

Whilst the correlates and determinants of CRF and PA in children have been well researched, the impact of second-hand tobacco smoke exposure on laboratory-measured CRF ($\dot{V}O_{2max}$ and $\dot{V}O_{2peak}$) has not been sufficiently explored. From the studies that do exist, both active and passive smoking have been shown to impact cardiorespiratory fitness in adults, measured by $\dot{V}O_{2max}$, with active and passive smokers showing statistically lower levels of CRF than non-smokers (De Borba et al., 2014; Papathanasiou et al., 2014; Kobayashi et al., 2004). Kaymaz et al. (2014) have shown that obese children exposed to SHS perform worse on the six-minute walk test, and Hacke & Weisser (2015) have found that systolic blood pressure is increased in exercising adolescents who are exposed to SHS. However, no research has yet examined the association of second-hand smoke exposure on children's laboratory measured $\dot{V}O_{2peak}$. There is a large amount of research exploring the determinants of physical activity in children (Martins et al., 2017; Bauman et al., 2012, Pearson et al., 2014, Trost et al., 2001), and qualitative research is beginning to explore children's perceptions and beliefs around physical activity and exercise (Noonan et al., 2016a, Tay-Lim et al., 2013).

However, research is yet to examine the impact of SHS exposure on children's attitudes, beliefs, and perceptions of physical activity, fitness, and exercise. A greater understanding of this subject may highlight areas for health improvement that previous research and interventions had not sought to address.

The low levels of fitness of CRF observed in modern children, in combination with the reduction in population CRF over time, are suggestive of a decline in population health (Tomkinson, Lang, & Tremblay, 2019). Understanding the impact of SHS exposure on children's CRF could uncover other avenues for addressing the multifaceted issue of declining CRF in children. Exercise-related health markers, such as $\dot{V}O_{2peak}$, may provide novel methods for measuring health in relation to tobacco smoke exposure in children. To date, no previous research has sought to examine the impacts of second-hand smoke exposure on children's laboratory measured $\dot{V}O_{2peak}$. In addition, there is a need to address the question of how SHS in the home might influence children's perceptions of physical activity and exercise. Therefore, the aim of this thesis is to use a combination of novel quantitative laboratory measures and creative qualitative methods to quantitatively and qualitatively, explore the association between second-hand smoke exposure and cardiorespiratory fitness, physical activity, and respiratory health in children, and children's attitudes to physical activity, fitness, and exercise.

1.2. Organisation of the Thesis

This chapter (Chapter 1) introduces the research problem and outlines the overarching aim of the thesis and the aims for the individual studies.

Chapter 2 provides a comprehensive review of the literature. The topics discussed are closely related to the aims of the thesis, and include cardiorespiratory fitness, physical activity, respiratory health, the prevalence, and health effects of second-hand tobacco smoke exposure, as well as drawing on qualitative research to complement the findings of quantitative studies. Chapter 2 concludes with the aims and research questions for the studies and discusses the methodological and ethical considerations for the research.

Chapter 3 (Study 1) consists of a cross-sectional observational study that examines the association between second-hand smoke exposure and children's laboratory measured cardiorespiratory fitness ($\dot{V}O_{2peak}$), respiratory markers, and self-reported physical activity and physical activity enjoyment.

Chapter 4 (Study 2) consists of a qualitative study that explores children from non-smoking and smoking homes' perceptions surrounding cardiorespiratory fitness and physical activity, through focus groups and thematic analysis.

Chapter 5 (Case Studies) takes a mixed-method case study approach, and presents six case studies that reflect the variation and diversity within the sample population, triangulating quantitative and qualitative data from Study 1 and Study 2.

Chapter 6 synthesises the results from the three studies, discusses the key findings and the strengths and limitations of the thesis as a whole.

1.3. Thesis Aim

The overarching aim of the thesis is to use a mixed-method approach to, quantitatively and qualitatively, explore the association between second-hand smoke exposure and cardiorespiratory fitness, physical activity, and respiratory health in children, and children's attitudes to physical activity, fitness, and exercise. The individual aims for each study are summarised below in Table 1.1, and are expanded upon in Chapter 2, and the respective study chapters.

1.4. Thesis Study Map

Each study will end with a thesis study map in order to concisely summarise the aim, research questions, and key findings for each study. Additionally, personal reflections will be included after each study to provide insight into the researcher's experience and personal learning.

Table 1.1. Thesis study map with aims only.

Chapter 3 - Study 1 The association between second-hand tobacco smoke exposure and cardiorespiratory fitness, physical activity, and respiratory health in children	**Aim:** To assess the association between second-hand tobacco smoke exposure on children's directly measured cardiorespiratory fitness ($\dot{V}O_{2peak}$), physical activity, physical activity enjoyment, and respiratory health indicators.
Chapter 4 - Study 2 Children of smoking and non-smoking households' perceptions of physical activity and cardiorespiratory fitness	**Aim:** To use creative and qualitative methodologies to explore the attitudes, beliefs, and perceptions of physical activity, fitness, and exercise of children from smoking and non-smoking households.
Chapter 5 - Case studies Using the mixed-methods case study approach to explore the behaviours and perceptions surrounding fitness and physical activity of children from smoking and non-smoking homes	**Aim:** To use a mixed-methods case study approach to provide rich, contextual insight into the lives, behaviours, and perceptions of a selection of participants, in relation to the above research aims and research questions.

Chapter 2
Literature Review

2.1. Introduction

The purpose of this chapter is to review the literature concerning cardiorespiratory fitness, physical activity, and respiratory health in children, second-hand tobacco smoke exposure in children, and the impact second-hand tobacco smoke has on children's cardiorespiratory fitness, physical activity, and respiratory health. Each topic will be reviewed individually from a range of research including experimental, longitudinal, and cross-sectional studies.

2.2. Cardiorespiratory Fitness

The purpose of this section is to define cardiorespiratory fitness (CRF), outline the methods for assessing CRF, discuss the health benefits of CRF, identify the recommended guidelines for CRF, and review the determinants of CRF.

2.2.1. What is cardiorespiratory fitness?

Physical fitness is a set of attributes that people have or achieve that relate to their ability to perform physical activity (Sherar & Cumming, 2017; Casperson et al., 1985). There are many components of fitness, including cardiorespiratory (i.e. cardiovascular or aerobic fitness), strength, flexibility, speed, power, and anaerobic endurance (Sherar & Cumming, 2017). Cardiorespiratory fitness (CRF) is a health-related component of physical fitness defined as the ability of the circulatory, respiratory, and muscular systems to supply oxygen during sustained physical activity (Lee et al., 2010). Two terms associated with fitness, but not to be confused with, are physical activity (PA) and exercise. Physical activity can be defined as any bodily movement produced by skeletal muscles that results in a substantial energy expenditure above resting (Sherar & Cumming, 2017), whereas exercise is a form of PA that is planned, structured, repetitive, and aims to improve or maintain one or more components of fitness (WHO, 2018). To an extent, CRF is a product of PA, and in particular moderate to vigorous PA (Knaeps et al., 2018), but there are many determinants of CRF including genetics (Schutte et al., 2016), sex, maturation, and body composition (Armstrong & Welsman, 2020a), all of which are discussed in the subsequent sections.

2.2.2. Health Benefits of Cardiorespiratory Fitness

Cardiorespiratory fitness (CRF) is a health-related component of physical fitness defined as the ability of the circulatory, respiratory, and muscular systems to supply oxygen during sustained physical activity (Lee et al., 2010). CRF is a physical condition that is now well established as a predictor of numerous adverse health outcomes, independent of physical activity levels (Perumal, et al. 2017). There is robust evidence that poor CRF is an independent risk factor for obesity, diabetes, and heart disease related mortality, and that a moderate to high level of CRF reduces the risk of all-cause cardiovascular disease (CVD) mortality (Kokkinos et al., 2008), a trend also found in children (Dencker et al., 2012). Many studies have shown a relationship between CRF and mortality for men and women, with higher CRF associated with reduced risk or cardiovascular disease and all-cause mortality (Laukkanen et al., 2020; Ekblom-Bak et al., 2019; Al-Mallah et al., 2016a). Although much of the research utilises CRF estimates, Imboden et al. (2018) directly measured CRF in 4137 healthy men and women, who were followed for between 1 and 49 years for mortality. CRF was inversely related to all-cause, CVD, and cancer mortality. Low CRF was associated with higher risk of all-cause mortality, CVD, cancer mortality, compared with higher CRF, with a hazard ratio of 1.7, 2.3, 2.1, for all cause, CVD, and cancer mortality, respectively. More recently, Imboden et al. (2019) has showed that change in CRF over time was inversely related to mortality outcomes, and that mortality was better predicted by CRF measured from a subsequent test.

Unlike adults, measuring health by mortality is impractical with children, and studies examining the health impacts of CRF on children must use risk factors, such as for cardiovascular disease. For example, low CRF is a strong predictor for clustering of CVD risk factors in children (Castro-Piñero et al., 2017; Anderssen, et al., 2007). Higher levels of CRF are associated with reduced abdominal adiposity, BMI, diastolic blood pressure, triglycerides, and overall cardiometabolic risk score in children and adolescents (Boddy et al., 2014; Bailey et al., 2012). Anderssen et al., (2007) found a strong association between CRF, measured by cycle ergometer, and the clustering of CVD risk factors in children. The odds ratios for clustering in each quartile of fitness, using the highest fitness quartile as a reference, were 13.0, 4.8, and 2.5, respectively, after adjusting for country, age, sex and SES, pubertal stage, family history of CVD and diabetes. Findings of The European Youth Heart Study suggest that CRF is strongly correlated to metabolic risk, more so than total PA, whereas body fat has a key role in the association of CRF and metabolic risk (Rizzo et al., 2007). Not only has CRF been shown to be beneficial for physical health, but has wider benefits including improved cognitive function in children (Álvarez-Bueno et al., 2019), memory (Kronman et al., 2020), increased mental health and wellbeing (Gu et al., 2019), and improved academic achievement (Marques et al., 2018).

2.2.3. Measurement of Cardiorespiratory fitness

2.2.3.1. Direct Measurement

The examination of human physiological responses during incremental exercise can be traced back to the 19th century and the physiologists Lavoisier and Zentz, whom have been credited with the first scientific examinations involving exercising humans (Beltz et al., 2016). In the 1920s, the pioneering work of Hill and Lupton (Hill & Lupton, 1923) used Douglas bags to collect expired air samples, Haldane gas analysers to determine concentrations of oxygen and carbon dioxide, and a Tissot gasometer to measure air volumes, to plot the relationship between exercise intensity and oxygen uptake ($\dot{V}O_2$) (Beltz et al., 2016). The research of Hill and Lupton gave rise to the concept of $\dot{V}O_{2max}$ in humans and revealed the near-linear relationship and eventual levelling off (plateau) of $\dot{V}O_2$ with increasing intensity, known as maximal oxygen uptake $\dot{V}O_{2max}$ (Armstrong and McManus, 2010).

There is a finite rate of oxygen transport from the lungs to the mitochondria to support oxidative production of ATP (Mondal & Mishra, 2017; Treacher & Leach, 1998) and maximal oxygen uptake ($\dot{V}O_{2max}$) is the highest rate at which oxygen can be consumed by the muscles during an exercise test to exhaustion (Armstrong and McManus, 2017). The maximum oxygen uptake achieved during severe intensity exercise, such as running and cycling measures, is the 'upper ceiling' of the oxygen transport and utilisation system (Pool and Jones, 2017). The maximal oxygen consumption ($\dot{V}O_{2max}$) attained during a graded maximal exercise to voluntary exhaustion has long been considered by the World Health Organisation as the single best indicator of CRF (Shephard et al., 1968), or 'gold standard' (Armstrong & Barker, 2017) and the criterion measure of young people's aerobic fitness since the early youth-focussed studies of the likes of Robinson (1938), Moorse et al. (1949) and Åstrand (1952). The modern development of rapid-response gas analysers has enabled measurement of breath-by-breath pulmonary gas exchange, gas exchange threshold, exercise efficiency, and $\dot{V}O_2$ kinetics (Poole and Jones, 2017). Breath-by-breath analysis systems have high validity and reliability, and allow the continuous measurement of gas volumes and concentrations and immediate display of this information, greatly increasing the gas analysis procedure (Carter & Jeukendrup, 2002). Cycle ergometry and treadmill running are the usual methods of choice for $\dot{V}O_{2peak}$ testing in children. The advantage of cycle ergometry is that it induces less anxiety in children than running, and the lack of upper body movement eases data collection of HR and blood pressure. However, treadmill running engages a larger muscle mass than cycling, enhancing cardiac output, and $\dot{V}O_{2peak}$ is usually 8-10% higher for treadmill-based tests (Armstrong & McManus, 2017).

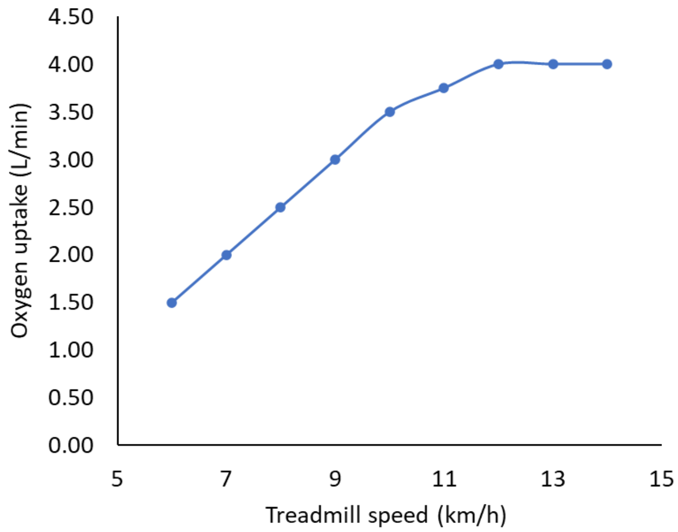


Figure 2.1. A typical pulmonary oxygen uptake response to incremental treadmill exercise showing a the near-linear relationship and plateauing at maximal uptake ($\dot{V}O_{2max}$). Adapted from Armstrong and McManus (2017).

Maximal oxygen uptake ($\dot{V}O_{2max}$) must not be confused with peak oxygen uptake ($\dot{V}O_{2peak}$), the latter of which is more often used in reference to children's CRF testing. Research by Astrand (1952) and Rowland (1993) has demonstrated that children often fail to reach a plateau of oxygen uptake (Figure 2.1) and therefore do not achieve $\dot{V}O_{2max}$ when defined by the plateau. Secondary criteria can be used to determine when the participant is at peak oxygen uptake and often include peak heart rate (HR) and peak respiratory exchange ratio (RER), although the exact endpoint values vary between studies. Peyer, Pivarnik, Coe (2011) state the need for child specific $\dot{V}O_{2peak}$ criteria and further conclude that maximal tests eliciting a peak RER of 0.88 may be valid in the absence of plateau if peak HR reaches 195 beats/min. Previous research with children has used a higher criterion for the RER of at least 1.0 and 1.05 (Boddy et al., 2014; Hopkins et al., 2010).

Armstrong, Welsman and Winsley (1996) have shown experimentally that there were no significant differences for anthropometrical or peak physiological data for children that did and did not exhibit a plateau in $\dot{V}O_2$. Rowland (1993) used treadmill tests with successively higher supramaximal workloads after an initial standard progress test to examine $\dot{V}O_2$ plateau in nine children. The study showed that, whilst 33% of children satisfied the criterion for $\dot{V}O_2$ plateau, mean peak oxygen uptake values from the supramaximal tests did not increase significantly above the initial test. Rowland (1993), Armstrong, Welsman and Winsley (1996), and more recently, Armstrong and McManus (2017), stipulate that $\dot{V}O_2$ plateau should therefore not be used as a requirement for defining a maximal exercise test in children. By contrast, Poole and Jones (2017) argue that peak $\dot{V}O_2$ is no longer acceptable, and that the secondary criteria (HR and RER) may result in 30-40% underestimation of true $\dot{V}O_{2max}$ and/or rejection of tests in which subjects had actually achieved $\dot{V}O_{2max}$. Pool and Jones suggest an alternative protocol which involves the incorporation of a second, constant work rate test, performed at ~110% of the work rate achieved on the initial ramp test, after 20-minutes recovery. If the $\dot{V}O_2$ increases further in the second test, further testing at a still higher work rate would be necessary (Poole and Jones, 2017). This protocol would reduce the likelihood of finding false negative and false positive results. In certain circumstances such as clinical settings or with vulnerable populations, repeated tests may not be feasible due to time constraints or participant motivation, and therefore this alternative form of assessment is not likely to be feasible with children.

2.2.3.2. Indirect Measurement

Laboratory based direct measurements of $\dot{V}O_2$ remains the 'gold standard' for CRF determination but field-tests and indirect measurement have a number of advantages. Maximum or peak oxygen can be estimated in the laboratory or using field-based methods, which have the benefit of low requirement for equipment, performed in easily accessible environments such as sports and school halls, and allow more participants to be tested over a shorter time. One such predictive measure is the 20-metre shuttle run test (20mSRT) which has been used increasingly over recent years (Zhang et al., 2020).

Performance in the 20mSRT is a function of an individual's willingness and capability to transport their body mass between two lines 20 m apart while keeping pace with audio signals which require running speed to increase each minute (Armstrong & Welsman, 2020b). A meta-analysis from Mayorga-Vega et al. (2015) has, however, shown the 20mSRT to be less valid with children and adolescents than in adults. The one-mile run/walk test, which is featured as part of the Fitnessgram aerobic fitness assessment (Meredith & Welk, 2010), is another established method commonly used to estimate $\dot{V}O_{2max}$ in adults and children (Roberts et al., 2010; Cureton et al., 1995). Field-based tests have been recommended and accepted for inclusion in fitness test batteries for children for population level surveillance (Lang et al., 2019; Plowman et al., 2006). Whilst field-based tests are valid in terms of the testing taking place in the 'real environment', they suffer from reliability issues concerning the changing environmental factors such as temperature and wind. Field-based fitness tests estimate $\dot{V}O_{2max}$ or $\dot{V}O_{2peak}$ based on test performance combined and are calculated using an established formula (Welk and Meredith, 2008; Plowman & Meredith, 2013; Lang et al., 2019), but the recently the validity of such tests (e.g. 20mSRT) has been disputed. Welsman and Armstrong (2019b) postulate that to 20mSRT reflects fatness rather than CRF and has poor validity grounded in its flawed estimation and interpretation of ratio scaled $\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$).

2.2.4. Scaling Issues for $\dot{V}O_{2peak}$ and Body Size

Peak $\dot{V}O_2$ is strongly correlated with body mass and the age-related increase in peak $\dot{V}O_2$ reflects the increase in muscle mass from childhood to young adulthood (Armstrong & McManus, 2017). To account for this, $\dot{V}O_{2peak}$ is commonly expressed as $mL \cdot kg^{-1} \cdot min^{-1}$. However, there is argument that scaling for mass 'over scales' and penalises heavy individuals and favours light individuals (Armstrong & McManus, 2017), but such scaling is the 'convenient and traditional' practice (Welsman & Armstrong, 2019b). The likes of Tanner have long cautioned against the use of per body mass standards of fitness, indicating that such standards would lead to inappropriate relationships with other lifestyle and behavioural factors (Tanner, 1949; Welsman & Armstrong, 2019b). As peak $\dot{V}O_2$ is strongly related to body mass, reflecting the amount of active muscle mass, controlling for size differences is therefore essential when comparing individuals or groups (Welsman & Armstrong, 2019b). Scaling for lean mass (McMurray, Hosick, &

Bugge, 2011) is one alternative to simple ratio scaling, but Welsman & Armstrong (2019b) argue that the effects of age and maturity status also need to be considered.

The assumption that there is a direct proportional relationship between $\dot{V}O_{2peak}$ and mass, is not confirmed in studies within the biological or sport and exercise sciences (Welsman & Armstrong, 2019b; Lolli et al., 2017). Adjustments using mass exponents, often the surface-area exponent of 0.67 or similar values (Doncaster et al., 2018; Lolli et al., 2017; Loftin et al., 2016; McMurray, Hosick, & Bugge, 2011), are alternatives to simple ratio scaling for overall body mass. Mass exponents are derived from log-linear regression analysis of $\dot{V}O_{2peak}$ and mass and taken as the calculated gradient (*b* value) and vary with sample populations (Welsman & Armstrong, 2019b). Taking 0.67 as an example mass exponent, the allometrically adjusted $\dot{V}O_{2peak}$ (mL·kg$^{-0.67}$·min^{-1}) is calculated by the division of absolute $\dot{V}O_{2peak}$ by the mass raised to the power of the exponent:

$$Allometrically\ scaled\ \mathrm{CRF} \ = \frac{\dot{\mathrm{V}}\mathrm{O}_2 peak}{mass^{0.67}}$$

Using mass exponents derived from log-linear regression analysis removes the effect of body mass, which can be simply checked by correlating the allometrically adjusted $\dot{V}O_{2peak}$ with mass, with the resulting correlation non-significant (Welsman & Armstrong, 2019b).

The continued use of body mass scaled $\dot{V}O_{2peak}$ is likely due to the absence of a universally appropriate alternative. Recently, Armstrong & Welsman (2020a) have determined that studies exploring CRF development in children should consider multilevel allometric modelling that consider sex-specific, concurrent changes in age and maturation driven covariates.

2.2.5. Children's Cardiorespiratory Fitness Guidelines

Numerous studies have sought to establish a cardiorespiratory fitness threshold at which children can be determined as healthy. Adegboye et al. (2011) states that health related cut-offs or thresholds are advantageous as they allow the user to distinguish between what is healthy, rather than what is normal, as with percentile charts. A number of studies have used statistical methods such as receiver operating characteristics (ROC) to examine the association of CRF with a clustering of metabolic risk factors in children, calculating a CRF level associated with low or high metabolic risk. Ruiz et al. (2007) tested CRF in 9-10 year old Swedish and Estonian children (n = 873) using a maximal ergometer bike test, and showed that CRF scores could identify low and high metabolic risk in boys and girls. The threshold for low metabolic risk was 37.0 and 42.1 mL·kg^{-1}·min^{-1} in girls and boys respectively. Adegboye, Anderssen, Froberg et al. (2011), using the European Youth Heart Study database of 4500 children, defined optimal cut-offs for identifying individuals at risk of cardiovascular disease. Cut-offs were calculated to be 37.4 and 43.6 mL·kg^{-1}·min^{-1} for females and males respectively. $\dot{V}O_{2peak}$ scores were obtained through a mixture of direct measurement of peak oxygen consumption and maximum cycle ergometer test. Welk et al. (2011) also used ROC to develop $\dot{V}O_{2max}$ thresholds for low risk of metabolic syndrome. $\dot{V}O_{2max}$ was estimated using a submaximal treadmill exercise test and extrapolation. Values at the low risk threshold ranged from 40 to 44 mL·kg^{-1}·min^{-1} for boys and 38 to 40 mL·kg^{-1}·min^{-1} for girls, however, these values are based on 12-18 year-old participants. Boddy, Thomas, Fairclough et al. (2012) used cross-sectional data from 16,919 9 to 13.9 year-olds and 20mSRT (an indirect measure of CRF) scores to estimate $\dot{V}O_{2peak}$ of thresholds of 41.9 and 46.6 mL·kg^{-1}·min^{-1} for girls and boys respectively. The variation in the fitness threshold values generated by the above mention studies may be due to the range of data collection methods (e.g. treadmill running or cycle ergometer assessments) and whether cardiorespiratory fitness was directly measured (laboratory based $\dot{V}O_{2peak}$ assessment) or estimated from field-best methods such as the 20mSRT.

Ruiz et al. (2016) performed a systematic review and meta-analysis of the relationship between CRF and CVD risk in children and adolescents. From the seven studies included in the analysis, the 95% CI region for healthy CRF thresholds ranged from 41.8 – 47.0 mL·kg^{-1}·min^{-1} for boys and 34.6 – 39.5 mL·kg^{-1}·min^{-1} for girls aged 8-19 years. The authors concluded that fitness levels below 42 and 35 mL·kg^{-1}·min^{-1} for boys and girls respectively should raise a red flag with regard to risk of CVD. More recently, Lang et al (2019) reviewed the criterion-referenced standards for cardiorespiratory fitness using Monte Carlo simulation and a pseudo-dataset of 1,142,026 children, aged 9-17 years from 50 countries. The authors conclude that the international criterion-referenced standards of 35 and 42 mL·kg^{-1}·min^{-1} (as per Ruiz et al., 2016) should be used to identify children and youth at risk of poor health, raising a 'clinical red flag' for those children which do not achieve such thresholds.

Whilst health related CRF thresholds are useful for identifying children at risk of CVD and poor health, Armstrong & Welsman (2020b) argue that use of pooled data from various ergometers to establish 'normal' values, has contributed to clouding the interpretation of CRF in youth. Additionally, as the above thresholds are based on peak $\dot{V}O_2$ scaled for body mass, the aforementioned issues with ratio scaling apply. The current thresholds of 35 and 42 $mL \cdot kg^{-1} \cdot min^{-1}$ are based on children at all stages of maturation, and peak $\dot{V}O_2$ changes significantly through adolescence (see section 2.2.7), which calls for more age or maturation stage specific CRF thresholds.

2.2.6. Trends in Cardiorespiratory Fitness

In high and upper-middle income countries, there has been a substantial decline in CRF for children and adolescents since the 1980s, with stabilisation in the trend since 2000 (Tomkinson, Lang & Tremblay, 2019), as shown in Figure 2.2. In the North-West of England, CRF in children has been decreasing over time, with 35.8% of boys and 59.7% of girls classified as unfit according to established CRF thresholds in 2004 (Stratton et al., 2007), and a decrease in CRF (as measured by $\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)) of 5.2% between 2000 and 2014. In comparison, 78% of boys and 83% girls from 30 countries were found to meet the standards for health CRF in a more recent study (Tomkinson et al., 2018). However, as CRF thresholds are based on peak $\dot{V}O_2$ by body mass, the overall decrease in CRF may be reflecting trends in increasing prevalence of overweight and obesity in children (Garrido-Miguel et al., 2019). Although data is regularly collected with regard to children's PA, population CRF data is not routinely monitored and it is proposed that surveillance of children's fitness should be undertaken within 'harmonised national health surveys' (Sandercock & Jones, 2019). Low prevalence and a temporal reduction in CRF are suggestive of a decline in population health (Tomkinson, Lang, & Tremblay, 2019).

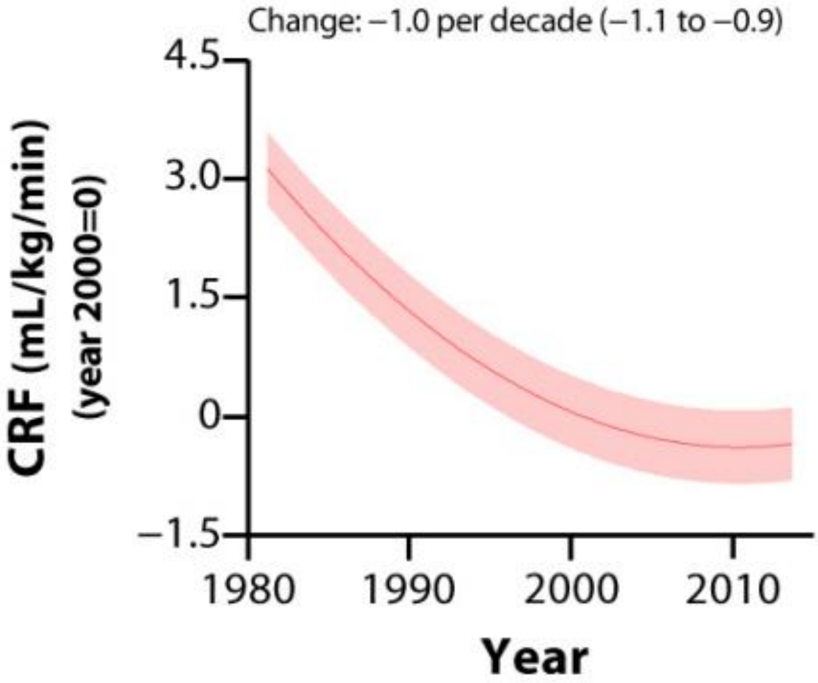


Figure 2.2. International temporal trends in mean CRF ($\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)) between 1981 and 2014. Solid lines represent the international change in mean CRF, and shaded areas represent the 95% CIs. From Tomkinson, Lang, and Tremblay, 2017.

2.2.7. Determinants of Cardiorespiratory Fitness

Determinants of cardiorespiratory fitness can be broadly classified into non-modifiable and modifiable factors. Non-modifiable determinants are permanent characteristics that are not under the control of the individual, such as age, sex, and genetics. Modifiable determinants are factors that it is possible to change, are the focus of most interventions, and include behaviours, psychological factors, exposures, socioeconomic status, and environment (Zeiher et al., 2019; Zaqout et al., 2016; Lintu et al., 2016).

2.2.7.1. Sex Differences in Cardiorespiratory Fitness

CRF is generally higher in males than females for both adults (Wang et al., 2010) and youth (Pate et al., 2006). According to Armstrong & Welsman (2020a), with age, maturity status, morphological covariates, and maximum cardiovascular covariates controlled for, there remains an unexplained 4% to 9% sex difference in peak $\dot{V}O_2$. Physiological differences between males and females that contribute to CRF disparity include skeletal muscle mass, heart size, and lung size (Al-Mallah et al., 2016a). Sex differences in blood concentration of haemoglobin may in part explain sex differences in $\dot{V}O_2$, and such variation becomes more apparent in mid to late teens (Armstrong & McManus, 2017).

There is some evidence to suggest that behaviour and social differences between males and females further leads to CRF disparities (Troiana et al., 2008; Doherty et al., 2017; Sport England, 2019; Armstrong, Welsman & Kirkby, 2000; Sallis et al., 2000) but sex differences in PA are explored further in section 2.3.5.

2.2.7.2. Age and Maturation and Cardiorespiratory Fitness

Longitudinal studies by Kemper et al. (2013) and Armstrong and Welsman (2001) have demonstrated that peak oxygen uptake increases with age in both sexes, with the greatest improvements occurring around the time of peak height velocity in boys (Geinthner et al., 2004). The Amsterdam Growth and Health Longitudinal Study followed adolescents for 25 years (Kemper et al., 2013). Males demonstrated a linear increase in $\dot{V}O_{2peak}$ through ages 12-17, with females increasing before levelling off over the same period. From ages 17-32, peak $\dot{V}O_2$ remained stable for males and females. When expressed per body mass, males peak $\dot{V}O_2$ remained level until around age 17, where it steadily declined, with a steady decline in females until age 21 before levelling off. Armstrong and Welsman (2001) produced similar findings in English children indicating an increase in peak $\dot{V}O_2$ from ages 12 to 17. However, a cross-sectional study by Pate et al. (2006) showed that whilst fitness ($mL \cdot kg^{-1} \cdot min^{-1}$) was higher for older males, the reverse finding was true for females, where younger participants had higher fitness. A large-scale US (Texas) based longitudinal study showed that after 20 years of age, a decline in CRF was non-linear, and was accelerated after 45 years of age (Jackson et al. 2009). Both Pate et al. (2006) and Jackson et al. (2009) found fitness to be related to weight status, and as demonstrated by Kemper et al. (2013), when fitness is expressed per body mass, there is an age-related decrease in fitness, but not in unadjusted peak $\dot{V}O_2$ values. Age related decline in fitness during adulthood may therefore be a product of a combination of lifestyle factors and weight gain rather than directly due to age alone.

As well as chronological age, maturation influences $\dot{V}O_{2peak}$ through increases in fat-free mass. Using multilevel modelling and longitudinal data from 132 adolescents, Armstrong & Welsman (2001) showed that $\dot{V}O_{2peak}$ (directly measured) increased with age and maturation in both sexes, with fat-free mass as the dominant influence. Almost 20 years later, Armstrong & Welsman (2019b) used multiplicative allometric models founded on 1057 peak $\dot{V}O_2$ tests (directly measured), to show how age, sex, maturation, mass, and skin-fold fitness influenced $\dot{V}O_{2peak}$ from ages 10 to 18. In addition to age and body mass, maturity status had a positive effect on $\dot{V}O_{2peak}$ for males and females and increases in fat-free mass explained the maturity effects.

2.2.7.3. Ethnicity and Cardiorespiratory Fitness

CRF in youth was not found to be related to race or ethnicity in the US 1999-2002 National Health and Nutrition Examination Survey (Pate et al., 2006). More recently, using data from an adult population in the Dallas Heart Study (US), Pandey et al. (2016) found that after adjusting for BMI, lifestyle factors, SES, and CV risk factors, individuals of black ethnicity had significantly lower CRF than Hispanic and whites. This trend has been reiterated by Ceaser et al. (2013), also as part of the National Health and Nutrition Examination Survey, who found that CRF was higher in Mexican Americans and non-Hispanic whites compared to non-Hispanic blacks, with race accounting for up to 20% of the variance in CRF. However, although blacks achieve lower CRF than whites, the relationship between CRF and mortality is not influenced by race (Al-Mallah et al., 2016b; Kokkinos et al., 2008). As concluded by Harber et al., (2017), more research is needed regarding the influence of race and ethnicity of CRF, and to aid in establishing normative data and threshold values, especially in children.

2.2.7.4. Genetic Determination of Cardiorespiratory Fitness

Heritability studies can estimate the effects of genetics and the environment on a particular trait, such as cardiorespiratory fitness. As $\dot{V}O_2$ is more difficult to measure directly than other aspects of fitness, research regarding the heritability of CRF is limited. The early work of Klissouras (1971) compared maximal aerobic power of monozygotic (MZ) and dizygotic (DZ) twins and concluded that aerobic power is 93.7% genetically determined, but the model assumed that no genotype-environment interaction exists. However, with a similar study with male twins, Maes et al. (1996) concluded that a shared environment was responsible for the similar CRF levels. Using a much larger sample size, Lortie et al. (1982) established that heredity is responsible for approximately 30-40% of the variation in fitness (maximal aerobic power), but age and sex accounted for more than half. Much more recently, Schutte et al. (2016) performed a meta-analysis and determined a heritability estimate of 59% ($mL \cdot min^{-1}$) and 72% ($mL \cdot kg^{-1} \cdot min^{-1}$) for $\dot{V}O_{2max}$. Not only is CRF itself determined in part by genetics, but a systematic review by Zadro et al. (2017) concluded that genetic factors may also explain individual variation in CRF in response to PA.

2.2.7.5. Body Composition and Cardiorespiratory Fitness

The relationship between body composition and CRF is complicated, and a dedicated discussion to the issues associated with scaling $\dot{V}O_2$ by body size can be found in section 2.2.4. Reviews (Zeiher et al., 2019) and cross-sectional studies (Zaqout et al., 2016) have found BMI to be negatively associated with CRF and CRF to be lower in overweight and obese children (Söğüt et al., 2019). The majority of research relating to CRF has expressed fitness relative to total body mass (Loftin et al., 2016), which as discussed earlier, over-scales for mass. Additionally, due to its practicality, a large proportion of the research utilises the 20mSRT. Overweight and obese youth are therefore doubly penalised by having to shift their metabolically inert fat mass during a 20mSRT, but also as performance is expressed as $\dot{V}O_{2peak}$ divided by body mass (Armstrong & Welsman, 2020b). Norman et al. (2005) showed that whilst overweight adolescents performed worse on a walk/run exercise test, absolute $\dot{V}O_2$ and lactate thresholds did not differ significantly from non-overweight adolescents, suggesting that overweight individuals are burdened by having to move their larger body mass, rather than CRF deconditioning. Additionally, a high BMI may be due to a dense structure of muscle mass rather than a high level of adiposity and therefore a high BMI does not necessarily determine an individual unfit (Zeiher et al., 2019). As it is skeletal muscle that is responsible for movement and PA, lean body mass (or fat free mass) should be considered when expressing $\dot{V}O_{2peak}$ in relation to body size (Loftin et al., 2016). Waist circumference, skin-fold measurements, and fat-free mass are therefore stronger determinants of CRF than overall body mass in relation to weight status (Armstrong & Welsman, 2020a; Ross & Katzmarzyk, 2003).

2.2.7.6. Physical Activity and Cardiorespiratory Fitness

Physical activity, and MVPA in particular, is an established determinant of CRF in adults (Zeiher et al., 2019) but the relationship between PA and CRF is less straightforward regarding children. Low to moderate associations have been observed between PA and CRF in children (Zaqout et al., 2016; Fairclough et al., 2017; Boddy et al., 2012) and MVPA has been found to be significantly correlated with CRF in children using the 20mSRT (Söğüt et al., 2019) and directly measured $\dot{V}O_{2peak}$ (Boddy et al., 2012; Fairclough et al., 2017). Inactive children have been shown to have lower CRF levels than active children (Boddy et al., 2012; Stabelini-Neto et al., 2011). Using analysis of compositional data, Fairclough et al. (2017) showed that reallocating time from sedentary time and light physical activity to MVPA had improvements in fitness and fatness. Even being more active during recess (break-time) at school has shown to improve $\dot{V}O_{2peak}$ in children. Calahorro-Cañada et al. (2020) found that children who are active for at least 15 minutes of recess were 44 times more likely to have healthy CRF levels than children that are not active for 15 minutes, although the 95% confidence intervals were very large (4–495 times). After accounting for fat free mass, maximal heart rate, sex, and age, Dencker et al. (2011) determined that PA explained an additional 3-6% of the variance in CRF in children aged 6-7 years. To characterise the dose-response association between PA and CRF, Nevill, Duncan, & Sandercock (2020; 2019) analysed longitudinal and cross sectional data for adolescents, and found a 'inverted u-shaped' curvilinear association between $\dot{V}O_{2max}$ (measured by 20mSRT) and self-reported PA. The findings suggest that the benefits of increasing PA on CRF are greater for children with lower levels of PA. Studies have shown that children and adolescents can improve their CRF through aerobic training (McNarry, Mackintosh, and Stoedafalke (2014). According to a review by Baquet, Van Paraagh, and Berthoin (2003), aerobic training in youth leads to a mean improvement in $\dot{V}O_{2peak}$ of 5-6%, and intensities higher than 80% of maximal HR are necessary for improvement. Overall, PA is a key determinant of CRF, and high intensity PA can lead to improvements in CRF. The low to moderate associations between PA and CRF may be explained in part by genetics and the heritability of CRF in response to PA (Zadro et al., 2017).

2.2.7.7. Socioeconomic status and Cardiorespiratory Fitness

There are numerous social inequalities in health and CRF is no exception. Socioeconomic status (SES) and level of education are associated with CRF (Zeiher et al., 2019). Based on an Australian longitudinal study, Cleland et al., (2009) showed that high maternal education was associated with a 59% increased likelihood of persistent fitness, and upward social mobility was associated with a greater likelihood of increasing fitness (90%) from childhood to adulthood. In a Spanish study of adolescents, parental education and professional levels were found to be correlated with CRF for girls, but not boys (Jiménez-Pavón et al., 2011). Similar trends, demonstrating a positive association between SES and CRF, have been found in other countries (Lindgren et al., 2016; Møller et al., 2006; Mutunga et al., 2006). As SES itself is multifaceted, there are many factors that may be directly and indirectly impacting CRF through SES. SES is associated with numerous other health behaviours and outcomes such as obesity, diet, smoking (plus second-hand smoke exposure), and PA (Lindgren et al., 2016), which may all contribute to the negative association between SES and CRF.

2.2.7.8. Other Factors that Influence Cardiorespiratory Fitness

Other modifiable factors including personal behaviours, diet, sleep (Tambalis et al., 2018) and exposure to environmental contaminants such as air pollution (Gao et al., 2013) or second-hand tobacco smoke (discussed in section 2.5.5.) are also impact children's CRF. A healthy diet, including fruit and vegetable intake is associated with healthy CRF levels (Zaqout et al., 2016), whereas skipping breakfast, fast food consumption, and regular sweet intake is associated with unhealthy CRF levels (Tambalis et al., 2018). Outdoor air pollution has been found to reduce CRF, and Gao et al. (2013) determined that $\dot{V}O_{2max}$ (mL·kg^{-1}·min^{-1}) in Chinese school children decreased by 1.53 ml per 10 µg m^{-3} increase in PM_{10} annual mean. The toxicity of particulate matter (PM) on CRF is discussed in sections 2.5.4.4. and 2.5.5.

Actual motor competence (discussed in section 2.3.5.1) and perceived competence are also correlates of CRF (Stodden et al. 2009; Vedul-Kjelsås et al., 2012). Fitness (including CRF and other measures of physical fitness) is associated with object control and game competence (Miller et al., 2019), and self-perceived competence in youth (Vedul-Kjelsås et al., 2012). Individuals are driven to engage in activities to demonstrate their skills, and high perceptions of competence lead to increased competence motivation (Harter, 1978), and therefore competence may be associated with CRF indirectly through PA. Psychological correlates of PA are discussed further in section 2.3.5.2.

2.3. Physical Activity

The purpose of this section is to define physical activity, and discuss the current physical activity habits and trends, as well as the determinants and health benefits of physical activity. Whilst literature concerning adults is discussed, the focus is on research regarding children.

2.3.1. What is Physical Activity?

Physical activity (PA) is defined as any bodily movement produced by skeletal muscles that results in a substantial energy expenditure above resting (Sherar & Cumming, 2017; Casperson, Powell, Christenson, 1985). Sedentary behaviour is any waking behaviour characterized by an energy expenditure ≤1.5 metabolic equivalents (METs), while in a sitting, reclining or lying posture (Tremblay et al., 2017). PA can be further categorised as moderate to vigorous physical activity (MVPA) which is defined as activity that requires a moderate amount of effort and noticeably accelerates the heart rate (3-6 METs) (Haseler et al., 2019). Examples of MVPA might include brisk walking, jogging, running, cycling, swimming, and team sports (Ainsworth et al., 2011). Physical activity should not be confused with 'exercise' which is a form of PA that is planned, structured, repetitive, and aims to improve or maintain one or more components of fitness (WHO, 2018).

2.3.2. Measuring Physical Activity

Physical activity can be measured objectively (device-based) or estimated via self-report surveys and diaries. One such survey is the Global Physical Activity Questionnaire (GPAQ) developed by the WHO (Armstrong & Bull, 2006) and validated by pairing with objectively measured PA (Cleland et al., 2014). For youth, the Physical Activity Questionnaire for Children (PAQ-C) and adolescents (PAQ-A) are available (Crocker et al., 1997; Voss, Ogunleye, & Sandercock, 2013). Both the PAQ-C and PAQ-A have been validated by a number of studies across various countries (Erdim et al., 2019; Aggio et al., 2016; Benítez-Porres et al., 2016; Voss et al., 2017). However, Troiana et al. (2008) warns that great care must be taken when interpreting self-reported PA as adherence to PA recommendations is substantially lower according to accelerometer data than self-reported data. Self-reported assessments of PA are prone to misclassification and social desirability bias, and have limited ability to differentiate low intensity PA from MVPA (Ekelund et al., 2020).

The 'gold standard' technique for assessing energy expenditure is through the use of doubly labelled water; a biochemical procedure that reflects the rate of metabolism in the body (Maddison et al., 2007). The doubly labelled water technique is highly accurate and objective but is too costly and impractical for large-scale studies (Melanson et al., 1996). A commonly used approach to measuring PA objectively is through the use of accelerometers, which is the most widely used assessment of PA in large scale population studies globally and from the UK (Doherty et al., 2017; Strath et al., 2013). Accelerometers are frequently used in PA research due to their ability to capture movement in 'real time' allowing PA assessment in specific periods of the day as well as across the day (Dollman et al., 2009). Attached as close as possible to the body's centre of mass, the participant wear's the accelerometer for a specified number of days, which provides researchers with real-time estimates of the frequency, intensity, and duration of physical activity (Trost, McIver, & Pate, 2005). Other methods of PA measurement include the inexpensive and straightforward use of pedometers to measure steps, heart rate monitoring to estimate energy expenditure, and direct observation of PA behaviours (Dollman et al., 2009). Nevertheless, device-based measurements are more costly than self-report surveys, require a high level of data interpretation, and are of high burden to the participant.

2.3.3. Physical Activity and Health

Insufficient PA is one of the leading risk factors for death worldwide diseases (WHO, 2018; Warburton et al., 2010) and a major independent modifiable risk factor for noncommunicable disease including CVD, ischaemic stroke, cancer, and diabetes (Wahid et al., 2016; O'Donnell et al., 2016; Guo et al., 2020). There is no shortage of reviews and epidemiological studies that have shown participation in PA to reduce the risk of premature overall mortality (Warburton et al., 2010; Ekelend et al., 2016; Saint-Maurice et al., 2018; Mok et al., 2019). The largest improvements to health can be gained by individuals in the very least active group, where only minor increases in PA can lead to greater health improvements (Rhodes et al., 2016; Arem et al., 2015; Mupin et al., 2015; Moore et al., 2012b; Wen et al. (2011). A dose-response relationship has been observed between PA and multiple health outcomes including hypertension (Liu et al., 2017), type 2 diabetes (Smith et al., 2016), breast and colon cancer, ischemic stroke, heart disease (Kyu et al., 2016), and mortality (Matthews et al., 2016).

As with adult populations, PA has been consistently associated with numerous risk factors and overall health and health related quality of life in children (Marker et al., 2018; Wu et al., 2017). In particular, MVPA has been shown to be more strongly associated with health in children than low intensity PA (Moore et al., 2018; Saunders et al., 2016). Using data from the International Children's Accelerometery Database, Moore et al. (2018) found significant associations between vigorous PA and waist circumference and insulin, and that substituting light intensity for vigorous PA was further associated with lower waist circumference and insulin. Aadland et al. (2018) used accelerometery and multivariate pattern analysis and determined that vigorous physical activity, in the range of 5000-7000 counts per minute, is most strongly associated with metabolic health. A combination of high MVPA, low sedentary behaviour, and adequate sleep, is shown to be most strongly associated with the positive health outcomes (Saunders et al., 2016). Vigorous intensity physical activity (VPA) has been shown to be correlated with a clustered risk score of cardiometabolic risk markers (cholesterol, blood pressure, LV mass index, trunk fat mass) in children aged 10-11 years (Gobbi et al., 2012), with children in the normal risk group accruing 4 minutes more daily VMPA than those in the higher risk group. A trend further demonstrated in inactive adolescents who had a high prevalence of metabolic syndrome (Stabelini-Neto et al., 2011). A review by Steele et al. (2008) indicated that PA, independently of CRF, is associated with metabolic syndrome.

In addition to health outcomes centred around cardiovascular and metabolic health, PA is associated with a number of other health outcomes including mental health and well-being. For example, PA is associated with bone mineral density (Janssen & LeBlanc, 2010), improved lung function (Gharbawi, 2020) reduced cancer risk and improved cancer prognosis (McTiernan, 2008), white brain matter integrity and activation of regions key to cognitive processes (Valkenborghs et al., 2019), regulation of the immune system (Fernandez, Clemente, and Giannarelli (2018), and sleep (Kredlow et al., 2015).

Low levels of PA and high levels of sedentary behaviour are also associated with depression and anxiety in adolescents (Bélair et al., 2018; Janssen & LeBlanc, 2010), and PA may be associated with increased mental health through improvements in physical self-perceptions (Lubans et al., 2016). PA may improve well-being through satisfying basic psychological needs for social connectedness, autonomy, self-acceptance, and purpose in life (Ryan & Deci, 2002; Lubans et al., 2016).

2.3.4. Physical Activity Guidelines

National and international public health authorities recommend that children and adolescents accumulate 60 minutes of MVPA per day, whereas adults should aim to do at least 150 minutes of MVPA throughout the week (Bull et al., 2020; WHO, 2018;

Department of Health, 2019). Globally, 25% of adults and 75-80% of adolescents do not meet the WHO recommendations for PA (Bull et al., 2020; Hallal et al., 2012; WHO, 2018). A study involving data from 12 countries including those from low, middle, and high incomes, showed that 44.1% of children met the MVPA guidelines over a 24-hour period in 2011-2013 (Roman-Viñas et al., 2016). Children from Finland were more likely to achieve the recommended level of MVPA (61.4%), whereas children China were least likely (15.1%). The United Kingdom (UK) guidelines state that children and youth aged 5–18 years should achieve at least an average of 60 min of MVPA daily (Department of Health, 2019), but less than half of all children and young people, including 51% of boys and 43% of girls, met these guidelines in England in 2019 (Sport England, 2019). Low PA in childhood is predictive of low PA in adulthood (Mäkelä et al., 2017, Telama et al., 2005) which emphasises the need for early intervention and uptake of PA by children.

2.3.5. Correlates and Determinants of Physical Activity

The correlates (factors associated with PA) and determinants (those with a causal relationship) are well studied. The correlates and determinants of physical activity can be classified as per the socioecological model of physical activity which describes factors as intrapersonal (individual), interpersonal, and community (environmental) levels (Moore et al., 2010). Welk (1999) developed a conceptual framework for understanding factors that influence physical activity in children (Figure 2.3). The framework consists of personal demographics (age, gender, ethnicity, SES), enabling factors (fitness, skills, access, environment), reinforcing factors (family, peer, and couch influence), and predisposing factors (perceived competence, self-efficacy, enjoyment, beliefs, attitudes), which comprise of other sub-factors.

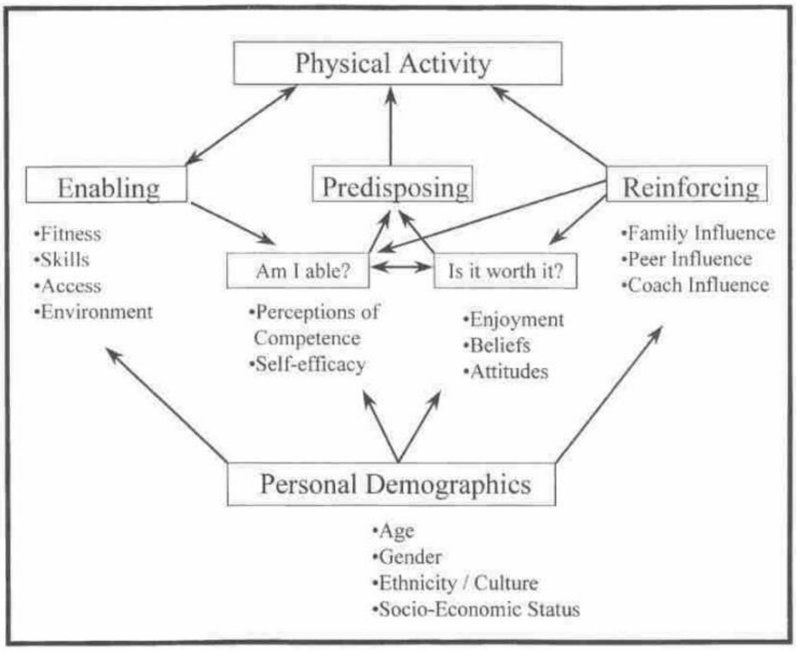


Figure 2.3. Conceptual diagram of the Youth Physical Activity Promotion Model. From Welk (1999).

2.3.5.1. Intrapersonal Factors and Physical Activity

Age, sex (and gender), and maturation are important non-modifiable determinants of PA. Although modifiable, SES is often classed as an intrapersonal factor and is discussed in greater detail in section 2.3.5.4. PA is not associated with age in a very early childhood (Biddle et al., 2011), and some research suggests the greatest change in physical activity can be observed during adolescence, when social and academic commitments become an increasing priority (Parry, 2015; Armstrong, Welsman, & Kirky, 2007). The term used to describe casement of PA from adolescence to adulthood is the 'Wolfenden gap' (Parry, 2015). More recently, longitudinal research as part of the Gateshead Millennium Cohort Study (North East England), found that the total volume of PA begins to decline from age 7 years for both sexes (Farooq et al., 2018), in contrast to previous research that found PA declines during adolescence. The findings support similar research that indicate PA declines from childhood into adolescence (Cooper et al., 2015; Kwon et al., 2015). In two of the studies above, one group of each cohort maintained high levels of MVPA throughout childhood and into adulthood suggesting less than 20% of youth maintain high MVPA into adulthood (Farooq et al., 2018; Kwon et al., 2015). Further, a recent review and meta-analysis has shown the relative decline in MVPA per year to be greater among girls (-5.3%) compared to boys (-3.4%) (Farooq et al., 2020).

Sex differences in PA begin to emerge during childhood, from 6 years of age. Whilst PA declines with age, overall PA levels are lower for girls than boys (Farooq et al, 2020; Telford et al., 2016). Using data from the National Health and Nutritional Examination Survey (years 2003-2004), Troiana et al. (2008) showed that males are more physically active than females across all age groups including children (6-11 years), adolescents (12-19 years), and adults (over 20 years). Sex differences have been consistently demonstrated from adolescence through to adulthood (Kwon et al., 2015; Sallis et al., 2000; Telama et al., 2005; Bauman et al., 2002). For children and adolescents, the majority of research suggests boys are more active the girls overall (Lahti et al., 2019; Armstrong, Hallal et al., 2012; Welsman, & Kirkby, 2007; Telama et al., 2005). Girls generally exhibit less favourable attributes associated with PA (higher percentage body fat, lower perceived competence) and are less favourably influenced by socio-ecological factors (Telford et al., 2016). Gender theories suggest that such differences are socially determined, with stereotyping and self-consciousness, playing key roles (Parry, 2015), with males and females experiencing different cues, benefits, and barriers to PA (Tergerson & King, 2009). Fortunately, the factors that contribute to sex differences in PA are potentially modifiable, which suggests the gap in PA can be reduced (Telford et al., 2016).

Maturation may be a confounding effect on sex differences in PA (Cumming et al., 2008) which has also been shown by Machado Rodrigues et al. (2010) who found that whilst adolescent males were more physically active and less sedentary than females, the sex difference were attenuated when maturation was controlled. On the other hand, the findings of a two-year longitudinal study of Spanish adolescents by Benítez-Porres et al. (2016) suggest that whilst PA behaviour is affected by sex, it is not modified by maturation. Cumming et al. (2011) tested the biocultural model of maturity-associated variance in PA and found that biological maturation directly and indirectly effects PA during adolescence, with indirect effects mediated through psychological factors and moderated by exogenous factors associated with pubertal maturation. Direct and indirect effects of pubertal status on PA have also been found by Lee et al. (2016), with indirect effects including body fatness, perceived barriers to PA, and self-efficacy. A recent systematic review by Moore et al. (2020) identified that overall, there is an inverse relationship between maturational timing and PA, and a positive relationship between maturation timing and sedentary behaviour.

The research regarding overweight and obesity as a correlate of PA is inconclusive. For example, Trost et al. (2003) showed that overweight pre-school boys are less active than their non-overweight peers, but the same trend was not found for girls. Other research has also found overweight and obese children to be less physically active and have lower levels of MVPA (Dorsey, Herrin, & Krumholz, 2012; Haerens et al., 2007). More recently however, no differences in accelerometer-measured PA were found between overweight and normal-weight Dutch children (Leeuwen et al., 2020). Motor competence and self-perception (discussed below) may contribute to observed differences in PA as the effects have been found to be stronger for overweight and obese children than for healthy-weight children (Utesch et al., 2018).

Motor competence is a correlate of PA and defined as a person's ability to execute different motor acts, including coordination of fine and gross motor skills that are necessary to manage everyday tasks (Henderson & Sugdon, 1992). Gross motor competence has been found to be moderately-strongly and positively associated with PA and MVPA (Utesch et al., 2018; Barnett et al., 2016; Castelli & Valley, 2007), and CRF and perceived competence may mediate the relationship between actual motor competence and PA (Khodaverdi et al., 2016). Perceived competence is an important psychological correlate of PA and is discussed further below.

2.3.5.2. Psychological Correlates of Physical Activity

Physical activity enjoyment is a motivational construct that is a significant determinant of children's and adolescent's physical activity behaviour (Burns, Fu, & Podlog, 2017; Gao et al., 2012; Sallis, Prochaska, & Taylor, 2000). Kendzierski and DeCarlo (1991) designed the Physical Activity Enjoyment Scale (PACES) as a single factor, multiple-item scale to assess enjoyment of PA in adults across exercise modalities (Moore et al., 2009), and PACES has been validated by a number of studies for use with adults (Teques et al., 2020) and children (Latorre Román; Moore et al., 2009). PA enjoyment has been found to predict PA participation in children (Allender, Cowburn, & Foster, 2006), with enjoyment of PA at age 10 associated with PA in adulthood (Parry, 2013). Enjoyment has also been found to be correlated with a number of PA correlates including self-efficacy

(Dishman et al., 2005), goal setting, self-determination, task orientation, and perceived competence (Moore et al., 2009).

Perceived competence is a likely correlate of PA (Utesch et al., 2018), although research is inconsistent. High perceived competence has been shown to improve the odds of being active by 3.8 times in adolescent boys and 5.2 times in adolescent girls (Inchley, Kirkby, & Currie, 2011), although in contrast, a review by Bauman et al. (2012) did not determine perceived competence to be a significant correlate of PA in adolescents. Interestingly, Fairclough (2003) found that whilst perceived competence and enjoyment were correlated in adolescents, low MVPA was associated with higher levels of enjoyment than the high MVPA group. Utesch et al. (2019) found motor competence and self-perception to be associated with PA. Self-perception accuracy was also associated with future PA, the effect of which was stronger in underweight and overweight/obese children. Overall, perceived competence shows moderate positive associations with PA, as well as perceived fitness, and general self-concept, of which sex and age are significant moderators (Babic et al., 2014).

2.3.5.3. Interpersonal Factors and Physical Activity

Interpersonal and social factors, including parental and peer support, are important determinants of PA in children, and have been alluded to in both quantitative and qualitative research (Wilk et al., 2018; Biddle et al., 2011; Beets et al., 2010; Beaulac, Bouchard, and Kristjansson, 2009; Brustad, 1996). A recent qualitative study by (Martínez-Andrés et al., 2020) has highlighted sociological factors that act as barriers or facilitators to children’s PA, and include fathers (less so mothers) acting as models of PA participation, children enjoying PA with their fathers and siblings, and children preferring activities with friends.

Familial factors, such as parent and sibling physical activity, and parental beliefs, are important correlates of physical activity in children (Lahti et al., 2019). Early work by Brustad (1996) identified that perceived parental encouragement, perceived parental enjoyment were highly influential on children’s own PA orientations, including a greater liking of games and sport, and higher physical competence, and later studies are consistent with Brustad (Dlugonski et al., 2020; Noonan et al., 2016a; Hohepa et al., 2007). Increasing parental PA levels are associated with increased PA in children, with one recent study demonstrating that each extra hour of PA among parents associated with 0.2 hours more weekly PA in offspring (Lahti et al., 2019). The same study also found that children with 'sporty' siblings achieved an additional hour of PA per week. Support from peers and friends is an important correlate of PA in youth (Fitzgerald, Fitzgerald, & Aherne, 2012) and friendship groups often have similar levels of PA (Stearns et al., 2019). Friendships may be influential on children's PA as they enhance enjoyment (Noonan et al., 2016a; Jago, Page & Cooper, 2012) and motivation for PA (Salvy et al., 2009).

2.3.5.4. Socioeconomic Status and Physical Activity

Research surrounding socioeconomic status and PA is inconsistent. Whilst some studies have found high SES to be associated with higher levels of PA (O'Donoghue et al., 2018; Lampinen et al., 2017; Fairclough et al., 2009; Janssen et al., 2006), others have found contrasting trends. In adults, SES is well associated with PA (O'Donoghue et al., 2018; Bauman et al., 2002), however with children, the trend association is less clear. Noonan & Fairclough (2018) used the UK Millennium Cohort Study data to show an association between low SES and overweight and obesity in children. However, the study found MVPA to be inversely associated with SES, and the most deprived children most likely to achieve 60 minutes of daily MVPA. Discrepancies have emerged with regard to the *type* of PA low and high SES populations participate in. Brockman et al. (2009) found that UK children from low-SES schools reported participating in more unstructured activities such as 'free play' with friends, whereas children from middle/high SES schools engaged in more sports clubs and organised activities. Financial barriers can restrict sport participation among children of low-SES (Clark et al., 2019; Holt et al., 2011) but Voss et al., (2008) demonstrated that in England, although low-income families attended fewer sessions of out-of-school activities, objectively measured PA showed no association with parental income.

2.3.5.5. Environmental Factors and Physical Activity

An 'obesogenic' environment that limits PA has been implicated as a major contributor to the increasing level of childhood overweight and obesity (Mei et al., 2020; Joens-Matre et al. 2008). In addition, children's PA varies between countries, partly due to income and geographic location (Rhodes et al., 2017). Several factors linked to lack of opportunity to be active due to urbanisation include perceived neighbourhood safety and crime, traffic and road safety (Malambo et al., 2018; An et al., 2017; Carver et al., 2008), air quality (An et al., 2018; Si & Cardinal et al., 2017), and lack of green space (Ward et al., 2016; Janssen & Rosu, 2015) and facilities (Mason et al., 2018). Joens-Matre et al. (2008) has shown that urban children are less active and have a higher incidence of overweight than rural children in the same Midwestern state (USA).

The family home environment is a critical influence on children's health behaviours and physical activity (Tandon et al., 2012). Access to media, parenting practices, sibling influence, family habits, access to active equipment, may all influence children's physical activity or sedentary behaviour (Jago et al., 2011; Fairclough et al., 2009). The family home environment is closely related to SES, and lower SES home environments have been found to be associated with more opportunities for sedentary behaviour and fewer for PA, with children from low income households having greater access to media in their bedrooms (Tandon et al., 2012).

2.4. Respiratory Health

This section outlines measures of respiratory health and lung function, with a particular focus on spirometry and fractional exhaled nitric oxide and explores the correlates and determinants of respiratory health.

2.4.1. What is Respiratory Health and Why is it Important?

Respiratory disorders are responsible for considerable morbidity and mortality in children, and account for the majority of all paediatric hospital visits and hospitalisations all over the world (Jat, 2013). Asthma is a common chronic condition with environmental (tobacco smoke exposure (see section 2.5.4.6), allergens, frequent respiratory infections) and genetic factors implicated in its causation (Dick et al., 2014), with 10% of UK children receiving a diagnosis of asthma in 2018 (Scholes & Mindell, 2019). Although having a diagnosis of asthma or exercise induced asthma does not prevent children from being active (Matsunaga et al., 2017), the fear of breathlessness may deter some children from participation (Welsh, Roberts, & Kemp, 2004). PA and CRF may be protective of lung health (Fuertes et al., 2018; Benck et al., 2017), and a longitudinal study with 2,735 adult participants found greater CRF in young adulthood to be associated with less decline in lung health over time (Benck et al., 2017). PA has also been shown to attenuate smoking-related lung function decline and a reduced risk of chronic obstructive pulmonary disease in smokers (Garcia-Aymerich et al., 2007).

Understanding how environmental exposures such as tobacco smoke impact lung function and respiratory health is therefore of great importance, especially in relation to the potential impact on children's PA and CRF.

2.4.2. Spirometry – A Measure of Lung Function

Spirometry is a physiological test that measures how an individual inhales or exhales volumes of air as a function of time (Miller et al., 2005). The following key terms refer to the four most common measures of spirometry and are defined according to Miller et al. (2005) in 'Standardisation of spirometry': Forced Vital Capacity (FVC) – the maximal volume of air exhaled with a maximally forced effort following a maximal inspiration, expressed in litres; Forced Expiratory Volume in 1 second (FEV_1) – the maximal volume of air exhaled in the first second of a forced expiration from a position of full inspiration, expressed in litres; Peak Expiratory Flow (PEF) – the highest flow achieved from a maximum forced expiratory manoeuvre started without hesitation from a position of maximal lung inflation, expressed in litres per second. The FEV_1/FVC ratio, sometimes referred to as the Tiffeneau-Pinelli index is another measure useful in diagnosing respiratory disease (Barisione et al., 2009).

It is common practice to record at least three attempts for each measure, with the largest value being accepted if all three values are within an acceptable range. Participant or patient cooperation and experience is key to performing spirometry manoeuvres, and child participants are less likely adults to achieve all test performance criteria (Arets, Brackel, & van der Ent, 2001) and so spirometry testing in children requires a certain level of training for the clinician or researcher. The standardised procedure for performing spirometry testing is described in detail by Moore (2012c) and Miller (2005) and is based on guidelines from the American Thoracic Society (ATS) and European Respiratory Society (ERS).

Values obtained from lung function test have no meaning unless compared against reference values. Reference values are derived from equations that contain data from population surveys which take into consideration height, age, sex, and ethnic origin (Talaminos-Barroso et al., 2018; Moore, 2012c; Quanjer et al., 2012). Stature (standing height) is the main determinant of pulmonary function, as lung volume increase with stature, with the largest increases in lung volume corresponding with childhood and adolescent growth spurts (Quanjer et al., 2012). Lung function increases with age up to around 25 years, in line with stature, and then declines with increasing age afterwards (Talaminos-Barroso et al., 2018; Moore, 2012c). Pre-pubescent males and females have similar lung function, but growth of the thorax is greater in males post-puberty arising to differences in lung volumes for males and females. Ethnic differences can be observed for spirometry values but anthropometric characteristics do not fully explain such differences, and other factors should be considered (Talaminos-Barroso et al., 2018). Nevertheless, the standard procedure is, for individuals of Japanese, Polynesian, Indian, Pakistani, African ethnicity or decent, to multiply the reference values by 0.9 (Moore, 2012c; Korotzer, Ong and Hansen, 2000). However, as societies become more ethnically mixed, this becomes unnecessary. Secondly, some authors argue that ethnic differences in lung function reflect lifelong exposure to toxicants (e.g. air pollution) and SES as opposed to inherent physiological differences. Braun (2015) argues that race-correction in spirometry may not be best practice, as racial differences in lung function may be reflecting the disproportionate exposures to toxic environments. On the other hand, studies have shown significant differences in spirometry performance by ethnicity, after SES and environmental exposure has been controlled for (Strippoli et al., 2013). Additionally, the reference equations produced by Quanjer et al. (2012) have been validated for use in ethnically diverse populations such as London, UK (Bonner et al., 2013). For adults, reference equations can be used to calculate predictive spirometry values, but for populations aged 3-25 years, look-up tables are most accurate and can be accessed online (Quanjer et al., 2012).

Spirometry can be used to diagnose one of four types of ventilation patters: normal, obstructive, restrictive, or mixed pattern (Jat, 2013). Obstructive lung diseases, such as asthma and chronic obstructive pulmonary disorder, lead to an increased difficulty exhaling air, whilst restrictive lung disease, such as pulmonary fibrosis, lead to an increased difficulty inhaling air. An obstructive pattern is usually characterised by decreased FEV_1 (<80% of predicted) and decreased FEV_1/FVC (<70%) and normal FVC, and a restrictive pattern is characterised by a proportional reduction in FEV_1 (<80%) and FVC (<80%) (Vandevoorde et al., 2006). A mixed pattern has decreased value of all three parameters (Jat, 2013). Although exact cut-off points for diagnosis vary across the literature (Vandevoorde et al., 2006; Fuhlbrigge et al., 2006), there is consensus that disease severity is associated with increased or decreased spirometry values. The

Australian and New Zealand Society of Respiratory Science recommend the interpretation of spirometry measurements using the lower limit of normal (LLN). Using the LLN, an obstructive disorder is indicated by an FEV_1/FVC below the LLN, and a restrictive disorder by a FEV_1/FVC larger than the LLN, and an FVC below the LLN (Brazzale, Hall, & Swanney, 2016).

2.4.3. Fractional Exhaled Nitric Oxide - A Measure of Airway Inflammation

Nitric oxide (NO) is an important marker of airway inflammation used in the diagnosis of asthma (Dweik et al., 2011), but also plays a key role in vasodilation (Guo et al., 2000). The role of NO in the airways and functionality of the lungs is complex and has many pathways (Ricciardolo, 2003). In exhaled air, NO originates in the airway epithelium, as a result of nitric oxide synthase enzyme up-regulation which occurs with inflammation (Guo et al., 2000). Airway inflammatory cell NO production can be estimated by measuring fractional exhaled nitric oxide (FeNO) (Dweik et al., 2011) and has been used in studies with adults (Kuo et al., 2019), children (Fielding et al., 2019), and elite athletes (Levai et al., 2016). The use of FeNO as an indicator of eosinophilic airway inflammation has been validated by a number of studies (Feng-jia et al., 2018; Dweik et al, 2011; Berry et al., 2005). Positive correlations have been observed between FeNO concentration and sputum eosinophil count (Gao et al., 2017; Berry et al., 2005), validating FeNO as indicator of eosinophilic airway inflammation.

Thresholds of clinical significance for FeNO have been suggested to aid diagnosis of eosinophilic asthma. There is some disagreement regarding appropriate cut-off points of normal FeNO level. Ferrante et al. (2013) suggest that using personalised cut-off values for each individual might be more suitable. Reference values suggestive of likely eosinophilic asthma range recommended by Dweik et al. (2011) are >50 ppb for adults and >35 ppb for children, with 25-50 ppb and 20-35 ppb suggestive of an intermediate risk for adults and children respectively.

Other factors that may impact FeNO levels include recent ingestion of food and drink, foods high in nitrates (Brody et al., 2013), rhinovirus infection and allergic rhinitis (Bjermer et al., 2014), and genetics. Around 30% of asthmatic individuals carry a genetic variant (T2206C) of the FCER2 gene which is associated with significantly lower levels of FeNO (Karimi et al., 2019) which may need to be considered when interpreting results. Exercise training can also increase NO bioavailability through increase NO synthase expression and activity, which can lead to an increased exercise capacity and cardiovascular protection (Kingwell, 2000).

2.4.4. Determinants of Respiratory Health and Lung Function

In addition to the above-mentioned factors, respiratory health and lung function can be influenced by a variety of individual and environmental factors. Excluding heritable respiratory diseases such as cystic fibrosis, family and twin studies have shown that pulmonary function is familial, but the reason for familial aggregation can be environmental, genetic, or both (Hukkinen et al., 2012; Chen, 1999). Heritability estimates for FEV_1 and FVC are approximately 32% to 36% and 42% to 35%, respectively (Hukkinen et al., 2012). A large proportion of lung function is therefore the result of environmental influence.

A major toxicant to lung health and functionality, tobacco smoke is the number one cause of lung cancer, emphysema, and chronic obstructive pulmonary disease (COPD), and is responsible for the majority of respiratory related morbidity and mortality (West, 2017). The impact of tobacco smoke exposure is discussed in more detail in section 2.5.4.6, but early life exposure to tobacco smoke synergistically modifies the effects of infant respiratory infection and early-life overcrowding on FEV_1 (Allinson et al., 2017). Early life respiratory infection, such as those caused by the respiratory syncytial virus, is associated with diminished lung function in adolescence and later life (Berry et al., 2016).

Socioeconomic status is an established determinant of respiratory health (Polak et al., 2019; Hegewald & Crapo, 2007). Low SES over a life course is associated with the lowest lung function, although upward social mobility is associated with improved lung function (Polak et al., 2019). The association between SES and lung health may be influenced by environmental exposures such as tobacco smoke (discussed elsewhere), and air pollution. Indoor and outdoor air quality (Franklin, 2007) and outdoor allergens (Pomés, Chapman, & Wünschmann, 2016) are important factors associated with respiratory health in children, with exposure to traffic-related air pollution over the entire childhood age range important for lung function development (Shultz, Litonjua, Melén, 2017). Grey space (the inverse of green space and an indication of the level of built environment) is associated with an increased risk of bronchitis in children and living near green space can reduce the risk of childhood wheeze and bronchitis (Tischer et al., 2017).

2.5. Tobacco Smoke

2.5.1. What is Tobacco Smoke?

Tobacco smoke is an aerosol of liquid droplets (the particulate phase) suspended within a mixture of gases and semi-volatile compounds (Thielen, Klus, & Müller, 2008), comprising of a toxic and a carcinogenic mixture of over 5,000 different chemicals including carbon monoxide, benzene, arsenic, chloroform and formaldehyde to name a fraction (Talhout et al., 2011). Public health organisations and regulatory authorities have drawn up toxicant lists believed to be relevant to smoking-related diseases; the 'Hoffmann Analytes' list (Hoffmann & Hoffmann, 1998). However, the Hoffman list is based on research from the early 1990s, and Talhout et al. (2011) argue that a new list of 98 hazardous components should be used for regulatory purposes instead. Sixty cancer and 48 non-cancer inhalation risk values are included in the Talhout list, with polycyclic aromatic hydrocarbons (PAHs) and a tobacco-specific nitrosamine likely being the most important respiratory carcinogens (Peterson, Urban & Hecht, 2010).

Approximately 83% of tobacco smoke is in an invisible and gaseous form (Gee et al., 2013) which inadvertently exposes non-smokers to the effects of tobacco smoke. Second-hand smoke (SHS), often referred to as environmental tobacco smoke (ETS) or passive smoking, is composed primarily of smoke that emanates from the end of the burning cigarette (side-stream smoke), smoke that the smoker inhales and exhales (mainstream smoke), and contaminants that diffuse through the cigarette paper (Acluff et al., 2016; Environmental Protection Agency, 1992). Inhalation of SHS consists of approximately 15% mainstream smoke and 85% side-stream smoke (Moon, Kong, & Kim, 2018). Both first and second-hand smoke have a similar composition except that in SHS many components such as nicotine, tar, nitric oxide, and carbon monoxide are more concentrated (Wong et al., 2004). A relatively new concept, third-hand smoke, describes the residual tobacco smoke gases and particles from second-hand smoke that settle on surfaces and dust (Acuff et al., 2016; Winickoff et al., 2009). Third-hand smoke exists in indoor environments on surfaces such as floors, counters, walls, and persists for months after smoking has occurred (Matt et al., 2011).

2.5.2. Measuring Exposure to Tobacco Smoke

Nicotine is rapidly and extensively metabolised by the liver, mainly by the liver enzyme CYP2A6, to cotinine (Hukkanen et al., 2005). Whilst the half-life of nicotine is approximately 3 hours, the half-life of cotinine averages around 16 hours (Benowitz, 2009), making it a suitable candidate for monitoring recent smoking and SHS exposure. Cotinine is further metabolised by CYP2A6 trans-3'-hydroxycotinine (3HC), and the ratio of cotinine to 3HC can be measured in the blood, saliva, or urine, as an indication of recent tobacco smoke exposure (Benowitz, 2009; Hukkanen et al., 2005). Jarvis, Feyerabend, and colleagues have conducted a large number of studies using cotinine to assess tobacco smoke exposure of adults and children in the UK (Sims et al., 2012; Whincup et al., 2004). Although serum, urine, and salivary cotinine measurements are all accurate predictors of tobacco smoke exposure, Binnie et al., (2004) found patients to prefer collection of serum and urine to saliva. Binnie et al. also established that mean cotinine levels (for all collection methods) were significantly higher in passive smokers than individuals who have not been exposed to SHS. Hair nicotine and cotinine can also be used as a less invasive tool for establishing recent tobacco smoke exposure (Li et al., 2017). As cotinine accumulates in the hair during hair growth, it is a useful marker of cumulative exposure to tobacco smoke (Florescu et al., 2009).

Exhaled carbon monoxide (eCO) measurement can be used to assess acute tobacco smoke exposure, and distinguish recent smokers and passive smokers from non-smokers. Deveci et al. (2003) showed that eCO levels are approximately 17.2 ppm for smokers, 5.2 ppm for passive smokers and 3.6 ppm for non-smokers, based on 322 adults. However, Deveci's study found that whilst there was a mean difference between eCO levels of passive smokers and non-smokers, this was not statistically significant. Cropsey et al. (2014) recommend that researchers and clinicians adopt a more stringent eCO cutoff of 3 ppm, which had a 97.1% correct classification using cotinine as a reference. Whilst most research around using eCO as an exposure marker is centred around adults, Dukellis et al., (2009) found that with 501 children aged 6-15 years, eCO predicted urine cotinine with a specificity of 85% but a sensitivity of only 10%. The eCO concentrations in Dukellis et al. are very low and average below 1 ppm for both smoking and non-smoking groups, which the authors suggest may be due to the participant age an inability to meet the demands of the breath-test. With adolescents, Gourgoulianis et al. (2007) showed that individuals with smoking mothers had increased eCO (6.0 ± 2.5 ppm) compared to those from non-smoking households (2.4 ± 0.6 ppm).

2.5.3. Second-hand Tobacco Smoke Exposure

Smoking in Great Britain was at its peak in the late 1940s when 82% of the population smoked cigarettes, cigars and pipes (Wald, 1991), see Figure 2.4. In 2019, 15.9% of men (3.8 million) and 12.5% of women (3.1 million) reported being current smokers, with people aged 25-34, people in routine or manual occupations, or with no formal qualifications, more likely to smoke (Office for National Statistics, 2020).

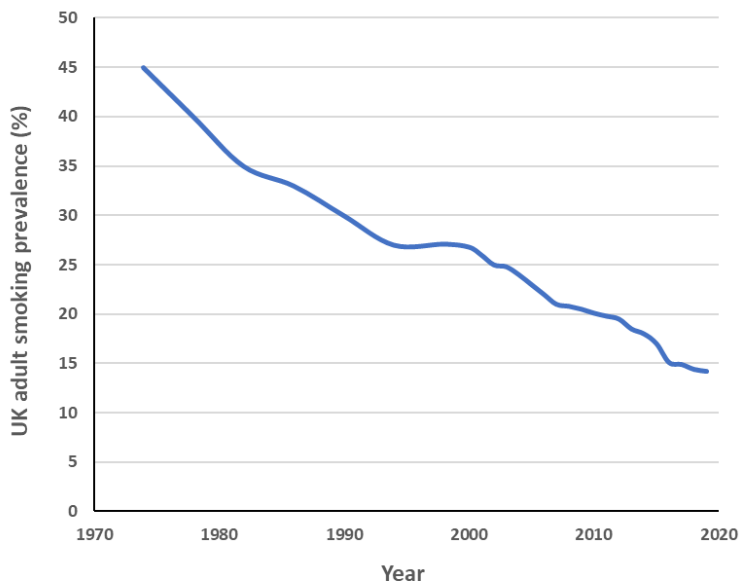


Figure 2.4. Adult smoking prevalence in the UK. Adapted from Office for National Statistics (2020) and Action on Smoking and Health (2020).

Since the World Health Organization (WHO) recommended compliance with Article 8 of the Framework Convention on Tobacco Control (FCTC) (WHO, 2003), smoke-free policies have been increasingly adopted all over the world (Carreras et al., 2019). Although exposure to SHS has declined over recent decades, many non-smokers are still exposed to SHS in the workplace, public places, at home, or in vehicles. A major global assessment of the burden of SHS was performed by Öberg et al., (2011) which, based on data from 192 countries in 2004, retrospectively estimated the exposure and burden of disease from SHS. The study found that 40% of children, and 34% of adults were exposed to SHS worldwide in 2004. Since, data from the Global Adult Tobacco Survey (GATS) has shown that the proportion of children exposed to SHS in the home varied greatly (4.5% to 79%) between low and middle-income countries (Mbulo et al., 2016). A longitudinal study by Olivieri et al. (2019) has shown the global smoking bans to be effective in reducing SHS exposure in Europe. The study found that workplace passive smoking has decreased from 31.9% in 1990-1995 to 2.5% in 2010-2014, and passive smoking at home has decreased from 28.9% to 8.8% over the same period. In Scotland, non-smokers' exposure to SHS has decreased by 97% in the past 20 years, although approximately 18.4% of non-smoking adults were found to have measurable cotinine, an indicator of recent SHS exposure, in their saliva (Semple et al., 2019).

The UK has been a strong adopter of the FCTC and in England, children's exposure to second-hand smoke has fortunately declined by 79% since 1998 due to the emerging social norm of smoke-free homes (Jarvis & Feyerabend, 2015). The smoking ban which came into effect July 2007, as a result of the Health Act 2006, made it illegal to smoke tobacco in enclosed places in England, with similar bans already introduced in Scotland, Wales, and Ireland earlier. Other tobacco control measures such as standardised packaging (Hiscock et al., 2020), raised taxes to increase the price of tobacco (Partos et al., 2018), marketing restrictions, graphic health warnings, and cessation treatment policies (Levy et al., 2018) have also contributed to the decline in smoking prevalence in the UK. Additionally, in 2015, England became one of the first nations to implement a law prohibiting smoking in private vehicles with children present (The Smoke-free (Private Vehicles) Regulations, 2015; Faber et al., 2019). Despite these tobacco control measures however, smoking is still permitted in private residences, and two main determinants of children's SHS exposure in England have been reported to be smoking by parents or caregivers, and whether smoking occurs in the home (Jervis et al., 2009; Sims et al. 2010). The proportion of smoke-free homes increased from 16% in 1998 to around 50% in 2008 in England (Jarvis et al., 2012) but previous research in North-West England found that 57% of children living in deprived areas reported having a family member that smoked (McGee et al., 2015). Furthermore, in a UK based cross-sectional survey by Moore et al. (2012a), among children from the poorest families, 96.9% of saliva samples contained detectable cotinine, compared with 38.2% among the most affluent. A later study suggests that 31.4% of children surveyed across England had detectable levels of salivary cotinine (Jarvis & Feyerabend, 2015), of which children of lower SES were also found to have the highest exposures of second-hand smoke, detected by salivary cotinine samples. The above research findings are in line with the trend that smoking is more prevalent among adults with routine and manual occupations (23.4%) compared to managerial and professional occupations (9.3%) (Office for National Statistics, 2020), which suggests children from the most deprived families are at greater risk of exposure and the associated ill-effects of second-hand tobacco smoke.

2.5.4. Second-hand Tobacco Smoke Exposure and Health

2.5.4.1. Overview of Tobacco Smoke Toxicity

Tobacco is the only legal drug that kills many of its users when used exactly as intended by manufacturers (WHO, 2015). The international agency for research on cancer (IARC) has classified the complex mixture of cigarette smoke as a known human (Group 1) carcinogen, and concluded that there is sufficient evidence that both active and involuntary smoking causes lung cancer in humans (IARC, 2004; IARC, 1986).

Since the early work of Doll and Hill and their seminal research ‘Smoking and Carcinoma of the Lung’ (Doll & Hill, 1950), the health effects of active smoking have been well researched and established. The main causes of death from tobacco smoking include coronary heart disease and stroke, cancers of the lung and upper airways, and chronic obstructive pulmonary disease (West, 2017). Worldwide, active smoking kills approximately 5.5 million people per year (WHO, 2015), and in England, approximately 500,000 hospital admissions (4% of total) and 77,600 deaths (16% of total) were attributable to smoking in 2016-2019 (Office for National Statistics (ONS), 2020).

Second-hand smoking is also responsible for a substantial proportion of global mortality and morbidity. The global disease burden of second-hand smoke exposure was retrospectively quantified by Öberg et al. (2011), who estimated that 603,000 deaths were attributed to SHS in 2004; approximately 1% of worldwide mortality. Estimated deaths from SHS exposure were due to ischaemic heart disease, lower respiratory infections, asthma, and lung cancer. Öberg et al. also estimated that SHS exposure amounted to 0.7% of the worldwide burden of disease in disability adjusted life years (DALYs) lost, with children accounting for 61% of the DALYs due to respiratory infections and asthma. More recently, one risk assessment estimated that in 2017, 1.2 million deaths were attributable to SHS exposure, of which 5% occurred in children under 10 years (GBD 2017 Risk Factor Collaborators, 2018). Although the number of deaths in

2017 far exceeds the Öberg 2004 estimate, the 2018 study also showed that the percentage change in the standardised death rate is fortunately decreasing, by approximately 15.9% from 2007 to 2017. However, a systematic review by Carreras et al. (2019) highlighted the need for more consistent and comparable research exploring global disease burden from SHS exposure, as data is currently lacking for a number of countries, and definitions, outcomes, and classifications are not consistent across the literature.

Some important hazardous components of cigarette smoke that are known carcinogens are polonium-210, benzene, benzo[a]pyrene, and tobacco-specific nitrosamines (Talhout et al., 2011). However, carcinogenesis is not an immediate effect, and many hazardous chemicals found in tobacco smoke have acute toxic effects (Table 2.1). Talhout et al. (2011) established thresholds of toxicological concern (TTC) for tobacco smoke, i.e. a 'safe' level of exposure, from the inhalation risk values found at 0.0018 µg per day for all risks including carcinogenicity, and 1.2 µg per day for all risks excluding carcinogenicity. Although, these values are based on a breathing rate of 20 m^3 day^{-1}, and children are particularly susceptible to the effects of second-hand smoke due to their high respiratory rates and immature organs (Longman & Passey, 2013)

Table 2.1. Components of tobacco smoke and associated general toxicities, adapted from Talhout et al. (2011). Substances that have only carcinogenic effects are excluded.

Effect	**Substance**
Respiratory and nasal	1,3-butadiene, acetaldehyde, acrolein, acrylic acid, acrylonitrile, ammonia, chromium VI, cobalt, copper, formaldehyde, hydrogen sulfide, naphtalene, nickel, *p*-, *m*-xylene, phenol, propionaldehyde, pyridine, selenium, vinyl acetate
Cardiovascular	Carbon monoxide, phenol
Neurological	Acetone, carbon disulfide, hexane, hydrogen cyanide, lead, manganese, *m*-cresol, mercury, methyl chloride, methyl ethyl ketone, *o*-cresol, *p*-, *m*-xylene, *p*-benzoquinone, *p*-cresol, styrene, trichloroethylene
Immune-related	Aniline, benzene, copper
Other	2-nitropropane, acetonitrile, chloroform, dimethylformamide, ethylbenzene, hydrazine, isopropylbenzene, *n*-propylbenzene, toluene

2.5.4.2. Carbon Monoxide Toxicity

Tobacco smoke contains the gas carbon monoxide (CO), a potent cardiotoxin, which displaces oxygen from haemoglobin due to its high affinity with the haemoglobin molecule forming carboxyhaemoglobin (COHb) which has no oxygen carrying capacity (West, 2017; Goldbaum, Ramirez, & Absalon 1975). Smoking individuals may have COHb levels of 4-15%, with passive smokers also experiencing elevated COHb levels after 1-2 hours exposure of smoke-polluted environments (Raub et al., 2000). The presence of COHb in the blood reduces the oxygen carrying capacity, with symptoms usually experienced at 10% COHb in blood, and include exhaustion in healthy people, angina in patients, and headaches, or dizziness, nausea, and dyspnea at 20% COHb (Omaye, 2002; Raub et al., 2000). As a response to chronic smoking and elevated COHb, individuals show dose dependent adaptive increases in haemoglobin concentrations (Pedersen et al., 2019).

2.5.4.3. Nicotine Pharmacology

Although not a major toxicant in the dose experienced by the active smoker, nicotine is a psychoactive and highly addictive component of tobacco smoke (Foll & Goldberg, 2009). Most smokers want to stop, but most have great difficulty (Chaiton et al., 2016), and continued tobacco use induces adaptive changes in the central nervous system that lead to drug dependence (Vieyra-Reyes et al., 2009). When tobacco is inhaled, nicotine is carried in smoke particles to the lungs where it is absorbed rapidly into circulation, quickly diffusing into brain tissue and binding to nicotinic cholinergic receptors (Benowitz, 2009). Nicotine is a sympathomimetic drug that releases catecholamines, increases heart rate and cardiac contractility, constricts cutaneous and coronary blood vessels, and increases blood pressure (Benowitz, 2003). However, studies have demonstrated that nicotine exposure without smoke (e.g. nicotine replacement therapy, snuff) does not increase the risk of cardiovascular disease or ischemic events (Lundblad et al., 2008; Benowitz et al., 2018). Although nicotine may not aggravate cardiovascular disease directly, nicotine is associated with increased risk of diabetes due to altered glucose metabolism (Chiolero et al., 2008) and a recent study by Duncan et al. (2019) has linked a transcription factor involved in both the cell signalling pathway that regulates insulin release, and nicotine addiction.

2.5.4.4. Particulate Matter Toxicity

Particulate matter < 10 µm (PM_{10}), <2.5 µm ($PM_{2.5}$), or < 1 µm (PM_1) in diameter, is a key component of the air pollution created by tobacco smoke, and particles are composed of a carbon core upon which high molecular weight organic chemical components and heavy metals deposit (Kelly & Fussell, 2012). Larger particles (up to 10 µm) deposit primarily in the bronchi and nasopharynx, but fine (<2.5 µm) and ultrafine (< 1 µm) particles have the ability to penetrate into the alveolar gas exchange region, where ultrafine particles have the ability the cross the air-blood barrier (Kelly & Fussell, 2012). PM concentrations emitted from three cigarettes are up to 10-fold those emitted from an idling diesel engine (Invernizzi et al., 2004), making cigarette smoke a significant contributor of PM pollution. The toxicity of PM is well researched, with detrimental impacts of respiratory conditions, cardiovascular disease, decreased lung function in children (Kelly & Fussell, 2012), increased asthma symptoms and onset of asthma in children (Gehring et al., 2010), and increased hospital admissions (Tecer et al., 2008; Anderson et al., 2001). A review by Cutrufello, Smoliga, & Rundell (2012) explored the impact of particulate matter (PM) on exercise performance in adults, and summarised that PM can impair pulmonary, cardiac, vascular, and immune function, through inflammation and oxidative stress.

2.5.4.5. Second-hand Tobacco Smoke Exposure and Cardiometabolic Health in Children

There is a well-established relationship between SHS and cardiovascular disease (Digiacomo et al., 2019). SHS increases CVD and atherosclerosis risk indirectly though effects on endothelial function (Heiss et al., 2008), arterial stiffness (Mack et al., 2003), inflammation (Jones et al., 2016), modification of lipid profile (Moffatt et al., 2004), platelet function (Digiacomo et al., 2019), and heart rate (Barnoya et al., 2005). In children, cardiometabolic risk factors are studied to assess the risk of developing cardiovascular disease, and include obesity, hyperglycemia, hyper-triglyceridemia, depressed high-density lipoprotein cholesterol, and elevated blood pressure (Ebrahimi et al., 2019). In a recent study with 14,400 Iranian children and adolescents, Ebrahimi et al. (2019) showed that triglyceride levels, and the risk of being overweight, or having metabolic syndrome, were considerably higher in children and adolescents exposed to SHS. A population based cross-sectional study of 10-year-old German children showed SHS exposure to be associated with a low-grade inflammatory response and altered markers of lipid metabolism, including elevated concentrations of leptin and c-reactive protein (Nagel et al., 2009). Tobacco smoke exposure has obesogenic effects (Thayer et al., 2012) demonstrated by Harrod et al. (2015) who showed prenatally exposed children to have a higher incidence of low birth weight, but rapid postnatal compensatory growth. SHS exposure (after birth) is associated with obesity in children, as shown by Raum et al. (2011) who found SHS to be positively associated with overweight at age six. Likewise, in-utero SHS and SHS exposure of the mother during pregnancy is associated with increased odds of obesity (Wang et al., 2014).

2.5.4.6. Second-hand Tobacco Smoke Exposure and Respiratory Health in Children

A range of studies exist regarding the impact of SHS on children's respiratory health and lung function, and SHS exposure has been shown to be detrimental to lung health in asthmatic children (Lajunen et al., 2019), children with cystic fibrosis (Kopp et al., 2016) and otherwise healthy children (Vanker, Gie, & Zar, 2017) which can persist into adulthood (Pugmire et al., 2014). Children with smoking parents are more likely to suffer from coughs and wheezing (Constant et al., 2011) and be at an increased risk of asthma (Li et al., 2000). A longitudinal study by Lajunen et al. (2019) showed that early-life exposure to tobacco smoke causes chronic airway inflammation and defects in lung function in children with asthma, the effects of which were measurable even a decade later. Changes in FeNO, blood eosinophil levels, impulse oscillometry, and spirometry that persisted into adolescence showed early second-hand smoke exposure to have a long-term effect on lung function. Although more research is required to establish a causal pathway between smoke exposure and reduced lung function, using path analysis, Balte et al. (2016) showed that the association between maternal smoking *during pregnancy* has adverse effects in lung function even in late adolescence. A large-scale study utilising the data from more than 20,000 children from nine countries, analysed the effect of pre- and postnatal exposure on the respiratory function of children aged 6-12 years. The study found that smoking during pregnancy and post-pregnancy was associated with decreases in a number of spirometry measures including FEV_1 and maximal expiratory flow at 25% of vital capacity left (MEF_{25}), although the associations with current smoking were weaker (Moshammer et al., 2006). In an earlier study, Gilliland et al. (2000) found similar results, with in-utero exposure to tobacco smoke associated with reductions in peak flow rate, mean mid expiratory flow, and forced expiratory flow, but not FEV_1. Similar to Moshammer et al. (2006), the study also found that adjusting for current smoking did not substantially change the in-utero associations. More recently, similar findings have been confirmed by Thacher et al. (2018) based on 2295 16-year-old adolescents. The study showed that maternal smoking during pregnancy was associated with a reduced FEV_1/FVC ratio of -1.1% at age 16. The above findings indicate that maternal smoking during pregnancy may be more detrimental to children than post-birth exposure, and the mechanism by which tobacco smoke is detrimental to lung function and health may be through inhibition of lung development during foetal growth.

2.5.4.7. Second-hand Tobacco Smoke Exposure and Exhaled Nitric Oxide

Decreased FeNO has been associated with particulate matter exposure of which tobacco smoke is a significant source. FeNO is decreased in active smokers and smoking asthmatics (Ahovuo-Saloranta et al., 2019; Bake, Torén, & Olin, 2012; Persson et al, 1994) with a dose-dependent trend. However, FeNO is still increased in untreated asthmatic smokers compared to non-asthmatic smokers (Ahovuo-Saloranta et al., 2019) which should be taken into consideration when interpreting FeNO values provided by smokers. Rundell et al. (2008) found that inhalation of high concentrations of PM_1 (particle diameter <1 μm) during bouts of exercise, caused a reduced alveolar contribution of exhaled NO, and proposed the mechanism to be through superoxide/NO formation of peroxynitrite, resulting in lipid peroxidation. Further, the study found the changes in exhaled NO following exposure to PM_1 were related to changes in FEV_1. A single blinded, placebo-controlled cross-over study by Yates, Breen, & Thomas (2001) exposed non-smoking volunteers to tobacco smoke and found that smoke exposure significantly reduced exhaled nitric oxide concentrations. In line with the research on active smokers, asthmatic children exposed to second-hand tobacco smoke have significantly lower levels of FeNO compared to unexposed asthmatic children (Bobrowska-Korzeniowska et al., 2019). Spanier et al. (2008) found that smoke exposure measured by airborne nicotine was associated with lower FeNO in children, but parent reported tobacco smoke exposure and child hair and serum cotinine markers were not. Overall, the vast majority of research has shown tobacco smoke exposure to reduce FeNO concentration. The mechanism for which is likely to be through the reduction in the enzymatic activity of nitric oxide synthase, in combination with superoxides (found in tobacco smoke in high concentrations) which react with NO to produce active nitrogen species (Matsunaga et al., 2020). Therefore, FeNO is reduced in active and passive smokers due to the suppression of production and elimination of NO.

2.5.4.8. Other Health Effects of Second-hand Tobacco Smoke Exposure

In addition to the well-known impacts on cardiovascular and lung health, SHS exposure is associated with a vast array of health effects including reduced bone mineral density (Moon, Kong, & Kim, 2018), vitamin D deficiency (Nwosu & Kum-Nji, 2018). SHS exposure from parental smoking has been shown to be an independent risk factor for higher blood pressure in children, in addition to BMI, prematurity and low birth weight (Simonetti et al., 2011). Ikävalko et al. (2018) found that daily parental smoking was significantly associated with lower psychological well-being in children.

As tobacco smoke exposure can cause epigenetic changes in the active smoker (Chen et al., 2020; Li et al., 2018), recent research has suggested possible epigenetic mechanisms linking in-utero exposure to tobacco smoke with adverse outcomes such as obesity and cancer risk through the identification of methylated cytosine-phosphate-guanine (CpG) base pairs in offspring (Rauschert et al., 2019). A meta-analysis of 6,685 new-borns and 3,187 identified 2,965 methylated CpGs associated with maternal smoking (Joubert et al., 2016). Epigenetic changes on genes linked to cancer development, obesity, developmental processes, detoxification, cell signalling, and nicotine dependence, have been shown to persist into adolescence (Rauschert et al., 2019).

2.5.4.9. Perceptions Surrounding Second-hand Smoke Exposure

Many parents and family members continue to smoke tobacco around children despite the well-known risks. One study based on 54 smoking mothers from Merseyside, England, found that whilst mothers were aware of the messages linking SHS exposure to childhood illness, they preferred to rely on explanations including genetics and pollution for ill-health in their children. This 'alternative dialogue' was found to be common within and between groups, and is linked to their personal need to smoke while caring (Robinson & Kirkcaldy, 2007). The study also found that smoking mothers attributed the risk of heart disease and cancer to active smoking, but did not attribute SHS with long term effects on children. Myers et al., (2020) have shown that whilst smoking parents were aware of the health risks associated with SHS, they were confused regarding which rules and behaviours to best protect children from exposure to SHS.

Children cannot easily protect themselves from SHS exposure, and previous research with children (4-8 years) in Liverpool showed that whilst children were prepared to verbally confront a smoker (usually a parent), they rarely took direct action and left the room themselves (Woods et al., 2005). Children from UK smoking families have been shown to express a strong dislike of family members' smoking, demonstrating overt and covert acts of resistance, including challenging relatives about their smoking, expressing disgust and concern, hiding or destroying cigarettes (Rowa-Dewar, Amos, Cunningham-Burley, 2014). However, previous research has shown that family and friends represent important influences on children's cognitive vulnerability toward smoking, and children with smoking siblings and friends are less likely to exhibit strong negative attitudes towards smoking (McGee et al., 2015).

2.5.5. The Effects of Second-hand Tobacco Smoke Exposure on Physical Activity and Cardiorespiratory Fitness

As CRF is closely related to a number of health outcomes as described above (2.2.2), therefore exposure to tobacco smoke not only harms health, but it may be detrimental to cardiorespiratory fitness too. The effects of SHS exposure on children's respiratory health are well-research and described above (2.5.4.6), but far less is known about the impact of SHS exposure on children's PA and CRF.

Much of the research surrounding smoking and physical activity concerns active smoking, and therefore the predominant age groups in focus are adults and adolescents (Condello et al., 2017), rather than children. Multiple studies have found an inverse relationship between active smoking and PA (Rovio et al., 2018; Papathanasiou et al., 2012; Kaczynski et al., 2008), including a longitudinal study (Salin et al., 2019) which found persistently active individuals were less like to be regular smokers. However, there is currently a distinct gap in the literature surrounding the effects of SHS exposure, or parental smoking, on children's PA. As PA is a key determinant of CRF, there is a need to explore this potential research area further.

The research regarding the impact of active and passive tobacco smoke exposure on CRF is largely centred around adults, with only a handful of studies exploring children's exercise performance. De Borba et al. (2014) found $\dot{V}O_{2max}$, measured by cardiopulmonary testing, was statistically lower in active and passive smokers compared to non-smokers. However, there were no statistical differences in CRF between the active and passive smoking groups. Kobayashi et al. (2004) compared the $\dot{V}O_{2max}$ of smokers and non-smokers and found non-smokers to have lower $\dot{V}O_{2max}$ when expressed both as raw $\dot{V}O_2$ and by lean body mass, however the difference was not statistically significant. Additionally, Kobayashi determined that smokers had a higher resting heart rate, and heart rate recovery was considerably slower in smokers. Both De Borba and Kobayashi found smokers to have a significantly increased waist circumference or higher percent body fat, respectively, which is an independent correlate of CRF. Although not using directly measured CRF, a recent study by Su et al. (2020) concerning military males in Taiwan, found that smoking was associated with lower aerobic fitness, as measured with a 3000 m run, and anaerobic fitness, measured using a sit-up and push-up test.

Flouris et al. (2011) conducted a randomised single-blind crossover experiment to determine the effect of passive smoke exposure on the cardiorespiratory response to 30 minutes moderate cycling. Eight women and nine men were exposed to 1 hour of 'restaurant levels' of tobacco smoke and the response was monitored at 1- and 3-hours following exposure and compared to baseline. Smoke exposure caused a 36.0% and 38.7% decrease in mean power output in men and women respectively which persisted up to 3 hours, with some of the effects exacerbated in less fit individuals. Carbon monoxide has been shown to reduce exercise capacity through a reduction of haemoglobin bound oxygen (West, 2017), and when carbon monoxide bound haemoglobin (COHb) reaches the 4.3% level, VO_2max is expected to decrease according to the equation: $\dot{V}O_{2max} = 0.91(\%COHb) + 2.2$ (Papathanasiou et al., 2014). In addition, due to down-regulation of β-adrenergic receptors, the maximum heart rate achieved by smokers during progressive exercise is lower than that of non-smokers (Savonen et al., 2006).

In children, research regarding the effects of SHS on fitness is limited. Although some studies have included parental passive smoking as a covariate when exploring other dependant variables (Ikävalko et al., 2018; Magnússon et al., 2009; Brage et al., 2004), very few studies have explored the impact of second-hand smoke on children's fitness in detail. A cross-sectional study by Magnússon et al. (2008) showed that fathers' smoking was an important predictor of fitness in 9-year old Icelandic children (n=229) when fitness was measured by a maximal cycle ergometer test. A cross-sectional study by Hacke and Weisser (2015), based on 532 adolescents aged 12 to 17 years, showed that parental smoking increased exercise (cycle ergometer test) systolic blood pressure, but not resting blood pressure, although CRF was not explored. Kaymaz et al. (2014) studied two groups of obese children; those exposed to passive smoking and those not exposed, who then performed the six-minute walk test (6MWT). Children exposed to passive smoking covered significantly less ground and on average managed to walk 59 meters less than children not exposed to passive smoking. Although the study was only limited to obese children, the absence of healthy weight children removes the possibility that differences in exercise performance were due to differences in body fat percentage.

The toxicity of tobacco smoke is an inherently complex subject due to the sheer volume of chemicals (at least 5000) of which tobacco smoke is comprised of. Establishing mechanisms by which tobacco smoke causes pathology is therefore difficult, although books which detail the fate and toxicity of the various constituents in the human body have been published (Bernhard, 2011). The mechanism by which tobacco smoke is detrimental to cardiorespiratory fitness, is less researched. There are countless pathways by which any of the 5000 components of tobacco smoke could impact CRF, of which a handful are described in the above sections. Although not within the scope of this research, utilisation and implementation of adverse outcome pathways (AOPs) (Roper & Tanguay, 2020), could begin to delineate the mechanism by which exposure to the various components of tobacco smoke are detrimental to CRF. Although, any toxicants that limit the coordinated ability of the cardiovascular, respiratory, and muscular systems to facilitate oxygen transportation, will be inhibitory to $\dot{V}O_2$ and therefore CRF.

2.6. Summary

Previous research has shown that CRF and PA are associated with a plethora of health benefits, and PA and CRF in children are associated with health in later life. There has been a steady decline in children's CRF over time, which may be indicative of a decline in population health. Decreasing PA, and increasingly sedentary lifestyles, combined with increasing levels of childhood overweight and obesity, may be contributing to the decline in CRF. However, the effect of environmental exposures on PA and CRF, such as

SHS, is often overlooked and under-researched. Exposure studies have shown that despite the UK's adoption of the FCTC and the introduction of smoke-free free policies, many children are still exposed to SHS in the home. Much research has indicated that SHS exposure is detrimental to pulmonary development and respiratory health in children, but few studies have explored the effects of SHS exposure on children's CRF and PA. Whilst a handful of experimental studies have demonstrated acute exposure to SHS to reduce exercise performance in adults, and a small number of studies have found an association between SHS exposure and CRF in adults, there is a distinct lack of research regarding the effects of SHS on children's PA and CRF. No studies have yet used directly measured VO2peak to explore the association between SHS and CRF. Additionally, little is known how household and familial smoking impacts children's attitudes, beliefs, and perceptions surrounding PA and CRF. Deeper understanding of the physiological and psychological impacts of household smoking and SHS exposure could reveal new avenues for health, PA, and CRF interventions for children.

2.7. Thesis Aims and Research Questions

The overarching aim of the thesis is to use a mixed-methods approach to, quantitatively and qualitatively, explore the association between second-hand smoke exposure and cardiorespiratory fitness, physical activity, and respiratory health in children, and children's attitudes to physical activity, fitness, and exercise.

Study 1

The aim of Study 1 is to assess the association between second-hand tobacco smoke exposure on directly measured $\dot{V}O_{2peak}$, physical activity, physical activity enjoyment, and respiratory health indicators in children, through the use of quantitative surveys and laboratory-based methods. The following research questions are used to address this aim:

1) Is second-hand tobacco smoke exposure associated with cardiorespiratory fitness in children?
2) Is second-hand tobacco smoke exposure associated with physical activity and physical activity enjoyment in children?
3) Is second-hand tobacco smoke exposure associated with respiratory health indicators in children?

Study 2

The aim of Study 2 is to use creative and qualitative methodologies to explore the attitudes, beliefs, and perceptions of physical activity, fitness, and exercise of children from smoking and non-smoking households. The following research questions are used to address this aim:

1) What are children from smoking and non-smoking households' reasons for being physically active?
2) What are children from smoking and non-smoking households' attitudes towards physical activity, exercise, and fitness?
3) What are the perceived barriers and facilitators to a child's ability to be physically active and does this differ for children from smoking and non-smoking homes?
4) What are children's perceptions of their own fitness and physical ability and does this differ for children from smoking and non-smoking homes?

Case studies

The aim of the case study chapter is to use a mixed-method case study methodology to provide rich, contextual insight into the lives, behaviours, and perceptions of a selection of participants, in relation to the above research aims and research questions.

2.8. Positionality Statement

The nature of qualitative (and mixed-methods) research sets the researcher as the data collection instrument, and it is possible that the researcher's beliefs and cultural background are important variables that may affect the research process (Bourke, 2004). My personal experiences and background should therefore be clear from the forefront.

I am a white-British female, in my late twenties, and I have lived in the North West of England, UK, for my entire life. I am the oldest of eight children, from a working-class family, and the first in my family to graduate from university. Prior to embarking on this PhD project, I had studied Biological Sciences and Environmental and Biochemical Toxicology at BSc and MSc level, and so the prospect of studying how second-hand smoke impacts children's health was extremely interesting to me. Not only do I have an academic interest in the topic, but having lived with two smoking parents growing up, and seeing them wrestle with the addiction and endless attempts to quit, it made the topic all-the-more interesting from a personal perspective.

2.9. The Methodological Approach

Quantitative research and qualitative research are distinct in the sense that one emphasises quantification and statistical data in the collection and analysis, and the other emphasises words and narratives (Bahari, 2010; Bryman, 2008). One key distinction between quantitative and qualitative research designs is the scale, or 'depth verses breadth' (Bahari, 2010). The two research designs are not only distinguished by methodology however but are based on two paradigms that differ in their principal orientation (deductive vs. inductive), epistemology (positivism vs. interpretivism), and ontology (objectivism vs. constructivism) (Alharahsheh & Pius, 2020; Bahari, 2010; Bryman, 2008).

The mixed-method approach, using both quantitative and qualitative approaches to explore a phenomena, is gaining momentum as the third methodology (Hall & Howard, 2008), although it is not without challenges. Where the quantitative approach calls for the researcher to adopt a position of distance and neutrality, the qualitative approach requires closeness and reciprocity (Hall & Howard, 2008). The key benefit of using the mixed methods approach is that it attempts to maximise the strengths and minimise the weaknesses of the quantitative and qualitative approaches (Bahari, 2010).

This research adopted a mixed-methods approach, encompassing a quantitative study, a qualitative study, and a mixed-methods case study chapter. The research questions presented in this thesis would not have been adequately addressed solely through quantitative or qualitative methodologies, but a mixed-methods approach provides richness and depth to understanding, and allows the triangulation of data (Creswell & Plano-Clark, 2011). Data was collected concurrently for both the quantitative (Chapter 3) and qualitative strands of the research, with a sub-cohort of participants selected for the qualitative study (Chapter 4). Chapter 5 adopts a mixed-method case study approach. Specifically, a convergent parallel design (Creswell & Plano-Clark, 2011) was used, where the quantitative and qualitative data collection was undertaken concurrently, producing two distinct and complementary datasets which were analysed separately (Chapters 3 and 4), and then finally 'merged' and analysed as one (Chapter 5). Whilst Study 1 and Study 2 are subject to the strengths and weaknesses of the quantitative and qualitative approaches, respectively, the thesis as a whole is afforded the advantages of the mixed-method approach.

2.10. Thesis Context

This thesis should be understood considering the geographical and demographical context in which the research was undertaken. All data collection took place in Merseyside, a county within the North West of the United Kingdom. Physiological data was collected during the University visit days at the state-of-the-art sport and exercise science facilities within the Tom Reilly Building of the Liverpool John Moores University City Campus. Qualitative data was collected on school premises, as described in later sections of the thesis. Participating schools were situated in either Liverpool or Wirral, Merseyside, UK.

Two schools each from Liverpool and Wirral (n=4) participated in the research, of which all were state-funded. All schools were situated within the 10% most deprived areas in England, based on the English Indices for Multiple Deprivation (EIMD) postcode look-up (Ministry of Housing Communities & Local Government, 2019). The majority of participants were also from neighbourhoods within the two most deprived deciles based on EIMD.

The participants were girls and boys aged 9-11 years, and in school years 5 or 6 of one of four English participating primary schools, at the time of data collection. Inclusion criteria were as above, but children who were not able to walk on a treadmill were excluded, as they would not be able to perform the maximal exercise test required. Participation was on an 'opt-in' basis, and so children who expressed a desire to take part did so, whereas children who were less interested in the topic refrained from participating. The findings of this research should therefore be understood in light of the above described geographical and demographical context.

2.11. Ethical Considerations of Research with Children

Ethics in research relates to 'the application of a system of moral principles to prevent harming or wronging others, to promote the good, to be respectful, and to be fair' (Sieber, 1993). According to Alderson and Morrow (2020), there are two basic ethical questions that should be considered prior to undertaking research with children: 1) Is the research worth doing? 2) Can the investigators explain the research clearly enough so that anyone they ask to take part can give informed consent or refusal? If the answer to these questions is 'yes', then the research can be undertaken.

Principle 1 of the Nuremberg Code states that the informed voluntary consent of the human subject is absolutely essential (Czech, Druml, & Weindling, 2018). Informed consent should be specific, where all procedures and methods, detailing exactly what is being asked of the participants and how the data will be processed, are made clear (Alderson & Morrow, 2020). With children, it is common practice to gain informed consent from a parent or guardian, in addition to 'assent' (affirmative agreement) from the child. Whilst parents or guardians provide legal consent, Ford et al. argue that it is vital to obtain children's informed assent to adapt a child-centred research approach (Ford, Sankey, & Crisp, 2007). For this research project, information about what the project would involve was provided verbally in the form of a presentation aimed at year 5 and 6 children, and via information packs for children to take home. The information packs contained child-friendly participant information, with child-centred language and imagery, as well as adult-orientated information for parents and guardians. Parental consent and child assent was obtained before participation.

The ‘opt in’ system has long been considered best practice for working with children. It is more respectful or privacy than the opt-out approach, and deemed ethically more defensible, by relying on active participation of the individual (Junghans et al., 2005). The present research used an opt-in approach to allow children and parents to make an active decision to take part. Skelton (2008), however, highlights the issue of inherent bias as a result of the opt-in method, where volunteer participants may be very far from a random sample. Regarding the present study, children who volunteered to take part in the research may have been more inclined to be physically active, or more confident in their physical abilities, whereas children who dislike physical activity may not have volunteered to participate. This subject is discussed further in the remaining chapters.

Anonymity and confidentially are important ethical considerations when planning and undertaking research with individuals. In a research context, confidentiality means not discussing information provided by an individual with others, and presenting findings in ways that ensure individuals cannot be identified, primarily through anonymisation (Wiles et al., 2008). For the quantitative aspects of the present research, anonymisation was achieved though assigning identification codes for participants. For the qualitative aspect of the research, such as during focus groups, only first names were used during discussions, but identification codes were used post-transcription. For ease-of reading, identification codes were replaced with pseudonyms for the case studies.

The ethical considerations and safeguarding procedures used within this body of research are discussed in the appropriate study chapters. As a broad overview, some key ethical considerations included:

- Confidentiality and anonymity
- Voluntary informed consent
- Safeguarding children (on university premises, travelling to the university, during focus groups at school) against physical and psychological harm
    - Risk assessments
    - Researcher training (first aid, recognising distress)
    - Signposting to relevant organisations

Ethical Approval

Ethical approval for this research was obtained from Liverpool John Moores Research Ethics Committee (Ref: 16/PBH/001). All procedures were in accordance with regulations and guidelines approved by the university ethics committee.

Chapter 3

Study 1 - The association between second-hand tobacco smoke exposure and cardiorespiratory fitness, physical activity, and respiratory health in children

3.1. Introduction

3.1.1. Cardiorespiratory Fitness

Cardiorespiratory fitness (CRF) is a health-related component of physical fitness defined as the ability of the circulatory, respiratory, and muscular systems to supply oxygen during sustained physical activity (Lee et al., 2010). CRF during childhood and adolescence is strongly associated with cardiovascular health in a later life (Harber et al., 2017, Jensen et al., 2016, Andersen et al., 2004) and research supports a cause-and-effect relationship between improved CRF and reduced mortality (Harber et al., 2017). The benefits of CRF include lower risk of cardiovascular disease (Henriksson et al., 2020) and cancer mortality (Imboden et al., 2018), as well as improved academic performance (Marques et al., 2017), cognitive function (Álvarez-Bueno et al., 2019), and improved weight loss (Berge et al., 2019). As explored in section 2.2, CRF is an established indicator for health in children and adolescents (Zaqout et al., 2016) which reinforces the importance of early intervention efforts to promote CRF.

In high and upper-middle income countries, there has been a substantial decline in CRF for children and adolescents since the 1980s, with stabilisation in the trend since 2000 (Tomkinson, Lang & Tremblay, 2019). In the North West of England, CRF in children has been decreasing over time, with 35.8 % of boys and 59.7 % of girls classified as unfit according to established CRF thresholds in 2004 (Stratton et al., 2007). In comparison, 78% of boys and 83% girls from 30 countries were found to meet the standards for healthy CRF levels in a more recent study (Tomkinson et al., 2018). Although data is regularly collected with regard to children’s PA, population CRF data is not routinely monitored and it is proposed that surveillance of children’s fitness should be undertaken within ‘harmonised national health surveys’ (Sandercock & Jones, 2019). Low prevalence and a temporal reduction in CRF are therefore suggestive of a decline in population health (Tomkinson et al., 2019).

3.1.2. Physical Activity

Physical activity (PA), in particular moderate-to-vigorous-intensity PA (MVPA), is positively associated with CRF (Knaeps et al., 2018; Brage et al., 2004) and low PA in childhood is predictive of low PA in adulthood (Mäkelä et al., 2017; Telama et al., 2005). The United Kingdom (UK) guidelines state that children and youth aged 5–18 years should achieve at least an average of 60 min of MVPA daily (Department of Health, 2019). Yet less than half of all children and young people, including 51% of boys and 43% of girls, met these guidelines in England in 2019 (Sport England, 2019). Physical activity enjoyment represents a positive attitude toward PA, and constitutes an important correlate of PA (Teques et al., 2020).

3.1.3. Second-hand Tobacco Smoke

Tobacco smoke is a toxic and carcinogenic mixture of over 5,000 different chemicals (Talhout et al., 2011). Second-hand smoke (SHS), often referred to as environmental tobacco smoke, is composed primarily of smoke that emanates from the end of the burning cigarette (sidestream smoke), smoke that the smoker inhales and exhales (mainstream smoke), and contaminants that diffuse through the cigarette paper (Acuff et al., 2016; EPA, 1992). In 2019, 15.9% of men (3.8 million) and 12.5% of women (3.1 million) reported being current smokers (ONS, 2020). Despite the smoking ban, smoking is still permitted in private residences and open public places, and as approximately 83% of tobacco smoke is in an invisible and gaseous form (Gee et al. 2013) which inadvertently exposes non-smokers to the effects of SHS. Two main determinants of children's SHS exposure in England are smoking by parents or caregivers, and whether smoking occurs in the home (Jarvis et al., 2009). UK based studies have shown approximately 31.5% of children to have detectable levels of salivary cotinine, an indication of recent tobacco smoke exposure (Jarvis & Feyerabend, 2015), with 96.9% of children from the poorest families demonstrating detectable levels of salivary cotinine (Moore et al., 2012a). Smoking is most prevalent among adults with routine and manual occupations (23.4%) compared to managerial and professional occupations (9.3%) (Office for National Statistics, 2020) which is in line with the above research findings. Children from low socio-economic status (SES) are therefore more likely to be exposed to SHS (McGee et al., 2015; Moore et al., 2012a), and consequently more likely to suffer the detrimental impacts of SHS exposure.

SHS is responsible for a substantial proportion of global mortality and morbidity for both adults and children (Carreras et al., 2019; Öberg et al., 2011). In adults, SHS can cause coronary heart disease, stroke and lung cancer, and exposed children can suffer from numerous health problems including, severe asthma attacks, respiratory infections, ear infections and sudden infant death syndrome (Naeem, 2015). Like all carcinogens, there is no risk-free level of SHS exposure. The risk from SHS exposure is time dependant, and therefore, limiting exposure early on is the most effective strategy for a reduction in tobacco smoke morbidity and mortality (Tantucci & Modina, 2012). Children are particularly susceptible to the effects of SHS due to their high respiratory rates and immature organs (Longman & Passey, 2013) and therefore, extra effort should be taken to safeguard children from SHS.

The impact of SHS exposure on cardiorespiratory fitness has been studied in adults, with SHS exposure associated with reduced exercise performance (Flouris et al., 2012; Flouris et al., 2011) and reduced $\dot{V}O_{2max}$ (De Borba et al., 2014). Two main constituents of cigarette smoke, nicotine and carbon monoxide (amongst others) exhibit toxic effects on cardiovascular function both at rest and during exercise in adults (Papathanasiou et al., 2014). For children, research is limited. From the small amount of research that currently exists, adolescents exposed to SHS have been found to have increased systolic blood pressure whilst exercising (Hacke and Weisser, 2015), and obese children exposed to SHS were found to have reduced performance on a six-minute walk test (Kaymaz et al., 2014). PA has been shown to reduce adolescent smoking uptake (Audrain-McGovern et al., 2013) and aid cessation (Horn et al., 2011) but there is little to no research exploring the association between SHS exposure, or having a smoking family member, on PA and PA enjoyment in children.

Children from smoking households are an often a neglected sub-population, and research which aims to explore their CRF, PA, and respiratory health may uncover novel strategies to improve health outcomes in this population. To date, no research has used laboratory based CRF measurements to explore the effect of SHS exposure on children's CRF, in particular $\dot{V}O_{2peak}$. Additionally, research is needed to understand whether PA and PA enjoyment differs between children from smoking and non-smoking homes. Understanding whether SHS exposure is detrimental to children's CRF will be of great value within the domain of public health and could provide novel pathways for CRF and health interventions with children.

3.1.4. Aim and Research Questions

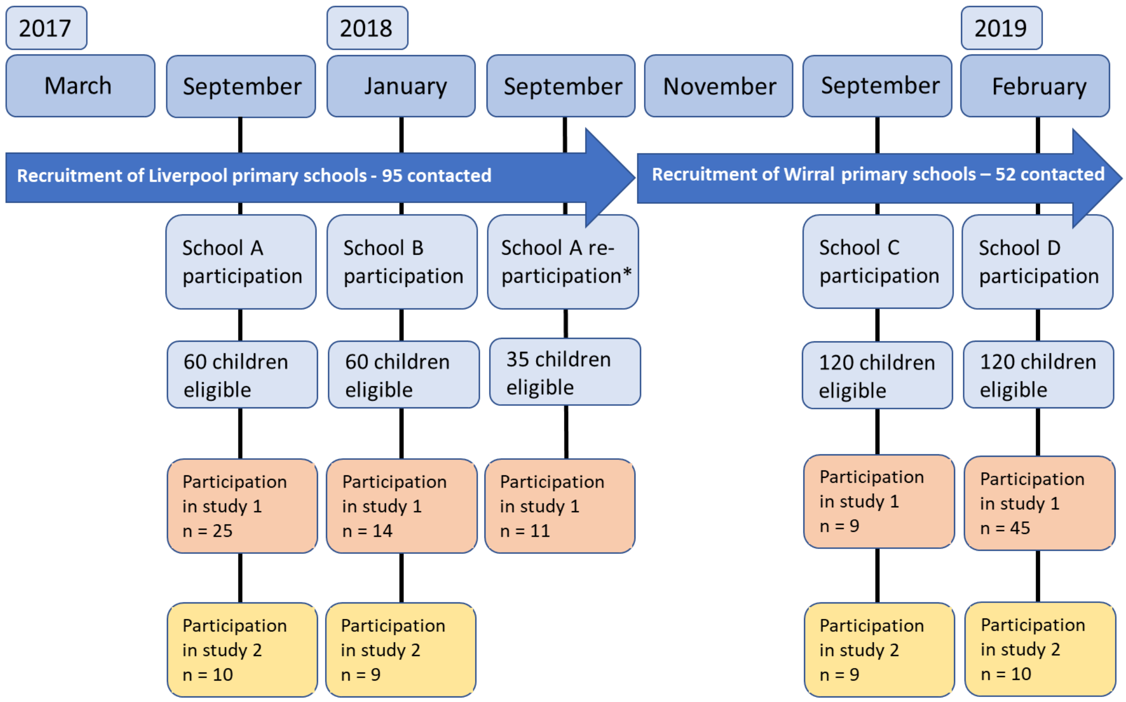
The aim of this study was to examine whether SHS exposure is detrimental to the health and cardiorespiratory fitness of children through the following research questions:

1) Is second-hand tobacco smoke exposure associated with cardiorespiratory fitness in children?
2) Is second-hand tobacco smoke exposure associated with physical activity and physical activity enjoyment in children?
3) Is second-hand tobacco smoke exposure associated with respiratory health indicators in children?

3.2. Method

3.2.1. Study design

This cross-sectional study presents observational data collected between September 2017 and February 2019. The research was granted ethical approval by the Research Ethics Committee of Liverpool John Moores University (Ref: 16/PBH/001). This study comprises the quantitative aspect of the larger mixed-methods research project and was conducted using a cyclical process where recruitment and data collection were concurrent and continued until the target for participant numbers was met. Figure 3.1 summarises the recruitment and data collection process throughout the project.



**School A participated again the following year with a new year group.*

Figure 3.1. Research timeline, showing recruitment, school participation, and participant selection over time.

3.2.2. Participants and setting

Primary schools within the Liverpool and Wirral areas of Merseyside, UK, were recruited as convenience samples. One-hundred-and-thirty primary schools were contacted across the region via an email containing study information, followed by a phone call. Gatekeepers (headteachers) were provided with gatekeeper information sheets and face-to-face meetings were organised with interested primary schools. Schools that declined (n=5, 3.8%) to participate provided a variety of reasons such as ‘too busy’, ‘no staff available to coordinate the project' and 'the project is too contentious'. Participating schools received informational presentations targeted at Year 5 and 6 children, during which children were free to ask questions about the study. Information packs containing participant information sheets for children and parents, child medical questionnaires, and parental consent and child assent forms were then distributed to all parents and guardians of Year 5 and 6 children via the participating schools. It was essential that completed consent and medical questionnaires were returned before participant involvement in the study.

Inclusion criteria were children aged 9-11 years old, in school years 5 and 6, and attend a Liverpool or Wirral primary school. Exclusion criteria were any medical conditions that limit a child's ability run on a treadmill, including heart conditions where vigorous exercise would put the child at risk.

3.2.3. Data collection

3.2.3.1. Data collection overview

Participants attended the Sport and Exercise Science laboratories at Liverpool John Moores University (LJMU) on one occasion to undertake measures on a convenient day and time for the participating schools. Participants and a member of school staff were transported to the laboratories from school, by the principal investigator in an LJMU hired vehicle. Participants visited the University in small groups of 3-4 children during school time (Monday-Friday 09:00-15:00) in either a morning or afternoon session.

The general study procedures are outlined in Figure 3.2. Following parental consent, child assent, and completed parental surveys, exhaled carbon monoxide measurements were made on the morning of the University visit. Once at the university, participants' anthropometric data was recorded. Fractional exhaled nitric oxide measurements were taken prior to spirometry for reasons detailed below, and children participated in cardiopulmonary testing once all respiratory measures had been completed. Children completed surveys in-between testing with the help of a school teaching assistant or a member of the research team.

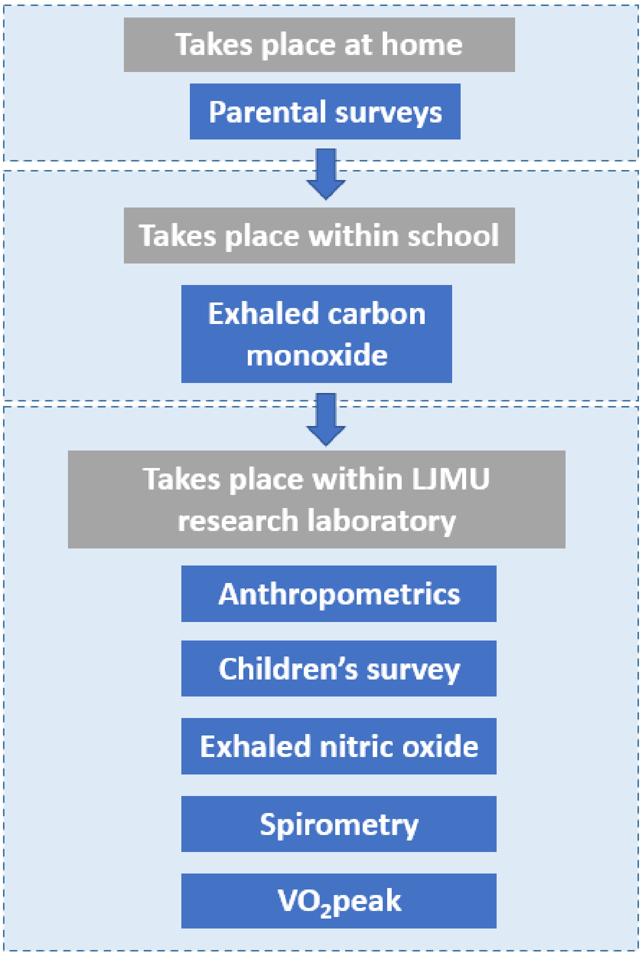


Figure 3.2. Summary of study procedures.

3.2.3.2. Parental questionnaires

Prior to children's visits to the laboratory, surveys to determine self-reported household smoking status, adapted from the Global Adult Tobacco Survey (GATS) by the Global Adult Tobacco Survey Collaborative Group (GATSCG, 2011), were sent home to be completed by a consenting parent or guardian (Appendix 4). Only survey questions that were relevant, appropriate, and addressed the research questions were included from the GATS. Questions determined the number of tobacco smokers living in the home, as well as which rooms in which smoking occurred and/or was permitted, and how many cigarettes were smoked each day per person. Space was provided for participants to include information regarding smoking habits for up to four members of the household, with more space available upon request. Similar information was collected for e-cigarette use and participant residential environment including road type. Participants were classified into 'non-smoking household' or 'smoking household' according to whether a household member smoked cigarettes or not, regardless of where smoking was permitted. Households were then further classified as permitting smoking 'indoors' or 'outdoors only'.

An extract from the parental survey used to determine smoking habits is included below (Figure 3.3). Questions used to determine overall smoking habits include:

- ❖ How many members of your household smoke:
  - ➢ tobacco products?
  - ➢ e-cigarettes?
- ❖ In which rooms of your house do people smoke tobacco in? Tick all that apply.

Participant (adult and child) demographic information was also obtained via the parental questionnaire. The English Indices of Multiple Deprivation (EIMD) (MHCLG, 2019) was assessed using participant home postcode using the Ministry of Housing, Communities, and Local Government postcode lookup tool (MHCLG, 2019).

Please complete for each member of the household that smokes <u>tobacco</u>. If you require more space please contact the research team.				
	1	2	3	4
7. Relation to the child participant? (e.g. mother, father, sister, not related, etc.).				
8. Typical number of cigarettes smoked in 1 day				
9. How long has this person smoked for (years, months)?				
10. Type of cigarette smoked (e.g. packet cigarettes, roll-ups)				
11. Does this person have a preferred brand? If yes, what is it?				
12. At what time does this person normally smoke <u>at home</u>? (Tick all that apply).	○ Morning ○ Afternoon ○ Evening	○ Morning ○ Afternoon ○ Evening	○ Morning ○ Afternoon ○ Evening	○ Morning ○ Afternoon ○ Evening
13. When is this person most likely smoke <u>at home</u>? (Tick all that apply).	☐ After waking ☐ Whilst preparing food ☐ After eating ☐ With friends and family (socially) ☐ When drinking alcohol ☐ Whilst eating ☐ Whilst relaxing (watching TV, on PC, reading) ☐ Before bed ☐ Other:	☐ After waking ☐ Whilst preparing food ☐ After eating ☐ With friends and family (socially) ☐ When drinking alcohol ☐ Whilst eating ☐ Whilst relaxing (watching TV, on PC, reading) ☐ Before bed ☐ Other:	☐ After waking ☐ Whilst preparing food ☐ After eating ☐ With friends and family (socially) ☐ When drinking alcohol ☐ Whilst eating ☐ Whilst relaxing (watching TV, on PC, reading) ☐ Before bed ☐ Other:	☐ After waking ☐ Whilst preparing food ☐ After eating ☐ With friends and family (socially) ☐ When drinking alcohol ☐ Whilst eating ☐ Whilst relaxing (watching TV, on PC, reading) ☐ Before bed ☐ Other:

Figure 3.3. Exert from the parental survey to ascertain tobacco smoking habits.

3.2.3.3. Children's questionnaires

During the visit to the laboratory, children completed a survey to determine self-reported level of physical activity (PAQ-C) based on Kowalski, Crocker, and Donen (2004). The PAQ-C requests responses for the last 7 days by asking participants to check a list of activities for frequency of participation, including PA during school time and out of school (Biddle et al., 2011). Each question is scored from 1 to 5, for example Question 10: On the last weekend, how many times did you do sports, dance, or play games in which you were very active? (Tick one). 'None' would equal a score of 1, and '6 or 7 times last week' would give a score of 5. A mean is calculated for all questions to give an overall PAQ-C score. The PAQ-C is a validated and reliable measure of PA levels in children (Voss et al., 2017; Kowalski, Crocker, & Donen, 2004) and regularly used in PA surveillance (Biddle et al., 2011).

Physical activity enjoyment was measured using an adapted physical activity enjoyment scale (PACES), originally by Kendzierski and DeCarlo (1991) and validated by a number of studies since (Mullen et al., 2011, Moore et al., 2009). The PACES consists of 16 statements which begin with "When I am physically active…" and uses a 5-point Likert-type scale (1 = 'Disagree a lot' to 5 = "Agree a lot"). Like the PAQ-C, an overall score is obtained by calculating the average of the 16 items.

3.2.3.4. Anthropometry

All anthropometric assessments were conducted to the standards of the International Society for the Advancement of Kinathropometry (Marfell-Jones et al., 2006). Children were assessed whilst wearing light clothing and shoes removed. Body mass to the nearest 0.1 kg (Seca, Birmingham, UK), stature and sitting stature to the nearest 0.1 cm (Seca, Birmingham, UK) were assessed using standard techniques (Lohmann et al., 1988). Body mass index (BMI) was calculated from stature and mass ($kg \cdot m^{-2}$) with age and sex specific International Obesity Task Force BMI cut-offs used to classify child BMI and weight status (Cole & Lobstein, 2012). Years to peak height velocity, a somatic indicator of physical maturity, was estimated using stature, sitting height and mass, into regression equations separately for boys and girls (Mirwald et al., 2002).

3.2.3.5. Exhaled Gases

Exhaled carbon monoxide (eCO) was measured in ppm using a breath Smokerlyzer PiCO device (Bedfont, UK) to determine recent tobacco smoke exposure. Previous studies have shown eCO to be a useful indicator for recent tobacco smoke exposure in adults (Cropsey et al., 2014; Tual et al., 2010; Deveci et al., 2004) and youth (Gourgoulianis et al., 2007). A threshold of 3-4 ppm is suggested to distinguish smokers from non-smokers (Cropsey et al., 2014) but there is currently little research regarding thresholds for children who are exposed to SHS. Pilot work indicated that (eCO) quickly declined several hours post-tobacco smoke exposure. Therefore, carbon monoxide (CO) measurements were taken on the morning (08:30) of laboratory visits, at school prior to departure, to better reflect second-hand smoke exposure from the home (mean value of two attempts). Participants were asked to hold their breath for 15 seconds before exhaling continuously with a constant force into the Smokerlyzer mouthpiece.

Fractional exhaled nitric oxide (FeNO), an indication of airway inflammation, was measured (mean value of two attempts) at rest using a NIOX® VERO device (Circassia, UK). This measured FeNO in the exhaled breath, at rest, at a constant flow rate of 50 mL/min. FeNO was performed prior to spirometry measures to avoid potential carryover effects (Eckel et al., 2015) and taken as the mean of duplicate measures (Dweik et al., 2011). FeNO offers additional benefits to spirometry by detecting eosinophilic airway inflammation (Dweik et al., 2011), an indication of asthma (Arnold et al., 2018). The non-invasiveness and instantaneous result makes FeNO a suitable method for assessing lung health in children (Hatziagorou & Tsanakas, 2007). For children, the following FeNO thresholds were used: <20 ppb (low), 20-35 ppb (intermediate), and >35 ppb (high) as per Dweik et al. (2011).

3.2.3.6. Spirometry

Spirometry measures including forced vital capacity (FVC), forced expiratory volume (FEV_1), peak expiratory flow (PEF), forced expiratory ratio (FER) were taken at rest using a digital micro-spirometer (Micro-plus spirometer, CareFusion, UK). Measurements were made in triplicate and the best value compared against predicted values for sex, and age (Quanjer et al., 2012). Spirometry values were also normalised by a factor of 0.9 for black children and 0.95 for children of other ethnicities (Korotzer, Ong and Hansen, 2000). An FEV_1 <80%, and FER <70% predicted was considered obstructive, and FEV_1 <60% and FVC <60% was considered restrictive (Vandevoorde et al., 2005). Information regarding respiratory disease including asthma (and general medical background) was collected via the medical questionnaire (Appendix 3).

3.2.3.7. Cardiorespiratory Fitness

Cardiorespiratory fitness (CRF), using peak oxygen uptake ($\dot{V}O_{2peak}$) as a marker, was assessed using an individually calibrated, discontinuous incremental treadmill test to volitional exhaustion using breath by breath analysis (Jaeger Oxycon Pro, Viasys Health Care, UK). $\dot{V}O_{2peak}$, as opposed to $\dot{V}O_{2max}$ (maximal oxygen uptake), was used as children often fail to reach a plateau (Armstrong & Van Mechelen, 2017). Experiments have shown that 'true' $\dot{V}O_{2max}$ values can be achieved in children without the need for plateau as long as test endpoints are met (Armstrong & Winsley, 1996). The following method is based on an established protocol and is supported by previous work (Boddy et al., 2014).

A paediatric facemask (Hans Rudolph, Kansas City) covering the nose and mouth was secured via an adjustable nylon harness prior to test beginning. Before using the treadmill, participants wore a specialised harness which would cause the treadmill to stop in case of any trips or falls. Children underwent a familiarisation period of walking and running on the treadmill prior to the test. To account for differences in age and limb length, $\dot{V}O_{2peak}$ test speeds were individually calibrated by anchoring treadmill speeds to set Froude (Fr) numbers (Hopkins et al., 2010). Participants completed 2-minute stages, stage one speed at Fr 0.25, stage two speed at Fr 0.5, with each additional stage determined by the difference in speed for stages one and two (~ 2 km/h). The treadmill remained at 1% gradient throughout. The test was terminated at the point of volitional exhaustion when the participant was unable to continue despite strong verbal encouragement.

Oxygen uptake ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) were measured breath-by-breath with an online system (Jaeger Oxycon Pro, Viasys Health Care, Warwick, UK). Prior to each testing session, the Oxycon Pro system was calibrated using known volumes of gases (0.5% CO_2 and 20.5% O_2) and known volumes (3.0 L/s). Heart rate was monitored continuously (Polar, Kempele, Finland).

$\dot{V}O_{2peak}$ was accepted as maximal index when participants exhibited any of the following subjective indicators of maximal effort; unsteady gait, hyperpnea, facial flushing, sweating, in addition to objective indicators: respiratory exchange ratio (RER) >1.05 and heart rate >199 beats/min (Boddy et al., 2014). $\dot{V}O_{2peak}$ was defined as the highest 15 second averaged oxygen uptake achieved during the test when participants reach volitional exhaustion, and the above endpoints met.

The Pictorial Children's Effort Rating Table (PCERT) was used to establish participants' perceived exertion (Figure 3.4). The PCERT uses pictures as well as numbers and descriptive language, reflecting the changing physiological demands of the exercise task (Daley et al., 2005) in a child friendly format. Participants were asked to state or point to the point on the scale which best described their effort rating at the end of each two-minute stage.

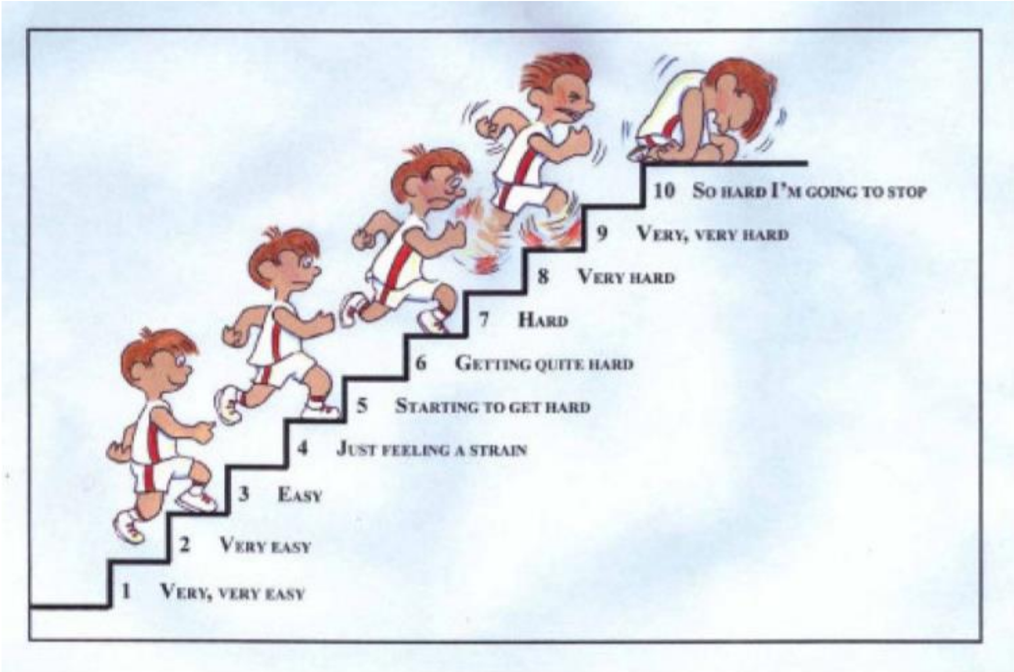


Figure 3.4. Pictorial Children's Effort Rating Table (PCERT), from Yelling, Lamb & Swaine, (2002).

Cardiorespiratory fitness was presented as absolute $\dot{V}O_{2peak}$ ($mL \cdot min^{-1}$), ratio scaled by body mass ($mL \cdot kg^{-1} \cdot min^{-1}$) or allometrically scaled using a sample-specific calculated mass exponent ($mL \cdot kg^{-0.526} \cdot min^{-1}$) for descriptive statistics but only absolute and allometrically scaled $\dot{V}O_{2peak}$ were used in linear regression analysis. Mass exponents were calculated using log-linear regression models of mass and absolute $\dot{V}O_{2peak}$, as described by Welsman and Armstrong (2019a), where the generated 'b' is the mass exponent. Whole sample and sex and age-group specific exponents were calculated but it was determined that the sample size did not allow for sex and age-group specific models. For the total sample, the mass exponent was calculated to be 0.526 (rounded to 0.53 when expressing as a unit). The generated mass exponent was 'tested' by correlational analysis between allometrically scaled absolute $\dot{V}O_{2peak}$ and mass which was found to be close to zero ($r = -0.046$, $p = 0.663$), indicating the influence of mass was successfully removed.

For descriptive purposes, participants were classified as fit or unfit according to published thresholds for identifying aerobic fitness and associated cardio-metabolic disease. Thresholds used were taken from the review by Lang et al. (2019) which incorporates data from 1,142,026 youth from 50 countries. $\dot{V}O_{2peak}$ scores below 42 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ for boys, and 35 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ for girls, indicate higher risk of cardiovascular risk and were classified as unfit.

3.2.4. Statistical Methods

Statistical analyses were performed using SPSS for Windows (version 26; SPSS, Chicago, IL, US). Data are expressed as mean ± standard deviation unless otherwise stated. Data that were not normally distributed were log natural transformed (EIMD, FeNO) or square-root transformed (total number of cigarettes smoked per day) prior to analysis, although are presented pre-transformation in descriptive tables for ease of interpretation. Binary data, including sex and asthma are coded as: boy = 0, girl = 1, and no asthma = 0, diagnosed asthma = 1. Differences by sex and household smoking status were assessed using independent sample Student *t* tests. Pearson's correlation coefficient was used to examine the association between all variables, and Spearman's rho was used to assess relationships in ordinal data. All correlation analysis use Pearson's unless stated otherwise. Univariate analyses of variance (ANOVA) were used to compare mean differences in exhaled carbon monoxide, cardiorespiratory fitness, PA, PACES, and lung function measures. Tukey post hoc tests were performed to further distinguish differences between groups. Statistical significance was set at an alpha level of 0.05.

Multiple linear regressions were performed for absolute $\dot{V}O_{2peak}$, ratio scaled $\dot{V}O_{2peak}$, allometrically scaled $\dot{V}O_{2peak}$, PA, PACES, FEV_1%, FVC%, PEF%, FER and FeNO. Regressions were run to determine whether household smoking predicted the above outcome variables in unadjusted and adjusted models. The forced entry (enter) method was used as the method of entry. Forced entry was selected over the stepwise method in order to include known correlates based on theoretical knowledge and past research, and to ensure the researcher had control over what variables were entered into the model (Field, 2018).

A number of indicators of household smoking status and level of smoking were available, and the number of cigarettes smoked per day was selected as a more precise measure of household exposure than the binary measure of household smoking status (smoking or non-smoking). Household smoking status was not entered into the linear regression models in addition to the number of cigarettes smoked due to the high correlation coefficient ($r > 0.9$) between these two variables. Exhaled CO was not significantly different for children from smoking and non-smoking homes ($p = 0.215$), and was not correlated with the number of cigarettes smoked per day ($r=0.157$, $p = 0.119$); similar findings have been observed in children in previous studies. Exhaled CO was therefore deemed inappropriate as a measure of second-hand smoke exposure in children for the present study. ANOVA and Tukey post-hoc determined that CRF, PA, and respiratory variables for children from non-smoking and e-cigarette using families were not statistically different (see Appendix 9 for statistical output), and therefore e-cigarette use was further classified as non-smoking.

All unadjusted models included the sole predictor of the square root transformed number of cigarettes smoked per day. In addition to the number of cigarettes smoked per day, variables for linear regression modelling were selected based on known determinants from previous research. For absolute $\dot{V}O_{2peak}$, sex, age, mass, stature, maturation, PA, and logEIMD (Zeiher et al., 2019; Armstrong & McManus, 2017; Fairclough et al., 2017) were included in the adjusted model. The adjusted models for ratio scaled and allometrically scaled $\dot{V}O_{2peak}$ included the same variables, with the exception of mass, as both ratio scaled, and allometrically scaled $\dot{V}O_{2peak}$, are already adjusted by mass within the calculation. PA and PACES adjusted models contained known determinants of PA including sex, age, BMI, maturation, logEIMD, and PA and PACES where appropriate (Gao et al., 2012; Biddle et al., 2011; O'Donoghue et al., 2018). As spirometry measures FEV_1%, FVC%, and PEF% values were already adjusted for known determinants of lung function, such as sex, age, height, and ethnicity prior to modelling, adjusted linear regressions for these measures included mass, diagnosed asthma, and logEIMD (Anuntaseree et al., 2020; Polak et al., 2019; Quanjer et al., 2012). Linear regressions for FER additionally included age, sex, and stature as FER values are not presented as percentages of predicted. Linear regressions for FeNO included sex, age, mass, stature, diagnoses asthma, and logEIMD in addition to the number of cigarettes smoked per day (Polak et al., 2019; Dweik et al., 2011).

For all models, there was linearity as assessed by partial regression plots and a plot of studentized residuals against the predicted values. There was homoscedasticity, as assessed by visual inspection of a plot of studentized residuals versus unstandardized predicted values. There was no evidence of multicollinearity as assessed by tolerance values greater than 0.1. Studentized deleted residuals greater than ±3 standard deviations were excluded from absolute $\dot{V}O_{2peak}$ (n=4), PEF% (n=1), FER (n=2), and PACES (n=3). There were no leverage values greater than 0.2 and no values for Cook's distance above 1. The assumption of normality was met, as assessed by a histogram and P-P Plot (Appendix 8).

3.3. Results

3.3.1. Participant Characteristics

3.3.1.1. General Description

Of the one-hundred-and-thirty primary schools contacted across the Merseyside region, four schools (two each from both Liverpool and Wirral areas) participated in the study between September 2017 and February 2019 (3% response rate). Total participation (consent rate) was 26.7% with 104 children taking part (46 boys, 58 girls) out of a possible 390 invited from the participating schools. Schools A and B (Liverpool) accounted for 36 (34.6%) and 14 (13.5%) of participants respectively, and Schools C and D (Wirral) account for 9 (8.7%) and 45 (43.3%) of participants respectively.

Out of the 104 participants with written parental consent and participant assent, ten children were excluded from the $\dot{V}O_{2peak}$ analysis for failing to reach 'peak' threshold criteria (n=7), unable to run on the day (n=2) and one participant requested not to undertake the fitness assessment. In total, 94 children (43 boys, 51 girls) were included in the $\dot{V}O_{2peak}$ analysis. One participant requested not to be weighed or have their height measured. Four participants have no corresponding exhaled carbon monoxide data due to unavailability at the time of testing. Eleven participants failed to provide a postcode, or the provided postcode did not generate an EIMD score, and therefore school postcode has been substituted in these cases. Two children failed to perform a successful FeNO test. In total, complete data is available for 92 participants.

Participant characteristics are presented in Table 3.1, split by gender in Table 3.2, and by household smoking status in Table 3.3.

Descriptive statistics for the sample (pre-transformation).

	N	Minimum	Maximum	Mean	SD
Anthropometry					
Decimal age (years)	104	8.5	11.5	10.1	0.6
Maturation	103	-4.1	0.1	-2.2	1.0
Stature (cm)	103	122.0	158.0	141.7	6.6
Mass (kg)	103	22.8	66.0	38.2	9.2
BMI ($kg \cdot m^{-2}$)	103	13.2	30.5	19.0	3.9
Cardiorespiratory fitness					
$\dot{V}O_{2peak}$ ($mL \cdot min^{-1}$)	94	843.0	2399.0	1659.5	307.9
$\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	94	24.8	59.5	45.0	7.7
$\dot{V}O_{2peak}$ ($mL \cdot kg^{-0.53} \cdot min^{-1}$)	94	157.5	322.6	247.2	36.3
Respiratory measures					
FEV_1 (%)	103	43.9	131.7	83.0	17.2
FVC (%)	103	44.3	136.0	89.0	19.7
PEF (%)	103	33.6	155.7	75.3	21.0
FEV_1/ FVC	103	52.7	100.0	89.6	11.0
FeNO (ppb)	102	<5	147	21.2	23.30
Children's survey					
Physical activity	103	2.1	5.0	3.6	0.7
Physical activity enjoyment	103	1.5	5.0	4.1	0.7
SHS exposure					
eCO (ppm)	100	0	7	1.8	1.2
Cigarettes per day	104	0	65	5.5	10.8
Deprivation				**Median**	**IQR**
EIMD rank	104	69	25530	1709	4582

Spirometry values expressed as percentage of predicted values for sex, age, ethnicity, and height: FEV_1 = forced expiratory volume in 1 second, FVC = forced vital capacity, PEF = peak expiratory flow, FeNO = fractional exhaled nitric oxide, eCO = exhaled carbon monoxide, EIMD = English indices of multiple deprivation. Physical activity and enjoyment are scored between 1 and 5, with 5 being the most active and most enjoyment.

Table 3.2. Descriptive statistics for the sample by sex.

	Boys			Girls			T-test
	N	Mean	SD	N	Mean	SD	*p*
Anthropometry							
Decimal age (years)	46	10.1	0.5	58	10.2	0.7	0.810
Maturation	45	-3.1	0.6	58	-1.5	0.7	**<0.001**
Stature (cm)	45	140.1	5.8	58	142.3	7.1	0.255
Mass (kg)	45	37.4	9.1	58	38.9	9.2	0.418
BMI ($kg \cdot m^{-2}$)	45	18.7	3.7	58	19.1	4.2	0.593
Cardiorespiratory fitness							
$\dot{V}O_2$peak ($mL \cdot min^{-1}$)	43	1736.7	285.5	51	1594.4	313.7	**0.025**
$\dot{V}O_2$peak ($mL \cdot kg^{-1} \cdot min^{-1}$)	43	47.7	8.5	51	42.7	6.1	**0.002**
$\dot{V}O_2$peak ($mL \cdot kg^{-0.53} \cdot min^{-1}$)	43	261.0	35.7	51	235.6	32.9	**<0.001**
Respiratory measures							
FEV_1 (%)	45	85.1	16.3	58	81.3	17.9	0.259
FVC (%)	45	89.4	21.3	58	88.8	18.5	0.876
PEF (%)	45	73.0	20.1	58	77.1	21.6	0.322
FEV_1/FVC	45	89.7	11.1	58	89.6	11.0	0.968
FeNO	45	23.5	27.4	57	19.4	19.5	0.317
Children's survey							
Physical activity	46	3.8	0.6	57	3.5	0.7	0.099
PACES	46	4.2	0.6	57	4.1	0.8	0.411
SHS exposure							
eCO (ppm)	43	1.7	1.2	57	1.8	1.2	0.570
Cigarettes per day	46	6.3	11.6	58	4.9	10.2	0.522
Deprivation							
EIMD rank	46	1566*	4641†	58	1709*	3595†	0.967

Spirometry values expressed as percentage of predicted values for sex, age, ethnicity, and height: FEV_1 = forced expiratory volume in 1 second, FVC = forced vital capacity, PEF = peak expiratory flow, logFeNO = log (fractional exhaled nitric oxide), eCO = exhaled carbon monoxide, EIMD = English indices of multiple deprivation. Physical activity and enjoyment are scored between 1 and 5, with 5 being the most active and most enjoyment. Values which are statistically significant are highlighted in **bold.** *median, † interquartile range.

3.3.1.2. Participant Demographics

The median English Indices for Multiple Deprivation (EIMD) rank was 1709 (IQR 4582) and the majority of participants' postcodes were within the first (69.2%) and second (16.3%) most deprived deciles. All four primary postcodes were within areas of very high deprivation (1st decile). The percentage of parents or guardians with no formal education was 3.3%, 33.7% were educated to high school level, 41.3% had completed college or sixth form, 13.0% had a Bachelor's degree, and 8.7% had a Master's degree or above. White British children made up 76.9% of the sample population, with 6.7% Black British, 2.9% White Polish, 1.9% White Portuguese, 1.9% Black African, 1% Black other, 1% Chinese British, 7.7% other.

3.3.1.3. BMI and Weight Status

Overall, out of 103 children (n = 58 girls and 45 boys), 35.0% were overweight or obese, including 28.9% of boys and 39.7% of girls. The mean BMI for boys was 18.7 and 19.1 for girls which was not statistically significantly different ($t(101) = -0.54$, $p = 0.593$).

3.3.2. Household Smoking Status

3.3.2.1. Smoking Prevalence

Tobacco smoking only, by one or more members of the household, was reported in 35 households (33.7%). In addition, three parents reporting using e-cigarettes in addition to smoking tobacco (2.9%), and parents from ten households reported using e-cigarettes only (9.6%). Therefore, a total of 38 (36.6%) parents reported smoking tobacco. Neither smoking tobacco cigarettes or using e-cigarettes was reported in 56 (53.8%) households. Of the 38 participating families that reported tobacco smoking, ten (26.3%) reported two people living in the home that smoked, with the remaining 28 participants (73.7%) reporting only one smoker living in the home. For tobacco smoking households, the mean total household cigarettes smoked per day was 16.6 (SD 14.2, range 60), with the majority of smoking parents/guardians reporting smoking 20 cigarettes or less per day (Figure 3.5).

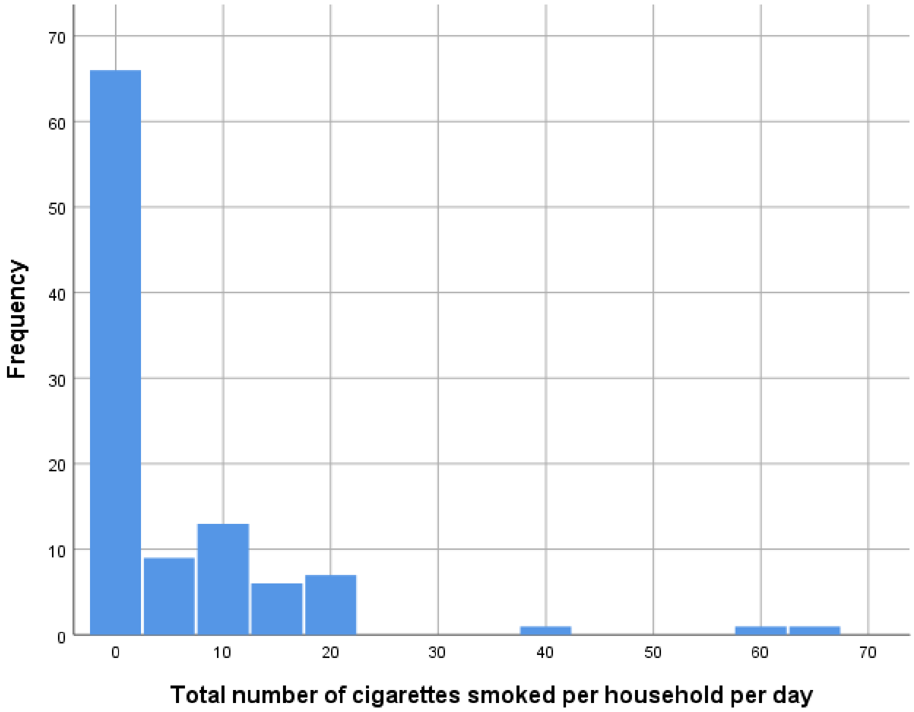


Figure 3.5. Histogram demonstrating the number of cigarettes smoked per household per day across the sample.

Overall, 61.9% of households did not allow smoking anywhere in or around the house, 27.8% allowed smoking outside only, and 10.3% allowed smoking inside. The vast majority of parents from non-smoking households (n=60, 90.9%) reported that smoking is not allowed anywhere at the home, not even outside, whilst 6 (9.1%) parents from non-smoking households stated that smoking was allowed outside (by visiting family and friends). For smoking households 24 (63.2%) stated that smoking was allowed outside only, and 14 (36.8%) reported that smoking was allowed inside. Out of the self-reported smoking households, 12.1%% responded that smoking is allowed in the car, although 7 parents failed to answer this question.

Participant characteristics, split by household smoking status, are shown in Table 3.3, and are explored in further detail below in the corresponding sections.

Table 3.3. Descriptive statistics by household smoking status and sex.

	Non-smoking household						Smoking household						T-test (p) Non-smoking vs smoking		
	All		Boys		Girls		All		Boys		Girls		*Boys*	*Girls*	All
	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)			
Anthropometrics															
Decimal age (years)	66	10.1 (0.7)	28	10.2 (0.6)	38	10.1 (0.7)	37	10.2 (0.5)	17	10.1 (0.3)	20	10.3 (0.6)	0.533	0.370	0.710
Maturation	66	-2.2 (1.1)	28	-3.2 (0.5)	38	-1.5 (0.7)	37	-2.1 (1.0)	17	-3.0 (0.8)	20	-1.5 (0.6)	0.285	0.936	0.808
Stature (cm)	66	141.6 (7.2)	28	140.8 (6.3)	38	142.1 (7.8)	37	141.9 (5.5)	17	140.9 (5.1)	20	142.8 (5.8)	0.952	0.759	0.807
Mass (kg)	66	36.4 (7.9)	28	34.9 (6.5)	38	37.5 (8.8)	37	41.6 (10.4)	17	41.3 (11.3)	20	41.6 (9.7)	**0.018**	0.106	**0.006**
BMI ($kg \cdot m^{-2}$)	66	18.1 (3.3)	28	17.5 (2.3)	38	18.5 (3.9)	37	19.0 (4.5)	17	20.7 (4.6)	20	20.4 (4.5)	**0.015**	0.103	**0.005**
Cardiorespiratory fitness															
$\dot{V}O_{2peak}$ ($mL \cdot min^{-1}$)	57	1645.8 (307.5)	26	1736.9 (259.3)	31	1569.5 (327.5)	37	1680.5 (311.5)	17	1736.2 (330.0)	20	1633.1 (295.0)	0.994	0.485	0.597
$\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	57	47.1 (7.1)	26	50.5 (6.9)	31	44.2 (5.8)	37	41.7 (7.6)	17	43.3 (9.1)	20	40.4 (6.0)	**0.005**	**0.028**	**0.001**
$\dot{V}O_{2peak}$ ($mL \cdot kg^{-0.53} \cdot min^{-1}$)	57	252.6 (36.7)	26	269.6 (30.7)	31	238.5 (35.6)	37	238.9 (34.5)	17	248.0 (39.5)	20	231.1 (28.4)	0.051	0.442	0.071

Table continued below.

Respiratory measures															
FEV_1 (%)	66	83.3 (16.7)	28	85.7 (16.9)	38	81.5 (16.6)	37	85.9 (20.9)	17	84.2 (15.6)	20	80.9 (20.5)	0.775	0.906	0.814
FVC (%)	66	90.8 (18.9)	28	91.0 (21.5)	38	90.6 (17.0)	37	84.5 (20.0)	17	86.7 (21.4)	20	85.2 (21.1)	0.516	0.293	0.227
PEF (%)	66	76.1 (22.7)	28	73.9 (23.1)	38	77.8 (22.5)	37	73.9 (17.7)	17	71.6 (14.2)	20	75.9 (20.4)	0.720	0.749	0.609
FEV_1/FVC	66	88.3 (11.7)	28	88.5 (12.5)	38	88.1 (11.2)	37	92.0 (9.3)	17	91.2 (8.9)	20	92.4 (10.2)	0.370	0.160	0.078
FeNO (ppb)	64	21.9 (22.7)	27	22.0 (22.7)	37	21.8 (23.0)	38	20.0 (24.6)	18	25.7 (33.9)	20	14.6 (9.3)	0.919	0.550	0.782
Children's survey															
Physical activity	66	3.7 (0.7)	28	3.8 (0.6)	38	3.5 (0.7)	37	3.6 (0.7)	18	3.7 (0.7)	19	3.5 (0.8)	0.400	0.912	0.604
Physical activity enjoyment	66	4.1 (0.8)	28	4.1 (0.6)	38	4.1 (0.9)	37	4.2 (0.8)	18	4.3 (0.6)	19	4.0 (0.5)	0.414	0.756	0.755
SHS exposure															
eCO (ppm)	63	1.7 (1.1)	26	1.7 (1.4)	36	1.6 (0.9)	37	2.0 (1.3)	17	1.7 (0.9)	20	2.2 (1.6)	0.832	0.200	0.215
Cigarettes per day	66	0	28	0	38	0	38	15.2 (13.2)	18	16.1 (13.7)	20	14.3 (13.1)	NA	NA	NA
Deprivation															
Median EIMD rank (IQR)	66	1907 (4625)	28	1808 (4584)	38	2348 (4861)	38	1642 (1637)	18	812 (1792)	20	907 (1632)	0.088	**0.044**	**0.008**

Spirometry values expressed as percentage of predicted values for sex, age, ethnicity, and height: FEV_1 = forced expiratory volume in 1 second, FVC = forced vital capacity, PEF = peak expiratory flow, FeNO = fractional exhaled nitric oxide, eCO = exhaled carbon monoxide, EIMD = English indices of multiple deprivation. Physical activity and enjoyment are scored between 1 and 5, with 5 being the most active and most enjoyment. Values which are statistically significant are highlighted in **bold**.

3.3.2.2. Smoking and Socioeconomic Status

Mean logEIMD was statistically higher in non-smoking households (t (102) = 2.7, p = 0.008) indicating an association between deprivation and smoking. The percentage of smoking households decreases as parental educational attainment increases, however a slight increase can be seen at 'Masters or above'. Chi-squared analysis showed the association to be almost significant at the 0.05 level (p = 0.058). Correlation analysis showed a weak statistically significant negative correlation between the square root transformed number of cigarettes smoked per day (sqrt-cigarettes) and educational attainment level (Spearman's rho r = -0.283, p = 0.006) and sqrt-cigarettes and logEIMD (Pearson r = -0.204, p = 0.038).

3.3.2.3. Household Smoking and Weight Status

Mean BMI was significantly different for boys (t (43) -3.1, p = 0.015) but not girls (t (56) = -1.7, p = 0.103) from smoking and non-smoking households (Table 3.3). The proportion of children classed as overweight or obese varied between smoking status groups, with children from non-smoking households most likely to have a healthy BMI. The proportion of children from smoking households who were overweight or obese was more than double (54.1%) that of non-smoking households, which was found to be statistically significant (Chi-Square (1) = 9.3, p = 0.002). There was a weak but significant positive correlation between sqrt-cigarettes and BMI (r = 0.225, p – 0.023), which was not significant when split by sex (r = 0.276, p = 0.067 for boys, r = 0.194, p = 0.145 for girls).

Table 3.4. Correlation (Pearson) matrix for all major variables. Statistically significant correlations highlighted in **bold.**

	SS	Cigs	$\dot{V}O_2$	$R\dot{V}O_2$	$A\dot{V}O_2$	PA	PAE	eCO	FeNO	FEV_1	FVC	PEF	FER	Age	Sex	Stat	Mass	Mat	BMI	IMD
SS	1																			
Cigs	**.909**	1																		
$\dot{V}O_2$	.055	.006	1																	
$R\dot{V}O_2$	**-.343**	**-.306**	**.267**	1																
$A\dot{V}O_2$	-.187	-.189	**.781**	**.804**	1															
PA	-.052	.003	.089	**.305**	**.269**	1														
PAE	.031	.046	.146	**.244**	**.242**	**.287**	1													
eCO	.125	.157	.126	-.031	.062	-.006	-.019	1												
FeNO	-.028	-.061	.127	**.244**	**.228**	.001	.079	-.155	1											
FEV_1	-.023	-0.17	-.097	.076	-.024	.001	.006	-.163	.078	1										
FVC	-.120	-.115	-.019	.070	.025	.056	.002	-.124	.023	**.800**	1									
PEF	-.051	-.067	-.011	.080	.037	.020	.120	**-.302**	.159	**.498**	**.265**	1								
FER	.163	.168	.013	.002	.006	**-.218**	-.075	.054	.124	**.214**	**-.306**	**.344**	1							
Age	.034	.060	**.317**	.066	**.239**	-.173	**.211**	.100	.105	-.171	-.161	-.068	.109	1						
Sex	-.048	-.064	**-.231**	**-.322**	**-.351**	-.163	-.082	.058	-.102	-.112	-.016	.098	-.004	.024	1					
Stat	.024	.009	**.493**	-.176	**.206**	**-.205**	.058	.001	.087	-.137	-.018	-.145	.012	**.461**	.113	1				
Mass	**.271**	**.201**	**.579**	**-.602**	-.046	**-.234**	-.073	.080	-.063	-.070	-.037	-.055	.059	**.196**	.081	**.495**	1			
Mat	.024	-.032	.097	**-.334**	-.158	**-.204**	.013	-.015	-.090	-.149	-.049	.060	.057	**.308**	**.787**	**.436**	**.379**	1		
BMI	**.298**	**.225**	**.461**	**-.609**	-.128	-.176	-.109	.101	-.102	-.040	-.049	-.005	.062	.029	.053	.150	**.930**	**.252**	1	
IMD	**-.260**	**-.204**	-.078	**.265**	.115	.078	-.026	-.137	.026	**.353**	**.352**	.135	-.021	-.015	-.004	**-.046**	**-.246**	-.051	**-.271**	1

SS = household smoking status, cigs = square route (number of cigarettes smoked per day), $\dot{V}O_2$ = absolute $\dot{V}O_{2peak}$ ($mL \cdot min^{-1}$), $R\dot{V}O_2$ = ratio scaled $\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$), $A\dot{V}O_2$ = allometrically scaled $\dot{V}O_{2peak}$ ($mL \cdot kg^{-0.53} \cdot min^{-1}$), PA = physical activity (PAQ-C), PAE = physical activity enjoyment (PACES), eCO = exhaled carbon monoxide (ppm), FeNO = log (fractional exhaled nitric oxide) (ppb), FEV_1 = forced expiratory volume in 1 second (% of predicted), FVC = forced vital capacity (% of predicted), PEF = peak expiratory flow (% of predicted), FER = forced expiratory ratio (FEV_1/FVC), age = decimal age (years), sex = boy (1) or girl (2), stat = stature (cm), mass = mass (kg), BMI = body mass index ($kg \cdot m^{-2}$), IMD = log (English indices for multiple deprivation).

3.3.3. Carbon Monoxide as a Measure of Second-Hand Tobacco Smoke Exposure

Exhaled carbon monoxide (eCO) had a range of 7 ppm, with a low value of 0 ppm (below the detection limit). Mean eCO was 1.8 ppm and this was not significantly different between boys and girls (t (98) = -0.6, *p* -= 0.570).

Although the mean eCO was higher for children from smoking households by 17.6% (Table 3.3), the finding was not significantly significant (t (98) = -2.3, *p* = 0.214). Exhaled CO was not correlated with the square-root transformed number of cigarettes smoked per day (r = 0.157, *p* = 0.119). The concentration of eCO was highest for children from homes where smoking was permitted inside, followed by outside, then no smoking (Figure 3.6), but the finding was not statistically significant (ANOVA (2,97) = 2.3, *p* = 0.104).

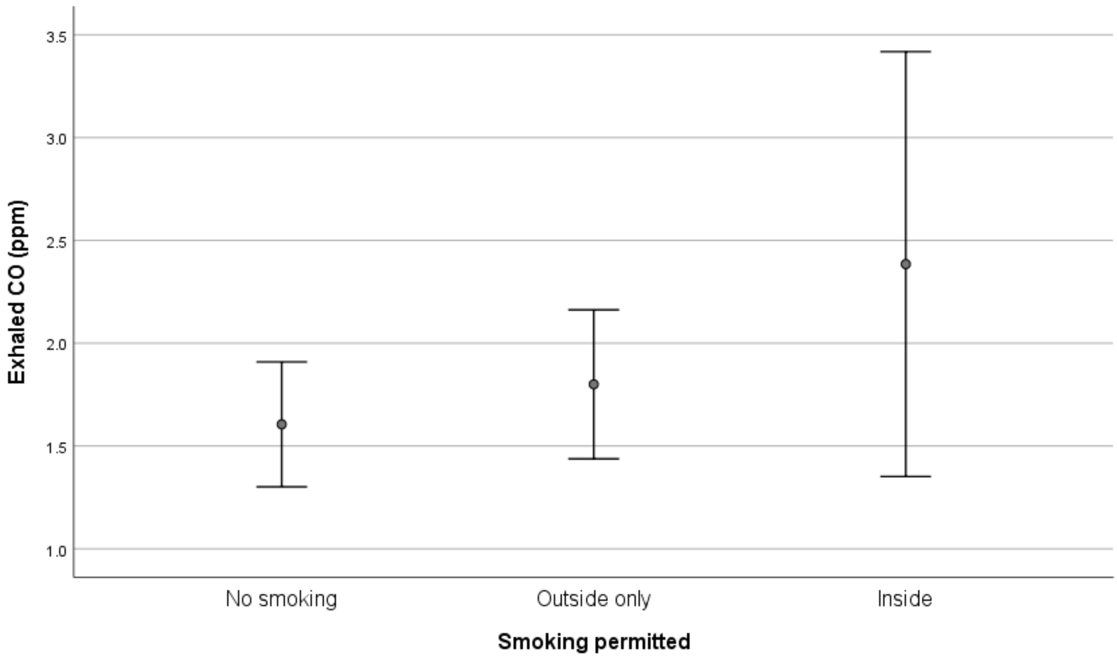


Figure 3.6. Mean exhaled CO (ppm) with 95% confidence per where smoking is permitted.

3.3.4. RQ1. Is second-hand tobacco smoke exposure associated with children's cardiorespiratory fitness?

3.3.4.1. Cardiorespiratory Fitness

Cardiorespiratory fitness is presented as absolute $\dot{V}O_{2peak}$ (mL·min^{-1}), $\dot{V}O_{2peak}$ ratio scaled for mass (mL·kg^{-1}·min^{-1}) and allometrically scaled $\dot{V}O_{2peak}$ (mL·kg$^{-0.53}$·min^{-1}) in Tables 3.1 – 3.3. Boys were found to have significantly higher absolute $\dot{V}O_{2peak}$ (t (92) = 2.3, p = 0.025), ratio scaled $\dot{V}O_{2peak}$ (t (75) = 3.2, p = 0.002), and allometrically scaled $\dot{V}O_{2peak}$ (t (92) = 3.6, p = 0.001) than girls.

Participants could be classified as fit or unfit according to established thresholds (Lang et al., 2019) based on ratio scaled $\dot{V}O_{2peak}$ (mL·kg^{-1}·min^{-1}). Using the CRF thresholds of 42 mL·kg^{-1}·min^{-1} for boys, and 35 mL·kg^{-1}·min^{-1} for girls, 83.0% of participants were classified as fit, including 86.3% of girls and 79.1% of boys, which was not statistically different, Chi-square (1) 2.3, p = 0.354.

A number of biological, demographic, and behavioural variables were significantly correlated with the three measures of CRF, which are summarised in Table 3.4. Age, sex, stature, mass, and BMI were significantly correlated with absolute $\dot{V}O_{2peak}$. Sex, mass, maturation, BMI, logFeNO, logEIMD, PA, PACES, household smoking status, and sqrt-cigarettes were significantly correlated with ratio scaled $\dot{V}O_{2peak}$. Allometrically scaled $\dot{V}O_{2peak}$ was significantly correlated with age, sex, stature, logFeNO, PA, and PACES. Of note, mass was moderately and positively correlated with absolute $\dot{V}O_{2peak}$ but moderately and negatively correlated with ratio scaled $\dot{V}O_{2peak}$, and not correlated with allometrically scaled $\dot{V}O_{2peak}$.

3.3.4.2. Cardiorespiratory Fitness and Second-hand Smoke Exposure

As shown in Table 3.8, absolute $\dot{V}O_{2peak}$ was not found to be significantly different between children of non-smoking and smoking households (t (92) = -0.5, *p* = 0.597), or when boys (t (41) = 0.01, *p* = 0.994) and girls (t (49) = -0.7, *p* = 0.485) were analysed separately. Ratio scaled $\dot{V}O_{2peak}$ was significantly different between children from smoking and non-smoking homes (t (92) = 3.5, *p* = 0.001), and for boys (t (41) = 3.0, *p* = 0.005) and girls (t (49) = 2.3, *p* = 0.028) separately. Allometrically scaled $\dot{V}O_{2peak}$ was not statistically different between household smoking status (t (92) = 1.8, *p* = 0.071), but was almost statistically significant for boys (t (41) = 2.0, *p* = 0.051), but not for girls (t (49) = 0.8, *p* = 0.442).

Absolute and allometrically scaled $\dot{V}O_{2peak}$ were not significantly correlated with sqrt-cigarettes whereas ratio scaled $\dot{V}O_{2peak}$ was moderately and negatively correlated (Table 3.4). When split by sex, ratio scaled and allometrically scaled $\dot{V}O_{2peak}$ were moderately and negatively correlated with sqrt-cigarettes for boys (r = -0.357, *p* = 0.019 and r = -0.0.319, *p* = 0.037, respectively), but absolute $\dot{V}O_{2peak}$ was not (r = 0.-0.117, *p* = 0.455). For girls, ratio scaled $\dot{V}O_{2peak}$ was weakly-moderately negatively correlated with sqrt-cigarettes (-0.297, *p* = 0.035) but absolute and allometrically scaled $\dot{V}O_{2peak}$ were not (r = 0.097, *p* = 0.500, r = -0.099, *p* = 0.488, respectively). When participants from non-smoking household households were excluded, no significant correlations were observed between sqrt-cigarettes and any CRF measures. Scatterplots demonstrating correlations between CRF and sqrt-cigarettes (for smoking households only) are presented (Figure 3.7).

The number of children classified as fit according to established thresholds was significantly different between SHS exposure groups (Chi-square (1) = 7.0, *p* = 0.008), with 91.2% and 70.3% of children from non-smoking and smoking homes, respectively, classified as fit. When split by sex, the difference remained significant for boys, of which 92.3% and 41.2% of boys from non-smoking and smoking households, respectively, were classified as fit (Chi-square (1) = 7.0, *p* = 0.008). For girls from non-smoking and smoking homes, 90.3% and 80.0% respectively, were classified as fit but the difference was not significant (Chi-square (1) = 1.1, *p* = 0.296).

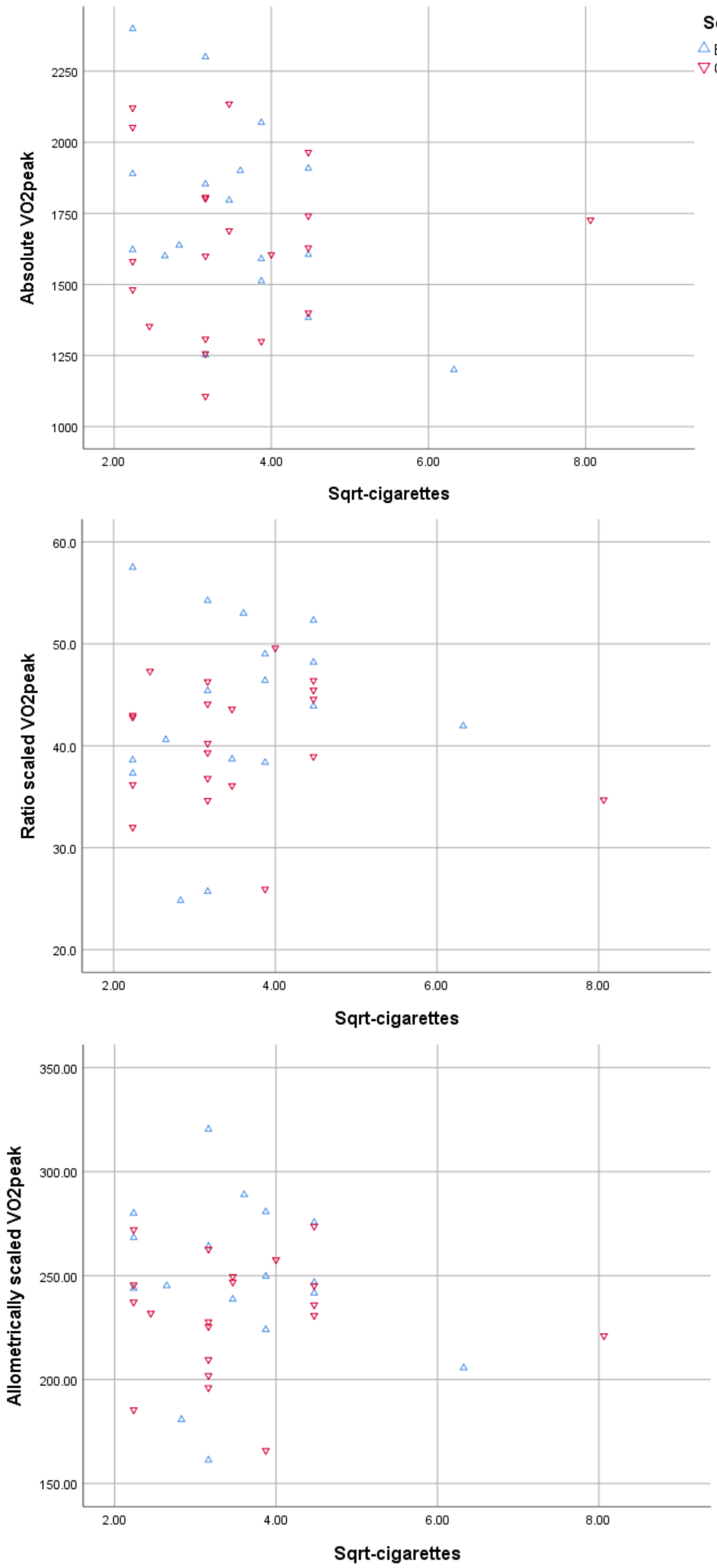


Figure 3.7. Square route transformed number of cigarettes smoked per day (sqrt-cigarettes) and three cardiorespiratory fitness measures for boys (upward pointing blue triangle) and girls (downward pointing red triangle). Top: absolute $\dot{V}O_{2peak}$ (mL·min^{-1}); middle: ratio scaled $\dot{V}O_{2peak}$ (mL·kg^{-1}·min^{-1}); bottom: allometrically scaled $\dot{V}O_{2peak}$ (mL·kg$^{-0.53}$·min^{-1}). Excludes participants from non-smoking homes.

Mean CRF was compared for where smoking was permitted including inside and outside the home (Table 3.5). No significant differences in absolute and allometrically scaled fitness were observed between exposure groups, but mean ratio scaled $\dot{V}O_{2peak}$ was significantly different between groups (ANOVA (2,91) = 5.5, p = 0.005). A Tukey post hoc test showed significant differences between the 'no smoking' group and both 'inside' and 'outside' groups (p = 0.015 and 0.041, respectively), but the 'inside' and 'outside' groups were not statistically different (p = 0.665). When split by sex, significant differences were observed between mean ratio scaled $\dot{V}O_{2peak}$ and where smoking is permitted for boys (ANOVA (2,40) = 4.8, p = 0.013) but not girls, which indicated significant differences between the 'outside' and 'no smoking' groups. However, when split by where smoking is permitted, and sex, groups sizes become as small as n=7.

Table 3.5. Mean (standard deviation) fitness for three measures of fitness, for where smoking is permitted around the home, and split by sex.

	No smoking			**Outside only**			**Inside**		
	Both	**Boys**	**Girls**	**Both**	**Boys**	**Girls**	**Both**	**Boys**	**Girls**
N	51	24	27	29	12	17	14	7	7
Absolute $\dot{V}O_{2peak}$	1648.7 (317.2)	1741.4 (262.9)	1566.3 (342.6)	1680.8 (271.9)	1715.4 (299.2)	1654.7 (257.3)	1656.6 (361.2)	1756.9 (374.0)	1556.4 (345.5)
Ratio scaled $\dot{V}O_{2peak}$	47.2* (7.4)	51.0 † (7.0)	43.9 (6.1)	43.0* (6.7)	43.5† (8.3)	42.6 (5.4)	40.9* (8.6)	43.4† (9.9)	38.5 (6.8)
Allometrically scaled $\dot{V}O_{2peak}$	253.1 (38.3)	271.2 (31.4)	237.1 (37.1)	242.8 (27.3)	247.3 (29.9)	239.6 (25.6)	234.8 (42.9)	249.6 (50.4)	220.0 (30.5)

*Statistically significant difference between groups when boys and girls analysed together (ANOVA).
†Statistically significant difference between groups for boys only (ANOVA).
Units: absolute $\dot{V}O_{2peak}$ ($mL\cdot min^{-1}$), ratio scaled $\dot{V}O_{2peak}$ ($mL\cdot kg^{-1}\cdot min^{-1}$),
allometrically scaled $\dot{V}O_{2peak}$ ($mL\cdot kg^{-0.53}\cdot min^{-1}$)

3.3.4.3 Linear Regression for Cardiorespiratory Fitness

i) Absolute $\dot{V}O_{2peak}$

A multiple regression was run to predict absolute $\dot{V}O_{2peak}$ (mL·min^{-1}) from the number of cigarettes smoked per day (sqrt-cigarettes), sex, age, mass, stature, maturation, PA, and logEIMD. See Table 3.6 for the full details of the unadjusted and adjusted models for absolute $\dot{V}O_{2peak}$. Sqrt-cigarettes was not a significant predictor in the unadjusted model (R^2 = 0.001, $F(1,87)$ = 0.1, p = 0.741; adjusted R^2 = -0.01). In the adjusted model, sex, mass, stature, and PA were significant predictors whereas sqrt-cigarettes, age, maturation, and logEIMD were not. Overall, the adjusted model significantly predicted absolute $\dot{V}O_{2peak}$, and had a high R^2 value, accounting for 70.0% of the variance (R^2 = 0.728, $F(8,80)$ = 26.7, $p < 0.001$; adjusted R^2 = 0.700), although sqrt-cigarettes was not a significant predictor (p = 0.090) at the 0.05 level.

Table 3.6. Linear regression for absolute $\dot{V}O_{2peak}$ (mL·min^{-1}).

Predictor	Unstandardised coefficient (B)	95% Confidence interval		Standard error of B	Significance
		Lower bound	Upper bound		
Model 1 R^2 = 0.001, p = 0.741, F = 0.1					
Constant	1661.3	1580.8	1741.9	40.5	**<0.001**
Sqrt-cigarettes	5.8	-29.2	40.8	17.6	0.741
Model 2 R^2 = 0.728, p **< 0.001**, F = 26.7					
Constant	-964.2	-2218.3	289.9	630.2	0.130
Sqrt-cigarettes	-17.4	-37.5	2.8	10.1	0.091
Sex	-322.4	-465.0	-179.7	71.7	**<0.001**
Decimal age (yrs)	13.8	-57.7	85.4	36.0	0.701
Mass (kg)	23.3	17.7	28.8	2.8	**<0.001**
Stature (cm)	11.0	3.8	18.2	3.6	**0.003**
Maturation	69.1	-8.0	146.1	38.7	0.078
PA	75.6	21.2	130.1	27.4	**0.007**
LogEIMD	47.4	-15.7	110.5	31.7	0.139

ii) Allometrically Scaled $\dot{V}O_{2peak}$

A multiple regression was run to predict allometrically scaled $\dot{V}O_{2peak}$ (mL·kg$^{-0.53}$·min^{-1}) from the number of cigarettes smoked per day (sqrt-cigarettes), sex, age, stature, maturation, PA, and logEIMD. See Table 3.7 for the full details of the unadjusted and adjusted models for allometrically scaled $\dot{V}O_{2peak}$. Sqrt-cigarettes was not a significant predictor in the unadjusted model (R^2 = 0.036, F(1,91) = 3.4, p = 0.068; adjusted R^2 = 0.025). In the adjusted model sqrt-cigarettes, sex, age, stature, and PA were significant predictors whereas maturation and logEIMD were not. Overall, the adjusted model significantly predicted allometrically scaled $\dot{V}O_{2peak}$ (R^2 = 0.352, F(7,85) = 6.6, p < 0.001; adjusted R^2 = 0.299), with a moderate R^2, explaining 29.9% of the variance.

Table 3.7. Linear regression for allometrically scaled $\dot{V}O_{2peak}$ (mL·kg$^{-0.53}$·min^{-1}).

Predictor	**Unstandardised coefficient (B)**	**95% Confidence interval**		**Standard error of B**	**Significance**
		Lower bound	**Upper bound**		
Model 1 R^2 = 0.036, p = 0.068, F = 3.4					
Constant	252.3	243.1	261.5	4.6	**<0.001**
Sqrt-cigarettes	-3.7	-7.6	0.3	2.0	0.068
Model 2 R^2 = 0.352, p **< 0.001**, F = 6.6					
Constant	-113.7	-331.9	104.5	109.7	0.303
Sqrt-cigarettes	-3.8	-7.3	-0.4	1.7	**0.030**
Sex	-26.2	-49.0	-3.4	11.5	**0.025**
Decimal age (yrs)	12.2	0.4	23.9	5.9	**0.042**
Stature (cm)	1.3	0.1	2.5	0.6	**0.036**
Maturation	0.1	-12.4	12.4	6.2	0.998
PA	15.4	6.0	24.8	4.7	**0.002**
LogEIMD	5.2	-5.7	16.0	5.5	0.347

3.3.5. RQ2. Do levels of physical activity and physical activity enjoyment differ between children from smoking and non-smoking households?

3.3.5.1. Physical Activity and Physical Activity Enjoyment

The mean level of self-reported physical activity (PA) and physical activity enjoyment (PACES) are presented in Tables 3.1 – 3.3. No significant differences were observed between boys and girls for PA or PACES (t (101) = 1.7, *p* = 0.099, and t (101) = 0.8, *p* = 0.411 respectively). Using a threshold score of 2.73 to classify children as active (Benítez-Porres et al., 2016), 87.4% of children in the sample were classified as physically active. When split by sex, 95.7% of boys, and 80.7% of girls, were classified as physically active which was statistically significant (Chi-square (1) = 5.2, *p* = 0.023).

PA and PACES showed weak-moderate positive correlation which was statistically significant (r = .287, *p* = 0.003). When split by sex, the correlation was moderate and remained significant for boys (r = 0.337, *p* = 0.022), but was not significant for girls (r = 0.242, *p* = 0.070).

Stature, mass, and maturation (negatively), and PA enjoyment, ratio scaled $\dot{V}O_{2peak}$ and allometrically scaled $\dot{V}O_{2peak}$ (positively) were correlated with PA. Age, ratio scaled $\dot{V}O_{2peak}$, allometrically scaled $\dot{V}O_{2peak}$, and PA were positively correlated with PA enjoyment (Table 3.4). For children from smoking homes only, mass (r = -0.333, *p* = 0.047) and BMI (r = -0.341, *p* = 0.041) were negatively correlated with PA enjoyment.

3.3.5.2. Physical Activity, Physical Activity Enjoyment, and Household Smoking

Mean PA and PACES (Table 3.3) were not significantly different between children of non-smoking and smoking households (t (101) = 0.5, *p* = 0.604, and t (101) = -0.3, *p* = 0.755 for PA and PACES respectively). The proportion of children classified as physically active was 87.0% for children from non-smoking homes, and 86.4% for children from smoking homes, which was not statistically significant (chi-square (1) = 0.04, *p* = 0.838). PA and PACES were also not significantly correlated with any smoking exposure measures including sqrt-cigarettes and eCO (Table 3.4). PA and PACES were not significantly different between groups of where smoking is permitted in and around the home (PA: ANOVA (2,100) = 0.7, *p* = 0.517; PACES: ANOVA (2,100) = 0.4, *p* = 0.695).

3.3.5.3. Linear regression for Physical Activity

A multiple regression was run to predict physical activity from the number of cigarettes smoked per day (sqrt-cigarettes), sex, age, BMI, maturation, logEIMD, and PA enjoyment. See Table 3.8 for the full details of the unadjusted and adjusted models. Sqrt-cigarettes was not a significant predictor in the unadjusted model ($R^2 < 0.001$, $F(1,100) = 0.05$, $p = 0.826$; adjusted $R^2 = -0.010$). None of the predictors were significant in the partially adjusted model, which was not significant overall. In the fully adjusted model, age and PA enjoyment were significant predictors whereas sqrt-cigarettes, sex, BMI, maturation, and logEIMD were not. Overall, the fully adjusted model significantly predicted PA ($R^2 = 0.180$, $F(6,95) = 3.5$, $p = 0.004$; adjusted $R^2 = 0.128$), although only 12.% of the variation in PA is explained by the model.

Table 3.8. Linear regression for self-reported physical activity (PAQ-C).

Predictor	**Unstandardised coefficient (B)**	**95% CI Lower bound**	**Upper bound**	**Standard error of B**	**Significance**
Model 1 $R^2 < 0.001$, $p = 0.826$, $F = 0.05$					
Constant	3.64	3.47	3.81	0.08	**<0.001**
Sqrt-cigarettes	0.01	-0.07	0.08	0.04	0.826
Model 2 $R^2 = 0.089$, $p = 0.104$, $F = 1.9$					
Constant	6.54	3.05	10.03	1.76	**<0.001**
Sqrt-cigarettes	0.03	-0.05	0.11	0.04	0.456
Sex	-0.29	-0.80	0.21	0.25	0.255
Decimal age (yrs)	-0.21	-0.47	0.04	0.13	0.100
BMI (kg·m^{-2})	-0.03	-0.07	0.01	0.02	0.104
Maturation	0.05	-0.22	0.31	0.13	0.732
LogEIMD	0.04	-0.20	0.28	0.12	0.751
Model 3 $R^2 = 0.180$, $p =$ **0.004**, $F = 3.5$					
Constant	5.49	2.10	8.88	1.71	**0.002**
Sqrt-cigarettes	0.02	-0.05	0.10	0.04	0.547
Sex	-0.20	-0.69	0.29	0.25	0.418
Decimal age (yrs)	-0.27	-0.52	-0.03	0.12	**0.031**
BMI (kg·m^{-2})	-0.02	-0.06	0.02	0.02	0.234
Maturation	0.01	-0.24	0.26	0.13	0.939
LogEIMD	0.06	-0.17	0.29	0.12	0.626
PACES	0.31	0.12	0.50	0.10	**0.002**

3.3.5.4. Linear regression for Physical Activity Enjoyment

A multiple regression was run to predict physical activity enjoyment from the number of cigarettes smoked per day (sqrt-cigarettes), sex, age, BMI, maturation, logEIMD, and PA. See Table 3.9 for the full details of the unadjusted and adjusted models. Sqrt-cigarettes was not a significant predictor in the unadjusted model (R^2 = 0.001, $F(1,97)$ = 0.09, p = 0.761; adjusted R^2 = -0.009). The partially adjusted model was not significant and none of the predictors were significant. In the fully adjusted model, only PA was a significant predictor whereas sqrt-cigarettes, sex, age, BMI, maturation, and logEIMD were not. Overall, the fully adjusted model significantly predicted PA enjoyment (R^2 = 0.151, $F(7,91)$ = 2.3, p = 0.032; adjusted R^2 = 0.086), although the model only explained 8.6% of the variance in PA enjoyment.

Table 3.9. Linear regression for self-reported physical activity enjoyment (PACES).

Predictor	**Unstandardised coefficient (B)**	**95% CI Lower bound**	**Upper bound**	**Standard error of B**	**Significance**
Model 1 R^2 = 0.001, p = 0.761, F = 0.09					
Constant	4.21	4.07	4.35	0.07	<0.001
Sqrt-cigarettes	-0.01	-0.07	0.05	0.03	0.761
Model 2 R^2 = 0.033, p = 0788, F = 0.5					
Constant	3.41	0.37	6.45	1.53	0.028
Sqrt-cigarettes	-0.01	-0.07	0.06	0.03	0.870
Sex	0.04	-0.41	0.49	0.23	0.861
Age age (yrs)	0.12	-0.10	0.35	0.11	0.274
BMI (kg·m^{-2})	-0.02	-0.05	0.02	0.02	0.266
Maturation	-0.02	-0.25	0.21	0.12	0.875
LogEIMD	-0.05	-0.26	0.16	0.11	0.652
Model 3 R^2 = 0.151, p = **0.032**, F = 2.3					
Constant	1.59	-1.45	4.63	1.53	0.301
Sqrt-cigarettes	-0.01	-0.08	0.05	0.03	0.662
Sex	0.13	-0.30	0.55	0.21	0.560
Age age (yrs)	0.18	-0.03	0.39	0.11	0.099
BMI (kg·m^{-2})	-0.01	-0.04	0.02	0.02	0.532
Maturation	-0.03	-0.25	0.19	0.11	0.775
LogEIMD	-0.07	-0.27	0.13	0.10	0.465
PA	0.30	0.13	0.47	0.09	**0.001**

3.3.6. RQ3. Is second-hand tobacco smoke exposure associated with respiratory indicators in children?

3.3.6.1. Spirometry

Spirometry values were compared against predicted for sex, age, height, and ethnicity, and are presented as percentages of predicted. The mean spirometry (%) values for the sample are shown in Table 3.1, split by sex in Table 3.2. For all four spirometry measures, mean values were below the predicted values for sex, age, height, and ethnicity (equivocal to 100%) by 10.3 - 24.7%, indicating lower than predicted spirometry across the sample. No significant differences were observed between the mean spirometry values for boys and girls (Table 3.2).

All four spirometry measures were significantly correlated with each other, as shown by the correlational matrix (Table 3.4). Spirometry values were expressed as percentages of predicted for sex, age, height, and ethnicity and therefore were not correlated with any anthropometric variables due to this prior adjustment. FEV_1% and FVC% were moderately and positively correlated with logEIMD.

3.3.6.2. Spirometry and Household Smoking Status

No significant differences were observed for mean spirometry values for household smoking status (Table 3.3), and there were no significant correlations between sqrt-cigarettes and any spirometry measures. However, PEF% was moderately and negatively correlated with eCO ($r = -0.302$, $p = 0.002$).

When spirometry values were compared for where smoking was permitted, significant differences were observed for FER only (Table 3.10). A Tukey post-hoc analysis showed a significant difference between the 'no smoking' and 'outside' groups only ($p = 0.038$).

Table 3.10. Comparison of mean values for four spirometry measures for where smoking is permitted in and around the home.

Spirometry measure	Mean (±SD)			ANOVA (2,100)	Significance *p*
	No smoking	Outside only	Inside		
FEV_1%	83.9 (17.1)	82.0 (20.1)	80.8 (10.8)	0.2	0.782
FVC%	92.1 (18.7)	84.7 (22.6)	84.7 (15.7)	1.8	0.172
PEF%	75.8 (22.3)	78.7 (20.6)	66.1 (12.6)	1.8	0.176
FER	87.8 (8.1)	93.7 (8.1)	89.0 (11.0)	3.1	**0.049**

3.3.6.3. Linear Regressions for Lung Function

A number of multiple regressions were run to predict FEV1%, FVC%, PER%, and FER from the number of cigarettes smoked per day (sqrt-cigarettes), mass, diagnosed asthma, and logEIMD. See Table 3.11 – 3.14 for the full details of the unadjusted and adjusted models for each spirometry measure.

For FEV_1%, sqrt-cigarettes was not a significant predictor in the unadjusted model ($R^2 < 0.001$, $F(1,101) = 0.3$, $p = 0.864$; adjusted $R^2 = -0.010$). In the adjusted model, logEIMD was a significant predictor but sqrt-cigarettes, mass, and asthma were not. Overall, the adjusted model significantly predicted FEV_1% ($R^2 = 0.138$, $F(4,100) = 3.9$, $p = 0.005$; adjusted $R^2 = 0.103$), although only 10.3% of the variation is explained by the model.

For FVC%, sqrt-cigarettes was not a significant predictor in the unadjusted model ($R^2 = 0.013$, $F(1,101) = 1.4$, $p = 0.247$; adjusted $R^2 = 0.003$). In the adjusted model, logEIMD was a significant predictor but sqrt-cigarettes, mass, and asthma were not. Overall, the adjusted model significantly predicted FVC% ($R^2 = 0.135$, $F(4,98) = 3.8$, $p = 0.006$; adjusted $R^2 = 0.099$), although only 9.9% of the variance is explained by the model.

For PEF%, sqrt-cigarettes was not a significant predictor in the unadjusted model ($R^2 = 0.002$, $F(1,100) = 0.2$, $p = 0.659$; adjusted $R^2 = -0.008$). In the adjusted model, none of the predictors were statistically significant. Overall, the adjusted model did not significantly predict PEF% ($R^2 = 0.064$, $F(4,97) = 1.7$, $p = 0.166$; adjusted $R^2 = 0.025$).

For FER (FEV_1/FVC) sqrt-cigarettes was not a significant predictor in the unadjusted model ($R^2 = 0.015$, $F(1,99) = 1.5$, $p = 0.227$; adjusted $R^2 = 0.005$). In the adjusted model, none of the predictors were statistically significant. Overall, the adjusted model did not significantly predict FER ($R^2 = 0.030$, $F(4,96) = 0.7$, $p = 0.561$; adjusted $R^2 = -0.010$).

Table 3.11. Linear regressions for spirometry measure FEV1%.

	Unstandardised coefficient (B)	95% Confidence interval		Standard error of B	Significance
		Lower bound	Upper bound		
Model 1 $R^2 < 0.001$, $p = 0.864$, $F = 0.03$					
Constant	83.2	79.0	87.3	2.1	**<0.001**
Sqrt-cigarettes	-0.2	-2.0	1.7	0.9	0.864
Model 2 $R^2 = 0.138$, $p =$ **0.005**, F = 3.9					
Constant	48.1	23.0	73.3	12.7	**<0.001**
Sqrt-cigarettes	0.4	-1.4	2.2	0.9	0.660
Mass (kg)	0.0	-0.4	0.4	0.2	0.964
Asthma	6.6	-4.7	17.9	5.7	0.250
LogEIMD	10.6	5.0	16.2	2.8	**<0.001**

Table 3.12. Linear regressions for spirometry measure FVC%.

	Unstandardised coefficient (B)	95% Confidence interval		Standard error of B	Significance
		Lower bound	Upper bound		
Model 1 $R^2 = 0.013$, $p = 0.247$, $F = 1.4$					
Constant	90.6	85.9	95.3	2.4	**<0.001**
Sqrt-cigarettes	-1.2	-3.3	0.9	1.1	0.247
Model 2 $R^2 = 0.135$, $p =$ **0.006**, F = 3.8					
Constant	47.2	18.4	76.0	14.5	0.002
Sqrt-cigarettes	-0.7	-2.8	1.3	1.0	0.494
Mass (kg)	0.1	-0.3	0.5	0.2	0.542
Asthma	4.6	-8.4	17.5	6.5	0.486
LogEIMD	11.8	5.4	18.2	3.2	**<0.001**

Table 3.13. Linear regressions for spirometry measure PEF%.

	Unstandardised coefficient (B)	95% Confidence interval		Standard error of B	Significance
		Lower bound	Upper bound		
Model 1 $R^2 = 0.002$, $p = 0.659$, $F = 0.2$					
Constant	75.4	70.6	80.2	2.4	**<0.001**
Sqrt-cigarettes	-0.6	-2.7	1.6	1.1	0.608
Model 2 $R^2 = 0.064$, $p = 0.166$, F = 1.7					
Constant	66.8	37.1	96.5	15.0	**<0.001**
Sqrt-cigarettes	0.0	-2.2	2.1	1.1	0.965
Mass (kg)	-0.2	-0.6	0.2	0.2	0.352
Asthma	12.4	-1.0	25.7	6.7	0.070
LogEIMD	4.6	-2.0	11.2	3.3	0.171

Table 3.14. Linear regressions for spirometry measure FER.

	Unstandardised coefficient (B)	95% Confidence interval		Standard error of B	Significance
		Lower bound	Upper bound		
Model 1 $R^2 = 0.015$, $p = 0.227$, $F = 1.5$					
Constant	89.5	87.0	91.8	1.2	**<0.001**
Sqrt-cigarettes	0.6	-0.4	1.7	0.5	0.227
Model 2 $R^2 = 0.030$, $p = 0.561$, F = 0.7					
Constant	81.3	66.0	96.7	7.7	**<0.001**
Sqrt-cigarettes	0.7	-0.4	1.8	0.5	0.204
Mass (kg)	0.1	-0.2	0.3	0.1	0.645
Asthma	-1.5	-8.4	5.3	3.5	0.658
LogEIMD	2.0	-1.5	5.4	1.7	0.260

3.3.6.4. Fractional Exhaled Nitric Oxide

The range for FeNO measurements was high (147 ppb) with a minimum value of <5 ppb (below the detection limit of 5 ppb) and a maximum of 147 ppb. The mean concentrations of FeNO are presented in tables 3.1 to 3.3 and were not statistically different between boys and girls ($t(100) = 0.9$, $p = 0.384$). FeNO levels could be classified as low, intermediate, and high according to established thresholds (Dweik et al., 2011). Most children (70.6%) had low levels (<20 ppb) of FeNO, 13.7% had intermediate levels (20-35 ppb), and 15.7% had high levels (>35 ppb). FeNO concentrations were not significantly different between children with diagnosed asthma (24.4 ± 12.7 ppb, n = 9) and those without asthma (20.9 ± 23.7 ppb), ($t(96) = -0.6$, $p = 0.567$).

LogFeNO was weakly and positively correlated with ratio scaled and allometrically scaled $\dot{V}O_{2peak}$ ($r = 0.244$, $p = 0.021$, $r = 0.228$, $p = 0.031$). When split by sex, the correlations were not significant, except for ratio scaled $\dot{V}O_{2peak}$ in boys ($r = 0.313$, $p = 0.050$). When split by household smoking status, logFeNO was weakly and positively correlated with allometrically scaled $\dot{V}O_{2peak}$ for non-smoking households only ($r = 0.278$, $p = 0.040$). LogFeNO also showed weak, positively correlation with ratio scaled $\dot{V}O_{2peak}$ which was almost significant ($r = 0.260$, $p = 0.055$) for children from non-smoking households. LogFeNO was not correlated with any CRF measure for children from smoking households.

3.3.6.5. Fractional Exhaled Nitric Oxide and Household Smoking

Mean logFeNO was not significantly different between children from smoking and non-smoking households (Table 3.3) and logFeNO was not correlated with the number of cigarettes smoked per day (Table 3.4).

Mean FeNO was lower for children from households where smoking is permitted inside (13.5 ± 12.2 ppb) compared to smoking outside (21.6 ± 26.4 ppb) and no smoking (22.9 ± 23.6 ppb) (Figure 3.8) although the difference was not significant (ANOVA $(2, 95) = 2.0$, $p = 0.135$).

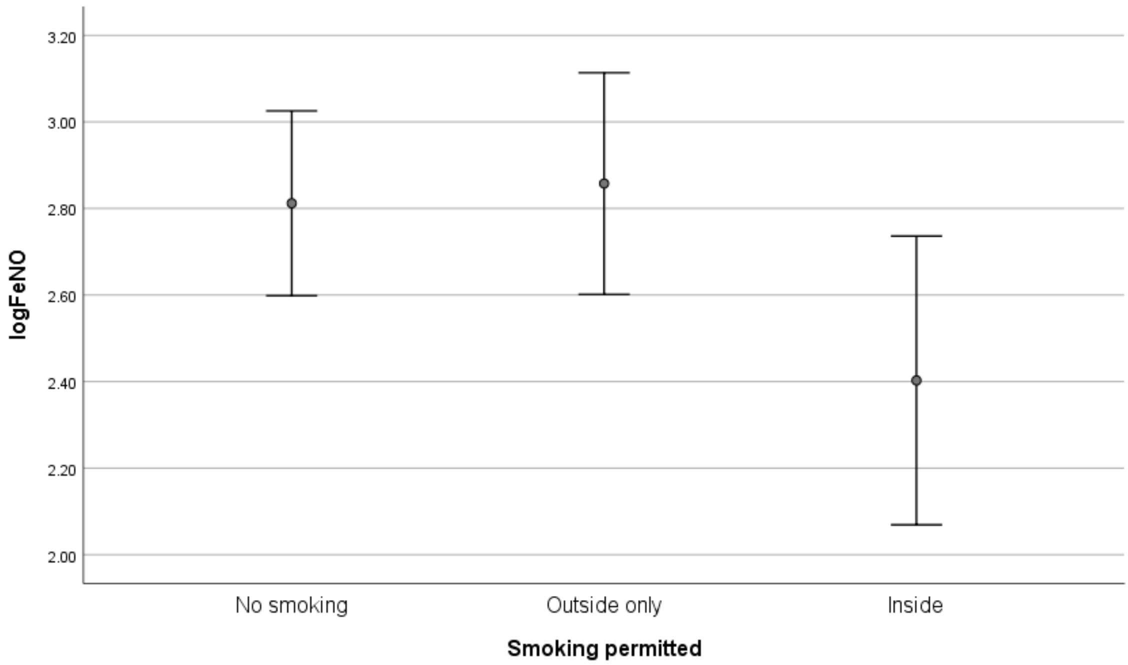


Figure 3.8. Mean logFeNO (natural log transformed FeNO concentration) for where smoking is permitted in and around the home, with 95% confidence intervals.

3.3.6.6. Linear regression for FeNO

A multiple regression was run to predict logFeNO from the number of cigarettes smoked per day (sqrt-cigarettes), sex, age, stature, mass, diagnosed asthma, and logEIMD (see Table 3.15). Sqrt-cigarettes was not a significant predictor in the unadjusted model (R^2 = 0.001, F(1,95) = 0.09, p = 0.760; adjusted R^2 = -0.010). In the adjusted model, no predictors were statistically significant, and the model was not statistically significant overall (R^2 = 0.050, F(7,89) = 0.7, p = 0.701; adjusted R^2 = -0.025).

Table 3.15. Linear regression for logFeNO.

	Unstandardised coefficient (B)	**95% Confidence interval**		**Standard error of B**	**Significance**
		Lower bound	**Upper bound**		
Model 1 R^2 = 0.001, p = 0.760, F = 0.1					
Constant	2.79	2.61	2.97	0.09	**<0.001**
Sqrt-cigarettes	-0.01	-0.09	0.07	0.04	0.760
Model 2 R^2 = 0.050, p = 0.701, F = 0.7					
Constant	0.18	-3.49	3.85	1.85	0.924
Sqrt-cigarettes	-0.01	-0.10	0.08	0.04	0.818
Sex	-0.19	-0.50	0.12	0.16	0.227
Age (years)	0.09	-0.18	0.37	0.14	0.512
Mass (kg)	-0.01	-0.03	0.01	0.01	0.237
Stature (cm)	0.02	-0.01	0.05	0.01	0.272
Asthma	0.20	-0.33	0.73	0.27	0.447
LogEIMD	-0.03	-0.29	0.24	0.13	0.835

3.4. Discussion

The study aimed to examine the associations between second-hand smoke exposure and children's cardiorespiratory fitness, physical activity, physical activity enjoyment, and respiratory health indicators. Results indicate that second-hand smoke exposure, as measured by the number of cigarettes smoked per day by the household, is negatively associated with children's CRF, but no significant associations were observed for PA, PA enjoyment, or respiratory measures.

3.4.1. Household Smoking

3.4.1.1. Household Smoking Overview

Over one third (36.6%) of participants lived with a family member that smoked tobacco, which is significantly less than the findings of McGee et al. (2015) who found 57.3% of children to have a family member that smoked. However, the current study was concerned with smoking individuals that *lived with* the participants, and smoking prevalence has in the UK has declined since 2015 (ONS, 2020). Presently, 14.1% of adults are current smokers nationally (ONS, 2020). Smoking is more common in adults in routine and manual occupations (ONS, 2020), low education status (Laaksonen et al., 2005), and overall low socioeconomic status (Hiscock et al., 2012). Findings of the present study support the association between SES and smoking, as low parental education, and low SES (English Indices of Multiple Deprivation (EIMD)) were significantly associated with household smoking. Salivary cotinine analysis by Jarvis and Feyerabend (2015) has shown 31.5% of children in England to be exposed to SHS, and the level of exposure has been shown to be higher for children from the poorest families (Moore et al., 2012a). The inequality gap that exists for smoking prevalence in England has widened significantly since 2012, with routine and manual workers twice as likely to smoke than other occupations (ONS, 2020). A significant number of children are therefore still exposed to SHS, with the children from the most deprived families at greater risk of exposure and the detrimental effects of SHS.

Although the household smoking survey was based on the well validated Global Adult Tobacco Survey (GATSCG, 2010), the nature of the survey of surveys is that they are subject to both recall bias and desirability bias. Participating parents/guardians were provided with information about the study and therefore were aware of the study aims.

The contentious nature of the research may have led to some smoking parents/guardians to report not smoking or smoking less. The use of exhaled carbon monoxide and cotinine as alternative indicators of recent SHS is discussed below.

3.4.1.2. Household Smoking and Weight Status

Overall, 35% of children were classified as overweight or obese. These findings are in line with the prevalence of Year 6 overweight, including obesity, for the Liverpool (39.5%) and Wirral (34.0%) regions (PHE, 2020). Children from smoking homes were more likely to be overweight or obese and have a greater BMI, with the proportion of children classed as overweight or obese from smoking homes more than double that of children from non-smoking homes. The number of cigarettes smoked per household per day was also significantly and positively correlated with mass, and BMI. There is a dose-response relationship between in-utero exposure to SHS and childhood obesity (Koshy, Delpisheh, Brabin, 2011). Children exposed to SHS prenatally have a higher incidence of low birth weight but rapid postnatal compensatory growth (Harrod et al., 2015) and SHS exposure pre- and post-birth is also associated with overweight and obesity and increased BMI in childhood (Raum et al, 2011; Wang et al., 2014 Giussani et al., 2013). The mechanism by which SHS exposure is associated with overweight and obesity is not fully understood but a possible pathway is through nicotine which acts as a developmental obesogen (Thayer et al., 2012). As well as SHS, mass was significantly and negatively correlated with ratio scaled $\dot{V}O_{2peak}$, and so may be a potential confounder. Welsman & Armstrong (2019b) describe how ratio scaling of $\dot{V}O_{2peak}$ per mass leads to spurious correlations with other health outcomes but a detailed discussion of $\dot{V}O_{2peak}$ scaling is found below in section 3.4.4.

3.4.2. Carbon Monoxide as a Measure of Second-hand Tobacco Smoke Exposure

Exhaled carbon monoxide (eCO) was not found to be significantly different between children from smoking and non-smoking homes, although mean eCO was 17.6% higher for children from smoking homes. Exhaled CO was also not significantly correlated with the number of cigarettes smoked per day. There are a number of explanations for this finding. Firstly, eCO may not be an accurate measure of recent tobacco smoke exposure with children. Exhaled CO is a validated tool for assessing recent smoke exposure (active and passive) in adults (Cropsey et al., 2014; Deveci et al., 2004). However, eCO has been shown to have a very low sensitivity when predicting SHS for children, which may be due to age related ability to perform the breath-test (Dukellis et al., 2009). The test requires children to inhale deeply and hold their breath for 10-15 seconds before exhaling which some children find uncomfortable. With children aged 6-15 years, the average concentration of eCO was less than 1 ppm in the Dukellis study. Likewise, in the present study, many children had an exhaled CO concentration of zero.

As highlighted above, eCO may not be associated with smoking behaviour in the present study due to social desirability and recall bias impacting the results of the smoking survey. In addition, children may become exposed to SHS from non-household individuals, including family friends, or on the journey to school on the day of testing. Knowing the research aims, smoking parents may have refrained from smoking around their child on the day of university visit and eCO test. Children can also become exposed to SHS and other sources of CO from the environment. Other sources of CO exposure include industrial processes, and combustion sources such as gas, coal, and wood stoves and fireplaces, fossil-fuel-burning heaters, and appliances (Raub et al., 2000). The road transport microenvironment is a significant contributor to an individual's CO exposure, with travel by vehicle causing the highest level of CO exposure, compared to walking and cycling (Kaur et al., 2007) with individuals from cities more likely to have increased eCO (Maga et al., 2017).

Cotinine, a metabolite of nicotine, can be found in the hair, saliva, urine, and blood of individuals exposed to SHS (Florescu et al., 2009; Benowitz, 2009; Hukkanen et al., 2005) and is regularly used in research to determine recent active and passive smoking (Semple et al., 2019; Kim, 2016). Cotinine is a sensitive and specific indicator of recent exposure to nicotine and is accepted as the best available biomarker of exposure to SHS (Jarvis & Feyerabend, 2015). As cotinine is highly specific to nicotine exposure, and eCO has not shown to be an effective determinant of SHS in children, cotinine would have made an excellent addition to the present study.

3.4.3. Cardiorespiratory Fitness

3.4.3.1. Cardiorespiratory Fitness Overview

Cardiorespiratory fitness (CRF) was presented as absolute $\dot{V}O_{2peak}$ (mL·min^{-1}), $\dot{V}O_{2peak}$ ratio scaled for mass (mL·kg^{-1}·min^{-1}) and allometrically scaled $\dot{V}O_{2peak}$ (mL·kg$^{-0.53}$·min^{-1}). Absolute $\dot{V}O_{2peak}$ was positively correlated with anthropometric variables age, stature, mass, and BMI and negatively with sex. Ratio scaled $\dot{V}O_{2peak}$ was positively correlated with PA, PA enjoyment, FeNO, and EIMD, and negatively with sex, mass, maturation, and BMI. Allometrically scaled $\dot{V}O_{2peak}$ was positively correlated with PA, PA enjoyment, FeNO, age, and stature, and negatively with sex.

As absolute $\dot{V}O_{2peak}$ is strongly correlated with body size, there is need to scale. The vast majority of research expresses CRF as $\dot{V}O_2$peak ratio scaled for mass, but expressing CRF in this way over-scales for mass and leads to spurious correlations with other health related outcomes (Welsman & Armstrong, 2019b). Alternatively, $\dot{V}O_{2peak}$ can be scaled for fat-free-mass, although no data was collected regarding fat-free mass in the present study. Recently, allometric scaling has been suggested (Welsman & Armstrong, 2019b) and is being used increasingly in research with youth (Yu et al., 2019; Lolli et al., 2017). Mass exponents can be generated for a sample population via log-linear regression (see methods). Whole sample and sex and age-group specific exponents were calculated but it was determined that the sample size did not allow for sex and age-group specific models, and the overall exponent of 0.526 was used. Allometrically scaled $\dot{V}O_{2peak}$ was not found to be correlated with mass and it was deemed that the effect of body size was successfully removed (Welsman & Armstrong, 2019b). Mass exponents are sample specific, and the generated exponent (0.526) of the present study is in-line with those found in previous research, which have ranged from 0.37 (Sutton, 1999) to 0.94 (Armstrong et al., 1991; Welsman & Armstrong, 2019b).

As the majority of research regarding CRF with children expresses fitness as $mL \cdot kg^{-1} \cdot min^{-1}$, it is useful to note both ratio and allometrically scaled $\dot{V}O_{2peak}$ in order to compare with previous relevant literature. The mean ratio scaled $\dot{V}O_{2peak}$ for boys (47.7 $mL \cdot kg^{-1} \cdot min^{-1}$) and girls (42.7 $mL \cdot kg^{-1} \cdot min^{-1}$) are in line with previous research with similar aged children from Liverpool. A study by Boddy et al. (2014), which used a similar laboratory-based protocol to measure CRF, found similar means of 46.7 and 40.2 $mL \cdot kg^{-1} \cdot min^{-1}$ for boys and girls, respectively. CRF levels in Liverpool children have been in decline in recent years (Boddy et al., 2012; Stratton et al., 2007), although the similarity of the results of the present study with that of Boddy et al. (2014) suggests the trend may have stabilised. The CRF levels of children and adolescents have not only declined in the UK, but the trend is replicated in most of the high-income and upper-middle income countries. Using data based on 20mSRT performance of over 960,000 youth, Tomkinson, Lang, and Tremblay (2019) showed a substantial decline in CRF since 1981, with a stabilisation of the trend since 2000. Youth physical activity (PA) is regularly monitored and under surveillance by researchers and health authorities (Sport England, 2019; WHO, 2018) but there is currently no such monitoring for CRF. Lang et al. (2018) suggest CRF measurement could provide novel surveillance opportunities in research, physical education and clinical settings.

3.4.3.2. Classification of Fitness

Despite the above commentary on the subject of ratio and allometric scaling, children were classified as fit or unfit according to their ratio scaled $\dot{V}O_{2peak}$ values, based on established thresholds (Lang et al., 2019). In the present study, 86.3% of girls, and 79.1% of boys reached the threshold for 'fitness', with the remaining children below the threshold and therefore raising a 'clinical red flag' and at risk of cardiovascular disease. For comparison, 78% of boys and 83% girls from 30 countries met the standards for healthy CRF, using the same criterion of 42 and 35 $mL \cdot kg^{-1} \cdot min^{-1}$ as the present study (Tomkinson et al., 2018). However, CRF in the aforementioned study was estimated based on 20mSRT performance. Using a different classification of unfitness based on the lowest third distribution of 20mSRT scores, Stratton et al. (2007) found that, with a similarly aged sample from Liverpool, only 64.8% of girls and 40.3% of boys were classified as fit, much lower than the proportion of 'fit' children in the present study. A number of issues exist with the use of the above fitness thresholds. Firstly, the thresholds are for use with youth aged 9-17 years, but $\dot{V}O_{2peak}$ changes dramatically through maturation, and the thresholds do not reflect the variation in pubertal status. Secondly, the thresholds are generated from estimates of $\dot{V}O_{2peak}$ from prediction equations which introduces error. The relatively high proportion of children classified as fit in the present study may also be due to bias, where predominantly active children with confidence in their abilities, volunteer to participate in the study (see 3.4.5.1. for further discussion on this subject).

3.4.3.3. Sex, Age, and Maturation Differences in Cardiorespiratory Fitness

Sex differences were observed for all three expressions of fitness. Males generally have higher $\dot{V}O_{2peak}$ values than females (Wang et al., 2010) and after controlling for other morphological covariates, 4-9% of the variance between males and females remains unexplained (Armstrong & Welsman, 2020a). Sex differences in CRF have been part-explained by skeletal muscle mass, heart size, and lung size (Al-Mallah et al., 2016a), blood concentration of haemoglobin (Armstrong & McManus, 2017), and PA behaviour disparities (Troiano et al., 2008; Armstrong, Welsman & Kirkby, 2000).

Age was significantly and positively correlated with absolute $\dot{V}O_{2peak}$ and allometrically scaled $\dot{V}O_{2peak}$ but not ratio scaled $\dot{V}O_{2peak}$. Longitudinal studies have shown $\dot{V}O_{2peak}$ to increase with age in both sexes until late adolescence where it levels off before declining through adulthood (Kemper et al., 2013; Armstrong and Welsman, 2001). Maturation is therefore associated with $\dot{V}O_{2peak}$ and which it influences through increases in fat-free mass (Armstrong & Welsman, 2001; Armstrong & Welsman, 2019). No data on fat-free mass is available for the present study but would have made an insightful addition. However, in the adjusted model for absolute $\dot{V}O_{2peak}$, age and maturation were no longer significant when mass (amongst other variables) was added. Age was significant in the ratio scaled and allometrically scaled model, where mass was not included. The children in the present study were within a small age bracket (9-11 years) which is perhaps why age and maturation were not significant once other factors such as mass were considered.

Deprivation (EIMD) was entered into the models for $\dot{V}O_{2peak}$ but was only a significant predictor for ratio scaled $\dot{V}O_{2peak}$. EIMD was significantly and negatively correlated with mass and BMI, suggesting low-SES is associated with higher weight status, which is supported by findings of previous research (Nevill et al., 2018). As mass is more influential in the calculation for ratio scaled $\dot{V}O_{2peak}$ compared to allometrically scaled $\dot{V}O_{2peak}$, the relationship between EIMD and mass may explain the significance of EIMD in only the ratio scaled $\dot{V}O_{2peak}$ model.

3.4.3.4. Cardiorespiratory Fitness and Second-hand Smoke Exposure

Absolute and allometrically scaled $\dot{V}O_{2peak}$ were not significantly different between children of non-smoking and smoking households, whereas ratio scaled $\dot{V}O_{2peak}$ was. The number of cigarettes smoked per day was significantly and negatively correlated with ratio scaled $\dot{V}O_{2peak}$. The number of children from smoking homes classified as fit was much lower (70.3%) than that of children from non-smoking homes (91.2%) which was statistically significant. Although, the strong correlation between mass and parental smoking status, may be confounding the correlation between ratio scaled $\dot{V}O_{2peak}$ and parental smoking status.

The linear regressions for $\dot{V}O_{2peak}$ were adjusted for sex, age, mass, stature, maturation, PA, and deprivation, in addition to the number of cigarettes smoked per day by the household. For absolute $\dot{V}O_{2peak}$, the number of cigarettes (square route transformed) was not statistically significant ($p = 0.091$), whereas the number of cigarettes smoked was a significant predictor in the ratio scaled and allometrically scaled $\dot{V}O_{2peak}$ models. In all adjusted models, the number of cigarettes smoked per day had a negative impact on $\dot{V}O_{2peak}$, regardless of how it was expressed. Although household smoking was associated with mass, allometric scaling reduces the influence of mass and therefore the number of cigarettes smoked per day was found to be a significant predictor of allometrically scaled $\dot{V}O_{2peak}$, independently of mass. Overall, the models explained 72.8%, 36.2%, and 29.9% of the variance for absolute, ratio scaled and allometrically scaled $\dot{V}O_{2peak}$ respectively.

Although no prior research has yet examined the impact of SHS exposure on children's laboratory measured $\dot{V}O_{2peak}$, the results are in line with Magnússon et al. (2009) and Brage et al. (2004) which have found children's CRF (measured by maximal cycle ergometer test) to be significantly reduced for those with smoking parents. Kaymaz et al. (2014) has also shown that children exposed to parental smoking have reduced performance on the six-minute walk test. Likewise in adults, exposure to SHS has acute and detrimental effects on exercise performance (Flouris et al., 2010) and reductions in $\dot{V}O_{2max}$ expressed as $mL \cdot kg^{-1} \cdot min^{-1}$ (de Borba et al., 2014).

The mechanism by which SHS exposure reduces $\dot{V}O_{2peak}$ cannot be determined in the present study, but key components of tobacco smoke such as CO and particulate matter, have each been shown to individually impact CRF. CO, which has a higher affinity for haemoglobin than oxygen, decreases aerobic capacity through hypoxaemia of peripheral tissues due to haemoglobin bound CO (Papathanasiou et al., 2014). Particulate matter exposure causes systemic inflammation, and increased oxidative stress, leading to impaired cardiovascular, immune, and pulmonary function (Cutrufello, Smoliga, & Rundell, 2012), and reduced exercise performance (Flouris et al., 2010). Chapter 2 describes the vast amount of literature surrounding the health effects of tobacco smoke which has emerged since the pioneering work of Doll and Hill in the 1950s (Doll & Hill, 1954). Recently, research in the emerging field of epigenetics has observed the transgenerational effects of tobacco smoke, whereby paternal and maternal smoking results in changes in DNA methylation for the offspring that persists many years after exposure (Kaur et al., 2019; Richmond et al., 2018).

It is possible and likely that there is a dose-response relationship between SHS exposure and CRF, and dose-response relationships have been observed between SHS exposure and a number of other health related variables. Birthweight, sudden infant death syndrome, cognitive and behavioural problems, respiratory issues, childhood obesity, and increased blood pressure 18 years post exposure have all been found to have dose-response relationships with SHS exposure (Högberg et al., 2012; Koshy, Delpisheh, Brabin, 2011; DiFranza, Aligne, & Weitzman, 2004). In the present study the range for the number of cigarettes smoked per household per day was large at 65, and the data was positively skewed due to the majority of participants coming from non-smoking households. Most of the participating parents/guardians that smoked reported smoking 20 or less cigarettes per day, with very few households smoking more than 20. Future work should aim to include more children from heavily smoking households, either through a larger sample size, or targeted recruitment. Additionally, as discussed above, cotinine testing has a very high sensitivity and specificity for SHS exposure, and would enable better understanding and quantification of the potential dose-response relationship between SHS and CRF in children.

Children may be more susceptible to the effects of SHS due to their increased respiratory rates and immature and developing organs (Longman & Passey, 2013). In addition, children may be especially vulnerable if exposed prenatally, as studies have shown that exposure to SHS during this critical stage of development is associated with a plethora of effects including decreased birthweight, intrauterine growth retardation, preterm birth, congenital malformations, still birth (Berlin & Oncken, 2018) and decreased pulmonary function (DiFranza, Aligne, & Weitzman, 2004). Although in-utero exposure was not within the scope of this research, there is need for longitudinal studies to examine the impact of SHS exposure across the life-course. Ideally, studies could determine foetal exposure and track exposure and health outcomes into adulthood, with a particular focus on cardiorespiratory fitness. It would be of great value to understand whether the apparent detrimental effects of SHS seen in children's fitness in the present study track into late adolescence and adulthood, and whether the effects persist even after SHS exposure has ceased.

3.4.5. Physical Activity and Physical Activity Enjoyment

3.4.5.1. Physical Activity and Physical Activity Enjoyment Overview

Mean physical activity levels, as per the PAQ-C, were not statistically different between boys and girls, but the proportion of children classified as 'active' according to PAQ-C thresholds (Benítez-Porres et al., 2016) was 95.7% for boys and 80.7% for girls, which was statistically significant. The Benítez-Porres et al. (2016) thresholds suggest use of a cut-point of 2.73 to discriminate >60 minutes of MVPA per day in children. Therefore, the proportion of children meeting the daily recommendation of 60 minutes of PA per day is very high in the present study, compared to the national average of 51% of boys and 43% of girls (Sport England, 2019). There are several explanations for this finding. Firstly, participants were made aware of research procedures and aims during informational talks at the participating schools, which may have resulted in the recruitment of those children enthusiastic about PA, i.e. 'sporty children'. Secondly, surveys are subject to desirability bias, and children may have overestimated their level of PA participation, although this is less likely as Sport England also use surveys to assess youth PA (Sport England, 2019). However, the mean PA score was 3.6 (SD 0.7) which is very similar that found by Noonan et al. (2016), also with Liverpool children from deprived neighbourhoods (3.5 (SD 0.7)).

Males have consistently been shown to be more active than females in childhood, adolescence, and adulthood (Sport England, 2019; Armstrong, Welsman & Kirkby, 2000; Sallis et al., 2000). Gender theories suggest such differences in PA are socially determined, with stereotyping and self-consciousness, playing key roles (Parry, 2015; Tergerson & King, 2009) but maturation may be confounding the effect both directly and indirectly (Cumming et al., 2008). The indirect effects of maturation have been found to be mediated through psychological factors (Cumming et al., 2011; Davison et al., 2007), body fatness, perceived barriers to PA, and self-efficacy (Lee et al., 2016). Maturation, mass, and stature were all significantly and negatively correlated with PA in the present study but only age was a significant predictor in the adjusted model (discussed below). In the present study, maturation may therefore explain the lack of gender effect in PA.

Physical activity enjoyment, as per the PACES, was not statistically different between boys and girls, although previous research has found boys to display lower levels of enjoyment compared to girls when age is controlled for (Moore et al., 2009). Age was significantly and positively correlated with PA enjoyment in the present study. The mean level of enjoyment (4.2 and 4.1 for boys and girls respectively) was slightly above those found in previous studies (3.9 for boys and girls in Moore et al., 2009; baseline 3.8 for girls preintervention in Huberty, Dinkel, & Beets, 2014) suggesting a high level of PA enjoyment across the sample. PA and PA enjoyment were weakly-moderately positively correlated (r = 0.287) but the correlation was stronger for boys (r = 0.337) than girls (r = 0.242), and was not significant for girls when split by sex. Previous studies have found objectively measured PA to be weakly and positively correlated with PA enjoyment (Moore et al., 2009; Davison et al., 2007). PA enjoyment is an important correlate of PA participation (Burns, Fu, & Podlog, 2017) although the association between enjoyment and participation is not always straightforward. Enjoyment has been found to predict PA participation (Allender, Cowburn, & Foster, 2006) and enjoyment at age 10 is associated with PA in adulthood (Parry, 2013). However, some studies have found higher enjoyment for children with lower MVPA (Fairclough, 2003) and organised sport participation associated with increased fitness irrespective of enjoyment (De Meester et al. 2020). For children from smoking households only, mass and BMI were negatively correlated with PA enjoyment, and recent study by Torre-Cruz et al. (2020) has shown that PA enjoyment is mediated by perceived CRF in overweight youth (self-perceived CRF is explored in Chapter 4 and Chapter 5).

3.4.5.2. Physical Activity, Enjoyment, and Second-hand Smoke Exposure

Mean PA and PA enjoyment were not significantly different between children from smoking and non-smoking homes, and no correlations were observed between the number of cigarettes smoked per day and PA and enjoyment. There was also no difference between the proportion of children who were classified as physically active between household smoking status. For PA, linear regression, which adjusted for sex, age, BMI, maturation, deprivation, and PA enjoyment, found only age and enjoyment to significantly predict PA, whereas the number of cigarettes smoked per day was not significant. For the linear regression of PA enjoyment, which adjusted for sex, age, BMI, maturation, deprivation, and PA, only PA was a significant predictor in the model and the number of cigarettes smoked per day was not. There is currently very little research which examines the impact of SHS on children’s PA and PA enjoyment, although multiple studies have found an inverse relationship between active smoking and PA (Salin et al., 2019; Papathanasiou et al., 2012; Kaczynski et al., 2008), and therefore this finding addresses the research gap.

It is interesting that only PA and PA enjoyment were significant predictors in the linear regressions for PA enjoyment and PA, respectively. Age, sex, and maturation are discussed above in relation to PA and PA enjoyment. Deprivation is a known correlate of PA in children (Martins et al., 2017) but using data from the Millennium Cohort Study, Noonan & Fairclough (2018) found that the most deprived children were most likely to achieve 60 min of daily MVPA. Deprivation (EIMD) was not a significant predictor in the model for PA or PA enjoyment in the present study, although this may reflect the low-SES across the sample. Research regarding BMI as a correlate of PA is inconsistent (Martins et al., 2017; Bauman et al., 2012), but Fairclough and Stratton (2006) found PA enjoyment to be lower in overweight youth compared to normal-weight youth, although no differences in MVPA were observed.

Overall, for children exposed to SHS, these findings are highly positive as results indicate SHS exposure is not impacting their level of PA and PA enjoyment, which has beneficial implications for subsequent disease risk. Although, due to the finding that BMI and mass were negatively correlated with PA enjoyment in children from smoking homes only, overweight children (especially from smoking homes) may require additional interventions to improve PA enjoyment, which may in turn lead to increased PA and improvements in CRF.

3.4.6. Spirometry

3.4.6.1. Spirometry Overview

Spirometry values were compared against predicted values for children's age, sex, stature, and ethnicity and expressed as a percentage of the predicted value. Across the sample, and for all measures (FEV_1%, FVC%, PEF%, FER), spirometry values were below the predicted values by 10.3 - 24.7%, suggesting lower than average lung function across the whole sample. Participant cooperation and effort are important factors when undertaking spirometry testing, and children require encouragement and practice in order to successfully undertake the forced manoeuvres required for a valid test (Jat, 2013). Despite the high levels of encouragement from the trained research team, some children may not have cooperated fully and therefore achieved sub-optimal spirometry performance.

FEV_1 and FVC were moderately and positively correlated with logEIMD, indicating higher deprivation is associated with decreased lung function. All participants' postcodes were within the lowest four EIMD deciles (high and medium deprivation), and 85.5% of participant postcodes were within the lowest two deciles. SES is an established determinant of lung function (Polak et al., 2019; Hegewald & Crapo, 2007) and the low spirometry values across the sample may be reflecting the low SES of the sample. Indoor and outdoor air quality are associated with respiratory health (Franklin, 2007), and living near major roadways is associated with decreased FVC and increased FeNO (Dales et al., 2008). Poverty and environmental exposures may explain the ethnic differences for spirometry performance observed within the literature (Braun, 2015). In the present study, spirometry values were normalised by a factor of 0.9 for black children and 0.95 for children of other ethnicities as per Korotzer, Ong and Hansen (2000). Due to the very small number of non-white participants from smoking households, analysis by ethnicity was not undertaken but future work with a larger sample size and more representative sample of non-white children from smoking homes could explore this topic further.

3.4.6.2. Spirometry and Second-hand Smoke Exposure

Neither FEV_1%, FVC%, PEF%, or FER were significantly different between household smoking status or correlated with the number of cigarettes smoked per day. Although, PEF% was negatively correlated with eCO. Linear regression analysis showed that the number of cigarettes smoked per day was not a significant predictor of FEV_1%, FVC%, PEF%, or FER when mass, asthma, and logEIMD were adjusted for. Age, sex, height, and ethnicity were not entered into the model as such factors were adjusted for with the use of predicted spirometry values. For the FEV_1% and FVC% models, EIMD was the only statistically significant predictor.

A vast quantity of research has found SHS exposure to be detrimental to lung function (Schivinski et al., 2017; Bird & Staines-Orozco, 2016; Moshammer et al., 2006; Li et al., 2000), with the effects of early life exposure observed decades later (Lajunen et al., 2019). Thacher et al. (2018), based on a large sample size of 2295 adolescents, showed that maternal smoking was associated with a small but significant reduction in FER (FEV_1/FVC ratio) of -1.1%. Li et al. (2000) suggests that results demonstrating the impact of SHS on children's lung health should be interpreted in light of in-uterine exposure. Data on in-uterine exposure was not collected in the present study but previous research indicates in-uterine exposure to tobacco smoke is especially detrimental to lung function, likely due to the effects of SHS on development and growth. A number of studies have shown that maternal smoking during pregnancy is associated with reduced lung function in children, such as PEF, mid-expiratory flow, FVC (Gilliland et al., 2000), and FER (Thacher et al. 2018). Whilst previous research has used large sample sizes to assess the association of SHS exposure with spirometry (Thacher et al., 2018), Schivinski et al. (2017) used a small sample size of 78 and found significant and negative associations between SHS and central airway resistance and airway obstruction. Although, the study used impulse oscillometry, an alternative measure of lung function to spirometry, which does not require forced expiratory manoeuvres. In the present study, spirometry was performed before participants undertook cardiopulmonary testing. However, future work could look to monitor lung function during and after maximal exercise, and may reveal exercise-related variations in lung function for children from smoking and non-smoking households.

3.4.7. Fractional Exhaled Nitric Oxide

3.4.7.1. Fractional Exhaled Nitric Oxide Overview

The range of FeNO concentrations was large (147 ppb), and most children (70.6%) had low levels (<20 ppb) of FeNO, 13.7% had intermediate levels (20-35 ppb), and 15.7% had high levels (>35 ppb). High levels of FeNO indicate eosinophilic airway inflammation, which is itself an indication of asthma (Kuo et al., 2019; Malinovschi et al., 2014; Dweik et al., 2011). Interestingly, although the FeNO concentrations of diagnosed asthmatics (n=9) were slightly elevated compared to non-diagnosed asthmatics, this was not statistically significant. However, this may indicate that asthma was successfully being treated in those diagnosed (Kuo et al., 2019). FeNO concentrations can also be influenced by recent ingestion of food and drink, foods high in nitrates (Brody et al., 2013), rhinovirus infection, allergic rhinitis (Bjermer et al., 2014), and genetics (Karimi et al., 2019).

FeNO (log transformed) was weakly and positively correlated with ratio scaled and allometrically scaled $\dot{V}O_{2peak}$, but only for children from non-smoking households when split by household smoking status. However, no research has examined the association between FeNO and $\dot{V}O_{2peak}$ in children. Nitric oxide (NO) is important for metabolic regulation during exercise, as a modulator of blood flow, regulating muscle contraction, and influencing muscle glucose uptake (Kingwell, 2000). NO bioavailability is associated with increased exercise performance in untrained individual, including a reduced O_2 cost of low-intensity exercise and improved exercise time to exhaustion (Shannon et al., 2016; Bailey et al., 2009) and exercise training elevates NO bioavailability (Kingwell, 2000). Agostoni & Bussotti (2009) found that whilst exhaled NO was lower in heart failure patients than controls at rest, during exercise, exhaled NO was reduced in normal individuals but not patients, and exercise induced changes were correlated with $\dot{V}O_{2peak}$. Although not directly related to any of the three research questions in the present study, the finding that FeNO is positively correlated with $\dot{V}O_{2peak}$ may be of significance, as FeNO is reduced in individuals exposed to tobacco smoke, discussed below, and therefore may have further implications for CRF in SHS exposed individuals.

3.4.7.2. Fractional Exhaled Nitric Oxide and Second-hand Smoke Exposure

FeNO was not statistically different between households with different smoking status and was not correlated with the number of cigarettes smoked per day. None of the predictors in the adjusted model, including the number of cigarettes, sex, age, mass, stature, asthma, or EIMD, were significant in the model for FeNO. However, FeNO was substantially reduced for children from homes where smoking was allowed indoors, although this was not statistically significant. For active and passive smokers, the association between FeNO and airway inflammation is more complicated. Although FeNO is increased in untreated smoking asthmatics (Ahovuo-Saloranta et al., 2019), FeNO concentrations are generally reduced in smokers and individuals exposed to SHS (Ahovuo-Saloranta et al., 2019; Zhou et al., 2018; Thomas, 2001). Increasing cotinine levels have been found to be associated with a progressive reduction in FeNO, and an increase in blood eosinophil count, in healthy individuals aged 6-80 years (Jacinto et al., 2017). The mechanism by which tobacco smoke reduces FeNO is likely to be through the reduction in the enzymatic activity of nitric oxide synthase, in combination with superoxides (found in tobacco smoke in high concentrations) which react with NO to produce active nitrogen species (Matsunaga et al., 2020). Therefore, FeNO is reduced in active and passive smokers due to the suppression of production and elimination of NO. Future work could look to understand how FeNO changes in exercising children exposed to SHS. As NO is important for a number of biological and exercise-related pathways, the reduction of NO in SHS exposed individuals may be significant in relation to CRF.

3.4.8. Strengths and Limitations

This study is the first to examine the association of SHS on children's CRF, determined by direct measurement of $\dot{V}O_{2peak}$, and the use of $\dot{V}O_{2peak}$ testing via a laboratory-based treadmill protocol is both a major strength and limitation of the study. Cardiopulmonary testing requires highly specialised equipment, a trained research team, and data can be collected for only one participant at a time. Taking into account the safety brief, warm up, test duration, and cool down, one $\dot{V}O_{2peak}$ test can take approximately 30 minutes for each participant, severely limiting the number of participants that could be tested per day. The strength of this approach is that a large amount of high-quality data is collected for each individual, including the directly measured maximum uptake of oxygen, maximum heart rate, and end respiratory exchange ratio. Additionally, care can be taken to ensure each participant reaches voluntary exhaustion and test endpoints are met. Compared to field-based methods for estimating CRF, such as the 20mSRT, where a larger quantity of participants can be tested at one time, cardiopulmonary testing allows the direct measurement of CRF and is the 'gold standard' measure of young people's CRF (Welsman & Armstrong, 2019a).

There were a number of obstacles in terms of recruitment, reflected by the school participation rate of 3%, resulting in a small sample size. There was high research saturation of Liverpool primary schools, during the study period, with many schools already taking part in research projects. Risk averse schools perceived the project to be contentious, which led to difficulties recruiting schools and smoking families. As a result, the study achieved a relatively small sample size of 104 participants, including 38 children from smoking households.

The sample population of this study are representative of 9-11-year-old children from deprived areas Liverpool and Wirral, Merseyside, UK. Therefore, generalisability of the results is limited to this population. Expanding on this project, future research should aim to include children from a greater variety of SES backgrounds, age groups, and geographic locations. Such work may identify similar or different trends in relation to other demographic groups. However, as smoking behaviour is highly associated with low-SES, the current sample population was a strength of the study, as a relatively high proportion of smoking families were required to take part.

This study could be improved with the inclusion of three additional measures. Firstly, the use of eCO as a method of SHS exposure quantification was selected due to the low-participant burden, low cost, ease of interpretation, and instant results. The use of cotinine would have made an excellent addition to the study, and may have revealed a dose-response relationship between SHS exposure and CRF, although no dose-response relationship was observed between SHS exposure and eCO. Secondly, objectively measured PA, through the use of accelerometers for example, could have provided further information regarding PA behaviour, including objectively measured MVPA, a key determinant of CRF. However, the use of accelerometers would have added to the already logistically complicated data collection. Finally, measurements of fat-free mass, a common measure in CRF studies, may have contributed to the linear regressions for CRF and to the overall picture of health of the sample.

3.4.9. Conclusion

The number of cigarettes smoked per day was a significant and negative predictor of ratio scaled ($mL \cdot kg^{-1} \cdot min^{-1}$) and allometrically ($mL \cdot kg^{-0.53} \cdot min^{-1}$) scaled $\dot{V}O_{2peak}$. The number of cigarettes smoked per day was not a significant predictor of physical activity, physical activity enjoyment, or respiratory health. Additionally, exhaled carbon monoxide was not found to correlate with self-reported household smoking. Overall, results indicate that second-hand smoke exposure is associated with a reduction in CRF in children, but not PA, PA enjoyment, or respiratory health. As CRF is an established indicator of health, these findings are indicative of lower health status in children from smoking households. Low CRF is associated with a plethora of negative health outcomes and as fitness tracks into adulthood, efforts should be made to improve CRF during childhood. Reducing SHS exposure may be an effective measure for improving CRF in children from smoking households, and a potential avenue for intervention aiming to improve CRF in low SES populations. To the author’s knowledge, this is the first study to examine the association between SHS and children’s CRF using direct measurement of $\dot{V}O_{2peak}$. Future work should aim to incorporate cotinine testing, instead of eCO, and a larger sample of children exposed to SHS, in order to determine and quantify the potential dose-response relationship between SHS and CRF. Additionally, research is now needed to determine the mechanism by which SHS exposure is detrimental to children's CRF, and longitudinal research could uncover long-term impacts of SHS exposure and children's CRF.

Thesis Study Map

Study 1 The association between second-hand tobacco smoke exposure and cardiorespiratory fitness, physical activity, and respiratory health in children.	**Aim:** To assess the association between second-hand tobacco smoke exposure on children's directly measured cardiorespiratory fitness ($\dot{V}O_{2peak}$), physical activity, physical activity enjoyment, and respiratory health indicators. **Research questions:** 1) Is second-hand tobacco smoke exposure associated with cardiorespiratory fitness in children? 2) Is second-hand tobacco smoke exposure associated with physical activity and physical activity enjoyment in children? 3) Is second-hand tobacco smoke exposure associated with respiratory health indicators in children? **Key findings:** • SHS exposure (as measured by the number of cigarettes smoked per household per day) was associated with reduced CRF in children. • SHS exposure was not associated with PA, PA enjoyment or respiratory measures. • SHS exposure was associated with increased BMI and weight status. • Exhaled carbon monoxide was not correlated with self-reported household smoking status or the number of cigarettes smoked per day. **Personal reflection:** Data collection days were extremely busy and had to run like clockwork to be successful. However, I have come to learn that children make the most enthusiastic of participants and I really enjoyed working with them. Whilst some results were surprising (low carbon monoxide readings, low spirometry values for children exposed to SHS), other findings, such as that SHS exposure was associated with lower CRF, increased BMI, and lower SES, were less surprising. Overall, the findings of this aspect of the research both challenged and confirmed my preconceived ideas about the effects of SHS on children's health.
Study 2 Children of smoking and non-smoking households' perceptions of physical activity and cardiorespiratory fitness.	**Aim:** To use creative and qualitative methodologies to explore the attitudes, beliefs, and perceptions of physical activity, fitness, and exercise of children from smoking and non-smoking households.
Case studies Using the mixed-methods case study approach to explore the behaviours and perceptions surrounding fitness and physical activity of children from smoking and non-smoking homes.	**Aim:** To use a mixed-methods case study approach to provide rich, contextual insight into the lives, behaviours, and perceptions of a selection of participants, in relation to the above research aims and research questions.

Chapter 4

Study 2 - Children of Smoking and Non-smoking Households' Perceptions of Physical Activity and Cardiorespiratory Fitness

4.1. Introduction

4.1.1. Importance of Cardiorespiratory Fitness and Physical Activity

Cardiorespiratory fitness (CRF) is a health-related component of physical fitness defined as the ability of the circulatory, respiratory, and muscular systems to supply oxygen during sustained physical activity (Lee et al., 2010). CRF during childhood and adolescence is positively associated with cardiovascular health in a later life (Harber et al., 2017, Jensen et al., 2017, Andersen et al., 2004). As explored in Chapters 2 and 3, CRF is an established indicator for health in children and adolescents (Zaqout et al., 2016) which reinforces the importance of early intervention efforts to promote CRF. Physical activity (PA), in particular moderate-to-vigorous intensity PA (MVPA) is strongly associated with CRF (Knaeps et al., 2018, Brage et al., 2004) and low PA in childhood is predictive of low PA in adulthood (Mäkelä et al., 2017, Telama et al., 2009). The United Kingdom (UK) guidelines state that children and youth aged 5–18 years should achieve at least an average of 60 min of MVPA daily (Department of Health, 2019), yet less than half of all children and young people, including 51% of boys and 43% of girls, met these guidelines in England in 2019 (Sport England, 2019). Lower socioeconomic status has been shown to be associated with lower levels of PA (Lampinen et al., 2017; Janssen et al., 2006) and physical fitness, including CRF (Wolfe, Lee & Laurson, 2020; Clennin & Pate, 2019) in youth. Health interventions aimed at improving CRF in children, should therefore consider MVPA in addition to other factors such as SES, diet, and tobacco smoke exposure.

In high and upper-middle income countries, there has been a substantial decline in CRF for children and adolescents since the 1980s, with stabilisation in the trend since 2000 (Tomkinson, Lang & Tremblay, 2019). In the north west of England, CRF in children has been decreasing over time, with 35.8 % of boys and 59.7 % of girls classified as unfit according to established CRF thresholds in 2004 (Stratton et al., 2007). In comparison, 78% of boys and 83% girls from 30 countries were found to meet the standards for health CRF in a more recent study (Tomkinson et al., 2018). Low prevalence and a temporal reduction in CRF are suggestive of a decline in population health (Tomkinson, Lang, and Tremblay, 2019). Therefore, deeper understanding of children's perceptions of PA and CRF may uncover potential areas for intervention and novel strategies to address the public health issue.

4.1.2. Barriers and Facilitators to Cardiorespiratory Fitness and Physical Activity

Understanding the barriers and facilitators children experience with regard to PA and CRF could be helpful in designing intervention and policy strategies to promote PA and improve CRF in children. There is an increasing amount of research regarding barriers and facilitators to children's participation in PA (Somerset & Hoare, 2018; Biddle et al., 2011, Brunton et al., 2003) of which many themes can be mapped onto the socio-ecological model for PA (Hesketh, Lakshman & van Sluijs, 2017). Barriers and facilitators are found within psychosocial and environmental domains (Dowda et al., 2020) and include perceived availability of time, interest and motivation (Biddle et al., 2011), parental support and safety concerns, and neighbourhood physical environment (Lee et al., 2015). Sedentary behaviour, including screen time, is a significant barrier to PA in children (Brunton et al., 2005), with many children spending more time watching television with family members than engaging in PA with them (Tandon et al., 2012). Low socioeconomic status (SES) has been shown to be associated with lower levels of PA but this association may be due in part to the comparatively hazardous neighbourhood environments (Davison & Lawson, 2006) or home environments which have fewer opportunities for PA (Tandon et al., 2012, Dowda et al., 2020). The perception of the neighbourhood environment, including availability of outdoor space, seeing other children be active, and perceived safety, is influential on children's PA (Dowda et al., 2020). Although low-SES populations are increasingly targeted for interventional research (Lonsdale et al., 2019; Bukman et al., 2014), children from low-SES communities may face different barriers and facilitators to PA than their high-SES counterparts, of which there is less research.

Although PA and CRF are strongly associated, they are distinctively different and we cannot assume that the facilitators and barriers for PA apply, or are similar to those of CRF. The determinants of CRF however, are known, with some wider determinants less clear. Genetics, sex, age, and maturity are non-modifiable determinants of CRF (Armstrong & McManus, 2017). PA is an established modifiable determinant of CRF

(Zaqout et al., 2016; Dencker et al., 2006), along with MVPA, diet, body mass (Armstrong & McManus, 2017, Zaqout et al., 2016), and SES influences CRF independently of PA (Jiménez-Pavón et al. 2010). Wider individual, social, and environmental determinants of CRF, particularly in children, are unclear and this information could support the development of interventions to improve CRF in children.

4.1.3. Tobacco Smoke Exposure

The previous chapters have examined the toxicity of tobacco smoke and second-hand smoke (SHS), and have demonstrated that that children from low SES are disproportionally exposed to SHS. Children of low SES were found to have the highest exposures of second-hand smoke (SHS), detected by salivary cotinine samples (Jarvis & Feyerabend, 2015; Moore et al., 2012a). Children are particularly susceptible to the effects of SHS due to their high respiratory rates and immature organs (Longman & Passey, 2013) and therefore extra effort should be taken to safeguard children from SHS. To reiterate, exposed children are at increased risk of chronic airway inflammation, lung function defects (Lajunen et al., 2019), severe asthma attacks, respiratory infections, ear infections, sudden infant death syndrome (Naeem, 2015), and increased risk of hospitalisation in asthmatics (Wang et al., 2015). Multiple studies have demonstrated that both active and second-hand smoking have a detrimental impact on cardiovascular function in adults (de Borba et al., 2014, Papathanasiou et al., 2014). However, research is limited with regard to the effect of SHS on children's PA and CRF which has implications for public health concerns such as obesity. Of the studies that do exist concerning youth, SHS exposure has been shown to reduce exercise performance (Kaymaz et al., 2014; Pavić et al., 2014) and increase blood pressure in exercising adolescents (Hacke & Weisser, 2014; Hacke & Weisser, 2015). Children from smoking households could therefore be at greater risk of low fitness and the associated health implications. No research has yet explored how children's perspectives surrounding PA and CRF compare for children of smoking and non-smoking households. Deeper understanding of the barriers to PA and CRF children face, and whether household smoking status is a significant factor, will allow better informed health intervention and health promotion strategies for this population.

4.1.4. Understanding Children's Perceptions of Physical Activity and Cardiorespiratory Fitness

When it comes to understanding the experiences and views of children, children are the experts, with their own unique perspective of the world (Harcourt, 2011). Qualitative methods can assist in capturing children's understanding and perceptions of physical activity and CRF, and whether these experiences and perceptions differ by household smoking status. Focus groups involving children have been previously used to explore children's perspectives and attitudes towards PA (Noonan et al., 2016a, Woolley, Edwards & Glazebrook, 2018) and children's thoughts and feelings when they are exposed to SHS (Porcellato, Dughill & Springett, 2002, Woods et al., 2005). Supplementing focus groups with activities such as the write, draw, show tell (WDST) method (Noonan et al., 2016), can keep children interested and engaged, and can allow children to express their ideas in a way where researchers can access children's meanings (Gibson, 2007).

This study therefore aimed to use qualitative and creative methodologies to explore the perceptions of children (9-11 years) from smoking and non-smoking homes surrounding cardiorespiratory fitness and physical activity. The study sought to address the following research questions:

1) What are children from smoking and non-smoking households' reasons for being physically active?

2) What are children from smoking and non-smoking households' attitudes towards physical activity, exercise, and fitness?

3) What are the perceived barriers and facilitators to a child's ability to be physically active and does this differ for children from smoking and non-smoking homes?

4) What are children's perceptions of their own fitness and physical ability and does this differ for children from smoking and non-smoking homes?

4.2. Methodology

4.2.1. Study Design

This research was granted ethical approval by the Research Ethics Committee of Liverpool John Moores University (Ref: 16/PBH/001) and follows the Consolidated Criteria for Reporting Qualitative studies checklist of reporting for qualitative studies (Tong, Sainsbury & Craig, 2007). The study formed part of a wider PhD programme of research examining smoking exposure, fitness and child health through quantitative and qualitative methods. The present qualitative study was approached with a humanistic philosophy, acknowledging children as experts, with their own unique perspective of the world (Harcourt, 2011). This unique perspective was explored using creative qualitative methodologies (Noonan et al., 2016a), giving a voice to children, from both smoking and non-smoking households. Participants were drawn from a concurrent quantitative investigation into the associations between smoking exposure, CRF and child health, conducted as part of the wider PhD programme of research (Chapter 3).

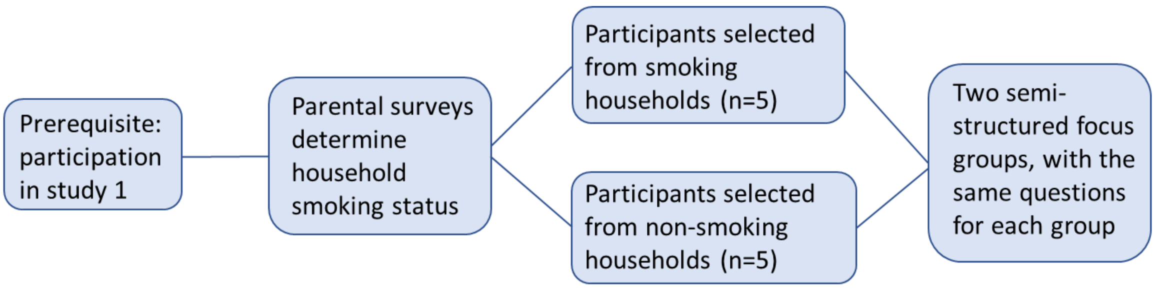


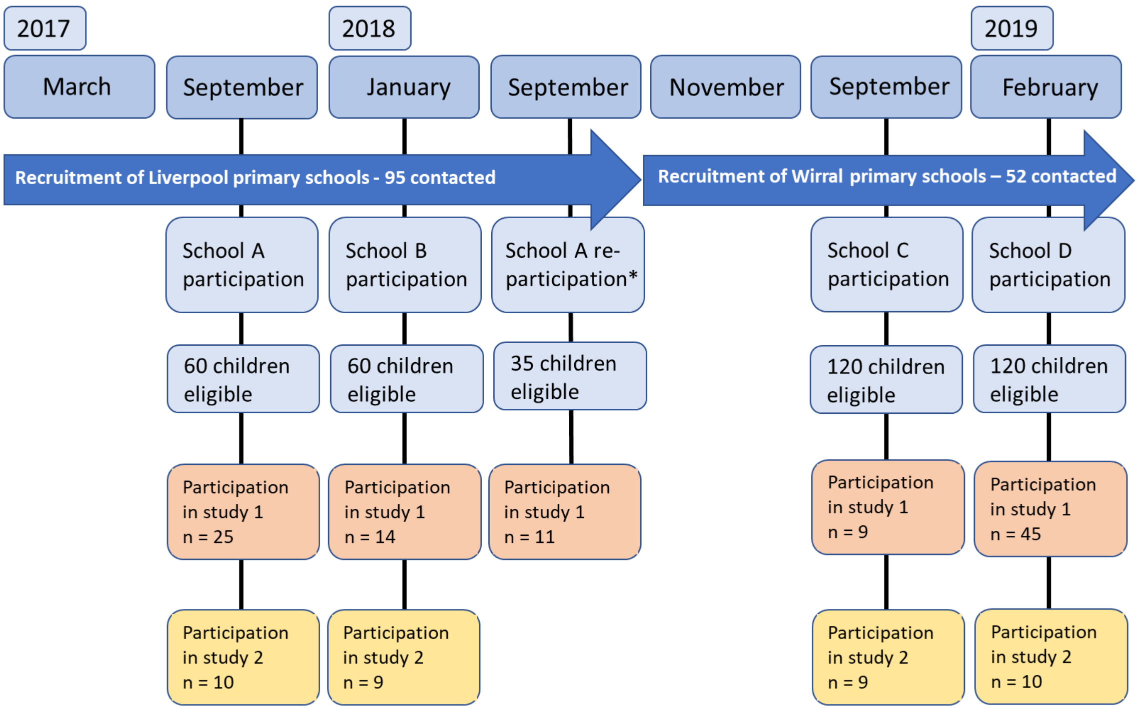
Figure 4.1. Overview of planned research design for Study 2 (target numbers per school).

The research design (Figure 4.1) aimed to conduct two focus groups, with a sub-sample of children recruited in each participating school, targeting participants from smoking (n=5) and non-smoking households (n=5), respectively (as determined by parental surveys). Data collection began in September 2017 and ended in February 2019, with schools participating at different timepoints throughout the year, determined by convenience for the schools (Figure 4.2).

4.2.2. Participant Selection and Setting

Participants were targeted as being aged 9-11 years old, and in year 5 or 6 at a Liverpool or Wirral state-funded primary school. One-hundred and forty-seven schools were approached as convenience samples and four schools agreed to take part in the research (2.7% response rate from schools), with all participating schools falling within the lowest two deciles for English Indices of Multiple Deprivation (EIMD) based on school post-code (Ministry of Housing, Communities & Local Government, 2019).

After receiving written informed gatekeeper consent from headteachers, presentations were given at the participating schools to provide information to the children about the research, and to invite children to take part. Information packs, including parental surveys, parental consent forms, and child assent forms, were given to children to take home to parents and guardians. One-hundred and five children returned parental consent and child assent and were eligible to take part in the PhD programme of research (26.5% response rate from invited families).



**School A participated again the following year with a new year group.*

Figure 4.2. Research timeline over time.

Figure 4.2 shows the flow of participants through the PhD programme of research, including quantitative (Chapter 3) and qualitative studies. At each participating school (n=4), two focus groups were held, one with children from non-smoking households, and another with children from smoking households.

Parental surveys used in the quantitative research study (Chapter 3) identified children from smoking and non-smoking households and were used to inform focus group membership. Focus group participants from each smoking exposure group were selected by stratified sampling, with the number of boys and girls controlled for to allow even representation. All eight focus groups involved the recommended group size of 4-6 participants (Mackintosh et al., 2011, Morgan et al., 2002). For some groups, there were not enough children identified from smoking households to meet the recommended group size. Therefore, to avoid excluding children from smoking households due to low numbers, children from non-smoking households were also invited to join in the focus group.

Table 4.1. Focus group membership.

Focus group	School	Girls	Boys	Non-smoking household	Smoking household
1	A	2	3	5	0
2	A	3	2	1	4
3	B	2	2	4	0
4	B	2	3	3	2
5	C	3	1	4	0
6	C	2	3	0	5
7	D	2	3	5	0
8	D	3	2	0	5
TOTAL		**19**	**19**	**22**	**16**

Focus group membership is outlined in Table 4.1. A sub-sample of 38 children, including 19 boys and 19 girls, participated in the focus groups. Forty participants were selected but one boy and one girl were absent at the time of data collection. The majority of participants were from non-smoking households, including 11 boys and 11 girls, with 16 children from smoking households, including 8 boys and 8 girls. The average age of focus group participants was 10.2 years, with white British children making up 65.8%, Black British 10.5%, 7.9% white-other (including Polish and Portuguese), and 15.8% of participants were of other ethnicities. The majority of participants' homes (79%) were amongst the lowest two deciles for neighbourhood deprivation in England (Ministry of Housing, Communities & Local Government, 2019).

4.2.3. Focus Groups

From September 2017 to February 2019, eight semi-structured, mixed gender, child-centred focus groups were facilitated. All focus groups were conducted by the first author (PhD candidate, female) following training in managing and facilitating focus groups. Focus groups took place in a familiar school setting (in a classroom or staffroom at the participants' school), during school time, and in a place where participants could be overseen but not overheard to comply with safeguarding procedures (Porcellato et al., 2002).

The four principal research questions informed the production of an age-appropriate focus group guide (Appendix 6), which encouraged children to consider their own thoughts, opinions, and beliefs (Table 4.2). Focus group questions were reviewed by a Health and Care Professions Registered Psychologist for age appropriateness with ordering and flow designed to facilitate interaction between children. Focus groups exploring children's perspectives should be small in number and interactive to maintain a high level of interest (Porcellato, Dughill, and Springett, 2002). The focus group design was therefore influenced by the recently established write, draw, show, and tell (WDST) method; an inclusive, interactive and child-centred methodology (Noonan et al. 2016a). Although drawing was not employed as a method in the current study, the visual methods such as 'write' and 'show' were used in combination with verbal articulation from the children. Most questions permitted thinking time, which allowed children to consider their own thoughts and opinions before sharing with the group. Interactive questions, for example with the use of sticky notes, offered an opportunity for children to contribute to the discussion, who were less comfortable sharing their thoughts verbally.

All focus groups were recorded by Dictaphone and field notes were not taken due to the level of interaction and facilitation required throughout the sessions. Verbal consent was sought from each child before the focus group commenced, following explanation to the participating children from the facilitator. The children were told there were no right or wrong answers, and that the focus group was a way to share their thoughts and opinions, but they did not have to answer if they did not want to. The focus groups started with introductions, basic group expectations (e.g. 'Please do not try to talk over each other'), and an icebreaker was used to allow the children to practice speaking freely in the group. Further details of the focus group activities is provided below. Participants were provided with the opportunity to give any further thoughts and opinions on the focus group topics at the end of each focus group.

Table 4.2. Research questions and related focus group questions and activities.

Research question	Example focus group questions and activities
RQ1. What are children from smoking and non-smoking households' reasons for being physically active?	▪ I'm going to ask you to have a think, then choose which physical activity you enjoy the most and tell me why.
RQ2. What are children from smoking and non-smoking households' attitudes towards physical activity, exercise, and fitness?	▪ Is it important to be physically fit? Why? Is it important to you? ▪ What kind of things can you do to help you to improve your fitness? You can have a moment to think about this, then pick one or two main ideas. ▪ *[Using picture scale]* At which level of activity would you choose to work at? Why?
RQ3. What are the perceived barriers and facilitators to a child's ability to be physically active and does this differ for children from smoking and non-smoking homes?	▪ *[Sticky notes]* Think about what things help you to be physically active, and what things might stop you. ▪ Do any adults who live with you, care for you, help or prevent you from being active? How?
RQ4. What are children's perceptions of their own fitness and does this differ for children from smoking and non-smoking homes?	▪ *[Photograph activity]* I'm going to give you some pictures of children doing various activities or sports and I'd like you to decide how hard you would find each activity and place them on the scale ▪ How physically fit do you feel, on a scale of 1-10? With 1 being not very fit at all, 10 being the fittest you could be. ▪ Can you improve your fitness? How? ▪ How did you feel during the fitness challenge?

Icebreaker

Children were asked, 'Write down on the sticky note three words that you think describe physical activity.' What PA meant to the children was explored, before defining PA as 'Any body movement with our muscles that uses energy'.

RQ1. What are children from smoking and non-smoking households' reasons for being physically active?

To ascertain children's reasons for being physically active, children were asked about their favourite physical activities and to discuss what they enjoy and dislike about PA. In order to pose the research question in a child-accessible way, the following question was used: 'I'm going to ask you to have a think, then choose which physical activity you enjoy the most and tell me why.' Reasons for being active were explored further with prompts, such as 'What do you enjoy about the activity?'

RQ2. What are children from smoking and non-smoking households' attitudes towards physical activity, exercise, and fitness?

To elicit children's responses regarding their attitude towards physical activity, exercise, and fitness, interactive tasks and a range of questions were used in conjunction. A key step taken towards answering this research question was to establish the difference between PA, exercise, and fitness. Questions used to orientate the children with the key terms were used, for example 'What does fitness mean?', before the researcher defined the key terms in a child-appropriate way for clarity. A number of focus group questions mapped onto the second research question (Table 4.2), including 'Is it important to be physically fit?', with prompts such as 'Is it important to you?'.

The 'show me' picture activity allowed children to show how a certain activity made them feel, using the PCERT scale (Figure 4.3) they had experienced in an earlier aspect of the overall PhD programme of study (Chapter 3). Children were shown photographs of children participating in different physical activities (Figure 4.4), including playing on park apparatus, gymnastics, sprinting, walking, and swimming. The activities were selected to include a range of metabolic equivalent of tasks (METs) from casual walking, MET 3.6, to sprinting, MET 10 (Ainsworth et al., 2011), but also to incorporate a range of components of fitness, including cardiorespiratory fitness, muscular strength, flexibility, agility, balance, power, speed, and coordination.

Children were asked to place the photographs on the scale to demonstrate how exerting they found each activity, with the following instruction:

'Look at this scale showing how hard an exercise is, with the easiest level of work at the bottom, and the hardest at the top, you might remember it from the fitness challenge.

I'm going to give you some pictures of children doing various activities or sports and I'd like you to decide how hard you would find each activity. When you're ready, come and place the pictures on the scale, showing how hard you would find each activity.'

Figure 4.4. Pictures used in the exercise 'show me' task. Pictures demonstrate gymnastics (crab), running (sprinting), swimming, playing on park apparatus (monkey bars), walking (to/from school). Pictures (copyright free) are for illustrative purposes and are not the actual pictures used, as these could not be shared due to copyright.

RQ3. What are the barriers and facilitators to a child's ability to be physically active and does this differ for children from smoking and non-smoking homes?

Coloured post-it-notes and a flipchart were used as interactive resources. Children were asked to write down things that 'help' them to be physically active on the green post-it-note, and things that 'stop' them being physically active on the red post-it-note. This was followed up with a question about how adults can limit or facilitate children's physical activity.

4.2.5. Migration of Data

In two focus groups, children from non-smoking households were included in the 'smoking household' focus groups (FG2 and FG4) for reasons described above. Where possible, the data obtained from the focus group attributable to these children, e.g. quotes, pictures, sticky note activity data, and agreements/disagreements was migrated into the 'non-smoking household' dataset. This was made possible due to the lack of discussion between the children. In the focus groups, children tended to answer the questions in relation to themselves, with little comparison and contrast between other group members' answers. Data migration was therefore practical and did not impact on the remaining set or the set to which it was added. However, where discussion, agreement or disagreement did occur, a larger portion of the data was migrated to not lose context from the discussion and to ensure reverse tracking within analysis procedures could occur.

RQ4. What are children's perceptions of their own fitness and physical ability and does this differ for children from smoking and non-smoking homes?

The fourth research question was answered with a mixture of open questions and interactive activities. The interactive activity using the PCERT and photographs, as described above, was also used to answer this research question. In addition, questions centred around fitness were used, such as 'How physically fit do you feel, on a scale of 1-10? With 1 being not very fit at all, 10 being the fittest you could be.'

4.2.4. Data Analysis

Focus groups lasted an average time of 36 min (range 29-44 min), were audio recorded and transcribed verbatim, resulting in 118 pages of Arial size 12 font, double spaced, raw transcription data. The principal researcher was the sole coder, but generated themes were discussed and refined with the wider research team. Participants did not provide feedback on the findings, but had been provided with the opportunity to give any further thoughts and opinions at the end of the focus group. Quotations are presented verbatim, with reference to the participant number, sex, school, and household smoking status (more detail below).

4.2.6. Thematic Analysis

Thematic analysis was employed to analyse the data, the process of which consisted of six stages: 1 - familiarisation with the data, 2 - generation of codes, 3 - generation of initial themes, 4 - reviewing themes, 5 - defining and naming themes, and 6 - synthesis of the report (Braun & Clarke, 2013, Braun & Clarke, 2019). Verbatim transcripts were read and re-read to allow familiarisation of the data and then imported into QSR NVivo 10 software package. The process of re-reading and re-listening improves researcher familiarisation with the data. Items of interest, and initial thoughts and ideas, were noted during the familiarisation phase. Codes were generated inclusively, comprehensively, and systematically, and captured data that were related to the research questions. Themes were generated as an active process, organising smaller amounts of data associated with codes, into larger clusters of data with similar codes, to produce themes. Thematic maps and tables were used to visualise and consider the relationships between themes and review potential themes. Themes had to have meaningful data in support, and those that did not have enough data were discarded. Stage five of the thematic analysis involved defining and naming themes. The themes were described in their relation to the overall 'story', and in answer to the research questions. Finally, the report was produced as an analytic commentary, using quotes and extracts from the data to demonstrate the themes generated in relation to the research questions. Quotations are labelled by the participant pseudonym, boy (B), girl (G), ID number, school (A,B,C,D) and household smoking status, smoking (S), and non-smoking (NS). For example, B6B/NS, would be boy 6 from school B, and a non-smoking household.

4.2.7. Pen Profiles

A pen-profiling approach, increasingly used to report and support creative methodologies (Ridgers, Knowles & Sayers, 2012; Knowles, 2009) was used to represent thematic analysis outcomes. Pen profiles are considered appropriate for representing analysis outcomes from large datasets via a diagram of composite key developed themes (Mackintosh et al., 2011). To expand the pen profiles, verbatim quotations were used directly from the transcripts. This technique presents findings in a way that is accessible to researchers who have an affinity for both qualitative and quantitative backgrounds (Knowles, 2009).

4.2.8. Trustworthiness of the Research

The following measures were taken to ensure the trustworthiness of the research (Shenton, 2004):

Credibility

- **Established methods.** Established research methods were used, such as the use of focus groups with elements of the WDST method (Noonan et al., 2016a) with the recommended group size for children (Mackintosh et al., 2011).

- **Familiarisation.** The researcher and the participating children were familiar to each other prior to the focus groups due to the earlier laboratory-based aspect of the larger research project.
- **Honesty in informants.** A rapport was built between researcher and participants which helped the participants to feel at ease. Participants were also told that there were no right or wrong answers, and that they could speak freely. Other tasks, such as the ‘show’ and ‘write’ tasks, allowed participants who felt uneasy sharing with the group, to present their opinions in a non-verbal manner. Focus groups were held in a room where they could be overseen but not overheard, and participants were reminded that they could withdraw from the study at any time, without reason.
- **Peer scrutiny.** The supervisory and advisory team regularly provided feedback on all aspects of the research, from planning and data collection to interpretation of the findings and generation of the themes.
- **Member checking.** To clarify participant meaning, statements were often read back to the participants, and probing questions used to check and establish that the statements match what the participants intended.
- **Description of the phenomenon.** Participant quotes have been included within the text and pen-profiles to allow the reader to assess how the themes relate to the participant responses.

Transferability

The boundaries of the study are made clear, and the results reflect the reality of the participants involved at the time of data collection. A description of the contextual setting, including the geographical and demographical context of the thesis is included in section 2.10, and referred to throughout the chapter.

Dependability

The process of the study is reported in detail above, which may allow future researchers to repeat the work. This section (4.2.) details the study design, participant selection and setting, focus group procedures, data analysis, and data presentation. An appraisal of the study, including the strengths and limitations is found in section 4.4.7., and in section 6.3. for the overall research project.

Confirmability

A positionality statement is provided in section 2.8. As above, an in-depth methodological description allows the integrity of the findings to be scrutinised. Additionally, generated themes and findings were discussed with the wider research team to reduce the effect of investigator bias. The study and overall research is evaluated in sections 4.4.7. and 6.3.

4.3. Findings

4.3.1. What is Physical Activity?

Words to describe physical activity used by the children in the icebreaker activity could be categorised into either type of physical activities such as team sports, organised activities, and solo activities (n=72), words to describe what physical activity is (n=32), and how it made the children feel (n=8). Physical activity was most commonly associated with sports (n=15), football (n=12), running (n=10), and swimming (n=8). When assessing smoking exposure groups separately, children from non-smoking households more frequently used descriptors such as ’sports’ (n=11), ‘health’ (n=6), and ‘fun’ (n=7), while children from smoking households were more likely to give examples of physical activities such as ‘football’ (n=6) and less likely to describe physical activity as ‘fun’ (n=1). Although not constituting a theme, one participant from a smoking home described physical activity as ‘tiring’ which was the only negative description of PA by any of the participants.

4.3.2. RQ1. What Are Children from Smoking and Non-smoking Households’ Reasons for Being Physically Active?

Football was the most common favourite physical activity (n=11, 29%), followed by swimming (n=5, 13%)[1], and dance (n=5, 13%). Children from non-smoking homes chose more metabolically demanding activities as their favourite physical activity, for example, martial arts and cycling, whereas children from smoking households often favoured less metabolically demanding activities, such as walking and darts, although both groups frequently favoured football and swimming.

A pen profile representing children’s reasons for being physically active is presented in Figure 4.5. Four major themes were generated in response to the first research question, including positive feeling (n=19, 50%), perceived benefit (n=15, 39%), perceived competence (n=5, 13%), and social influence (n=7, 18%).

[1] Percentages in the text are for the whole sample of participants (n=38) unless stated otherwise. Percentages in the pen-profiles are split by household smoking status.

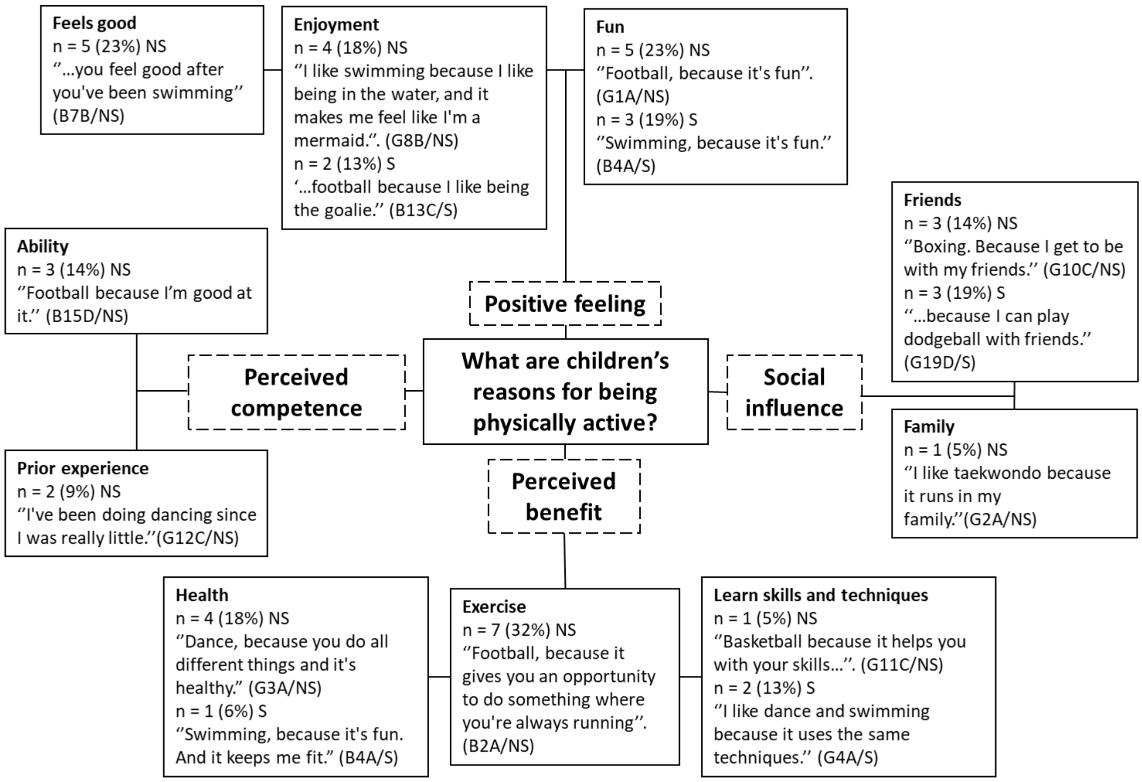


Figure 4.5. Pen-profile demonstrating children's reasons for being physically active for children from non-smoking (NS) homes and smoking (S) homes. Percentages represent the proportion of each group that contributed to the theme for children from smoking (n=22) and non-smoking homes (n=16).

The positive feeling theme consisted of three sub-themes including fun (n=8, 21%), enjoyment (n=6, 16%), and feels good (n=5, 13%, NS only). Fun and enjoyment were common reasons associated with participating in physical activity among both groups. One child noted enjoying the feeling of competition he got from PA; 'I just like being competitive. And in dodgeball you can throw balls at people and just whack them!' (B19D/S).

Perceived competence (n=5, 13%) was a theme identified from the responses from children from non-smoking homes only. Reasons for being physically active provided by non-smoking children, which related to their perceived competence, included prior experience (n=2, 5%) and ability (n=3, 8%), e.g. 'I've always been able to do gymnastics' (G11C/NS).

A third theme, social influence (n=7, 18%), made up of friends (n=6, 16%) and family (n=1, 3%) was reflected in the responses of children from both smoking (n=3) and non-smoking households (n=3). One participant stated that playing Xbox was his favourite (physical) activity for reasons related to playing with friends: 'Playing on my Xbox. Because I can play with my friends. And I get to play Fortnight, and it warms my thumbs up.' (B12C/S). When discussing whether playing Xbox was a physical activity or not, a minority of children believed it could be classed as PA (n=2, 5%) as it involves 'moving your thumbs' (B12C/S).

Children reported reasons associated with a perceived benefit to being physically active (n=15, 39%) with children from non-smoking homes referring to benefits of PA more often (n=12) than children from smoking households (n=3). For example, exercise was a reason often provided by children from non-smoking households (n=7), 'Football, because you need some exercise.' (B3A/NS). Health reasons, for example, 'Football, because it's healthy and fun' (B2A/NS), were frequently reported by children from non-smoking homes (n=4) and by one children from a smoking home. Children also reported the benefit of learning new skills and techniques as a reason for taking part in PA (n=3, 8%).

4.3.3. RQ2. What Are Children from Smoking and Non-smoking Households' Attitudes Towards Physical Activity, Exercise, and Fitness?

4.3.3.1. Perceptions of physical activity guidelines

Children were asked how much physical activity they believe they should do per day in order to assess their current understanding of the physical activity guidelines. Overall, the most common answer was 60 minutes per day (n=8, 21%), followed by 90 minutes (n=7, 18%) and 120 minutes (n=7, 18%) per day. Children from non-smoking households frequently stated that children should do 60 minutes of PA per day (n=6, 27% of children from non-smoking homes), whereas children from smoking households most frequently stated that children should do 90 minutes of PA per day (n=5, 28% of children from smoking homes). In terms of intensity for improving or maintaining CRF, some children stated that they should build up the exercise intensity throughout the activity (n=5, 13%), for example, 'I think we should start at quite light, and then like build up.' (G3A/S). Some children believed they should work hard throughout (n=4, 11%), 'Hard, so… like 100%.' (G1A/NS), and some stated they should put 'medium' effort in (n=3, 8%), whereas some children believed they should work as hard as they feel like at the time (n=2, 5%), 'I feel how much I want to do. If you don't want to do that much that day, don't do that much.' (B3A/NS).

4.3.3.2. Importance of fitness

All participating children believed that it is important to be physically fit. A higher order theme generated for why children believed physical fitness to be important was capability (n=24, 63%), which was split into three sub-themes (Figure 4.6): physical activity and sport performance (n=13, 34%), physiological aspects of ability (n=6, 16%), and future capability (n=5, 13%). Children from non-smoking homes valued fitness in terms of performance (n=10, 45% of children from non-smoking homes) in PA such as sport and games, for example 'Like you play a game of tag or something, and someone's tagged you and you're on, you need to be fit to try and get them.' (B2A/NS). Children from smoking homes more often talked about the physiological impacts of fitness (n=4, 25% of children from smoking homes): '…because if you don't keep physically fit, you're just going to run out of breath all the time when you're walking somewhere or down somewhere at the park…' (B14C/S). Fitness was believed to be important for the future by children from non-smoking homes (n=5, 23% of children from non-smoking homes), 'Well, it'll help you in your future' (B10B/NS). However, children from smoking homes did not discuss fitness being important for the future. Although not constituting a major theme, self-esteem was discussed by children from both exposure groups (n=3, 8%). Children reported fitness was important because '…you get more confidence from it' (G18D/S) and 'It's important to me because you could get bullied and stuff because you're not fit…' (B7B/NS).

The theme of health benefits of fitness constituted two minor themes including general health (n=7, 18%) and weight status (n=5, 13%). Children from non-smoking homes were more likely to report reasons surrounding the health benefits (n=7): 'Because it's good for your body and your bones and stuff.' (G8B/NS), whereas children from smoking homes did not discuss the health benefits directly. Fitness was important to children from smoking and non-smoking homes for reasons linked to weight status (n=5), with children from both groups relating fitness to fatness.

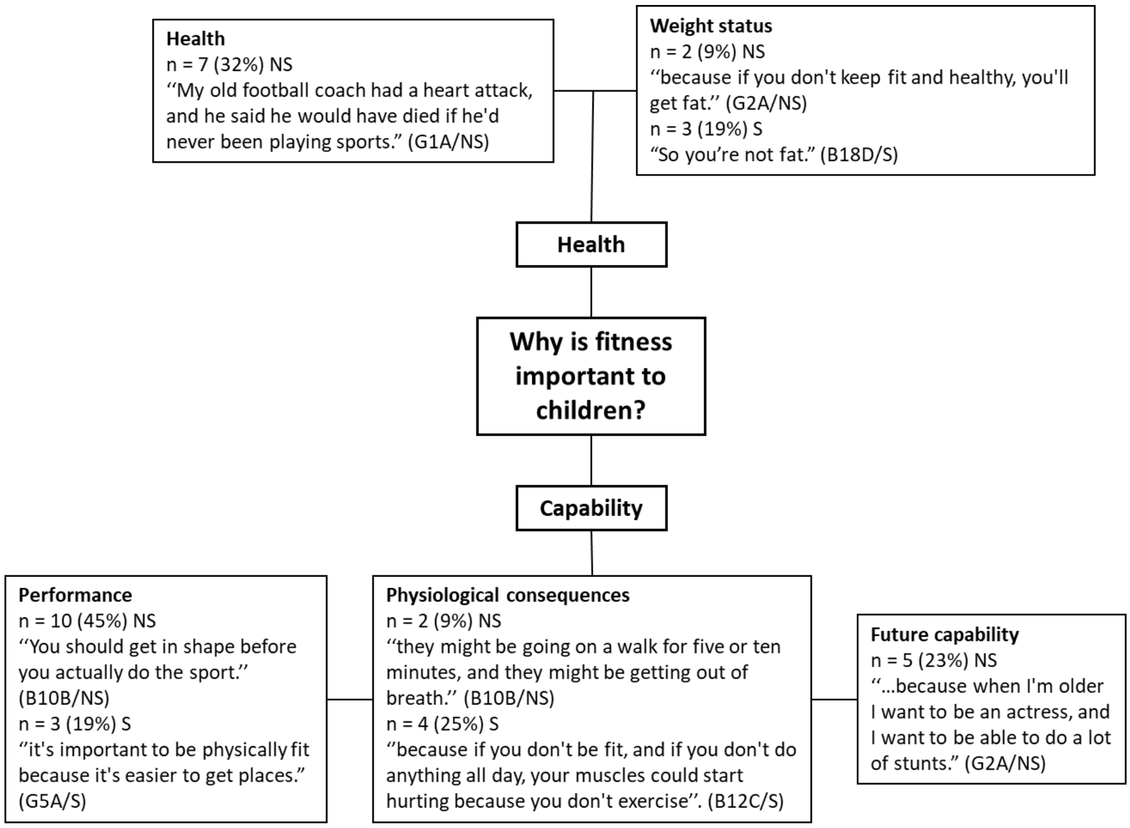


Figure 4.6. Pen profile showing children's reasons why fitness is important to them. S = children from smoking households, NS = children non-smoking households. Percentages represent the proportion of each group that contributed to the theme for children from smoking (n = 22) and non-smoking homes (n = 16).

4.3.3.3. Improving fitness

The consensus from all participants was that children can improve their fitness, for example:

'I think you can always improve your fitness, because you can improve it by doing more workouts and stuff, but I think it will never be a ten (out of ten). You can always improve it, because I think you can always get better.' (G1A/NS).

Children believed they could improve their fitness by increasing their level of PA (n=17, 45%), a theme constituted of two sub-themes (Figure 4.7); exercise (n=15, 39%) and sports (n=2, 5%). Increasing exercise frequency and intensity were the most common themes discussed by children from non-smoking homes (n=10) and smoking homes (n=5). Some statements from the participants indicate that children conceptualise fitness more widely than only cardiorespiratory fitness. For example, one child noted that a 'fast' child must exercise a lot, 'If someone's faster than me, then I think that they must be doing a lot of exercise.' (B1A/NS).

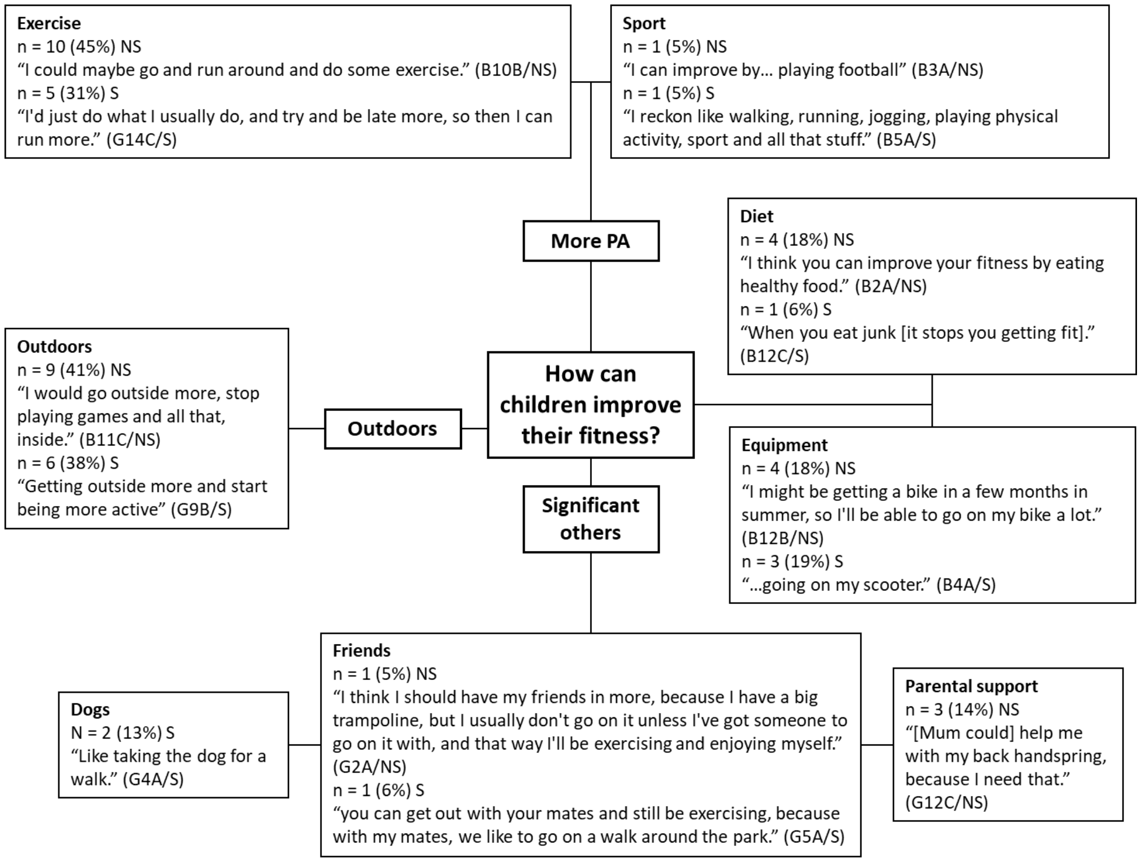


Figure 4.7. How can children improve their fitness according to children from smoking and non-smoking homes. Percentages represent the proportion of each group that contributed to the theme for children from smoking (n = 22) and non-smoking homes (n = 16).

Getting outdoors to improve fitness was a major theme generated from the responses from both groups of children (n=15, 39%). Children often commented on how going outdoors could improve their fitness. For example: 'Going to the park, going out for walks, runs, going on my scooter.' (B4A/S). When discussing going outdoors, children often expressed parental restriction due to safety concerns as a limiting factor, for example, '[Adults should] let you go outside all the time, even if it's raining or anything.' (G11C/NS). One participant spoke about how she was often grounded but could improve her fitness by going outside more; 'If I was grounded, I would sneak out of the house, climb out of the window.' (G12C/NS).

A theme of significant others (n=7, 18%) was developed which included three sub-themes; parental support (n=3, 8%), friends (n=2, 5%), and dogs (n=2, 5%). Both groups referred to the importance of friends in improving fitness. However, only children from smoking homes discussed dog ownership, whilst only children from non-smoking homes discussed parental support as a way that they could improve their fitness: 'Because Mum and Dad can drive, they can take me out places where I can get fit.' (B11C/NS).

A good diet (n=5, 13%) was considered an important factor for improving fitness by children with more children from non-smoking homes (n=4) discussing diet than children from smoking homes (n=1). One girl explained how, to improve her fitness, she might change her diet with the involvement of her parent; 'I would say to my Mum, 'I'm not having any like carbs or junk for maybe two months or something."' (G8B/NS).

A second minor theme generated by the responses of children was centred around the provision and availability of equipment, for example ownership of bicycles, scooters, trampolines and treadmills. Some children stated that having a treadmill at the home allowed them to increase their fitness (n=2, 5%), but one girl from a smoking household noted how no people in the house use the treadmill; 'But we're getting rid of [the treadmill] soon. Only the dog uses it.' (G4A/S).

4.3.4. RQ3. What Are the Barriers and Facilitators to a Child's Ability to be Physically Active and Does this Differ for Children from Smoking and Non-smoking Homes?

4.3.4.1. Barriers

Children identified a range of factors which limit their ability to be physically active (Figure 4.8). The majority of factors identified by children from both smoking and non-smoking homes were associated with sedentary behaviours (n=29, 76%), including screen time (n=16, 42%) and other general sedentary behaviour (n=13, 34%). Screen time was described to be a major factor preventing children from being physically active, for example: 'If my sister didn't go to school, she would spend all day in bed, literally, watching YouTube.' (B12C/S), and 'I'm always on my laptop. That's all I'm ever on at home.' (B7B/NS).

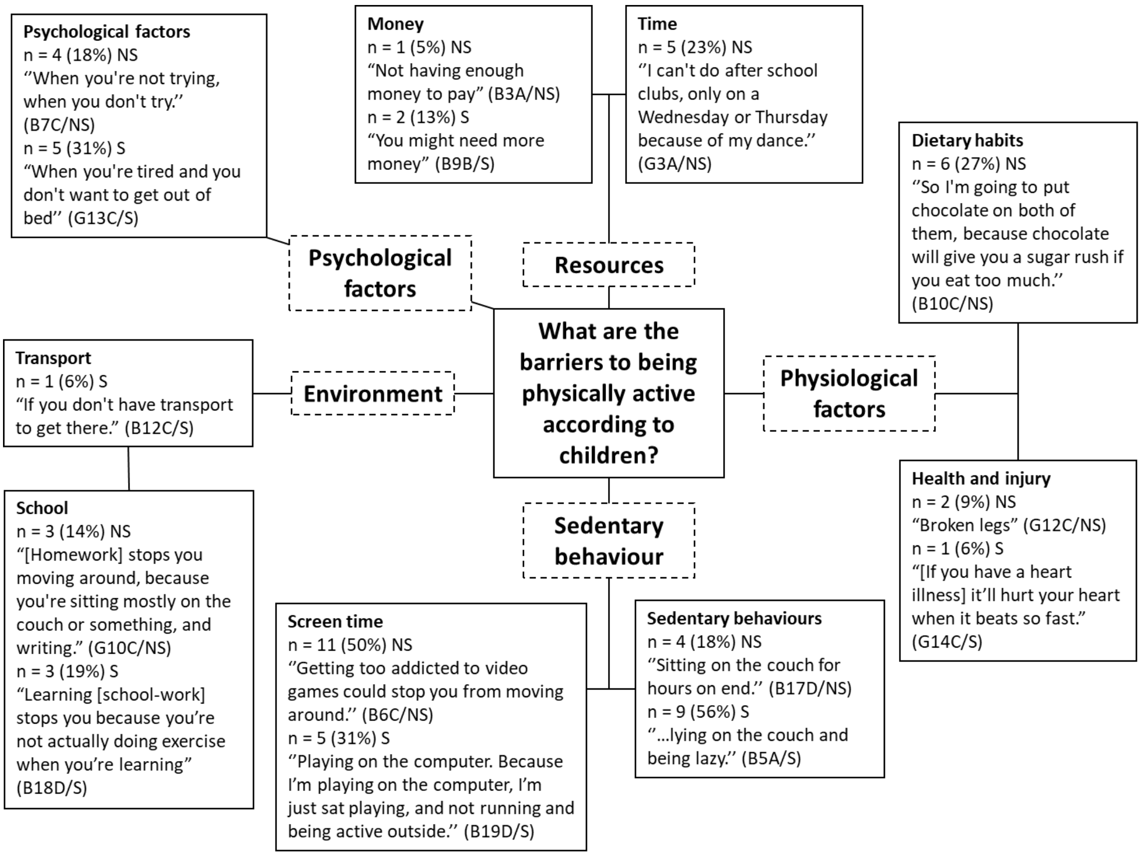


Figure 4.8. Pen-profile demonstrating the barriers to being physically active according to children from non-smoking (NS) and smoking (S) homes. Percentages represent the proportion of each group that contributed to the theme for children from smoking (n = 22) and non-smoking homes (n = 16).

A second higher order theme of resources was generated (n=8, 21%), which was linked to two sub-themes, money (n=3, 8%), and time (n=5, 13%). Children from non-smoking homes were especially concerned with the amount of free time they had available to be active, particularly due to commitments to organised activity clubs outside of school. Money was discussed as a limiting factor by children from both exposure groups, in terms of needing money to pay for various physical activities.

Psychological factors was a theme generated from the responses from both groups of children as a factor which limits a child's ability to be physically active (n=9, 24%). A negative psychological state, for example feeling lazy or tired, children believed limited their ability to be physically active as they were less motivated to do so.

Physiological factors (n=9, 24%) were noted as barriers and consisted of two subthemes, dietary habits (n=6, 16%), and health and injury (n=3, 8%). The latter was discussed by both groups of children, whilst nutritional factors were only discussed by children from non-smoking homes. Environmental barriers (n=7, 18%) to activity, consisting of school (n=6, 16%) and transport (n=1, 3%), were reported by both groups, particularly with regard to the sedentary nature of school-work and homework.

4.3.4.2. Facilitators

Children commonly discussed the physiological factors (n=20, 53%) that facilitate their ability to be physically active (Figure 4.9). Three sub-themes made up the physiological factors theme: dietary habits (n=10, 26%), health (n=6, 16%), and sleep (n=4, 11%). Children from non-smoking homes more frequently talked about health and diet, compared to children from smoking homes who more often reported sleep as important factor facilitating their ability to be physically active.

A theme of significant others was generated (n=18, 47%), which consisted of four sub-themes: siblings (18%, NS only), friends (n=6, 16%), adults (n=5, 13%), and dog ownership (n=3, 8%). Friends was an important factor for PA facilitation for children from both smoking (n=3) and non-smoking households (n=3). Children from smoking households more frequently mentioned the influence of adults (n=4). For example, 'Well, my Mum helps me be active. Well, when I ask if I can play out, she's like, "Just get out"…' (G14C/S). Dog ownership was referred to as a factor facilitating PA with children from non-smoking households only (n=3).

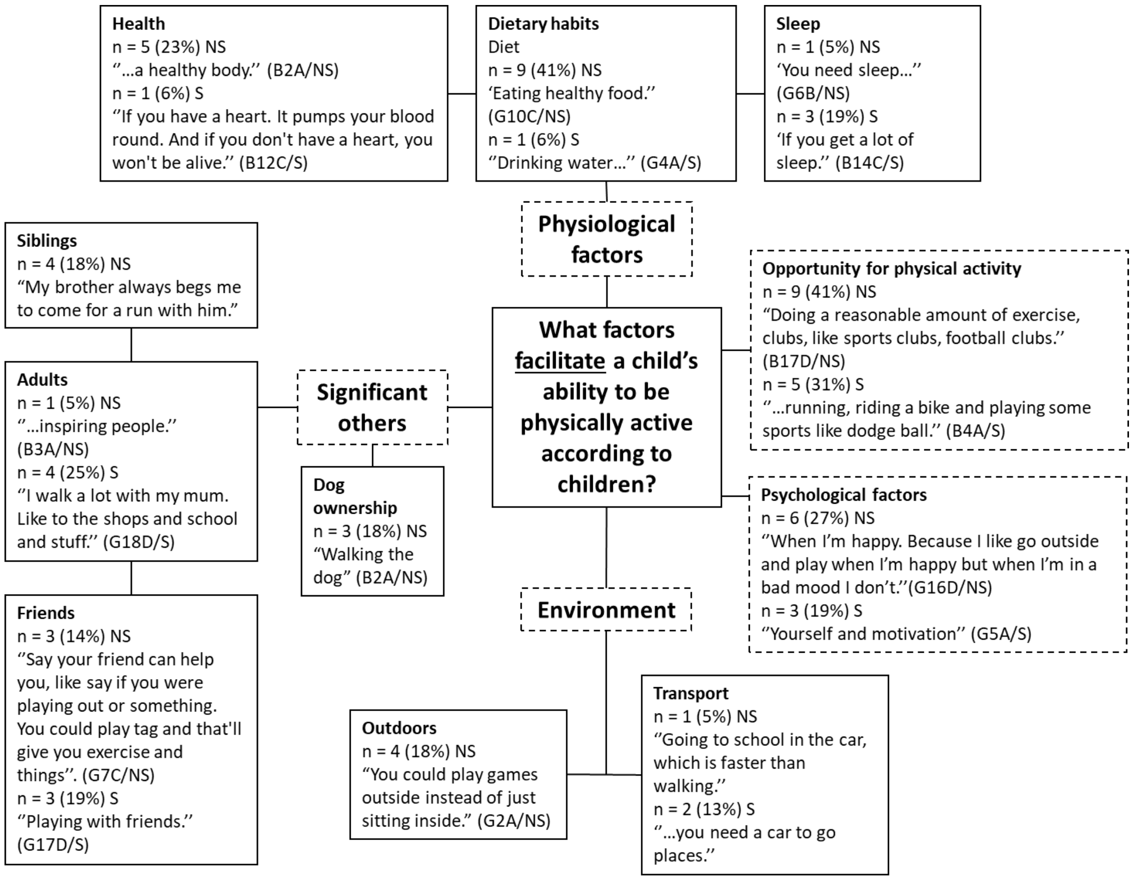


Figure 4.9. Pen-profile demonstrating what factors facilitate a child's ability to be physically active according to children from non-smoking (NS) and smoking (S) homes. Percentages represent the proportion of each group that contributed to the theme for children from smoking (n = 22) and non-smoking homes (n = 16).

Opportunity for physical activity (n=14, 37%) was a theme generated from responses of children from both smoking and non-smoking households, with participation in various clubs and different types of physical activities noted. Although it did not constitute a theme, one child noted that being active from a young age would encourage PA later in life: 'Like if you be really active when you're little, then you can grow up to be more active. Like you want to be active then.' (G6B/NS).

Psychological factors were also discussed positively in relation to factors which facilitate a child's ability to be active (n=9, 24%), with children from non-smoking homes (n=6) and smoking households (n=3) describing positive attitudes such as 'determination and commitment' (B3A/NS) and 'when you're energised.' (G4A/S).

A theme of environment (n=7, 18%) was generated which consisted of outdoors (n=4, 11%) and transport (n=3, 8%). Outdoors was a factor only discussed by children from non-smoking homes, e.g. '…like say if you were playing out or something. You could play tag and that'll give you exercise and things.' (G7B/NS). Transport was discussed by both children from smoking homes (n=3, 8%).

4.3.4.3. How do adults limit or facilitate children's PA according to children from smoking and non-smoking households?

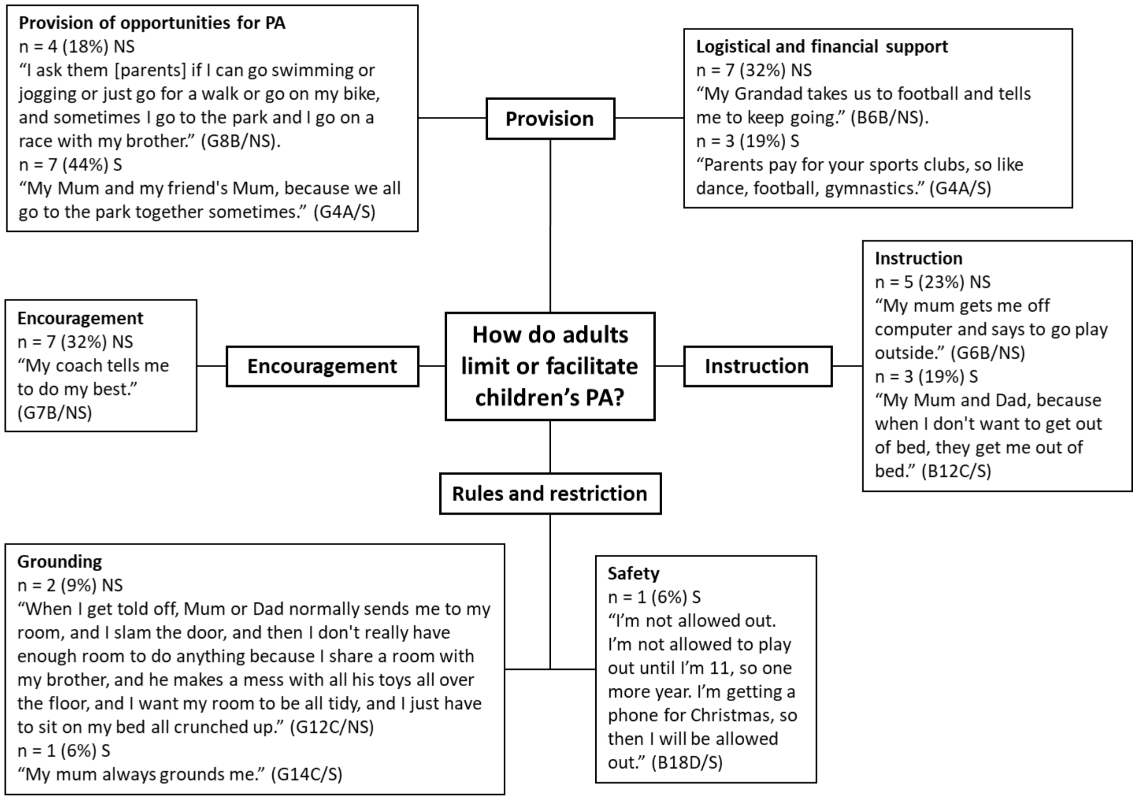


Figure 4.10. Pen-profile demonstrating how adults limit or facilitate a child's ability to be physically active according to children from non-smoking (NS) and smoking (S) homes.

Children from smoking (n=14) and non-smoking households (n=10) commonly identified parents as positive influences on their ability to be physically active (n=24, 63%) (Figure 4.10). Less frequently, parents were identified as negative influences (n=6, 16%) for children from smoking (n=2, 13% of children from smoking homes) and non-smoking homes (n=4, 18% of children from non-smoking homes). Other family members including siblings were identified as positive influences on PA by children (n=4, 11%) of non-smoking (n=3) and smoking homes (n=1). Coaches and teachers were identified as positive influences by children from non-smoking households only (n=11, 50% of children from NSH), whereas friends of family were identified as positive influences by children from smoking homes only (n=2, 13% of children from SH).

Four higher order themes were generated in response to the discussion about how adults influence children's ability to be physically active including provision (n=21, 55%), instruction (n=8, 21%), encouragement (n=7, 18%), and restriction (n=4, 11%). Provision was split into two sub-themes, logistical and financial support (n=10, 26%) which describes provision of financial and logistical support for participation in sports clubs, training and organised activities, and provision of opportunities for PA (n=11, 29%), which describes physical activities which are not part of sports clubs, or regular training. Children from smoking (n=3, 19%) and non-smoking homes (n=7, 32%) often commented on how adults facilitate organised PAs through logistical and financial means, for example, '[Adults] take you to football training.' (B2A/NS). Children from smoking homes discussed provision of opportunities for PA (n=7, 44%) more frequently than children from non-smoking homes (n=3, 18%): 'My Mum and Dad normally walk me round the block and all that, and then sometimes I go on a bike ride with my Dad.' (G4A/S).

Children from non-smoking homes described how encouragement from adults helped them to be physically active (n=7, 32%), for example 'My bother goes to 5Fit and makes me want to go' (B7B/NS), whereas children from smoking homes did not discuss encouragement. Rather, children from smoking homes discussed instruction from adults (n=3, 19% of children from smoking homes), as did children from non-smoking homes (n=5, 23% of children from non-smoking homes). Children described how parents (in both smoking and non-smoking homes), will give instructions to be more physically active, for example, 'My Mum will tell me to go outside and have a play outside instead of sitting in.' (G4A/S), and 'My mum tells me to go on a run with my sister, or if she doesn't do that, she tells me to take the dogs.' (G15D/NS).

The theme of rules and restrictions was comprised of two sub-themes; grounding (n=3, 11%), safety (n=1, 3%). Children from both groups reported that grounding as a punishment limited their ability to be physically active. One child from a smoking home also reported that parental concerns for safety prevented him from being physically active (Figure 4.10), whilst another child reported that they were not always able to go places to be physically active for logistical reasons; ‘I have to stay at home because there's not enough room in the car.’ (G13C/S).

4.3.5. RQ4. What Are Children’s Perceptions of Their Own Fitness and Does this Differ for Children from Smoking and Non-smoking Homes?

Children were asked, ‘How physically fit do you feel, on a scale of 1-10? With 1 being not very fit at all, 10 being the fittest you could be.’ The median self-perceived fitness score given by children from non-smoking homes was 8.0 (range 2-9), and 8.0 (range 1-10) for children from smoking homes (Mann-Whitney U test p = 0.925). Whereas only 6% (n=1) of children from non-smoking homes rated their own fitness as the maximum level (10 out of 10), 21% (n=3) of children from smoking homes rated their own fitness as the maximum level. Two children from smoking homes rated their own fitness as 1, whereas the lowest score provided by the children from non-smoking homes was 2.

Children were provided with five photographs (Figure 4.4). Participants were asked to put the photographs on the PCERT scale (Figure 4.3) which they were familiar with from the laboratory-based aspect of the research as described in section 4.2.3. All but two (95%) of the participants rated walking as the easiest activity. Differences were observed between household smoking status groups as well as sex differences between how difficult the children rated the remaining activities. Overall, at least half of boys (n=4, 50%) and the majority girls (n=5, 63%) from smoking homes rated running as the hardest activity with descriptions such as ‘Running, it's kind of hard because it tires me out’ (B4A/S) and ‘I just don't like running’ (G5A/S). Boys and girls from non-smoking homes did not rate running as the hardest, but most commonly rated gymnastics (n=7, 64%) and monkey bars (n=5, 45%), respectively, as the hardest activities. Table 4.3 summarises the consensus from boys and girls from smoking and non-smoking homes as to the difficulty of each physical activity.

Table 4.3. Activities ranked in overall order of 'hardest' to 'easiest' as described by participating children, by household smoking status and sex.

	Non-smoking Boys	Smoking Boys	Non-smoking Girls	Smoking Girls
Hardest	Gymnastics	Running	Monkey bars	Running
	Running	Gymnastics	Running	Gymnastics
	Swimming	Swimming	Swimming	Monkey bars
	Monkey bars	Monkey bars	Gymnastics	Swimming
Easiest	Walking	Walking	Walking	Walking

Once the children had arranged the pictures onto the PCERT scale, they were asked to describe and explain their choices. Example responses from one girl (smoking household), and one boy (non-smoking household) are demonstrated in Figures 4.11 and 4.12.

Figure 4.11. Example result from pictorial task for (G4A/S).

Participant G4A/S explained her choices:

'Walking a one, swimming a two, running a five or a six, gymnastics a three, and the park a four. Walking's easy because it's everyday stuff. Swimming, I've been swimming since I was three and a half, so it's kind of in my blood. Gymnastics, I've done that for a few years, so it's like easy. The park, I go to the park all the time with my little brother and my Mum, my Dad and my dog. And running, I just don't like running.’ (G4A/S).

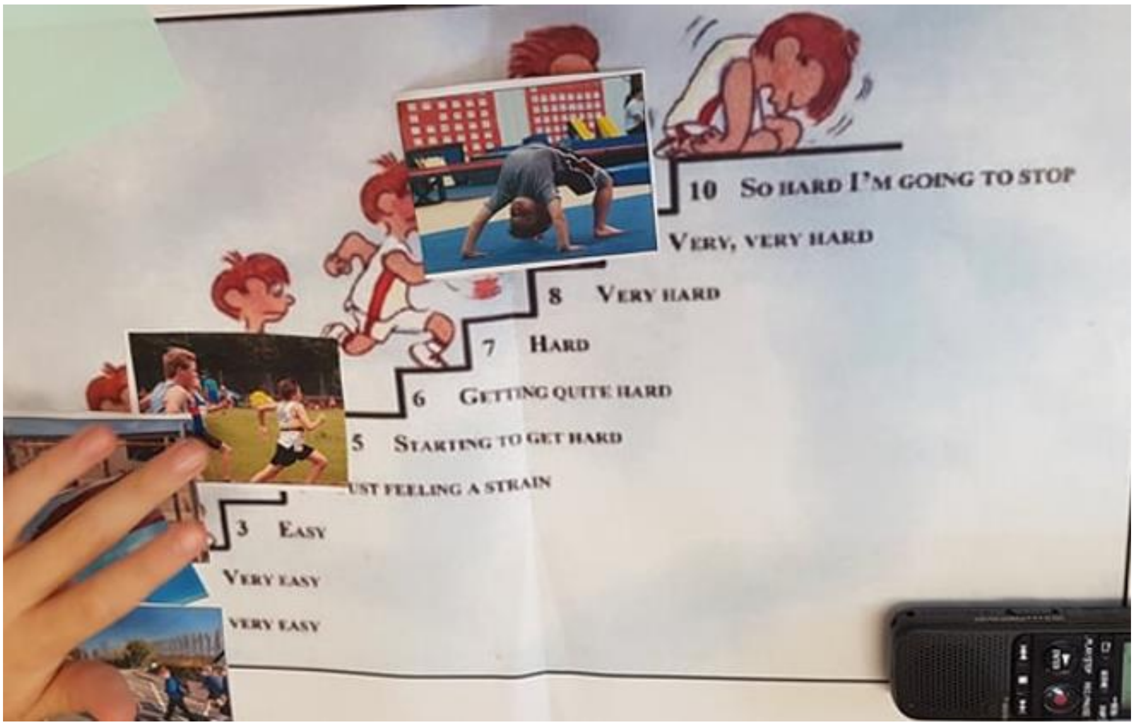


Figure 4.12. Example result from pictorial task (B15D/NS).

Participant B15D/NS explained his choices:

‘Walking easy, swimming, I find that just easy. Monkey bars are easy as well. Running is like easy at the start, then at the end gets harder. Crab, I can’t do that at all.’ (B15D/NS).

When asked at which intensity on the PCERT scale the children would prefer to work at during physical activity, most children expressed that they like to work hard; with median preferred intensity of 7 (range 4-10) and 10 (range 3-10) for children from non-smoking homes and smoking homes respectively. Four children from smoking homes said they would prefer to work at an intensity of 10 out of 10, compared to only one participant from a non-smoking home. Many children commented that they would like to work at a range of intensities; ‘I would prefer to go there (10) until I'm all tired out, and then I can just go down to one.’ (B13C/S). One participant provided a reason for her choice of 9 out of 10: ‘I would say a nine because if it's a ten, it [PCERT scale] says “so hard you're going to stop”. You don't want to stop, because then you don't do nothing. But nine's really, really, hard, so you're working as hard as you can.’ (G3A/NS).

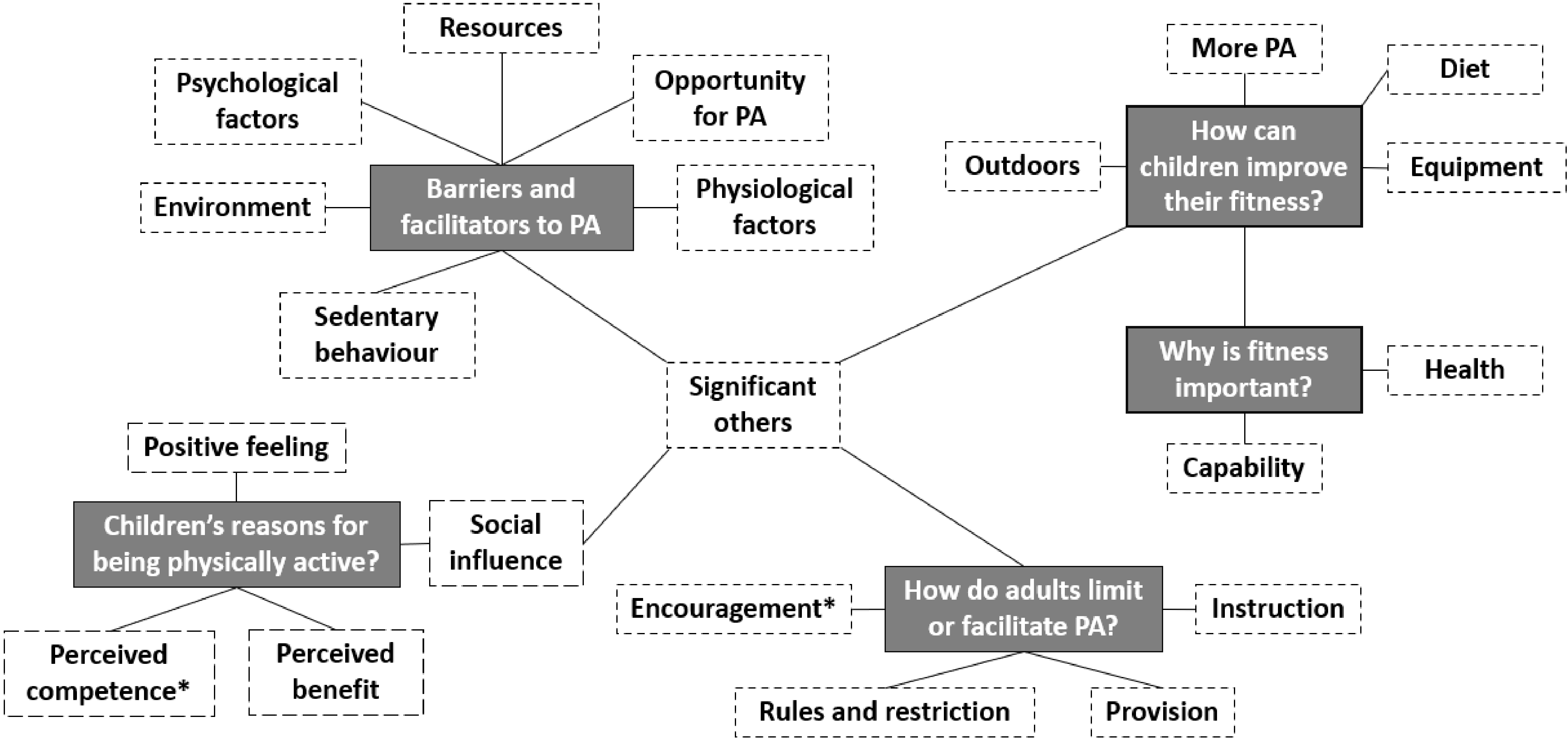


Figure 4.13. Overarching thematic map showing overlapping themes in relation to research questions.
* Indicates themes generated from participants from non-smoking households only.

4.4. Discussion

4.4.1. Summary

The aim of this study was to explore children from smoking and non-smoking homes' attitudes, thoughts, beliefs, and perceptions surrounding physical activity and fitness, using qualitative and interactive methodologies. The results demonstrate similarities and differences for the above for children from smoking and non-smoking homes.

Children noted taking part in PA for reasons linked to positive feelings, social influence, and perceived benefit. Children from non-smoking households also noted that they took part in PA for reasons linked to perceived competence. Fitness was important to children from non-smoking households for health, performance, and future benefit, whereas children from smoking households believed fitness was important to them to avoid negative physiological consequences. Children believed more physical activity, significant others, the outdoors, active equipment, and a good diet could assist them in improving their fitness. The perceived barriers and facilitators to PA were centred around psychological factors, physiological factors, significant others, the environment, resources, sedentary behaviour, and opportunity for PA. The majority of children perceived their CRF to be higher than their actual CRF level. Variances were observed for the ranking of physical activities by difficulty between boys and girls, and exposure group. A handful of themes, including significant others, opportunity for PA, health, and the outdoors, were found to be especially significant to participants and overlap of these themes was apparent across the research questions.

4.4.2. What is Physical Activity?

When prompted to describe physical activity in three words, the most common words used by both groups of children included sports, football, running, and swimming. This finding may reflect the sports of the UK national curriculum for key stage 2 (Department for Education, 2013), with 68% of children age 7-11 years taking part in team sports, 46% taking part in running, and 31% taking part in swimming activities (Sport England, 2019). All participating schools in the study are within Merseyside which has strong community links to the two major football clubs. Football clubs in Liverpool have a history of working with the community with schemes such as 'Football in the Community' (Parnell et al., 2013) and the city of Liverpool has a rich football culture

(Evans & Norcliffe, 2016). This, alongside the fact that football is a highly popular sport globally, may be reflected in the participant responses which often centred around football.

The word ‘fun’ was used to describe PA by children from non-smoking homes more frequently than children from smoking households. In a previous study with children, fun was often reported as a major predictor of participation in PA, rather than health benefits (Allender, Cowburn, and Foster, 2006). Parry (2013) has shown that enjoyment of PA at age 10 is associated with PA in adulthood. Children from non-smoking households in the present study also used words such as ‘health’ and ‘healthy’ to describe PA, whereas children from smoking households did not. Whilst children from smoking households more often used words to describe what PA is, children from non-smoking households used words to describe PA in terms of positive associations such as ‘fun’ and ‘healthy’. The one negative word used to describe PA, ‘tiring’, was provided by a participant from a smoking household.

4.4.3. RQ1. What Are Children from Smoking and Non-smoking Households’ Reasons for Being Physically Active?

The findings support the main hypothesised mediators of physical activity in children; self-efficacy, enjoyment, perceived benefits (Lubans, Foster, Biddle, 2008) and social support (Cohen et al., 2017). The findings also align with previous research that identified the top reasons why children found physical activity ‘fun’ as being skilled and competent in PA, being active with family members, learning new skills and knowledge, feelings experienced during movement, competition and winning (Hopple, 2018). Although Hopple (2018) specifically explored why children find PA *fun*, as opposed to the reasons children *take part* as in the current study, the same factors of feelings, social influence, perceived competence, and perceived benefit, appear to be important factors in children’s PA according to children. Reviews (Biddle et al., 2011; Sallis, Prochaska & Taylor, 2000) have identified major correlates of PA in children of which perceived competence, sensation seeking, and previous PA, were major correlates, which relates to the themes of positive feeling, perceived competence, and the subtheme of prior experience generated in the current study.

Children from both smoking and non-smoking homes identified reasons for participation related to fun and enjoyment, but only children from non-smoking homes provided reasons relating to feeling good. For example, participants from non-smoking homes described positive feelings they get from swimming '…you feel good after you've been swimming' (B7B/NS), and cycling 'I like the feeling of being able to go really fast really easily' (B17D/NS). Social Cognitive Theory (Bandura, 1986) identifies cognitive (personal), behavioural, and environmental factors that influence behaviours. Outcome expectations are personal factors that relate to behaviour, and when outcome expectations are positive, there is greater chance of engagement with the behaviour (Bandura, 2004). In the case of the participants in the present study, positive outcome expectations were observed for both groups of children, although more frequently for children in the non-smoking group. Heitzler et al. (2006) found positive outcome expectations or beliefs about the benefits of PA to be related to children's participation in PA. O'Dea (2003) used focus groups with similar aged children, where participating children also highlighted enhancement of physical sensation as a benefit of PA. Participants from smoking households were found to have lower CRF levels than the children from non-smoking households (Chapter 3), which may be reflected in these participants responses. In later focus group questions, children from smoking homes indicate that they find vigorous PA more difficult than their non-smoking household counterparts which could explain why these participants do not refer to feeling good physically during their chosen PA. It is interesting that children from smoking homes did not discuss feeling good physically as a reason for participation, despite reflecting positively on their chosen favourite physical activities. This original finding warrants further research which may unearth further differences in how children from smoking and non-smoking homes feel when taking part in PA.

Children also reported taking part in PA for reasons linked to autonomous forms of extrinsic motivation through perceived benefits of such as activities, including health, exercise, and to learn skills and techniques. Overall, these findings are in line with O'Dea (2003) which found children's perceived benefits of PA to include psychological status, physical sensation, sports performance, and social benefits (O'Dea, 2003). However, children from non-smoking households were more likely to report perceived benefits such as exercise and health, than children from smoking homes. Children from non-smoking households appeared to be more aware of the health benefits of PA, ‘Football, because it’s healthy.’ (B2A/NS), and that PA fulfils the need for regular exercise. Non-smoking adults are more likely to be physically active than smoking adults (Salin et al., 2019), and children from non-smoking homes may be echoing parents’ opinions when they state that they take part in PA because it is ‘exercise’ and ‘healthy’. The finding may also be an indication that the participants from non-smoking households have greater health literacy (Nutbeam, 2008) and physical literacy (Whitehead & Durdon-Myers, 2018) and demonstrate greater knowledge and understanding of the benefits of PA and health behaviours. Studies have shown that SES is associated with health literacy (Protheroe et al., 2017), with children whose parents have high educational background more knowledgeable about health topics (Schmidt et al., 2010), and children from high and medium-SES perceive PA participation to be of greater importance (Seabra et al., 2013). Further research could explore the level of understanding regarding the benefits of PA and CRF for children from smoking and non-smoking households. Such information could inform interventions centred around health education, which may need to target low-income and/or smoking families.

A theme of competence, which consisted of ability and prior experience, was developed from the responses of children from non-smoking households only. Competence motivation theory states that individuals are driven to engage in activities to demonstrate their skills, and high perceptions of competence lead to increased competence motivation (Harter, 1978). Reasons for taking part in PA relating to competence, e.g. ‘because I’m good at it’, were common for children from non-smoking homes and relate to competence motivation. Although self-perceived competence is discussed further below, it is worth noting that De Meester et al. (2016) showed perceived motor competence to be associated with higher levels of PA, regardless of actual motor competence. Parry (2015) used longitudinal data to show that perceived ability at age 10 was associated with sport motivation at age 16, and that perceived ability is a crucial mediator of the relationship between participation and enjoyment. Perceived competence was not a reason provided by children from smoking households, which suggests other factors are more important drivers for PA in this group. A study by Welk & Schaben (2004) showed that when given similar opportunities to be active, some children will seek out ways to be active whereas others choose to be less active, a finding thought to be mediated through perceived athletic competence. Self-perception of fitness is explored below but more detailed research exploring children from smoking households' self-perceptions of motor competence would provide useful information about whether perceived competence is lower in this group, or less important than other drivers of PA, compared to children from non-smoking households.

4.4.4. RQ2. What are Children from Smoking and Non-smoking Households' Attitudes Towards Physical Activity, Exercise, and Fitness?

4.4.4.1. Awareness of the physical activity guidelines

Twenty four percent of participants stated that children should do 60 minutes of PA per day which is in line with the current UK guideline for youth PA which states children should do at least an average of 60 minutes MVPA per day (Department for Health and Social Care, 2019). Therefore, approximately three in four children were unaware of the current UK PA guidelines, which suggests more promotion of the PA guidelines are needed for children in this age group. When split by household smoking status, children from smoking households most often stated that children should do 90 minutes per day, whereas children non-smoking households more frequently stated that children should do 60 minutes per day. Knowing how much PA children are recommended to do could be a potential facilitator for some children (Roth & Stamatakis, 2010). For girls aged 11-15, Roth and Stamatakis (2010) found that knowing the PA guidelines was associated with meeting them, but the association was weak among boys. A Northern Ireland study with adults found that 47% of respondents were unaware of the PA guidelines, with males with lower education, more deprivation, and females who are younger and in poor health, more likely to be unaware of the guidelines (Hunter et al., 2014). As the present study highlights disparity in knowledge of the PA guidelines between children from smoking and non-smoking households, physical activity promotion strategies should aim to include improvements in awareness of PA guidelines for children in this age group.

4.4.4.2. Is fitness important?

Fitness was important to all participating children but there were similarities and differences between the two exposure groups as to *why* fitness is important. The most prevalent reason centred around capability, which was made up of physiological consequences, performance, and future capability, with the latter two more important to children from the non-smoking household group. The theme of future capability encompassed children's beliefs that being fit would benefit them as adults in several ways including in their careers; 'because when I'm older I want to be an actress, and I want to be able to do a lot of stunts' (G2A/NS), and in family life; 'So when you're an adult and you have kids, and you take them out and make sure they're fit as well' (G12C/NS). Children may be reflecting on what they have seen and heard from influential adults in their lives, including parents and teachers. The children are also showing evidence of 'future thinking' (Atance, 2008) and an element of delayed gratification (Carlson et al., 2018; Mischel, Shoda, Rodriguez, 1989) by acknowledging that fitness is important not just for the present, but also for their future selves.

Children from non-smoking homes described health reasons for why fitness was important; 'Because it's good for your body and your bones and stuff,' (G8C/NS). When children from smoking homes discussed exercise as important to health, this was often centred around weight status. Similar perceptions that fitness is the absence of overweight has been found in previous research with children (Powell & Fitzpatrick, 2015) who's responses to what fitness means is mirrored by those of children in the present study; 'Getting fit basically just means, like, non-fat'. The differences in responses in children from smoking and non-smoking homes as to why fitness is important may be due to echoing of parental attitudes but might also be reflecting these children's individual concerns and insecurities as participants from smoking homes were found to be more likely overweight or obese (Chapter 3).

As well as health, children from non-smoking homes felt fitness was important to them for reasons relating to performance (in PA and sport), whereas children from smoking homes were more concerned with the physiological consequences of fitness. The variation may be explained by differing levels of fitness between the two groups. As stated above, the children in this study from smoking households have lower CRF (Chapter 3), and 'getting out of breath' was mentioned more by these children than those from non-smoking households.

4.4.4.3. How can children improve their fitness?

There was consensus across both exposure groups as to how children believed they could improve their fitness, with slight differences in relation to themes, of which could be mapped on to the socioecological model including individual, social, and environmental factors (Richard, Gauvin, & Raine, 2011). Overall, children believed they could improve their fitness by increasing physical activity, through significant others, spending more time outdoors, improving their diet, and with the use of active equipment.

Children from both groups identified individual factors such as diet and weight status for improving fitness, which suggests children are thinking about the larger picture of physical fitness rather than CRF only. A US study with similar aged participants found that most children did not usually think about food choices (Borra et al., 2003). Children have limited control over their own diet, as one participant suggests she can improve her diet with the assistance of a parent 'I would say to my Mum, "I'm not having any like carbs or junk for maybe two months or something.'" (G8B/NS). Children identified that they should consume less 'junk' food and 'fast food', and more 'healthy food' instead. Although 'healthy food' was not further defined by the children in this discussion, previous statements by the children defined healthy food and drink as fruit, vegetables, and water.

Children identified parents, friends, and dog ownership as social factors for improving fitness. Interestingly, only children from smoking homes identified dogs as way of improving their fitness, in terms of taking their dogs for more regular walks, whereas only children from non-smoking homes identified parents. Yet the reverse finding is apparent when children were asked about facilitators for PA (see 4.4.5.1). Parents that value PA and fitness serve as role models, transmitting their desirable habits to their children (Anderssen, Wold, & Torsheim, 2006) and parental exercise is positively associated with children's sport participation and fitness (Cleland et al., 2005). Social factors are key determinants of PA in children, with participation with family and friends positively correlated with PA in children (Ramirez, Kulinna & Cothran, 2012; Gustafson & Rhodes, 2006). PA participation has been associated with an array of psychosocial benefits for children (Eime et al., 2013) including emotional control, relationship building (Holt et al., 2011), social well-being (Linver, Roth & Brooks-Gunn, 2009), sportsmanship and teamwork (Wiersma & Fifer, 2008). Interventions to improve fitness in this population should consider the impact of social influence and significant others, which could be utilised to enhance interventions. As social factors are important to this population of children, peer-group or family focused interventions may be an effective strategy for improving CRF.

In terms of environmental factors, often the two ideas of more PA and spending time outdoors would go hand-in hand, for example, ‘Getting outside more and start being more active’ (G9B/S). To improve their fitness, the recommendation of children in the present study is to be more physically active and spend more time outdoors. The children’s suggestions are sensible as research shows time spent outdoors is positively associated with MVPA (Cooper et al., 2010; Pearce et al., 2014, Oreskovic et al., 2015), and MVPA is itself a determinant of CRF in children (Zaqout et al., 2016). A systematic review by Hoyos-Quintero and García-Perdomo (2019) concluded that environmental factors, such as play in open spaces, has strong influence on children’s PA in early childhood, although the review focussed on a younger population than the present study.

The provision and availability of equipment, for example, bicycles, scooters, treadmills, and trampolines, were often referred to by children from both smoking and non-smoking homes. According to Dumuid et al. (2016) possession of active play equipment is not necessarily related to children’s MVPA, with the exception of bicycles, which is demonstrated by an insightful quote by a participant in the present study: ‘I think I should have my friends in more, because I have a big trampoline, but I usually don't go on it unless I've got someone to go on it with, and that way I'll be exercising and enjoying myself’. The gap between active equipment ownership and equipment use may explain inconsistencies in the literature regarding the relationship between ownership and MVPA (Harrington et al., 2016; Dumuid et al., 2016). Previous studies have found that that children from low-income households, of which most participants in the present study are from, had lower access to active play equipment such as bikes and jump ropes (Tandon et al. 2012) and lower access to a garden or green space for outdoor play (Mueller et al., 2018; Hughey et al., 2017). Interventions seeking to improve MVPA and cardiorespiratory fitness in this population should therefore consider strategies that support accessibility to outdoor spaces and the use of active equipment. Further research could illuminate the level of access to outdoor space and active equipment for children from smoking households, which would determine whether this group require specific interventions to improve access to the above.

4.4.5. RQ3. What Are the Perceived Barriers and Facilitators to a Child's Ability to be Physically Active and Does this Differ for Children from Smoking and Non-smoking Homes?

4.4.5.1. Perceived barriers and facilitators

As a number of factors were described as both facilitators and barriers of PA by the participants, such themes are discussed in conjunction below. For example, psychological factors were discussed positively as facilitators, such as 'feeling motivated', as well as negatively as barriers, e.g. 'being in a bad mood'. Psychological status appeared to be an important facilitator and barrier to both groups of participants, a finding consistent with previous research in youth (Abdelghaffar et al., 2019). Intrinsic motivation for PA and sport has been found to be associated with PA, particularly in boys (Schneider, 2018) and overweight and obesity is linked to less positive attitudes toward PA (Deforche, Bourdeaudhuik, & Tanghe, 2006). A study by Chen & Gu (2018) has shown that adolescents with positive attitudes towards PA are more likely to be active and have higher CRF.

Participants believed that opportunities for PA, for example taking part in sports, facilitated their ability to be active. In a similar study in the US which utilised focus groups to explore perceived barriers and facilitators for PA, accessibility to PA was found to be a major barrier as parents and children voiced concerns that there was little access to PA opportunities (Beaulac, Bouchard & Kristjansson, 2009). Taking part in sports, whether as part of a club, at school, or unstructured with friends, was often discussed as an opportunity to facilitate PA for the participants in the present study. Coté et al. (2009) highlight five psychosocial benefits conferred from sampling a range of sports during childhood: 1) life skills, 2) prosocial behaviour, 3) healthy identity, 4) diverse peer groups, and 5) social capital. Studies have also shown that childhood sport participation is an important correlate of PA in adulthood (Parry, 2015). Additionally, organised sport participation has been found to be associated with increased fitness levels, irrespective of enjoyment (De Meester et al., 2020). However, studies have demonstrated that financial barriers can restrict sport participation among children from low-SES (Clark et al., 2019; Holt et al., 2011) and participants in the present study, who are generally low-SES, did in fact identify finance as a barrier to PA participation. Children from low income families spend less time in out-of-school structured activities, such as sport sessions, but may make up PA time in unstructured activity (Voss et al., 2008). However, structured PA may confer additional benefits and increased MVPA (Kinder et al., 2019; Pearce et al., 2018).

Activity promoting voucher schemes offer valuable assistance to deprived communities to overcome financial barriers to PA (Reece et al., 2020; James et al., 2018), conferring improvements in MVPA, fitness, and socialisation, as shown by previous feasibility studies (Christian et al., 2016; Lowther, Mutrie, & Scott, 2002). In addition to sports, participants often referred to unstructured opportunities for PA such as running, walking, cycling, playing with friends. Brockman et al. (2009) found that UK children from low-SES schools reported participating in more unstructured activities such as 'free play' with friends, whereas children from middle/high SES schools engaged in more sports clubs and organised activities. However, structured activities require scheduling and time, and time availability was a barrier identified by children from non-smoking homes only. Discussion by children from non-smoking households reflected their commitments to other organised activities and sports clubs, not having enough time in the day, and having to wake up very early to get to morning training. Intervention strategies to improve PA in children should therefore be population and context specific. As participants from non-smoking households appeared to have access to structured PA, interventions could focus on provision of structured and unstructured opportunities for PA to low-SES families, perhaps through the provision of sport participation vouchers as described above.

The theme of the environment was made up of facilitators (transport and the outdoors) and barriers (transport and school). Children discussed the need for transport to get to places where they can participate in PA. Lack of transport was discussed as barrier by one participant from a smoking household, and is identified by low-SES groups in previous studies (Holt et al., 2011). There is a large amount of research exploring transport and physical activity (Larouche et al., 2014; Faulkner et al., 2009) including the benefits of active travel (Larouche, Mitra & Waygood, 2020). Participants in the present study rarely discussed active travel which may indicate a lack of awareness of opportunities to improve PA. Methods for active transport could be better promoted with this population, increasing awareness of opportunities for PA in order to achieve 60 minutes of daily MVPA. Although children did comment that school and homework prevented them from being active, previous discussions indicated that children took part in PA at break, lunch and after-schools clubs, but analysis of PA during the school day was not within the scope of this research. Although not discussed as a facilitator by children from smoking homes, a theme of outdoor play was developed from the responses of children from non-smoking households. Access to outdoor space is a correlate of PA (Wheeler et al., 2010) and increased outdoor time is associated with more minutes MVPA (Klinker et al., 2014). Parents of lower educational backgrounds have been shown to use yards as provision for PA with young children more frequently than parents of higher educational backgrounds (Määttä, Ray & Vepsäläinen, 2018). 'Outdoor play' was often discussed in conjunction with opportunity for PA, and significant others, by participants. The 'outdoors' was also discussed by participants in relation to improving fitness, and constituted a theme in relation to another research question, discussed above.

Significant others, consisting of friends, adults, siblings, and dogs, were important facilitators according to participating children, although dogs, and siblings were only noted by children from non-smoking households, and adults more frequently by children from smoking households. The provision of social support from significant others has been found to be a significant facilitator for children's PA (Lahti et al., 2019; Wilk et al., 2018; Beets et al., 2010; Beaulac, Bouchard, and Kristjansson, 2009). Social support from adults in particular, is explored in more detail and discussed further below (4.4.5.2). According to Duncan, Duncan & Strycke (2005), children from low-income families perceive less sibling social support for PA compared to children from higher income families. Similarly, in the present study, only children from non-smoking households identified siblings as facilitators of PA, often in terms of co-participation. Dog ownership, identified as a PA facilitator by children from non-smoking households, is associated with higher levels of PA (Westgarth, Christley & Christian, 2014), and greater odds of meeting PA guidelines (Westgarth et al., 2019). A qualitative study with a similar population to the present study also found that dog ownership was an enabling factor to PA (Noonan et al., 2017a).

Hohepa et al., (2007) argue that social networks, including friends and school peers, need to be considered during the development of PA promotion strategies, as low peer support has been found to be associated with reduced odds of activity in children.

Friends and peer groups have great influence on behaviour (Fitzgerald, Fitzgerald, & Aherne, 2012), and friendship groups often have similar levels of PA (Stearns et al., 2019). In the present study, children from both smoking and non-smoking homes identified friends as facilitators of PA, acknowledging that playing with friends offers more enjoyment and provided support through co-participation. In previous research, friends have been shown to enhance enjoyment (Noonan et al., 2016a; Jago, Page & Cooper, 2012) and motivation for PA (Salvy et al., 2009). Therefore, PA promotion strategies for this population could look to target friendship groups for intervention, which may have similar activity levels, and will offer the additional benefit of peer support from existing relationships.

Screen time was highlighted as a significant barrier to participating children from both smoking and non-smoking households, although screen time and technology were referred to slightly more frequently by children from non-smoking homes. Technology has been found to be a perceived barrier to children's PA in other qualitative studies (Joseph et al., 2019; Bassett-Gunter et al., 2017; Beaulac, Bouchard, and Kristjansson, 2009) and smartphone and tablet use has been shown to be associated with lower PA in adolescents (Raustorp et al., 2020). Children from smoking households expressed that sedentary behaviours (other than screen time) such as 'lying on the couch', were barriers to their PA, more frequently than children from non-smoking households who more frequently discussed screen time in particular. Tandon et al. (2012) has shown that lower SES home environments provide more opportunity for sedentary behaviour and fewer for PA, which is relevant to the participants in the present study as the majority were from low-SES. Participants from smoking households classified one sedentary behaviour, 'sleep', as a facilitator of their PA, explaining that getting enough sleep allows them to be consequently more active. This factor linked closely with the psychological factors identified by children such as 'feeling too tired'. Interestingly, all references to feeling 'too tired' as a barrier to PA were made by participants from smoking households.

Physiological factors, such as health, diet, and sleep, were discussed as both barriers and facilitators to PA. Diet was discussed far more frequently by participants from non-smoking homes than those from smoking homes. One participant identified chocolate as both a facilitator and a barrier as 'chocolate will give you a sugar rush if you eat too much' (B10C/NS), indicating a consideration for the nutritional cost and benefits of food. Children from non-smoking households appeared to be very aware of the need to eat 'healthy' food and less 'junk food' and 'sweets'. O'Dea (2003) used focus groups with child participants, who also identified 'junk food' as a barrier to PA due to the 'sluggish' feeling associated with eating such foods. As children from smoking households did not discuss diet, with the exception of one child, it may be the case that diet is neither an important perceived facilitator or barrier for these participants, or they were thinking about more direct influences on PA rather than indirect factors such as diet. Health (including injury) was discussed as a facilitator and barrier more often by children from non-smoking households. Injuries were often discussed as important barriers to PA, along with references to physiology including the heart: 'If you have a heart. It pumps your blood round.' (B12C/S). The finding that health, including 'a healthy body', is discussed more by children from non-smoking households may further indicate a greater level of health literacy (Nutbeam, 2008) or physical literacy (Whitehead, Durdon-Myers & Pot, 2018) in this group, as described above in relation to the reasons why children take part in PA.

4.4.5.2. How do adults limit or facilitate children's physical activity according to children from smoking and non-smoking households?

Children expressed that adult support was provided in the form of logistical and financial form, opportunities for PA, and through verbal instruction and encouragement. Restriction from adults was due to punishment (grounding) and safety concerns. The findings of the present study are consistent with Noonan et al. (2016a) which also found that whilst logistical forms of support are correlates with child PA, they are less influential on children's PA compared to verbal methods of support such as encouragement.

Children from non-smoking homes discussed verbal encouragement from adults as a way in which adults facilitated their PA, referring to adults as 'motivating' and that adults encourage the children to 'do their best'. Although children from smoking homes did report verbal *instruction* from adults as a facilitator for PA, for example 'get off your computer and go play outside', children from smoking homes did not refer to verbal *encouragement*. Noonan et al. (2016a) found that verbal encouragement had the greatest effect on children's emotions and their PA, although 'encouragement' also included ‘instruction’. In the present study, encouragement and instruction have been separated to show the nuances of the language used. Through the words of encouragement and instruction echoed by the children, it seems apparent that both parents who smoke and do not smoke are aware that children should be physically active and try to facilitate this through verbal methods. Brockman et al. (2009) found that children from high-SES schools were assisted in PA through actions such as logistical and financial support, whereas children from low-SES schools were encouraged through verbal encouragement and demands. Hohepa et al. (2007) found that children that receive high levels of encouragement from parents were more active, regardless of whether encouragement was provided by two parents or the sole parent. The findings in the present study are consistent with Brockman et al. (2009) with regard to low-SES, as much of the facilitation for children’s PA by adults was through the form of verbal instruction and encouragement as discussed above.

Children from smoking homes identified parental provision of opportunities for PA disproportionately more than children from non-smoking homes. Children frequently talked about how parents facilitate their PA by going to the park as a family, walking to the shops, walking to school, and other forms of unstructured PA such as cycling together. Participating parents in a study by Joseph et al. (2019) acknowledged that taking their child to specific locations, like the park, could help facilitate more PA, and parents have previously expressed the desire for more opportunities for parental involvement (Bassett-Gunter et al., 2017). Parental PA and sport participation influences offspring PA (Voukia et al., 2018; Schoeppe et al., 2016) and MVPA (Dlugonski et al., 2020), and a longitudinal study has shown parental PA to be associated with offspring PA from childhood until middle age (Kaseva et al., 2017). Parental modelling and support have also been found to relate to child and adolescent PA (Yao & Rhodes, 2015; McMinn et al., 2013). It is clear from the focus group discussions, particularly of those from smoking households, that children perceive parents to be aiding their PA levels by proving opportunities including family co-participation in PA. However, an apparent difference between the discussion of both groups of children is the type of PA provided by parents, with children from non-smoking homes more frequently discussing structured PA, which includes attending sports clubs and training. Structured PA, such as organised sport, may result in higher levels of MVPA (Kinder et al., 2019; Pearce et al., 2018) and increased levels of fitness (De Meester et al., 2020) compared to unstructured PA. However, time spent outdoors, whether structured or unstructured, results in more active time and MVPA than time spent indoors (Pearce et al., 2018). The benefits of structured PA participation are discussed above in relation the facilitators and barriers to PA and include enhanced MVPA and increased fitness, as well as many psychosocial benefits. Some children commented how 'inspiring people' and role models often motivate them to be engaged in PA. Recent research has shown that family-based interventions are rated as more 'fun' and lead to greater improvements in MVPA (Guagliano et al., 2020), and so strategies to enhance PA could therefore target co-participation via family-wide interventions, which would confer the additional benefits of social support and adult behaviour modelling. Social support from family, friends, teachers, and coaches, could also be utilised in strategies to assist children in overcoming the discussed perceived barriers to PA for this population.

4.4.6. RQ4. What are Children's Perceptions of Their Own Fitness and Physical Ability and Does this Differ for Children from Smoking and Non-smoking Homes?

No difference could be observed between the perceived fitness scores for children from smoking and non-smoking households. Most children perceived their own fitness above average (e.g. more than 5 out of 10). This finding may be explained by the better-than-average-effect; the tendency to evaluate oneself more favourably than an average peer (Alicke & Govorun, 2005). Some studies have shown that self-perception is strongly related to physical fitness and motor competence (Utesch et al., 2019; Vedul-Kjelsås et al., 2011, Chan et al., 2003), whereas others have found only moderate correlation (De Meester et al., 2016) or no correlation (Bolger et al., 2019). Most children in the present study estimated their fitness very highly, which is a similar finding to Weiss and Amorose (2005) who found that similar aged children had higher than actual self-perceptions of motor competence. Previous studies involving youth have found participants to overestimate their motor competence (De Meeser et al., 2016) and movement skill competency (Bolga et al., 2019). In terms of participation in PA, overestimation is preferred as underestimation may negatively influence motivation and greater self-perception increases participation in PA (Bolger et al., 2019). It is therefore a positive finding that children in the present study, from smoking and non-smoking households, have inflated perceptions of their own fitness, as this is likely to encourage motivation for, and participation in, physical activity. However, as self-perception accuracy increases with age (Utesch et al., 2019; Weiss & Amorose, 2005), if the children with low fitness remain low-fit into adolescence, their self-perception may decrease accordingly. Social desirability bias may have impacted the children's choices of self-perception scores, by choosing to either increase or decrease their scores based on another child's response, and due to the influence of social norms (Morgan et al., 2002). A strategy to reduce peer influence on participants' rating of their own fitness would be to have children rate their fitness individually and privately, via questionnaire for example.

Boys and girls from smoking homes both rated running as the hardest activity during the pictorial task, for reasons such as not enjoying it, and because it is 'tiring'. For children from non-smoking homes, gymnastics (boys) and monkey bars (girls) were rated as the hardest, followed by running. Differences in the perception of difficulty may be explained by children from smoking households, who generally have low CRF in this sample, as genuinely experiencing running as physiologically more difficult due to low CRF. Children's perceptions of difficulty suggest that aspects of fitness other than CRF, regardless of the metabolic demand (METs) of the activity, are used by children to determine how 'difficult' or 'hard' an activity is. For example, the 'monkey bars' require the component of fitness that is strength, whereas the 'crab' requires flexibility, agility, and strength. Participants that rated activities other than running as the most difficult may have low perceived competence in particular aspects of fitness, such as strength and flexibility, compared to CRF. The sex differences in perceived difficulty of the monkey bars and gymnastics demonstrated could also be subject to group desirability bias.

4.4.7. Strengths and limitations

The above findings should be interpreted in light of a number of limitations. Although the sample size was relatively small with 38 participants, the small sample allowed for the generation of rich data, which is a major strength of the study. Future research could expand on this sample population to include participants from other regions of the North West, and the UK, as well as participants from a wider age range. Younger children and adolescents may have different thoughts and perceptions surrounding PA and fitness, and likely vary in the barriers and facilitators they face. The majority of participants lived in neighbourhoods within the lowest two deciles for deprivation based on the English Indices of Multiple Deprivation (EIMD). However, low-SES areas were targeted in order to recruit as many tobacco smoking families as possible. The findings are therefore less applicable to children of medium-high socioeconomic status. The sample population was diverse and represented a range of ethnicities and backgrounds, with approximately 34% of the sample of other-ethnicity than White British.

Due to ethical concerns regarding eliciting anxiety within the children when considering the smoking status of their parents and family members, tobacco smoking was not discussed with the children. As a result, we were not able to gain insight into children's opinions and thoughts about smoking or second-hand smoking, or how having a smoking family member made them feel. This information would be highly valuable and could aid campaigns to prevent smoking uptake as well as smoking cessation. In addition, whilst the focus group has strengths in eliciting group discussion, there were some children that were considerably less talkative than other children. Some children may not have felt comfortable sharing their honest thoughts with the group, but this barrier was attempted to be addressed using more interactive methods, discussed as a strength below.

One strength of this research is that, to the author's knowledge, it is the first to represent the thoughts, beliefs, and perceptions surrounding physical activity and fitness for children from smoking households. This research provides a voice to a population of children who may have additional health risks due to second-hand smoke exposure and may face other barriers to PA and fitness than their non-smoking household counterparts. A second strength is the methodology which utilised activities in addition to discussion. The use of sticky notes, writing, photographs, and diagrams aided discussion and allowed shy children to communicate in alternative ways. The research aimed to elicit as much information from children from smoking households as possible, through a multitude of methods. A further strength of the work is that it is informed by a complimentary quantitative study. Analysis was able to utilise information gathered from quantitative aspects, such as fitness scores, which allowed for better informed analysis.

4.4.8. Conclusion

The purpose of this study was to use focus groups to explore the thoughts, opinions, perceptions, and beliefs surrounding physical activity and fitness of children from non-smoking and smoking households.

The findings support the main hypothesised mediators of PA in children including self-efficacy, enjoyment, perceived benefit, and social support. However, the variance in the reasons why children from smoking and non-smoking households report for taking part in PA, indicate the need for more context specific interventions. Strategies to increase participation in PA for children from smoking households could therefore focus on facilitating friendship/peer group physical activities that children regard as 'fun' and 'enjoyable'.

As less than a quarter of participants were aware of the guidelines, strategies to improve children's awareness of the PA guidelines is recommended to increase PA participation. Whilst all children agreed fitness was important to them, differences emerged between groups for *why*. Based on children's perceptions, interventions to improve CRF in this population should support access to PA participation through active equipment and safe outdoor space.

The perceived barriers and facilitators discussed are in line with previous research, but variances emerged between important barriers and facilitators for children from smoking and non-smoking homes. Strategies to overcome barriers for these groups are discussed, and should be context specific with consideration to household smoking status, and focus on the utilisation of the perceived facilitators. The majority of children perceived their own fitness to be high or above average. Variances were observed for the ranking of physical activities by difficulty between boys and girls, and exposure group, with children from smoking households rating running as the hardest.

A handful of themes overlap across more than one research question and thread through children's responses throughout the study. Such examples of these overlapping themes include health, significant others, opportunity for physical activity, and the outdoors. Significant others, which includes family, friends, and dog ownership, is a theme that is important to participants from both smoking and non-smoking households in relation to reasons why they participate in PA (RQ1), and as ways to improve fitness

(RQ2), and a key facilitator of PA (RQ3). Health was a theme developed in response to why children take part in PA such as for health benefits (RQ1), why fitness is important to the participants (RQ2), and as a perceived barrier and facilitator to PA (RQ3). The outdoors was a theme that was relevant to how children can improve their fitness (RQ2) and as a facilitator for PA (RQ3). Diet was also discussed as a way to improve fitness (RQ2), and as both a barrier and facilitator to PA (RQ3). These themes are important to the participants and therefore should have greater focus when planning interventions to improve PA and CRF.

One potential difference between the perceptions of children from smoking and non-smoking households this study has highlighted, is the understanding of the health benefits of PA and fitness, and warrants further exploration. Throughout, participants from non-smoking households demonstrated greater awareness of the PA guidelines, referred to extrinsic motivators of PA, the health benefits of fitness, and had considerations for the future self. Future work could explore and compare the level of physical literacy, in particular the psycho-social/cognitive factors, of children from smoking and non-smoking households, which may illuminate a potential area for intervention.

To the author's knowledge, this work is the first to explore and compare the perceptions of children from smoking and non-smoking households regarding physical activity and fitness. Interventions to improve the levels of PA and CRF in children from low-SES and smoking households could benefit from these child participant's perspective in order to create relevant and effective strategies.

Thesis Study Map

Study 1 The association between second-hand tobacco smoke exposure and cardiorespiratory fitness, physical activity, and respiratory health in children	**Aim:** To assess the association between second-hand tobacco smoke exposure on children's directly measured cardiorespiratory fitness ($\dot{V}O_{2peak}$), physical activity, physical activity enjoyment, and respiratory health indicators. **Research questions:** 1) Is second-hand tobacco smoke exposure associated with cardiorespiratory fitness in children? 2) Is second-hand tobacco smoke exposure associated with physical activity and physical activity enjoyment in children? 3) Is second-hand tobacco smoke exposure associated with respiratory health indicators in children? **Key findings:** • SHS exposure (as measured by the number of cigarettes smoked per household per day) was associated with reduced CRF in children. • SHS exposure was not associated with PA, PA enjoyment or respiratory measures. • SHS exposure was associated with increased BMI and weight status. • Exhaled carbon monoxide was not correlated with self-reported household smoking status or the number of cigarettes smoked per day. **Personal reflection:** Data collection days were extremely busy and had to run like clockwork to be successful. However, I have come to learn that children make the most enthusiastic of participants and I really enjoyed working with them. Whilst some results were surprising (low carbon monoxide readings, low spirometry values for children exposed to SHS), other findings, such as that SHS exposure was associated with lower CRF, increased BMI, and lower SES, were less surprising. Overall, the findings of this aspect of the research both challenged and confirmed my preconceived ideas about the effects of SHS on children's health.
Study 2 Children of smoking and non-smoking households' perceptions of physical activity and cardiorespiratory fitness	**Aim:** To use creative and qualitative methodologies to explore the attitudes, beliefs, and perceptions of physical activity, fitness, and exercise of children from smoking and non-smoking households. **Research questions:** 1) What are children from smoking and non-smoking households' reasons for being physically active? 2) What are children from smoking and non-smoking households' attitudes towards physical activity, exercise, and fitness? 3) What are the perceived barriers and facilitators to a child's ability to be physically active and does this differ for children from smoking and non-smoking homes? 4) What are children's perceptions of their own fitness and physical ability and does this differ for children from smoking and non-smoking homes? **Key findings:** • The findings support the main hypothesised mediators of PA in children including self-efficacy, enjoyment, perceived benefit, and social support. • Less than a quarter of children were aware of the PA guidelines. • Fitness was important to all children, but for differing reasons (e.g., health, performance, future benefit, to avoid negative physiological consequences).

	• The perceived barriers (e.g., sedentary behaviour, resources, environment, psychological and physical factors) and facilitators (e.g., significant others, environment, opportunities for PA, physiological and psychological factors) discussed are in line with previous research. • Children from smoking and non-smoking households showed similarities and variances in their perceived barriers and facilitators of PA. • Most children perceived their own fitness to be high, but children from smoking households rated running as more difficult than children from non-smoking households. **Personal Reflection** The children were very insightful as participants within the focus groups. Sometimes questions would be responded to with one-word answers but at other times children would demonstrate that they truly are the experts of their own lives. With a personal affinity for quantitative methods, learning to conduct qualitative research was a steep learning curve, but I have a new-found appreciation for qualitative research methods. The focus groups have allowed me to have an insight into the thoughts and feelings of children with regards to PA, and fitness, and I have found the process and results fascinating.
Case studies Using the mixed-methods case study approach to explore the behaviours and perceptions surrounding fitness and physical activity of children from smoking and non-smoking homes	**Aim:** To use a mixed-methods case study approach to provide rich, contextual insight into the lives, behaviours, and perceptions of a selection of participants, in relation to the above research aims and research questions.

Chapter 5

Case studies - Using the mixed-methods case study approach to explore the behaviours and perceptions surrounding fitness and physical activity of children from smoking and non-smoking homes

5.1. Introduction

The previous chapters have highlighted the numerous health benefits associated with cardiorespiratory fitness (CRF) and physical activity (PA) in adults and children. Chapter 3 quantitatively examined the association between second-hand tobacco smoke (SHS) exposure and CRF, PA, and respiratory outcomes. The findings indicate that children from smoking households were more likely to have lower CRF, but PA and respiratory measures were not associated with household smoking. Additionally, household smoking was also associated with overweight and obesity, and lower socioeconomic status (SES). PA enjoyment was the only significant predictor of PA, and vice versa, and SES was the only significant predictor of lung function. In order to provide additional insight to compliment the findings of Study 1, Chapter 4 qualitatively explored how the perceptions of PA and CRF vary by children from smoking and non-smoking households. The findings from Study 2 have alluded to similarities and differences between children from smoking and non-smoking homes with regard to their perceptions of PA and CRF. Therefore, this chapter aims to use a mixed-methods case study design to provide rich, contextual insight into the behaviours and perceptions surrounding PA and CRF for children from smoking and non-smoking homes.

Mixed-method case study research incorporates two complimentary approaches, offering unique methodological advantages in understanding complex research problems and issues (Cook & Kamalodeen, 2019). The primary purpose of the case study is to provide an in-depth understanding of a topic (Simons, 2009), whereas a mixed-methods case study design provides in-depth evidence for cases for comparative analysis, utilising quantitative and qualitative data and integration (Creswell & Plano-Clarke, 2018). The mixed methods convergent parallel design consists of a quantitative strand and qualitative strand, where quantitative and qualitative data collection takes place concurrently and the separate data sets are ‘merged’ and consequently interpreted as a whole. The purpose of the convergent parallel design is to obtain different but complementary data on the same topic (Creswell & Creswell & Plano-Clark, 2011). The benefit of this design is that it brings the trends and generalisations of quantitative approach together with the details and depth of the qualitative approach. Carolan, Forbat, & Smith (2016) argue that mixed methods and case study research are not separate entities, but the boundary between them is permeable and fluid.

5.2. Method

5.2.1. Design

This mixed-methods case study chapter presents data collected between September 2017 and February 2019. The research was granted ethical approval by the Research Ethics Committee of Liverpool John Moores University (Ref: 16/PBH/001). This study comprises the triangulation of the quantitative (Chapter 3) and qualitative (Chapter 4) aspects of the larger research project.

The case study approach (Sparkes & Smith, 2013) was utilised to provide rich contextual insight into the perceptions and behaviours of a sub-cohort of participants from Study 1 and Study 2. A mixed methods convergent parallel design (Creswell & Plano-Clark, 2011) was used in order to complement and triangulate the quantitative and qualitative data from the overarching PhD research project. The mixed methods convergent parallel design consists of a quantitative strand and qualitative strand (Figure 5.1). Quantitative and qualitative data collection takes place concurrently and the separate data sets are 'merged' and consequently interpreted as a whole. The quantitative and qualitative aspects of the research have been analysed and interpreted separately in Chapter 3 and Chapter 4, respectively, but the present study is concerned with interpretations from the complimentary, yet distinct, datasets provided by both laboratory-measured outcomes and focus group data collection, in relation to six distinct cases.

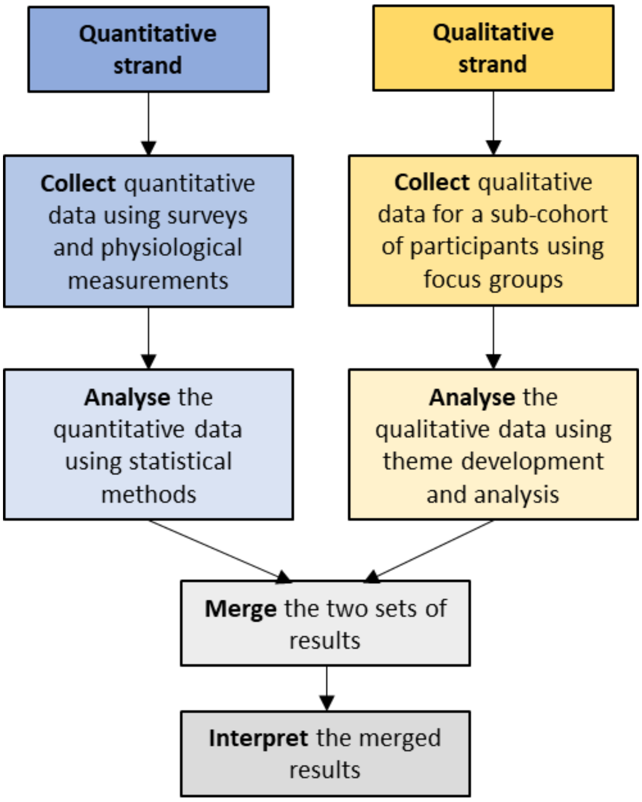


Figure 5.1. Overview of the procedures for the convergent mixed methods design of the present study. Adapted from Creswell & Plano-Clark (2011).

5.2.2. Participants

As per the larger research project, primary schools within Liverpool and Wirral areas of Merseyside, UK, were recruited using purposeful sampling. Of the 104 participating children of Study 1, 38 children participated in Study 2. Following data collection for Study 1 (Chapter 3) and Study 2 (Chapter 4), six participants were selected as distinct and interesting cases in order to reflect the varied and contrasting circumstances of the participating children and their families. Cases were purposively selected based on sex, household smoking habits, child CRF score, and PA data. Prior to writing the case studies, the research team reached consensus that the selected participants would allow the study aim to be achieved. For balance, three each of boys and girls were selected, as well as children with low and high fitness, and children from tobacco smoking, e-cigarette using, and non-smoking homes. For confidentiality, participants' real names are not presented, and pseudonyms are used.

Participants were six children (3 girls and 3 boys) in years 5 and 6 (aged 9-11 years) who attend four primary schools in Merseyside, England, UK. A summary of the six participants and key characteristics can be found in Table 5.1.

5.2.3. Procedures

Data collection was undertaken as per Study 1 (Chapter 3) and Study 2 (Chapter 4). Data was collected for the quantitative (Study 1) and qualitative (Study 2) strands and triangulated for each case to provide insight into children's behaviours and perceptions surrounding PA and CRF. See sections 3.2 and 4.2 for full details of the quantitative and qualitative data collection procedures, respectively. A case study is expected to catch the complexity of a single case (Sparkes & Smith, 2013) and the case studies in this study were constructed as 'profiles' for each of the six children using as much data as was available from the quantitative and qualitative data sets.

In summary, after parental consent, child assent, and completed parental surveys, exhaled carbon monoxide measurements were made on the morning of the University visit. Once at the university, participants' anthropometric data was recorded. FeNO measurements were taken prior to spirometry, and children participated in cardiopulmonary testing once all respiratory measures had been completed. Children completed surveys in-between testing with the help of a school teaching assistant or a member of the research team. Additionally, participant postcodes were used to establish approximate distance from the school (as the crow flies), and to determine the availability and accessibility of green space and parks.

Following quantitative data collection, a sub-cohort of participants was selected for Study 2 which comprises the qualitative element of the larger research project. Focus groups provided rich qualitative data regarding children's perceptions of PA and CRF. For each case, as much qualitative data as possible was extracted from the focus group transcripts, from all aspects and questions of the focus groups. If there was ambiguity as to which child was responsible for the statement or response it was not included, and only data (responses, discussion) that could be confidently attributed to each individual in each case was included. The statements, discussions, as well as the results from the pictorial task, are presented in line with quantitative data collected for each of the six participants in the present study.

5.2.4. Analysis

Statistical analyses of quantitative data were performed using SPSS for Windows (version 26; SPSS, Chicago, IL, US) as per Study 1. Individual values are presented for each case, and where appropriate, compared against the mean generated for the larger cohort in Study 1, to give an indication of where the individual ranks relative to the larger sample. CRF is expressed in two ways in the present study; as ratio scaled $\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$), and as allometrically scaled $\dot{V}O_{2peak}$ ($mL \cdot kg^{-0.53} \cdot min^{-1}$). Ratio scaled $\dot{V}O_{2peak}$ is calculated by simple division of the absolute $\dot{V}O_{2peak}$ by total mass (kg), whereas allometrically scaled $\dot{V}O_{2peak}$ is the absolute $\dot{V}O_{2peak}$ divided by mass to the power of the generated exponent (0.526) from Study 1. For comparison between cases, percentiles for each ratio and allometrically scaled $\dot{V}O_{2peak}$ were generated from the larger cohort sample of Study 1. Ratio scaled $\dot{V}O_{2peak}$ values ($mL \cdot kg^{-1} \cdot min^{-1}$) were also compared against percentiles for European children of a similar age (Tomkinson et al., 2017) and used to categorise children as fit or unfit according to established thresholds (Lang et al., 2019).

Table 5.1. Summary of participants and key characteristics.

Pseudonym	Sex	Age	Household smoking status	EIMD decile	BMI	Weight status	PA	PACES	Absolute $\dot{V}O_2peak$	Ratio $\dot{V}O_{2peak}$ (percentile)	Allometric $\dot{V}O_{2peak}$ (percentile)	EU	Perceived fitness
Alice	Girl	10.8	Smoking	2	23.4	Obese	4.2	4.1	1727	34.7 (10th)	221.1 (25th)	5th	8.5
Isabelle	Girl	11.5	Non-smoking	4	17.7	Healthy	3.2	3.9	2144	50.2 (90th)	297.6 (95th)	90th	5.0
Rebecca	Girl	9.9	Non-smoking	2	16.4	Healthy	3.9	4.3	1386	39.0 (25th)	212.0 (20th)	5th	10.0
Alex	Boy	10.3	Non-smoking	1	15.8	Underweight	4.3	4.1	1713	53.5 (65th)	276.7 (60th)	90th	6.5
Luke	Boy	10.3	Smoking / e-cigarette	1	21.4	Overweight	3.9	3.0	1890	42.7 (25th)	257.3 (45th)	20th	9.5
Ryan	Boy	9.9	E-cigarette	4	16.8	Healthy	3.9	4.1	1843	59.5 (95th)	302.7 (85th)	95th	9.0

Abbreviations: EIMD = English indices of multiple deprivation rank, BMI = body mass index, PA = physical activity (PAQ-C), PACES = physical activity enjoyment scale, EU = percentile based on European children for ratio scaled $\dot{V}O_{2peak}$ (Tomkinson et al., 2017).
Units: Age (decimal years), BMI ($kg{\cdot}m^{-2}$), absolute $\dot{V}O_{2peak}$ ($mL{\cdot}min^{-1}$), ratio scaled $\dot{V}O_{2peak}$ ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$), allometrically scaled $\dot{V}O_{2peak}$ ($mL{\cdot}kg^{-0.53}{\cdot}min^{-1}$).

5.3. Results – Case Studies

Six case studies are presented below, including three boys and three girls with a range of fitness levels, and from tobacco smoking, e-cigarette using, and non-smoking households.

5.3.1. Alice

Alice lives with her mother, father (unmarried), brother and two grandparents, in a neighbourhood with an EIMD rank of 3478 (2nd most deprived decile), which is representative of the study average. The family home is on a residential road that is 'sometimes busy with traffic', although very close to a major city A-road. The nearest park with substantial green space is 800 m away. The house is 1 km from the school, and Alice walks the 10 minutes to school each day. Alice's mother has a secondary school education and works as a care-worker. Both grandparents are heavy smokers and smoke inside the house without restriction, reportedly smoking a combined total of 65 cigarettes per day.

Alice is 10.8 years old, white British and has BMI of 23.4 $kg \cdot m^{-2}$ which would classify her as obese according to age and sex specific BMI cut-offs (Cole & Lobstein, 2012). Respiratory measures indicated that Alice has no respiratory diseases and has healthy lung function, but her concentration of exhaled carbon monoxide was high compared to the study average (4 ppm). Alice's ratio scaled $\dot{V}O_{2peak}$ was 34.7 $mL \cdot kg^{-1} \cdot min^{-1}$, which is around the lowest 10% for the larger cohort, and within the lowest 5% compared to normative values for European females of a similar age (Tomkinson et al., 2017). This ratio scaled $\dot{V}O_{2peak}$ value would classify her as unfit and at an elevated risk of cardiovascular disease according to established thresholds (Lang et al., 2019). Alice's allometrically scaled $\dot{V}O_{2peak}$ was 221.1 $mL \cdot kg^{-0.53} \cdot min^{-1}$, which is around the 25th percentile for the larger cohort sample. Alice perceived her own fitness level to be 8.5 out of 10. Alice explained her reason for her perceived fitness score: 'Because I don't lose my breath easily, and I like to stay active.'

Alice's self-reported PA score is 4.2, which is above the study average of 3.6. Her PA enjoyment score is 4.1 which is representative of the study average, and the number of PA activities Alice claimed to enjoy was 14, which is much higher than the study average of 9.2. Alice described PA in three words when prompted (in no particular order): sport, fitness, and exercise. During the focus group discussions, Alice contributed to the discussion noting she enjoyed sports such as football, 'because you can tackle', and swimming. Alice stated that she had been swimming since she was 3 years-old, and so swimming was ‘in her blood’. She described things that helped her to be active as the gym, having self-motivation, friends, family, and sport. Having a social life, and technology, such as phones, iPads, computers, Xboxes, are things that Alice believed prevented her from being active. Alice stated that she regularly goes to the park with her family; ‘I go to the park all the time with my little brother and my Mum, my Dad and my dog.’ Alice only negatively described one activity, stating that she did not enjoy running. Alice believed it was important to be fit ‘because it's easier to get places without losing your breath’. To improve her fitness, Alice suggested she could go outside more: ‘because you can get out with your mates and still be exercising, because with my mates, we like to go on a walk around the park with a few of our dogs.’ During the pictorial task (Figure 5.2), Alice rated the activities as the following: ‘Walking a one, swimming a two, running a five or a six, gymnastics a three, and the park a four.’

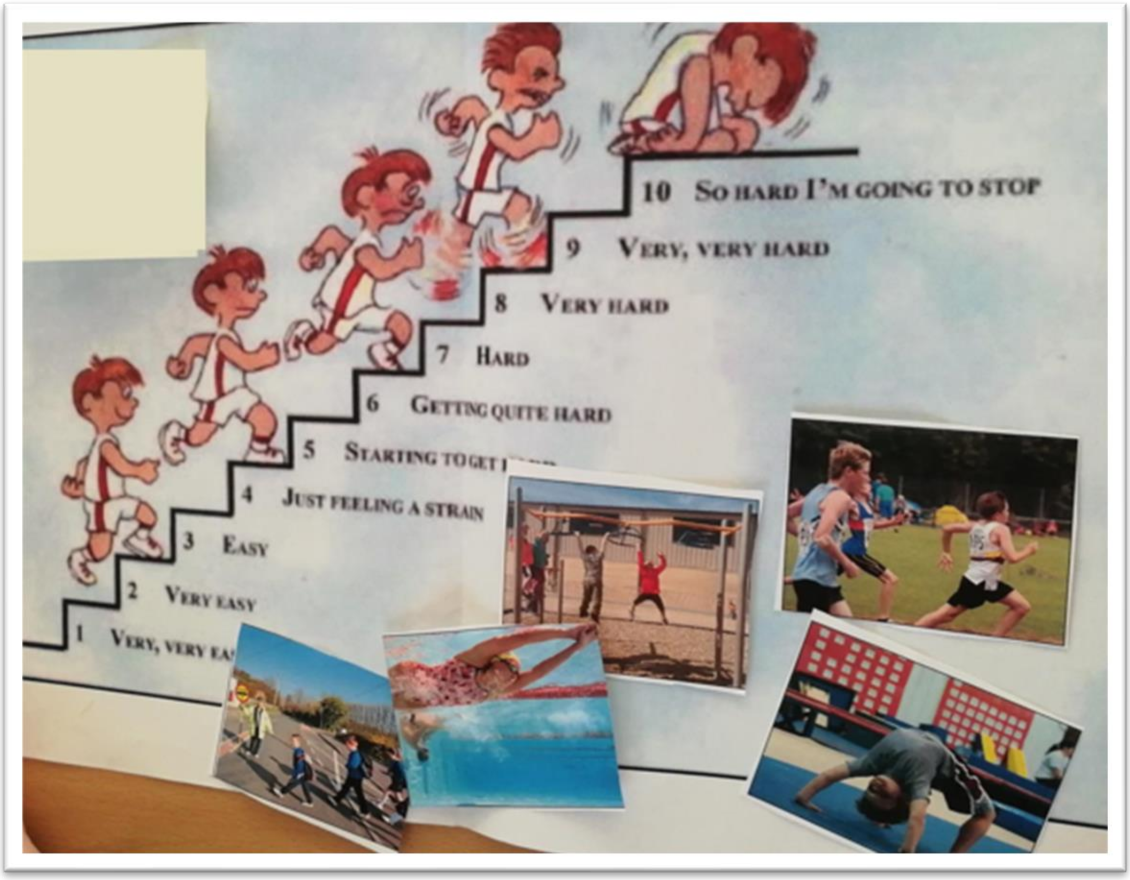


Figure 5.2. Photograph matching task for Alice.

5.3.2. Isabelle

Isabelle lives with her mother and father (married) in a neighbourhood with an EIMD rank of 11,426 (4th most deprived decile) which is considerably more affluent than the study average. The house is on a cul-de-sac, in a residential area, 200 m from a park with green space, but less than 100 m away from a busy A-road. Isabelle travels 5 minutes in the car to school each day (1 km). Isabelle's mother is further education college educated, self-employed and owns her own business. Nobody in the household smokes and smoking is not permitted in the home or outside.

Isabelle is 11.5 years old, white British, and has a BMI of 17.7 $kg \cdot m^{-2}$ which would classify her as a healthy weight according to age and sex specific BMI cut-offs (Cole & Lobstein, 2012). Respiratory measures indicated that Isabelle had no respiratory diseases and has healthy lung function, but she did have elevated levels of exhaled carbon monoxide (4 ppm) above the study average. Isabelle's ratio scaled $\dot{V}O_{2peak}$ was 50.2 $mL \cdot kg^{-1} \cdot min^{-1}$, which is around the 90th centile for the larger cohort, and also compared to normative values for European females of a similar age (Tomkinson et al., 2017). Her ratio scaled $\dot{V}O_{2peak}$ would classify her as fit and healthy according to established thresholds (Lang et al., 2019). Isabelle's allometrically scaled $\dot{V}O_{2peak}$ was 297.6 $mL \cdot kg^{-0.53} \cdot min^{-1}$, which is around the 95th percentile for the larger cohort. Isabelle perceived her own fitness level to be 5 out of 10. Isabelle explained her reason for her perceived fitness score as being 'about halfway'.

Isabelle's self-reported PA score is 3.2, which is slightly below the study average of 3.6. Her PA enjoyment score is 3.9 which is similar to the study average of 4.1, and the number of PA activities Isabelle claimed to enjoy was -3 (she disliked more activities than she liked), which is much lower than the study average of 9.2. Isabelle described PA in three words: sport, running, and football. During focus group discussions, Isabelle stated that her mother encourages her to go running with her sister; 'We go a long way, we were once out for 2 hours running!'. Isabelle also stated that when she exercises, she likes to work at an effort of around 8 to 10 out of 10. When describing the difficulty of the given activities (Figure 5.3), Isabelle described running as 'you get a bit out of breath sometimes, so it's a bit hard', but the hardest activity for Isabelle was the monkey bars; 'your arms get tired so it starts to get quite hard'. Isabelle stated that 'unhealthy foods' are something that limit her ability to improve her fitness and one way she could improve her fitness would be to 'cut down on McDonalds and KFC – fast-food.'

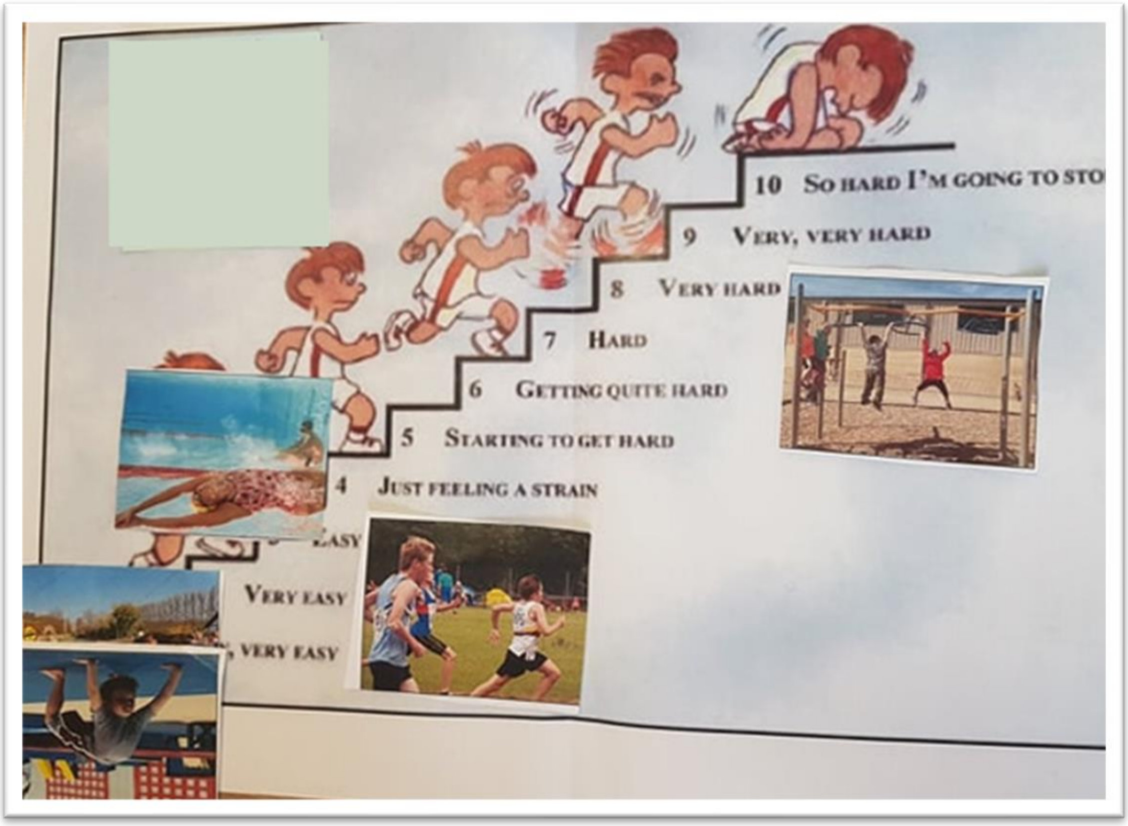


Figure 5.3. Photograph matching task for Isabelle.

5.3.3. Rebecca

Rebecca lives with her mother and father (un-married) in a neighbourhood with an EIMD rank of 6445 (2nd most deprived decile) which is representative of the study average. The terraced house is on a quiet rode, in a residential area, but less than 100 m away from a busy A-road, with the nearest park and green space approximately 200 m from Rebecca's house. Rebecca travels 5 minutes by car to school each day (1 km). Rebecca's mother has a Bachelor's degree and is employed part-time as a teacher. Nobody in the household smokes and smoking is not permitted in the home or outside.

Rebecca is 9.9 years old, white British, and has a BMI of 16.4 $kg \cdot m^{-2}$ which would classify her as a healthy weight according to age and sex specific BMI cut-offs (Cole & Lobstein, 2012). Respiratory measures indicated that Rebecca had no respiratory diseases and has healthy lung function, and low levels of exhaled carbon monoxide (<1 ppm). Rebecca's ratio scaled $\dot{V}O_{2peak}$ is 39.0 $mL \cdot kg^{-1} \cdot min^{-1}$, which is around the 25th percentile for the larger cohort, and within the lowest 5% compared to normative values for European females of a similar age (Tomkinson et al., 2017). Rebecca's ratio scaled $\dot{V}O_{2peak}$ would classify her as fit and healthy according to established thresholds (Lang et al., 2019). Rebecca's allometrically scaled $\dot{V}O_{2peak}$ is 212.0 $mL \cdot kg^{-0.53} \cdot min^{-1}$ which is around the 20th percentile for the larger cohort. Rebecca perceived her own fitness level to be 10 out of 10 (originally 20 out of 10).

Rebecca's self-reported PA score is 3.9, which is slightly above the study average of 3.6. Her PA enjoyment score is 4.3 which is above the study average, and the number of PA activities Rebecca claimed to enjoy was 1, which is much lower than the study average of 9.2. Rebecca's favourite PA is boxing, which she attends training for and has taken part in boxing competitions. She states that she enjoys boxing because she gets to be with her friends. She also goes for runs with her dad, but he will walk whilst she runs. Rebecca used to attend swimming club but does not anymore, and she describes how she is a competent swimmer, being able to swim half a length under water. Sleep and healthy food are things that Rebecca believes help her to be physically active, whereas her iPad, eating chocolate, and homework can prevent her from being active. She explained her choice to include homework: 'It stops you moving around, because you're sitting mostly on the couch or something, and writing. And it doesn't pump your blood up round your body'. Although she did not wish to elaborate further, Rebecca suggested her boxing teacher both helped her 'get more fit and not fit'.

Rebecca defined fitness as ‘good health, and maybe strength through activity. And you’re able to do things.’ She believed it was important to be fit because ‘it takes me a lot to do runs and stuff with people, and you have to be quite fit’. Given the choice, Rebecca said she would prefer to work at an effort level of 10 out of 10, because she likes being active.

During the pictorial task (Figure 5.4), Rebecca rated all of the activities as ‘very, very easy’. She explained her choice: ‘I think running's very easy, and walking to school. The crab is very easy. The monkey bars I'm getting very, very good at, and then swimming, I'm really good at it. I can swim like halfway under the water, like half the length.’

Figure 5.4. Photograph matching task for Rebecca.

5.3.4. Alex

Alex lives with his mother, father (married), and brother, in a neighbourhood with an EIMD rank of 695 (1st highest decile for deprivation), which is representative of the study average. The family home is on a quiet residential road, close to a park and playing field. The house is 1 km from the school, and Alex varies between walking the 13 minutes to school or travelling 4 minutes by car. Alex's s father has a Bachelor's degree and is employed part-time as a driver. Nobody in the household smokes and smoking is not permitted in the home or outside.

Alex is 10.3 years old, of Yemeni-British ethnicity, and has BMI of 15.8 $kg \cdot m^{-2}$ which would classify him as underweight according to age and sex specific BMI cut-offs (Cole & Lobstein, 2012). Respiratory measures indicated that Alex had no respiratory diseases and has healthy lung function, but slightly elevated levels of exhaled carbon monoxide (2 ppm). Alex's ratio scaled $\dot{V}O_{2peak}$ was 53.5 $mL \cdot kg^{-1} \cdot min^{-1}$, which is around the 65th percentile for the larger cohort, and within the highest 10% compared to normative values for European males of a similar age (Tomkinson et al., 2017). Alex's ratio scaled $\dot{V}O_{2peak}$ would classify him as fit and healthy according to established thresholds (Lang et al., 2019). Alex's allometrically scaled $\dot{V}O_{2peak}$ is 276.7 $mL \cdot kg^{-0.53} \cdot min^{-1}$ which is around the 60th percentile for the larger cohort. Alex perceived his own fitness level to be 6.5 out of 10. Alex explained his reason for his perceived fitness score: 'Because I play out but not all the time and I get out of breath when I run hard.'

Alex's self-reported PA score is 4.3, which is above the study average of 3.6. His PA enjoyment score is 4.1 which is representative of the study average, and the number of activities Alex claimed to enjoy was 12, which is slightly higher than the study average of 9.2. Alex described PA in three words when prompted (in no particular order): getting fit, swimming, and basketball. During the focus group discussion, Alex suggested that children should try to do 60 minutes of PA each day, and that his favourite PA is football because it is 'fun' and 'healthy'. Alex stated that junk food like pizza and cake, is something that limits his ability to be physically active. Alex's brother inspires him to want to go to a gym class specifically for children at the local youth club. During the pictorial task (Figure 5.5), Alex rated running as the 'hardest' activity at 9/10 out of 10, followed by swimming at 8, then gymnastics at 5, monkeys bars at 4, and then walking at 2.

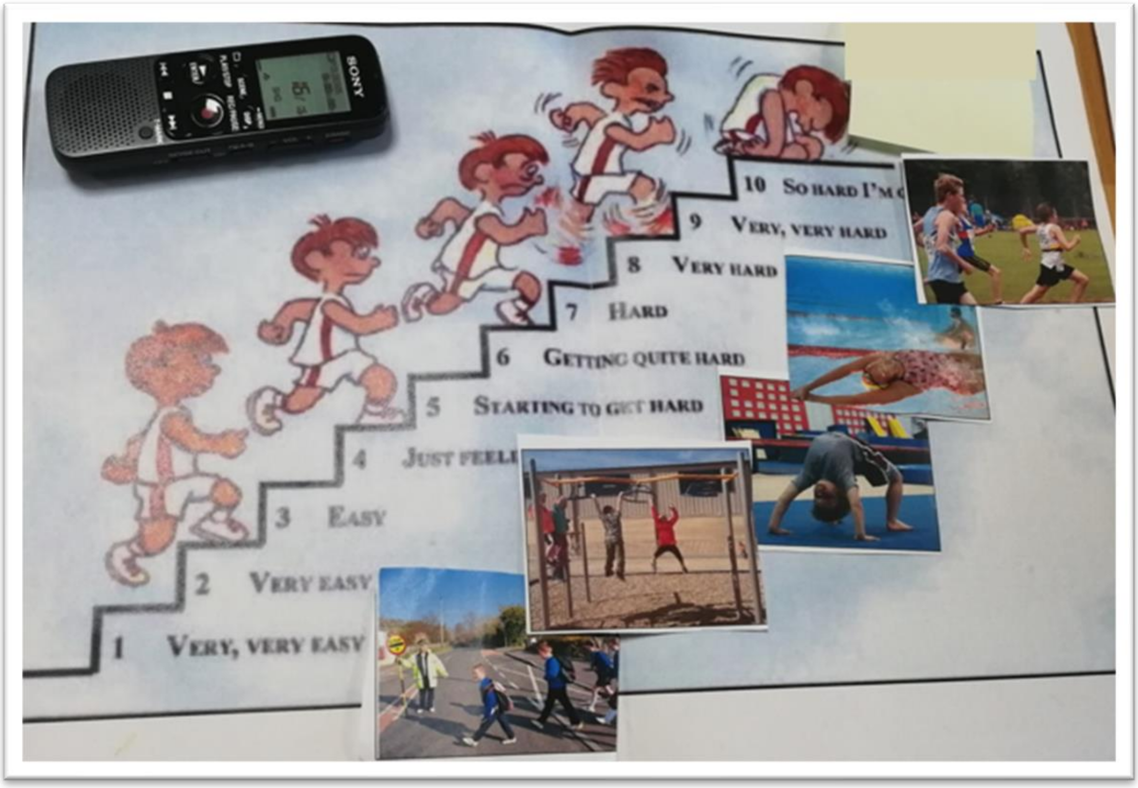


Figure 5.5. Photograph matching task for Alex.

5.3.5. Luke

Luke lives with his mother and father (married) in a neighbourhood with an EIMD rank of 856 (1st highest decile for deprivation), which is representative of the study average. The family home is on a quiet residential road with the nearest park with green space 500 m away. The house is 700 m from the school, and Luke varies between walking the 10 minutes to school or travelling 5 minutes by car. Luke's mother is further education college educated and works as a nursery nurse. Luke's father has recently given up smoking tobacco cigarettes after 15 years, and now uses e-cigarettes as a form of replacement therapy. Smoking is allowed by friends and family outside the house only.

Luke is 10.3 years old, white British and has BMI of 21.4 $kg \cdot m^{-2}$ which would classify him as overweight according to age and sex specific BMI cut-offs (Cole & Lobstein, 2012). Respiratory measures indicated that Luke has a reduced lung function in terms of peak flow and forced expiratory volume in 1 second, and low levels of exhaled carbon monoxide (1.5 ppm). Luke's ratio scaled $\dot{V}O_{2peak}$ was 42.7 $mL \cdot kg^{-1} \cdot min^{-1}$, which is around the 25th percentile for the larger cohort, and within the lowest 25% compared to normative values for European males of a similar age (Tomkinson et al., 2017). Luke ratio scaled $\dot{V}O_{2peak}$ would classify him as fit according to established thresholds (Lang et al. 2019), but close to the threshold for increased risk of cardiovascular disease (42.0 $mL \cdot kg^{-1} \cdot min^{-1}$). Luke's allometrically scaled $\dot{V}O_{2peak}$ was 257.3 $mL \cdot kg^{-0.53} \cdot min^{-1}$ which is around the 45th percentile for the larger cohort sample. Luke perceived his own fitness level to be 9.5 out of 10, but did not elaborate further.

Luke's self-reported PA score is 3.9, which is similar to the study average of 3.6. His PA enjoyment score is 3.0 (below the study average of 4.1), and the number of PA activities Luke claimed to enjoy was 15, which is higher than the study average of 9.2. Luke described PA in four words when prompted (in no particular order): football, golf, swimming, and darts. Luke's favourite physical activities are football, because he likes 'being the goalie', and darts, because he likes 'hitting the bullseye'. During the focus group discussion, Luke stated that fitness and sleep are things that facilitate his ability to be physically active. Luke has access to a treadmill which he uses at the weekends, but finds that Xbox, chores, and helping his father with the family business sometimes prevents him from being physically active. To Luke, fitness means 'When you're out of breath, you get ready and you start to go to run, and I do like five miles'.

When ranking the difficulty of the activities provided (Figure 5.6), Luke placed gymnastics at 9 (very, very hard), and the remaining activities at 1 (very, very easy) and explained his reason: '…because I'm good at swimming, I'm good at walking, I'm good at running and I'm good at doing monkey bars. But I love swimming. Because every Monday I used to go, but I know how to swim now, like confident, so I don't go now, but I still go to football.'

Figure 5.6. Photograph matching task for Luke.

5.3.6. Ryan

Ryan lives with his mother and father (married), in a neighbourhood with an EIMD rank of 10511 (4^{th} decile for deprivation), which is more affluent than the study average. The family home is on a quiet cul-de-sac, 200 meters away from a busy A-road, and the nearest park with green space is 500 m away. The house is 650 m from the school, and Ryan travels 5 minutes by car to school each day. Ryan's s mother has a college-level education and is employed part-time as a civil servant. Nobody in the household smokes tobacco but Ryan's father has used an e-cigarette daily for the previous two years, which is permitted in most rooms of the house, with an open window.

Ryan is 9.9 years old, of White-British ethnicity, and has BMI of 16.8 $kg \cdot m^{-2}$ which would classify him as a healthy weight according to age and sex specific BMI cut-offs (Cole & Lobstein, 2012). Respiratory measures indicated that Ryan had no respiratory diseases and has healthy lung function, and a low concentration of exhaled carbon monoxide (< 1 ppm). Ryan's ratio scaled $\dot{V}O_{2peak}$ was 59.5 $mL \cdot kg^{-1} \cdot min^{-1}$, which is around the 95^{th} percentile for the larger cohort, and within the highest 5% compared to normative values for European males of a similar age (Tomkinson et al., 2017). Ryan's ratio scaled $\dot{V}O_{2peak}$ would classify him as fit and healthy according to established thresholds (Lang et al., 2019). Ryan's allometrically scaled $\dot{V}O_{2peak}$ is 302.7 $mL \cdot kg^{-0.53} \cdot min^{-1}$, which is around the 85^{th} percentile for the larger cohort sample. Ryan perceived his own fitness level to be 9 out of 10, but did not elaborate further.

Ryan's self-reported PA score is 3.9, which is slightly above the study average of 3.6. His PA enjoyment score is 4.1 which is representative of the study average, and the number of activities Ryan claimed to enjoy was 15, which is higher than the study average of 9.2. Ryan described PA in three words when prompted (in no particular order): healthy body, exercise, and working. During the focus group discussion, Ryan suggested that children should try to do 30 minutes of PA each day, and that his favourite PA is football because 'you need some exercise' and 'you get achievement from it'. Ryan stated that having too much on (lack of free time), money and equipment are things that limit his ability to be physically active. Whereas inspiring people, determination and commitment, a healthy body, and being sporty, are things that help him to be active.

During the pictorial task (Figure 5.7), Ryan stated that he found gymnastics the most difficult, followed by swimming, monkey bars, running, and walking. He explained his choices: ‘Walking's easy. Then Then that [monkey bars], because that's the bar. I put it on there, when I can do it. Then swimming, I can do that as well. And then I could do that one [gymnastics as the hardest]. But I can do a strong flick on trampoline.’

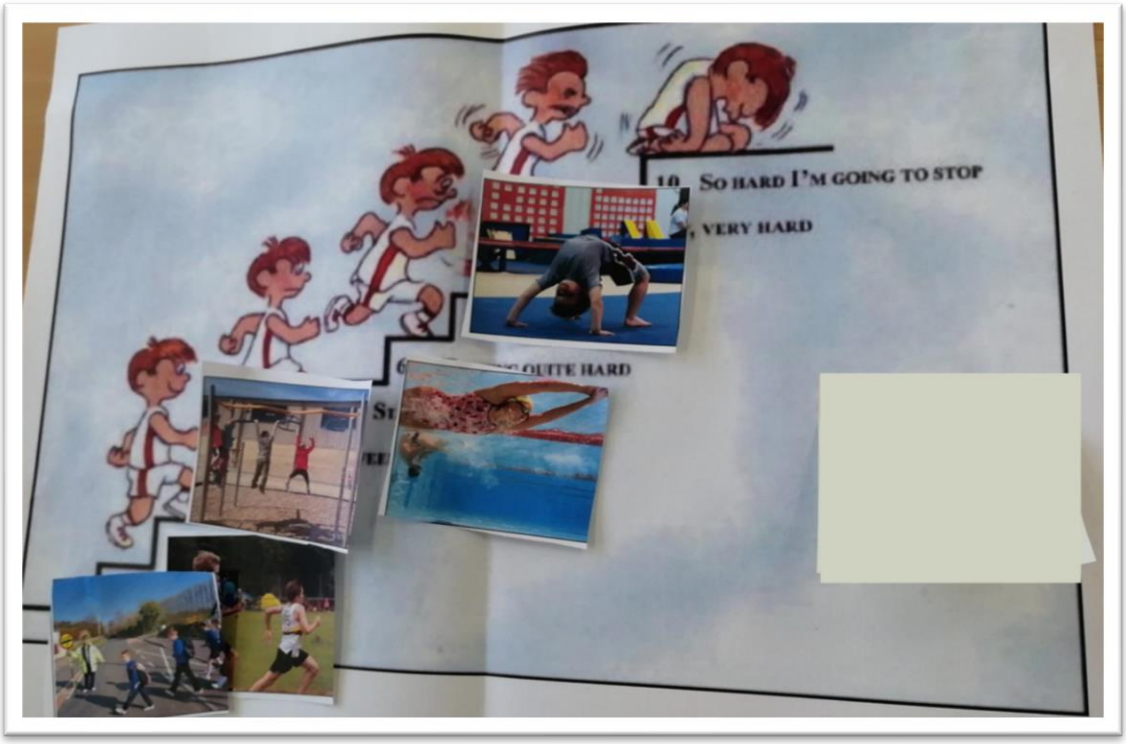


Figure 5.7. Photograph matching task for Ryan.

5.4. Discussion

This section discusses the six case studies in relation to key topics explored within the thesis, such as cardiorespiratory fitness (CRF), physical activity (PA), PA enjoyment, respiratory health, and household smoking habits. The case studies are compared and contrasted, and findings are explored in relation to previous research.

5.4.1. Cardiorespiratory Fitness

5.4.1.1. Measured Cardiorespiratory Fitness

The validity of expressing CRF as a ratio of mass is a highly contentious subject and is discussed in greater detail in Chapters 2 and 3. For the purpose of this study, it was deemed necessary to express CRF in this way in order to classify participants as fit or unfit according to established thresholds (Lang et al., 2019), and to compare CRF against percentiles for European children of a similar age and sex (Tomkinson et al., 2017). A range of fitness levels were represented through the cases, with ratio scaled $\dot{V}O_{2peak}$ ranging from 34.7 to 50.2 $mL \cdot kg^{-1} \cdot min^{-1}$ for girls and 42.7 to 59.5 $mL \cdot kg^{-1} \cdot min^{-1}$ for boys, and allometrically scaled $\dot{V}O_{2peak}$ ranging from 212.0 to 297.6 $mL \cdot kg^{-0.53} \cdot min^{-1}$ for girls, and 257.3 to 302.7 $mL \cdot kg^{-0.53} \cdot min^{-1}$ for boys. Only one child, Alice, was classified as unfit according to established thresholds (Lang et al., 2019), although Luke was only 0.7 $mL \cdot kg^{-1} \cdot min^{-1}$ above the threshold for being classified as unfit.

Comparing the three values for CRF and percentiles demonstrates the impact of different approaches to scaling for body size. Summarised in Table 5.2, weight status has a large effect on ratio scaled $\dot{V}O_{2peak}$, the finding supports the notion that such a measure over scales and favours light individuals (Armstrong & McManus, 2017). The overweight children, such as Alice and Luke, achieved lower ratio scaled $\dot{V}O_{2peak}$ percentiles compared to the percentiles generated from their allometrically scaled $\dot{V}O_{2peak}$. Conversely, Alex, who is underweight, achieved a higher percentile form his ratio scaled $\dot{V}O_{2peak}$ value than his allometrically scaled $\dot{V}O_{2peak}$. Rebecca, who is of healthy weight, achieved a ratio scaled $\dot{V}O_{2peak}$ percentile of around 25% within the sample, but 5% compared to European children. However, when $\dot{V}O_{2peak}$ was allometrically scaled, Rebecca's $\dot{V}O_{2peak}$ percentile was reduced to around 20%. Isabelle and Ryan (healthy weight) achieved consistently high percentiles, regardless of how CRF was expressed.

The above demonstrates the ratio scaling issues described by Welsman & Armstrong (2019a), and how overweight children can be penalised by simple ratio scaling. Overweight children appear to fare even worse when compared to percentiles generated from predicted $\dot{V}O_{2peak}$ (e.g. from 20mSRTs), likely due to the nature of the 20mSRT, or the influence of mass in the $\dot{V}O_{2peak}$ prediction equation. Children are required to shift their mass between two points during a 20mSRT, and children with a high level of metabolically inert mass (fat mass) are disadvantaged by the test, whereas lighter individuals are favoured (Welsman & Armstrong et al., 2019a). Although limited to a small sample of six in this instance, these findings support the conclusion of Welsman & Armstrong (2019a) and Armstrong & Welsman (2020b) that estimated $\dot{V}O_{2peak}$ from the 20mSRT partially reflects fatness, rather than CRF.

5.4.1.2. Perceived Cardiorespiratory Fitness

When prompted to score their own fitness out of 10, three of the six children largely overestimated their fitness. Taking the deciles of the measured fitness as a proxy for 'actual fitness' scored out of 10 (see Table 5.2), the children's 'actual' fitness scores (out of 10) ranged from 0.5 to 9.5, depending on whether deciles were used based on the ratio or allometrically scaled $\dot{V}O_{2peak}$ data, or from Tomkinson et al. (2017). Alice and Rebecca perceived their own fitness to be 8.5 and 10 out of 10, respectively, which are significant overestimations as both have measured fitness scores within the lowest quartile. Likewise, Luke, who had a measured fitness score below average, estimated his fitness at 9.5 out of 10. Ryan and Alex were relatively accurate in their perceived fitness, with Ryan scoring himself as 9 out of 10, and Alex scoring himself as 6.5, which were consistent with their measured fitness (very high, and above average, respectively). Isabelle was the only child who perceived her fitness to be lower than the measured value. Isabelle rated her fitness as 5 out of 10, when in fact her fitness was above the 90th percentile.

The better-than-average-effect; the tendency to evaluate oneself more favourably than an average peer (Alicke & Govorun, 2005) may explain why, like Study 2 (Chapter 4), children overestimated their CRF level. Discussed in Study 2, some studies have shown that self-perception is strongly related to physical fitness and motor competence (Utesch et al., 2019; Vedul-Kjelsås et al., 2011, Chan et al., 2003), whereas others have found only moderate correlation (De Meester et al., 2016) or no correlation (Bolger et al., 2019). Previous studies have found similar aged children to have high self-perceptions of motor competence and movement skill competency (Bolga et al., 2019; De Meester et al., 2016; Weiss & Amorose, 2005), and positive self-perceptions are associated with beneficial cognitive and behavioural outcomes, including intrinsic motivation, enjoyment, and participation in PA (Bolger et al., 2019; Elbe et al., 2017). With regards to the discussed case studies, overestimation is preferred as underestimation may negatively influence motivation and greater self-perception increases participation in PA (Bolger et al., 2019). However, as self-perception accuracy increases with age (Utesch et al., 2019; Weiss & Amorose, 2005), if the children with low fitness remain low-fit into adolescence, their self-perception may decrease accordingly. It would therefore be beneficial for Isabelle, and perhaps Alex, to be made aware of their high competence in CRF, in order to maintain their motivation for, and participation in PA. For the children that overestimate, it may not be as useful to make them aware of their low competence, but rather interventions that facilitate increased MVPA may be more suitable.

5.4.2. Physical Activity

The highest reported level of PA was by Alex (4.3), followed by Alice (4.2), Luke, Rebecca, Ryan (3.9), and Isabelle (3.2). Although in Study 1 (Chapter 3), PA was found to be positively correlated with CRF, some of the included case studies are exceptions to such a trend. For example, Isabelle, who has a very high CRF score, reported below-average PA levels. Whereas Alice, who has a CRF score in the lowest quartile, reported relatively high PA levels. PA, in particular MVPA, is a major determinant of CRF (Fairclough et al., 2017; Zaqout et al., 2016), but other factors such as adiposity, BMI, and tobacco smoke exposure also play a role, discussed below.

Alice believes she is highly physically active, demonstrated by her PA score, and quote ‘I like to keep active’. Although she stated that she enjoys football and swimming, which are generally high metabolic equivalent (MET) activities (Ainsworth et al., 2011), Alice also stated that she regularly takes her dogs for walks around the park with her family and friends, which are lower MET activities. One activity Alice claimed to not enjoy was running, further demonstrated during the pictorial task where she rated running as the most difficult activity. Isabelle’s self-reported PA score is slightly below the study average, but Isabelle claims to run ‘a long way’ with her sister. Isabelle did not rate running as the hardest activity, describing it as ‘a bit hard’, but rather she rated the monkey bars as the most difficult. Rebecca’s PA score is slightly above average, and her favourite activity is boxing (METs 5.5-12.8). She claims to go running with her father, but he will walk whilst she runs. Despite her high reported level of PA, Rebecca's CRF is low. Luke and Ryan have the same PA score, but Ryan has a much higher level of fitness than Luke. Both boys claim to enjoy football (METs 4-10) but vary in their reasons. Luke enjoys football because he likes 'being the goalie', whereas Ryan and Alex enjoy football because 'you need some exercise', 'you get achievement from it', it's 'healthy', and 'fun'. Other activities Luke claimed to enjoy include golf (METs 4.8) and darts (METs 2.5), which, in combination with his preference to be 'goalie', suggests Luke has a preference for lower intensity physical activities.

Alice is the only child that consistently walks to school, with Alex and Luke alternating between walking and travelling by car, and Imogen, Rebecca, and Ryan always travelling by car. All children live 1 km away from the school or less (as the crow flies) which would take approximately 10 – 20 mins to walk. Although active commuting increases overall PA, previous and recent research, including a study in Liverpool based on similar aged children (Noonan et al., 2017b) has found a counterintuitive relationship between obesity, CRF, and active commuting (Noonan, 2021). Like Alice, the more deprived children in the Noonan study were more likely to actively commute to school but were also more at risk of being obese and unfit. Nevertheless, regular active commuting would be one behaviour change that all the children could potentially benefit from.

The combination of qualitative data generated through focus group discussion, in conjunction with quantitative PA scores, allows for deeper insight into the children's PA behaviours. For some children that claim to be very active, a closer look at the type of activities they engage in, uncovers possible reasons for low fitness. MVPA is a better determinant of CRF than overall PA (Fairclough et al., 2017), and the children that appear to engage with high levels of MVPA (Isabelle, Alex, and Ryan), with the exception of Rebecca, show higher levels of CRF. However, Rebecca and Alice, who do claim to take part in vigorous activities, may be experiencing other barriers related to their personal circumstances, that are limiting their CRF. Building on this body of research, future work could utilise real time PA monitoring through accelerometers to assess whether the PA and MVPA levels vary for children of smoking and non-smoking homes.

5.4.3. Physical Activity Enjoyment

Isabelle had a PA enjoyment score (3.9) similar to the study average (4.1), but disliked more activities than she enjoyed (-3). Conversely, Alice and Rebecca scored higher for enjoyment (4.1 and 4.3 respectively). But whilst Alice enjoyed more activities than the study average (14), Rebecca did not enjoy a wide variety of activities (1). Alice and Rebecca frequently discussed taking part in various sports and organised physical activities such as football, swimming, and boxing, whereas Isabelle described taking part in less structured forms of PA, such as running with her sister. Alice and Rebecca show, through quantitative scores and discussion, that they consider themselves to be active children, and have a positive relationship with PA, and show good levels of PA enjoyment. Exposure to variety of sports and activities during childhood confers psychosocial benefits including life skills, prosocial behaviour, healthy identity, diverse peer groups, and social capital (Coté et al., 2009). Davison et al. (2007) found PA enjoyment to reduce with pubertal development in adolescent girls. Isabelle is 11.5 years old, and therefore likely at a more advanced maturation status than Alice and Rebecca, which may in part explain her low enjoyment of PA compared to the other girls. However, Isabelle's reduced PA enjoyment does not appear to be inhibiting her CRF, and De Meester et al. (2020) have shown that organised sport participation is associated with increased fitness levels, irrespective of enjoyment. Although Isabelle does not take part in organised sport or enjoy a variety of physical activities, regularly running with family members, a potential source of MVPA, may be enough to sustain her high level of CRF.

Alex and Ryan show average levels of PA enjoyment (4.1), whereas Luke scored low for PA enjoyment (3.0), and all indicated enjoying a large variety of activities. The quantitative and qualitative data for Alex, Ryan and Luke suggests that all three boys have a positive relationship with PA, with words used to describe their favourite physical activities such as 'fun' and 'achievement', although their enjoyment scores indicate an area for potential intervention. Enjoyment is a key factor for involvement in PA (Davison et al., 2007), and intrinsic motivation for PA increases the likelihood of participation (Zhang et al., 2011). Additionally, PA enjoyment has shown to mediate the effects of school-based interventions (Elbe et al., 2017; Dishman et al., 2005). As enjoyment is associated with PA participation, improving enjoyment may be an effective strategy to increase participation, especially in maturing adolescents. Although, as Alice, Rebecca, Alex, and Ryan, indicate high levels of enjoyment and motivation for PA, interventions to improve PA participation and enjoyment may not be effective or required, and instead, level of MVPA, diet, and environmental exposures are other avenues of potential investigation.

5.4.4. Respiratory Health

Only Luke showed reduced lung function, with a reduced peak flow and forced expiratory volume in 1 second, compared to the predicted value for his age, height, sex, and ethnicity. Study 1 demonstrated that spirometry performance was significantly and negatively correlated with deprivation, but not SHS exposure. Previous research has found SES to be associated with lung health, with increased deprivation associated with reduced lung function (Polak et al., 2019; Hegewald & Crapo, 2007). In utero and post-birth exposure to SHS is detrimental to children's lung function and respiratory health (Thacher et al., 2018; Pugmire et al., 2014). As Luke's father is a recent ex-smoker and current e-cigarette user, in addition to the high level of neighbourhood deprivation, this may explain Luke's reduced lung function. Fortunately, Alice appears to have a healthy lung function, despite the high level of smoking in her household. As Alice's parents do not smoke themselves, Alice may not have been exposed to SHS for many years, or in utero, although such information is not available, but it would make a valuable addition to the study.

5.4.5. Household Smoking Habits

Alice was selected as an exceptional case due to living with heavily smoking grandparents. Alice's grandparents smoked an average of 30 and 35 cigarettes per day each, which was allowed indoors without restriction. To put such a level of smoking into perspective, Alice's grandparents would each have to smoke two cigarettes per hour over 15 waking hours to be able to smoke 65 cigarettes per day. No data is available to determine how long Alice has been living with her grandparents and therefore exposed to SHS, but her elevated concentration of exhaled carbon monoxide (eCO) suggests she may have been exposed recently. However, the health impacts of SHS exposure are substantial and rapid, with acute effects on the various body systems including respiratory, circulatory, and immune system (Talhout et al., 2011), even after brief exposure (Barnoya & Glantz, 2005). Fine particulate matter ($PM_{2.5}$) concentrations are approximately ten times higher in smoking homes than non-smoking homes, which over a lifetime, is the equivalent to living in a polluted city such as Beijing (Semple et al., 2015). For Alice, the obvious recommendation would be to reduce her exposure to SHS. Implementation of household smoking rules, for example where smoking is only permitted outside, would be a simple and effective method for improving her exposure. Although the ideal situation would be total smoking cessation of the household; such is not easy to implement and maintain due to the difficult process of smoking cessation (Chaiton et al., 2016). The ‘7 Steps Out’ advice in England recommends smoking parents take seven steps away from the house when smoking, in order to reduce the amount of tobacco smoke that enters the home (Tameside.GOV.UK, 2020), and may be a useful strategy for Alice’s family to employ. Although, it is not clear how effectively smoking outside reduces exposure to SHS, particularly when third-hand smoke is considered. Behaviour change techniques including information about health consequences are other potential strategies for reducing SHS (Brown et al., 2020). In addition to SHS exposure, there is evidence that parental (Bantle & Haisken-DeNew, 2002), sibling, and friend (McGee et al., 2015) smoking increases the risk of smoking uptake in children. Therefore, household smoking not only poses a risk to health of children through the direct effects of SHS exposure, but additionally through the increased risk of smoking uptake, potentially generating future smoking adults.

Luke’s father has recently given up smoking after 15 years, and now uses e-cigarettes as a form of replacement therapy, but smoking is allowed by friends and family outside the house. It is therefore likely that Luke has been exposed to SHS over the course of his life, although his relatively low concentration of eCO suggest Luke was not exposed to smoke recently. Ryan’s father has used an e-cigarette daily for the previous two years, which is permitted in most rooms of the house, with an open window. For Ryan, tobacco smoking habits prior to the uptake of e-cigarettes is unknown, but Ryan’s low eCO concentration suggests he was not exposed to smoke recently. E-cigarette use is England has been on an upward trend over the previous decade and is positively associated with the overall rate of smoking cessation (Beard et al., 2019), and the most common reason given for using e-cigarettes is as an aid to stop smoking (ONS, 2020). E-cigarettes may be a less harmful alternative to tobacco smoking due to significantly lower levels of cigarette smoke (Taylor et al., 2016), although the long-term effects of e-cigarette vapour exposure warrant further research, including longitudinal population studies. For Luke and Ryan, any potential risks to health may come from previous smoke SHS exposure in Luke’s case, or the effects of inhaling e-cigarette ‘vapour’, of which longitudinal exposure research is currently limited. However, research has shown that although there are less chemical components in e-cigarette vapour compared to tobacco smoke (McAuley et al., 2012), the vapour may still cause significant lung damage (Reinikovaite et al., 2018), whereas other research has found no significant risk (McAuley et al., 2012). Children with parents who use e-cigarettes are more likely to have tried e-cigarettes themselves, and e-cigarette use is associated with increased intentions to smoke in children (Moore et al., 2016). Therefore, Luke and Ryan may be at an elevated risk of becoming e-cigarette users or tobacco smokers themselves.

Interestingly, Isabelle’s eCO concentration was elevated, although nobody in Isabelle’s household smoked. Whereas Rebecca, also from a non-smoking household, had a very low concentration of eCO. The use of eCO to determine recent tobacco smoke exposure (from both active and passive smoking) is validated in adults (Sandberg et al., 2011), but use of the test in children may not be as accurate as with adults (Chapter 2 and Chapter 3). There are alternative sources of carbon monoxide exposure including nearby burning, industry, and vehicle exhausts (Raub et al., 2000), all of which Isabelle may have been exposed to on her journey to school on the day of testing. In addition, it may be possible that Isabelle was exposed to SHS on the morning of the test, although not from a member of her household.

Prior to a SmokeFree Sports intervention with Liverpool children, 59-69% of children believed that smoke from others is ‘definitely harmful’, but around 10% less believed smoke ‘definitely affects sports performance’ (McGee et al., 2016). During focus groups in the present study, children were not asked questions concerning their thoughts and perceptions of smoking behaviours, due to ethical concerns regarding highlighting the harm of smoking to the already exposed children. However, previous research with children (4-8 years) in Liverpool showed that whilst children were prepared to verbally confront a smoker (usually a parent), they rarely took direct action and left the room themselves (Woods et al., 2005). Children cannot easily protect themselves from SHS, but children have been found to express a strong dislike of familial smoking, demonstrating overt and covert acts of resistance (Rowa-Dear, Amos, Cunningham-Burley, 2013), although the influence of which is limited due to their position in the family. The results from Study 1 (Chapter 3) indicate that household smoking is associated with reduced CRF in children. Although Rebecca is an exception to the trend, Alice and Luke, who have lived or live with smokers, show low levels of CRF, whereas the remaining children show higher levels of CRF. As stated above, reducing SHS exposure may be an effective strategy for improving CRF in children from smoking households.

5.4.6. Weight Status

Alice is classified as obese, and Luke is classified as overweight. Despite reporting high levels of PA, and taking part in a number of high intensity activities such as football, and swimming, these children show lower than average levels of CRF, of which increased mass may be a contributing factor. Isabelle, Rebecca, Ryan are classified as a healthy weight, with Alex being classified as underweight. The children who have a healthy weight status show a range of CRF, and the issue of mass scaling and fitness is discussed in more detail above (section 5.4.1.1).

Active and passive smoking is associated with overweight and obesity (Raum et al., 2011) although the mechanism for the association is not clear. Alice, who is from a smoking home, and Luke, who is from a previously smoking home, are obese and overweight respectively. Previous research has found prenatal exposure to SHS to be associated with increased BMI (Braun et al., 2010) and obesity (Qureshi et al., 2018) in children, and SHS exposure is associated with an increased risk of type-2 diabetes in adults (Huang et al., 2020). Though, the mechanism by which overweight and obesity is associated with smoking status is not possible to determine in the present study. In Liverpool, the prevalence of overweight and obesity among reception and Year 6 children increased between 2006 and 2012, with socioeconomic disparities in overweight and obesity between the most deprived communities and less deprived communities widening (Noonan, 2018). One key factor that is a likely determinant of weight status within the presented case studies is the impact of diet. However, the extent to which SHS exposure is associated with weight status directly, or indirectly through other unhealthy behaviours, requires further study.

5.4.7. Diet

No quantitative data was collected regarding diet, but children did refer to diet of their own accord during focus group discussions. Unhealthy dietary habits (e.g. fast food and chocolate) were described as a barrier to PA or fitness by Isabelle, Alex, and Rebecca, who were all from non-smoking households. Diet was not mentioned by the three children from smoking and e-cigarette households. Smoking behaviour is associated with clustering of multiple risk behaviours, including alcohol misuse, and an unhealthy diet (Meader et al., 2016). Diet is a likely confounding factor and this would be a useful and insightful extension to the present body of research. It may be the case that smoking households exhibit additional unhealthy behaviours to smoking, and the observed association between household smoking and weight status may influenced by other unhealthy behaviours. Noonan and Fairclough (2018) found that whilst SES was related to overweight and obesity, the association was not due to PA. In the majority of the presented case studies, the children report adequate levels of PA, yet of the 'active' children, Alice and Luke are classed as obese and overweight respectively. A healthy diet is more expensive than a less healthy one (Morris et al., 2014), and inequalities in diet and obesity are established across SES (Burgoine et al., 2018). In the UK, neighbourhood deprivation is associated with the number of fast-food outlets (Cummins, McKay & MacIntyre, 2005), contributing to the 'obesogenic' environment associated with poorer neighbourhoods.

5.4.8. Socioeconomic status

Four out of the six children were from neighbourhoods within the two most deprived deciles, with the exception of Ryan and Isabelle who were from neighbourhoods within the fourth most deprived decile. Of the children with deprivation levels within the lowest two deciles, most had CRF levels below average, whereas Isabelle and Ryan have very high CRF levels. Ryan, referred to finances, 'money and equipment', as a barrier to PA, and previous studies have demonstrated that financial barriers can restrict sport participation among children from low-SES (Clark et al., 2019; Holt et al., 2011). Although the association between SES and PA, and CRF, is inconsistent, there is substantial evidence that neighbourhood deprivation is linked to obesity and lower CRF (Noonan & Fairclough, 2018). Interestingly, Noonan and Fairclough, found that the most deprived children in the Millennium Cohort Study were most likely to achieve 60 minutes of daily MVPA compared to less deprived children. The association between SES, PA, and CRF in children is not straightforward. SES is associated with clustering of multiple risk behaviours, with low occupational SES and low education associated with increased odds of health risk behaviours, including smoking (Martinez et al., 2018; Meader et al., 2016). Smoking is associated with both material and perceived dimensions of SES, including education, occupational status, household income, housing tenure, economic difficulties, and economic satisfaction (Laaksonen et al., 2005). The web of correlations between SES, health behaviours (PA, smoking, and diet), and health outcomes (obesity, CRF, and respiratory health) demonstrates the importance of understanding health inequalities in relation to CRF and PA.

5.4.9. Environment and Neighbourhood Factors

Alex lives very close to a park with play equipment and green space, whereas Alice lives approximately 800 m from her nearest usable green space and park. The remaining children live approximately 200-500 m away from the nearest green space with or without play equipment. Whilst Alice describes going to the park ‘all the time’ with her friends and family, other children refer to spending time being active at the park indirectly, such as Rebecca who states she is ‘getting very good’ at the monkey bars. The perception of the neighbourhood environment, including availability of outdoor space, seeing other children be active, and perceived safety, is influential on children’s PA (Dowda et al., 2020). A population study based on UK adults found a dose-response relationship between access to and quality of green spaces with reduced psychological distress (Pope et al., 2018). For children, Noonan et al. (2016) found that homes and environments in highly deprived neighbourhoods were unconducive of health-promoting behaviours, with reduced access to gardens and backyards, increased access to bedroom media, and reduced neighbourhood aesthetics. Unfortunately, access to green space is not a factor that families have much control over, and so family-based interventions should look to improve access and opportunity for PA within the constraints of neighbourhood or in and around the home.

Alice, Rebecca, and Luke all refer to electronic devices such tablets and consoles as barriers to either their PA or CRF. It is interesting to note that the children who describe such barriers, all have CRF levels below average. Screen time exposure has been shown to lead to obesity through increased eating while viewing; exposure to high-calorie, low-nutrient food and beverage marketing that influences children’s preferences, purchase requests, consumption habits; and reduced sleep duration (Robinson et al., 2017). Previous research has found that children of low SES have greater access to bedroom media and low SES environments provide more opportunities for sedentary behaviour (Noonanet al., 2016; Tandon et al., 2012). Although, quantitative data on screen time or access to media was not collected as part of this body of research, such would make an interesting addition. It would be also insightful to gain information regarding media and screen time access and rules, and whether these differ between non-smoking and smoking households.

5.4.10. Individual differences

The strength of the case study approach is that, unlike quantitative analysis, individual differences can be identified and explored. When particular cases do not fit the general trend, case studies allow the researcher to tease apart the various circumstances and context that make the case unique. Childhood personality traits have been shown to influence health behaviours in adulthood. A population based longitudinal study by Hampson et al. (2007) showed childhood agreeableness, conscientiousness, intellect, and imagination to influence adult health status indirectly through educational attainment, healthy eating habits, and smoking. Personality, which is not explored in the present study, is a likely factor contributing to individual differences.

5.4.11. Recommendations for each case

Aside from the high level of SHS exposure, Alice appears to lead a healthy life, is sufficiently physically active, and has a good level of PA enjoyment. Reducing SHS exposure in the home would be one key recommendation for Alice's family. As Alice appears to spend a lot of time indoors, which is particularly associated with screen time for Alice, reducing the level of tobacco smoke in the home could make significant improvements to the family home environment. Limiting smoking to outside the house would likely result in great improvements to the indoor air quality in Alice's home. Additionally, as suggested by Alice herself, being more physically active *outside* may reap further benefits to her fitness, primarily through increased levels of PA, but secondarily through reduced exposure to indoor tobacco smoke. Additionally, as Alice is obese, it would be useful to gain information regarding her diet, which may allude to other pathways for improvements in her weight status and CRF.

Isabelle has an excellent level of CRF which is likely through her apparent level of MVPA due to running with family. Unfortunately, Isabelle has a low level of PA enjoyment, and low perceived competence, which may lead to a reduction in PA and MVPA during and after adolescence if she is not motivated to participate in PA. Although Isabelle is not currently in need of any CRF intervention, her PA participation and enjoyment should be monitored through adolescence and it may be beneficial for Isabelle to sample a wider range of PA and sport. Isabelle should be made aware of her high level of CRF and it is recommended that Isabelle continues running with her family to maintain her excellent CRF.

Rebecca's case is interesting due to her keen interest in boxing, which she attends training for and has obvious familial support for, but her relatively low fitness level is of concern. It may be the case that Rebecca needs to participate in more MVPA, rather than low-intesnity PA, although no data was collected regarding PA intensity. Rebecca does not enjoy a wide range of activities, which could be a second area of intervention, and like Isabelle, Rebecca may benefit from sampling a range of physical activities.

Alex has a good level of fitness and a positive relationship with PA. Alex also understands that children must aim for an average of 60 minutes of PA per day. Alex appears to be part of active family which will likely be a positive influence on his PA and CRF. One area of recommendation would be to further understand Alex's dietary habits, as Alex is currently underweight.

It seems that whilst Luke enjoys PA, he appears to prefer low intensity activities. Therefore, one key improvement Luke could make would be to participate in more MVPA or high MET activities. Luke states that he enjoys football, and often plays as goalie, but perhaps Luke should sample a variety of football positions (e.g., striker, defence) to improve his MVPA. Luke is also overweight, and so information regarding his diet may highlight other avenues for intervention.

Ryan has excellent CRF and appears to have a very positive relationship with PA, and his favourite sport in particular, football, which he gets a sense of achievement from. Ryan has an ideal situation where he has high level of perceived competence which tallies well with his actual competence. It is therefore recommended that Ryan continues his high level of PA in order to maintain his level of CRF.

5.4.12. Strengths and Limitations

The case study approach is sometimes criticised for lacking scientific rigour (Crowe et al. 2011). However, there has been great transparency in the methods used to collect, analyse, and triangulate the quantitative and qualitative data utilised for this study. The case study approach also lacks generalisability (Crowe et al. 2011). Unlike Study 1, the findings in this study are not statistically generalisable, and such is the nature of the case study that they are unique to each case.

The strength of this case study design is that it allows an in-depth analysis of six contrasting individual cases; the exceptions and non-exceptions to the trends highlighted in Chapters 3 and 4 can be explored in detail using the case study method. The mixed-methods approach is a strength as it allows the synthesis of complimentary quantitative and qualitative data, to provide a rich insight into each case. Case studies provide contextual understanding and illuminate individual circumstances. A single data point in a quantitative study, becomes a story itself using the case study method.

5.4.13. Conclusion

This mixed methods study presents six contrasting case studies which demonstrate the variety of CRF, PA, and household smoking behaviours from within the larger study cohort. Triangulation of the data from the quantitative and qualitative aspects of the larger research project provides rich contextual insight into the behaviours and perceptions of six child participants. Quantitative information detailing cardiorespiratory fitness ($\dot{V}O_{2peak}$), physical activity participation and enjoyment provides insight into the participant behaviours, and, in combination with rich data on perceptions, thoughts, and feelings regarding PA and CRF, a full picture of each participant can be demonstrated. The findings of the present study highlight the need to take individual circumstances into consideration when exploring the determinants of CRF in children. Suggestions are offered for why highly active children such as Alice and Rebecca, have low fitness levels, or why children with low PA enjoyment and low self-perception like Isabelle, have excellent fitness levels. The cases presented shed light on the potential reasons why the relationships between PA, CRF, weight status, and SES are not straightforward, and how context specific interventions may be an effective strategy for under-represented populations such as children exposed to second-hand tobacco smoke.

Thesis Study Map

Study 1 The association between second-hand tobacco smoke exposure and cardiorespiratory fitness, physical activity, and respiratory health in children	**Aim:** To assess the association between second-hand tobacco smoke exposure on children's directly measured cardiorespiratory fitness ($\dot{V}O_{2peak}$), physical activity, physical activity enjoyment, and respiratory health indicators. **Research questions:** 1) Is second-hand tobacco smoke exposure associated with cardiorespiratory fitness in children? 2) Is second-hand tobacco smoke exposure associated with physical activity and physical activity enjoyment in children? 3) Is second-hand tobacco smoke exposure associated with respiratory health indicators in children? **Key findings:** • SHS exposure (as measured by the number of cigarettes smoked per household per day) was associated with reduced CRF in children. • SHS exposure was not associated with PA, PA enjoyment or respiratory measures. • SHS exposure was associated with increased BMI and weight status. • Exhaled carbon monoxide was not correlated with self-reported household smoking status or the number of cigarettes smoked per day. **Personal reflection:** Data collection days were extremely busy and had to run like clockwork to be successful. However, I have come to learn that children make the most enthusiastic of participants and I really enjoyed working with them. Whilst some results were surprising (low carbon monoxide readings, low spirometry values for children exposed to SHS), other findings, such as that SHS exposure was associated with lower CRF, increased BMI, and lower SES, were less surprising. Overall, the findings of this aspect of the research both challenged and confirmed my preconceived ideas about the effects of SHS on children's health.
Study 2 Children of smoking and non-smoking households' perceptions of physical activity and cardiorespiratory fitness	**Aim:** To use creative and qualitative methodologies to explore the attitudes, beliefs, and perceptions of physical activity, fitness, and exercise of children from smoking and non-smoking households. **Research questions:** 1) What are children from smoking and non-smoking households' reasons for being physically active? 2) What are children from smoking and non-smoking households' attitudes towards physical activity, exercise, and fitness? 3) What are the perceived barriers and facilitators to a child's ability to be physically active and does this differ for children from smoking and non-smoking homes? 4) What are children's perceptions of their own fitness and physical ability and does this differ for children from smoking and non-smoking homes? **Key findings:** • The findings support the main hypothesised mediators of PA in children including self-efficacy, enjoyment, perceived benefit, and social support. • Less than a quarter of children were aware of the PA guidelines. • Fitness was important to all children, but for differing reasons (e.g., health, performance, future benefit, to avoid negative physiological consequences).

	- The perceived barriers (e.g., sedentary behaviour, resources, environment, psychological and physical factors) and facilitators (e.g., significant others, environment, opportunities for PA, physiological and psychological factors) discussed are in line with previous research. - Children from smoking and non-smoking households showed similarities and variances in their perceived barriers and facilitators of PA. - Most children perceived their own fitness to be high, but children from smoking households rated running as more difficult than children from non-smoking households. **Personal Reflection** The children were very insightful as participants within the focus groups. Sometimes questions would be responded to with one-word answers but at other times children would demonstrate that they truly are the experts of their own lives. With a personal affinity for quantitative methods, learning to conduct qualitative research was a steep learning curve, but I have a new-found appreciation for qualitative research methods. The focus groups have allowed me to have an insight into the thoughts and feelings of children with regards to PA, and fitness, and I have found the process and results fascinating.
Case studies Using the mixed-methods case study approach to explore the behaviours and perceptions surrounding fitness and physical activity of children from smoking and non-smoking homes	**Aim:** To use a mixed-methods case study approach to provide rich, contextual insight into the lives, behaviours, and perceptions of a selection of participants, in relation to the above research aims and research questions. **Key findings:** - The case studies provide context and shed light on the individual differences and the heterogeneity of the sample. - Extreme cases (e.g., a girl living grandparents who smoked 65 cigarettes per day indoors), and exceptions to the trend (a very active girl, with a keen interest in PA, with very low CRF) are highlighted. - Behaviours, perceptions, and circumstances that may be contributing to the individual's health outcomes are identified and explored. **Personal reflection** Once I had collected the quantitative and qualitative data, I wanted to explore how both sets of complimentary data could be used to paint a more detailed picture of each participant. Sifting through the data with a fine-tooth comb in order to produce the case-studies, meant I got to know all aspects of my data very well. The process of compiling the case studies also allowed me to understand my participants much better, and to discover how their socioecological environment, behaviours, and personality, impacted their thoughts, feelings and perceptions of PA and fitness.

Chapter 6
Synthesis of Findings

6.1. Introduction

The purpose of this chapter is to draw together the findings and conclusions of the preceding chapters and discuss the overall findings and themes that have emerged within the thesis. The overall strengths and limitations are discussed, and implications, recommendations, and suggestions for future work are detailed. Finally, this chapter contains a personal reflection and an overall conclusion.

6.2. Review of the Thesis

6.2.1. Thesis Aims

The purpose of this thesis was to use a mixed-methods approach to, quantitatively and qualitatively, explore the association between second-hand tobacco smoke (SHS) exposure and cardiorespiratory fitness (CRF), physical activity (PA), and respiratory health in children, and children's attitudes to physical activity, fitness, and exercise.

The quantitative strand of the thesis aimed to assess the association between SHS exposure on children's directly measured CRF ($\dot{V}O_{2peak}$), PA, PA enjoyment, and respiratory health indicators (Chapter 3). The qualitative strand of the research aimed to use qualitative and creative methodologies to explore children from smoking and non-smoking homes' perceptions surrounding CRF and PA (Chapter 4). Finally, a mixed methods case study approach was used to combine the complementary quantitative and qualitative strands, which aimed to provide a rich insight into the behaviours and perceptions of CRF and PA for children from smoking and non-smoking homes (Chapter 5). The following research questions sought to address each of the study aims.

Study 1:

1) Is second-hand tobacco smoke exposure associated with cardiorespiratory fitness in children?
2) Is second-hand tobacco smoke exposure associated with physical activity and physical activity enjoyment in children?

3) Is second-hand tobacco smoke exposure associated with respiratory health indicators in children?

Study 2:

1) What are children from smoking and non-smoking households' reasons for being physically active?
2) What are children from smoking and non-smoking households' attitudes towards physical activity, exercise, and fitness?
3) What are the perceived barriers and facilitators to a child's ability to be physically active and does this differ for children from smoking and non-smoking homes?
4) What are children's perceptions of their own fitness and physical ability and does this differ for children from smoking and non-smoking homes?

Case studies:

The aim of the case study chapter was to provide rich, contextual insight into the lives, behaviours, and perceptions of a selection of participants, in relation to the above research aims and research questions.

6.2.2. Main Findings

Study 1 is the first study to examine the impact of SHS exposure on directly measured $\dot{V}O_{2peak}$ in children. The study found SHS exposure, as measured by the number of cigarettes smoked by the household per day, to be significantly and negatively associated with children's CRF, but was not associated with PA, PA enjoyment, or respiratory health indicators. Household smoking was also associated with children's BMI and weight status, but the use of allometrically scaled $\dot{V}O_{2peak}$ indicated that household smoking was associated with CRF independently of weight status. Exhaled carbon monoxide (eCO) was not correlated with self-reported household smoking status or the number of cigarettes smoked per day. Spirometry markers were not associated with household smoking, although fractional exhaled nitric oxide (FeNO) was substantially reduced in children from households that permit smoking indoors (although not statistically significant).

Study 2 identified similarities and differences between children from non-smoking and smoking homes' reasons for PA participation, attitudes towards PA, exercise, and CRF, perceived barriers and facilitators, and perceptions of their own fitness. The findings support the main hypothesised mediators of PA in children including self-efficacy, enjoyment, perceived benefit, and social support. Less than a quarter of children were aware of the PA guidelines, and whilst all children agreed fitness was important to them, differences emerged between children from smoking and non-smoking households for *why*. The perceived barriers (e.g. sedentary behaviour, resources, environment, psychological and physical factors) and facilitators (e.g. significant others, environment, opportunities for PA, physiological and psychological factors) discussed are in line with previous research, but variances emerged between important barriers and facilitators for children from smoking and non-smoking homes. The majority of children perceived their own fitness to be high, but variances were observed for how difficult children found various physical activities. This study is unique in the sense that it provides a voice to children from smoking homes, and is also the first to explore and compare the perceptions of PA and fitness for children from non-smoking and smoking homes.

The case study chapter draws together the complimentary data from Study 1 and Study 2 and explores six selected cases in detail. The case studies provide context and shed light on the individual differences and heterogeneity of the sample, as well as highlight extreme examples, and cases which contradict the general trend. Exploration of the six unique cases has identified behaviours, perceptions, and circumstances that may be contributing to the individual's health outcomes including CRF, respiratory health, and health promoting behaviour such as PA participation. This chapter also made recommendations for each case considering their fitness, health, behaviours, perceptions, and personal circumstances.

6.2.3. Discussion of Main Findings and Themes

6.2.3.1. Cardiorespiratory Fitness

Study 1 found SHS, as measured by the number of cigarettes smoked by the household, to be associated with a reduction in CRF in children. This is the first study to demonstrate the relationship between household smoking and directly measured $\dot{V}O_{2peak}$ in children. The findings are in-line with previous research with adults (De Borba et al., 2014), and studies that utilised other measurements of fitness and health in children (Hacke and Weisser, 2015; Kaymaz et al., 2014; Magnússon et al., 2009).

It could be argued that the association between household smoking and CRF found in Study 1 is brought to the surface through discussion in Study 2. Children from smoking households enjoyed less metabolically demanding activities, and generally rated running as the most difficult activity during the pictorial task. Children from smoking homes were also more concerned about the physiological consequences of being unfit, such as ‘getting out of breath easily’. However, despite their low CRF, and indirect references to the effects of low CRF, children from smoking homes did not *perceive* themselves to be unfit. This is demonstrated by the high perceived fitness scores in Study 2, and by a selection of cases in Chapter 5. Research regarding the association between perceived competence and fitness is inconsistent (Bolger et al., 2019; De Meester et al., 2016; Vedul-Kjelsås et al., 2011) but greater self-perception increases participation in PA (Bolger et al., 2019). It is therefore positive that most of the participating children, regardless of household smoking status, or actual CRF, perceive their fitness to be high as this will encourage motivation for and participation in PA. However, self-perception accuracy increases with age (Weiss & Amorose, 2005), so it is important that interventions take place before adolescence to allow actual CRF levels to rise and potentially meet the perceived fitness levels.

Children believed they could improve their fitness by increasing PA, through significant others, spending more time outdoors, improving their diet, and with the use of active equipment. The two ideas of more PA and spending time outdoors would often go hand in hand. As children are leading more sedentary lives (Saunders et al., 2014) and spending more time indoors (Steinle, Reis, & Sabel, 2013), spending more time being active outdoors would be an excellent strategy for improving PA and CRF. The suggestion is even more appropriate for children who have family members that smoke inside the house. Providing there is safe and suitable outdoor space, taking part in PA outside of the home and away from second-hand tobacco smoke, would be an effective measure that children from smoking household could take to improve their CRF.

6.2.3.2. Physical Activity and Enjoyment

Overall PA, as measured by the PAQ-C, was similar between children from smoking and non-smoking homes. Using linear regression analysis, the only significant predictor of PA was PA enjoyment (discussed below). However, qualitative data provided by Study 2 highlights the nuances in the PA behaviours of children from smoking and non-smoking homes. The themes generated from the research questions relating to PA can be mapped on to the socioecological model for physical activity (Moore et al., 2010). Figure 6.1 demonstrates how the themes generated from children of smoking and non-smoking homes can be categorised as intrapersonal, interpersonal, and community/environment level factors.

Many of the themes generated related to intrapersonal factors, including themes associated with physical activity enjoyment. PA enjoyment, as measured by PACES, was not significantly different between children of smoking and non-smoking homes, and the level of PA was the only significant predictor of PA enjoyment in the linear regression model. Sensation seeking and enjoyment are key correlates of PA identified by various reviews (Biddle et al., 2011; Sallis, Prochaska & Taylor, 2000; Lubans, Foster, Biddle, 2008). For children from smoking homes only, BMI was negatively correlated with PA enjoyment. However, overall, the quantitative data for PA enjoyment had negative skew, and PA enjoyment was generally high across the sample. Qualitative data from Study 2 illuminate subtle differences in the reasons why children from smoking and non-smoking homes participate in PA. Whilst both groups of children refer to PA as 'fun' and 'enjoyable', almost one quarter of children from non-smoking homes described PA as 'feeling good', compared to no children from smoking homes. Although subtle, how the children from different groups describe the positive feelings they associate with PA warrants further study.

Opportunities for PA, and parental provision of PA, were key themes generated which relate to community and interpersonal level factors on the SEM of PA. Children from non-smoking homes more frequently discussed attending structured PA, including attending sports clubs and training, whereas children from smoking homes more often discussed unstructured forms of PA such as going to the park with family members. Childhood sport participation is an important correlate of PA in adulthood (Parry, 2015) and organised sport participation is associated with increased fitness levels (De Meester et al., 2020). Structured PA may also result in higher levels of MVPA compared to unstructured PA (Kinder et al., 2019; Pearce et al., 2018). Children from low SES families are more likely to engage in unstructured forms of PA, such as 'free play' with friends, whereas children from middle/high SES schools engaged in more sports clubs and organised activities (Brockman et al., 2009; Voss et al., 2008).

Financial barriers can restrict organised sport and structured PA participation among children from low-SES (Clark et al., 2019; Holt et al., 2011). Participating families in the present study are generally low-SES, but smoking households were significantly more deprived than the non-smoking households. The variation in the type of PA children participate in according to household smoking status, may therefore be reflecting deprivation level rather than household smoking status specifically. Neighbourhood safety, a community level factor, was only discussed by children from smoking homes, which may also be explained by relative SES. Children from smoking households This is an avenue for future work which is discussed below.

Children participated in the research on an opt-in basis, and as discussed in earlier chapters, the sample may represent children who are ‘sporty’ or enthusiastic about PA (reflected by the overall high PA enjoyment). During the focus group discussions, PA was only referred to negatively by one child who described PA as ‘tiring’. With a less PA-enthused sample, different themes could be developed, including why some children *don’t* enjoy PA. Using an opt-out strategy may have resulted in a more normal distribution of PA and PA enjoyment, and therefore should be considered for future research. Overall, the finding that household smoking status does not impact children’s enjoyment of PA is highly positive.

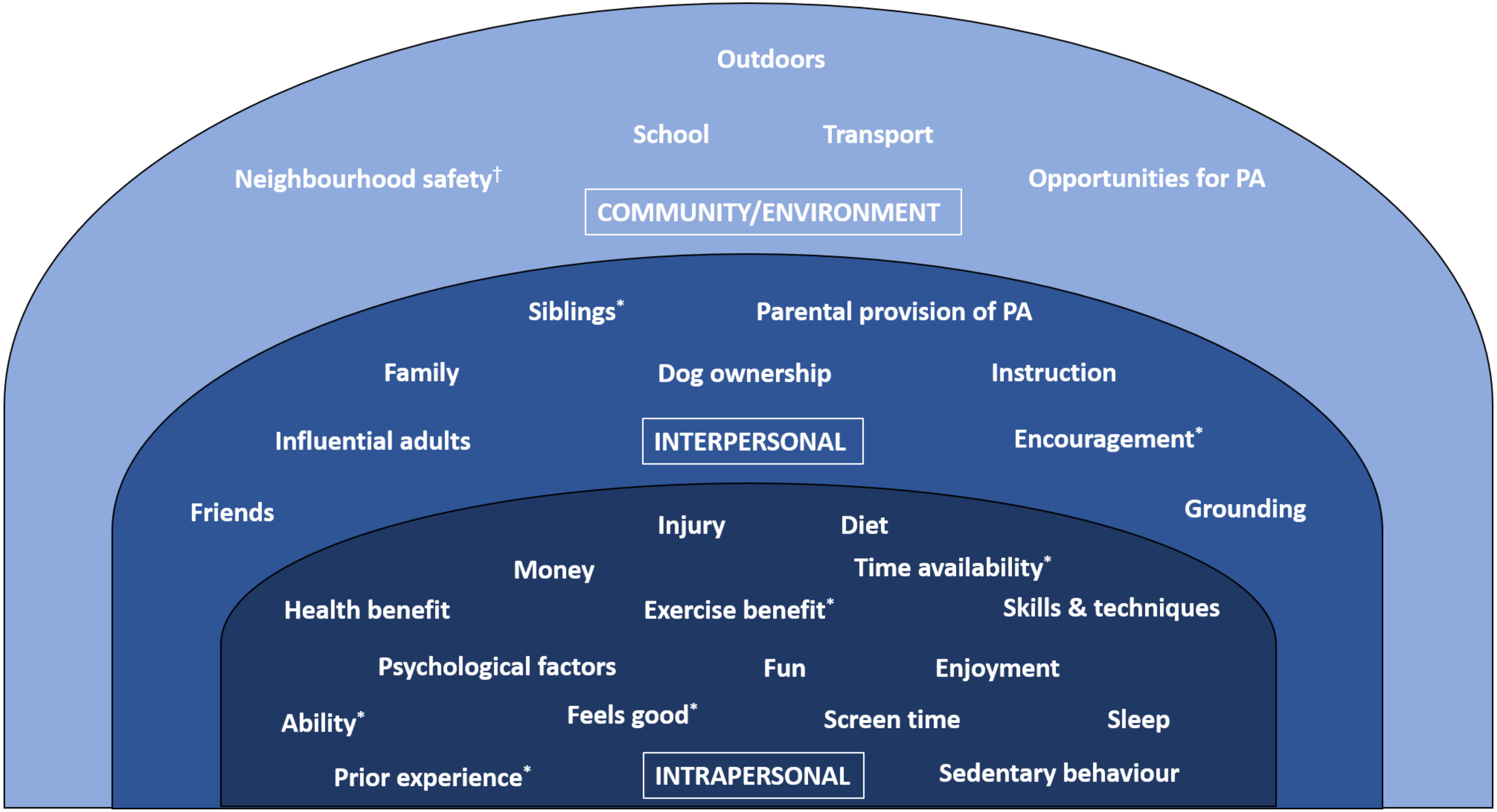


Figure 6.1. Adaptation of the socioecological model of physical activity, showing themes generated for research questions concerning PA. Key: * and † indicates themes generated from the responses of children from only non-smoking and smoking homes only, respectively.

6.2.3.3. Socioeconomic Status

Socioeconomic status (SES) is a key correlate of many of the variables explored within this thesis. SES is associated with smoking behaviour, CRF, PA, respiratory health, and weight status. In the UK, there exists stark health inequalities with regard to SES, with the gap in life expectancy at birth almost a decade between the least and most deprived areas in England (ONS, 2020). The sample in the present study had a high level of deprivation, with 85.5% of participants from neighbourhoods within the two most deprived deciles according to postcode EIMD. Although SES (EIMD) was not a significant predictor of CRF, PA, or PA enjoyment in the linear regression models, a high level of deprivation was associated with reduced FEV_1 and FVC. The clustering of environmental factors, exposures, and behaviours associated with deprivation therefore needs further examination. Qualitative data in Study 2 indicated that some children faced barriers related to SES which inhibited their ability to be active (Figure 6.1) and/or improve their fitness. For example, children often referred to logistical and financial support, and access to active equipment as facilitators and barriers to PA and CRF. The differences in responses observed between children of smoking and non-smoking homes may reflect their low-SES, although as stated above, the total sample was of low SES overall. The quantitative and qualitative findings should therefore be understood in light of the high deprivation level of the sample.

6.2.3.4. Weight Status

For the total sample, 35% were overweight or obese, which is in line with the average for similarly aged children from Liverpool and Wirral, at 39.5% and 34.0% respectively (PHE, 2020). BMI was associated with both household smoking and EIMD, with household smoking and higher deprivation associated with increased BMI and incidence of overweight and obesity. Obesity itself is associated with health indicators other than CRF, including an increased risk of diabetes, arterial hypertension, coronary artery disease, not only during youth but later in life (Barton, 2012). Findings from Study 2 indicated that children from smoking households associated fitness with a lack of fatness, and discussed health in terms of weight status, more often than children from non-smoking homes. However, the children from smoking households were more likely to be overweight and such findings may be reflecting these children's individual concerns and insecurities. The issues associated with ratio scaling for $\dot{V}O_{2peak}$ are discussed in the preceding chapters and Chapter 5 demonstrates how different methods of scaling and comparisons with 20mSRT generated thresholds can lead to varying estimates of relative CRF. However, the overall findings of this thesis indicate that children from smoking households are more likely to be overweight *and* unfit, but not less active, and these findings should be considered as two independent health risks.

6.2.3.5. Respiratory Health

The finding that household smoking is not associated with reductions in spirometry function is positive, albeit surprising, as much of the previous research has found parental smoking to be detrimental to children's lung function. However, the high level of deprivation in the present study sample may be overshadowing the relationship between lung function and SHS exposure, and the finding should be understood in the light of the lower-than-average spirometry performance of the sample. Deprivation is a known correlate of lung function and lung health (Polak et al., 2019; Hegewald & Crapo, 2007), and EIMD was the only significant predictor of FEV_1 and FVC in the present study, indicating a significant deprivation effect, even across the relatively low SES sample.

As stated elsewhere, in-utero exposure to tobacco smoke is detrimental to pulmonary development, and perhaps more detrimental than only post-birth exposure (Balte et al., 2016; Moshammer et al., 2006). As the prevalence of smoking has declined over the previous decade (ONS, 2020), it is likely that a proportion of the non-smoking parents are in-fact previous smokers, although this information was not collected. Data on in-utero tobacco smoke exposure would have made a useful addition to the study, which is discussed below.

6.3. Strengths and Limitations

A major strength of this research is the use of directly measured $\dot{V}O_{2peak}$ which is the 'gold standard' for CRF measurement. Cardiopulmonary testing is a superior method for $\dot{V}O_{2peak}$ determination compared to other methods that estimate $\dot{V}O_{2peak}$ based on test performance such as the 20mSRT (Welsman & Armstrong, 2019a). The strength of the direct approach is that a large amount of high quality, objective, data is collected for each individual, including the directly measured maximum uptake of oxygen, maximum heart rate, and end respiratory exchange ratio, and care can be taken to ensure each participant reaches voluntary exhaustion and test endpoints are met. Further, this research has considered contemporary literature regarding the optimal method for mass scaling. The use of allometric scaling is now considered a more appropriate strategy for scaling for mass, compared to the traditional use of simple ratio scaling (Welsman & Armstrong, 2019b). However, the testing requires highly specialised equipment, a trained research team, and data can be collected for only one participant at a time. Each test last approximately 20 minutes in total, which severely limits testing capacity within a limited timeframe.

The relatively small sample sizes of 104 participants for Study 1, and 38 for Study 2, are a limitation of this research. Consequently, the number of participating smoking families is small for Study 1 (n = 38) and Study 2 (n = 16). On the other hand, whilst a large sample provides statistical power for quantitative research, the relatively small sample size is less of a weakness for qualitative research, where data saturation is key. The primary school participation rate was very low at 3%, and reasons provided included ‘too busy’, ‘no staff available to coordinate the project’ and ‘the project is too contentious’, resulting in only four schools participating in the research. However, once gatekeepers had given permission for schools to participate, child/parent/guardian participation (assent and consent rate) was 26.7%, although this varied between schools. There was good representation from both sexes, and girls made up slightly more than half (55.8%) of the sample, and slightly more than half of the cohort of children from smoking homes (53.6%). Using an opt-out approach rather than the opt-in approach employed in the present research, may have led to the recruitment of more participants from each school, and a more representative sample. It is possible that the opt-in approach generated bias as ‘sporty’ and active children, who are confident in their abilities, may have volunteered for the study whereas children who are not interested in PA may have refrained.

The level of deprivation was consistently high across the sample, with a majority of participants from neighbourhoods within the lowest decile (highest deprivation) based on postcode English Indices for Multiple Deprivation (EIMD) rank. All four schools were also within the lowest decile for deprivation. As deprivation is associated with smoking prevalence, the recruitment of relatively deprived families may have led to more representation from smoking families than if a less deprived population were to be sampled. As a multitude of health inequalities exist between the most and least deprived populations nationally, understanding the factors associated with health and health behaviours in children of deprived communities is therefore of great importance. On the other hand, the findings of this research are only generalisable to children from more deprived communities, and the findings may not be applicable to more affluent populations. Geographically, this research is based on children from Liverpool and Wirral, and therefore the findings may not reflect the circumstances of children nationally or internationally.

Self-reported household smoking was used as an indication of second-hand smoke exposure which is a limitation of this research. Surveys are susceptible to recall bias and desirability bias, and the nature of this research, and the fact participants were fully informed about the research aims, may have influenced parent/guardian accuracy when reporting their smoking habits. Exhaled carbon monoxide (CO) has been used in previous research, mostly with adults, to effectively and objectively determine recent (<8 hours) active and passive smoking, and used to discriminate passive smokers from non-smokers (Deveci et al., 2004). However, in the present study, exhaled CO was not significantly correlated with self-reported smoking. Additionally, a number of children had exhaled CO concentrations of zero (or below the detection limit), and explanations for this finding are discussed in Chapter 3. Cotinine (salivary or hair) would have been an excellent addition to this research, as cotinine is a highly sensitive and specific biomarker of recent SHS exposure (Benowitz et al., 2009). It would have been useful to compare children's cotinine concentrations against and children's exhaled CO concentrations the self-reported smoking habits of the household.

One shortcoming of the cross-sectional observational study is the inability to draw causation from the correlations, although the nature of the topic means experimental studies are not ethical, appropriate, or possible. There exists a multitude of in-vivo animal studies which delineate possible mechanisms by which tobacco smoke is toxic to health (Li et al., 2018) as well as in-vitro studies with human cells (Taylor et al., 2016). However, there are a limited number of experimental studies with humans which examine the acute effects of tobacco smoke exposure on adult exercise performance (Flouris et al., 2012; Flouris et al., 2010), and such studies require volunteers to be willingly exposed to a known toxic substance.

Indoor particulate monitoring of participant homes was planned in order to establish the air quality and particulate matter (PM) concentrations in smoking and non-smoking homes. Although it is established that PM concentrations are drastically increased inside smoking homes compared to non-smoking homes (Semple et al., 2015), this measure would have been useful in establishing particulate exposure for the participants in the present study. Associations between household PM concentrations, and other measures in the present research, such as exhaled CO, CRF, and respiratory variables, could have been explored. Unfortunately, only two participants from smoking households consented to have particulate monitors inside their homes, and therefore that arm of the research was abandoned.

Due to ethical concerns regarding eliciting anxiety within the children when considering the smoking status of their parents and family members, tobacco smoking was not discussed with the children. As a result, it was not possible to gain insight into children's opinions and thoughts about smoking or SHS, or how having a smoking family member made them feel. This information would be highly valuable and could aid campaigns to prevent smoking uptake as well as smoking cessation. However, Study 2 does highlight the similarities and differences in perspectives of CRF and PA for children from smoking and non-smoking homes, and to the author's knowledge, is the first study to do so.

Another strength of this research is the mixed-methods approach, which is the basis of Chapter 5. The mixed-method approach provides a much broader perspective than what can be interpreted with the use of one methodology. The quantitative and qualitative complimentary datasets provide a comprehensive insight into how household smoking is associated with physical and psychological outcomes in children.

6.4. Implications and Recommendations

The implications of this research are relevant for several stakeholders including public health, sport and exercise science, parents, teachers, and children. This section outlines the implications for the various stakeholders and offers recommendations in light of the research findings.

6.4.1. Public Health

The finding that household smoking is associated with reduced CRF is the most alarming. CRF reflects the ability of the circulatory, respiratory, and muscular systems to supply oxygen during PA, and the functionality of most bodily systems is being checked when CRF is tested (Ortega et al., 2008; Lee et al., 2010). CRF is therefore a reflection of overall health. Household smoking was also associated with increased BMI in children, in addition to reduced CRF. It is recommended that studies exploring the relationships between PA, CRF, and weight status in children, consider SHS exposure, especially in highly deprived populations. The relationships between CRF, PA, and overweight in youth are not straight-forward as those found in adults (Leeuwen et al., 2020; Zaqout et al., 2016; Fairclough et al., 2017), and for some studies, findings are counterintuitive (Noonan et al., 2017). Considering household smoking, and SHS exposure of children, may provide a new angle for understanding the sometimes less straightforward relationships between CRF, PA, and weight status in children.

Whilst there is a multitude of research concerning SHS exposure, and PA and CRF are also well researched, this is the first thesis to fully explore the impact of SHS exposure on PA and CRF in children. One key recommendation is that further research in public health should consider PA, CRF, and SHS exposure together. Public health interventions and strategies would also benefit from considering household smoking status, PA, and CRF in unison. Whilst UK Public Health has strategic plans to reduce smoking prevalence and SHS exposure, and improve PA levels, such strategies are independent of each other. Public health strategists should look to improve child health, including CRF and weight status, not only through increases in MVPA, but also through a multidisciplinary approach that encompasses a reduction in SHS exposure.

Qualitative data demonstrates that children from smoking and non-smoking homes vary in their perceptions, understanding, and beliefs surrounding PA and CRF, although there were also many similarities. The finding that children from smoking homes may face different barriers to PA and CRF has implications for strategies that aim to improve PA and CRF in children. Only one quarter of children were aware of the PA guidelines and so PA promotion strategies should aim to include improvements in awareness of PA guidelines for children in this age group.

Participants from non-smoking households demonstrated greater awareness of the PA guidelines, referred to extrinsic motivators of PA, the health benefits of fitness, and had considerations for the future self. Further research may uncover inequalities in health literacy and physical literacy between children from smoking and non-smoking homes.

Such information could inform interventions centred around health education and promotion, and children from smoking homes may be a particular sub-population in need of such interventions.

6.4.2. Sport and Exercise Science

Sport and Exercise Science research should consider household smoking status when exploring PA and CRF, or when designing interventions to improve PA and/or CRF in youth. The findings of Study 1 indicate that SHS exposure is associated with a decrease in CRF, and so should be considered as a variable in further research relating to CRF in children. Although Study 1 does not indicate that SHS exposure is associated with decreased PA, findings from Study 2 suggest that children from smoking and non-smoking households take part in PA for different reasons and may face differing barriers and facilitators to PA and CRF.

In terms of sport, children exposed to SHS are likely to have inhibited CRF as a result of the exposure, which will most likely result in a reduction in overall sport performance. For children to maximise their athletic potential, they should not be exposed to SHS smoke. Liverpool is a city with a culture of sport, and the two major football clubs have a history of working with the community. Schemes such as 'Football in the Community' (Parnell et al., 2013), or interventions similar to that of 'SmokeFree Sports' (McGee et al., 2016) could be utilised to deliver smoke-free messages in the context of sport and physical activity. Interventions and projects that deliver smoke-free messages through sport and PA should target both children and parents, with a family-wide approach simultaneously addressing multiple factors of PA participation identified in Study 2 (parental support, parental education, opportunity for PA, provision).

6.4.3. Teachers

Teachers and education leaders should be aware of the potential impact of SHS exposure on children's health, weight status, and CRF. Additionally, educational leaders should use the knowledge that children from smoking homes, or more deprived backgrounds, face different barriers and facilitators to PA and improving fitness. With this knowledge, extra-curricular opportunities for sport and activities that increase MVPA could be provided.

Although more research is needed to explore inequalities in health literacy between smoking and non-smoking families, findings from this research indicate that children from non-smoking home shave better understanding of the PA guidelines and benefits of PA and fitness to health. More emphasis could be given to health and fitness related topics at the primary school level, in order to provide *all* children with the baseline knowledge needed to be health literate, increasing their chances of becoming healthy adults.

6.4.4. Parents

Children must be safeguarded against SHS exposure. Smoking mothers do not always attribute SHS exposure with long term effects on children (Robinson & Kirkaldy, 2007), and can often be confused regarding which rules and behaviours best protect children from exposure to SHS. Parents should be made aware of the impact of SHS exposure on both CRF and overall health. In addition to the strategies suggested above, familial interventions that incorporate elements of behaviour change techniques (Brown et al., 2020) with education of the health harms of SHS (Durkin, Brennan, & Wakefield, 2012), may be best placed to reduce SHS in the home.

6.4.5. Children

Children have been the focus of this research, and all of the findings, implications, and recommendations concern children, and their PA, CRF, and health in particular. Every adult and child has the right to a smoke-free environment. Reiterating the recommendations above, children must be safeguarded against SHS exposure, and facilitated in improving their MVPA in a safe and smoke-free environment. Children themselves made recommendations on how to improve their fitness as part of the focus groups. As the experts of their own lives, children recommend they should ‘be more active’, ‘outside’, and ‘with friends’.

6.5. Future Research

The following suggestions for future research direction have been considered in response to the findings of this thesis as well as identified gaps in the literature. Whilst the Studies in this thesis have answered the research questions the originally proposed research questions, it has also resulted in the generation of a number of new questions.

To reiterate previous sections, cotinine testing would have made a useful addition to the present study. Cotinine is a more reliable indication of recent tobacco smoke exposure than self-reported smoking, and would have been useful in the validation of exhaled CO as a marker of SHS in children. Future work could utilise cotinine testing in combination with $\dot{V}O_{2peak}$ measurement, which may allude to, and assist in the quantification of, a dose-response relationship.

Household particulate matter (PM) monitoring was planned as an additional measure in the present body of research but was not feasible due to the low uptake by participants. Future work, with an effective recruitment strategy, could use PM monitoring to explore the associations of indoor air quality on the health outcomes such as CRF and respiratory indicators, with children from smoking and non-smoking homes.

Objectively measured PA, such as through the use of accelerometers, provides real-time measurements of PA and can differentiate between PA intensities, therefore providing information on the level of MVPA. Future work could explore the PA behaviours of children from smoking and non-smoking homes in finer detail, through the use of objectively measured PA and MVPA.

Quantitative data on sedentary time, screen time, or access to media was not collected as part of this body of research, but such would make an interesting addition. It would be also insightful to gain information regarding media and screen time access and rules, and whether these differ between non-smoking and smoking households.

As some studies with youth have noted increased blood pressure in SHS exposed individuals during exercise, but not at rest (Hacke & Weisser, 2015) it may be the case that more pronounced differences in respiratory indicators (spirometry and FeNO) can be observed during exercise. An avenue for future work could be to examine flow volume loops of FeNO during and after exercise, for children exposed and not-exposed to SHS.

The results of Study 1 indicate that household smoking is associated with increased BMI and overweight and obesity, and weight status was a topic discussed by children in Study 2. Diet, which has clear associations with weight status, is a likely influencing factor that was not accounted for in the present study. Future research should examine nutritional and dietary factors, and whether these differ for children from smoking homes. The extent to which SHS exposure is associated with weight status directly, or indirectly through other unhealthy behaviours, requires further study.

Longitudinal studies which monitor SHS over the life course, including in-utero, could shed light on the influence of pre-natal exposure compared to post-natal, as well as providing understanding about whether early-life SHS exposure impacts individuals' CRF into adolescence and adulthood. In terms of interventions for smoking parents, it would be of great interest to determine whether smoking during or post-pregnancy is most detrimental to CRF.

Qualitative analysis revealed variances between the perceptions of children from smoking and non-smoking homes that warrant further exploration. More research is needed to understand children's self-perception of fitness and motor competence, which would provide useful information about whether perceived competence is lower for children from smoking homes.

The influence of parental behaviour and perceptions on offspring PA has been studied previously (Voukia et al., 2018; Schoeppe et al., 2016), as well as parental influence on CRF (Anderssen et al., 2006). However, future work could use such data in combination with qualitative methods, employing a mixed methods approach to explore how parental perceptions, beliefs, and behaviours regarding PA, CRF, and smoking, impact offspring health outcomes and perceptions. Understanding the parental influence on children's PA and CRF in terms of parental smoking status may guide future health interventions for both parents and children.

Highlighted in Study 2, children from non-smoking homes demonstrated greater understanding of the health benefits of PA and CRF, the PA guidelines, and had more consideration for the future self, than children from smoking homes. This warrants further exploration and future work could examine and compare the physical literacy, in particular the psycho-social/cognitive factors, of children from smoking and non-smoking households, which may illuminate potential areas for intervention.

Nitric oxide (NO) may be an avenue of interest as previous research has shown NO to be positively associated with exercise performance and negatively associated with tobacco smoke exposure. Additionally, blood markers such as triglycerides, cholesterol, high density lipoprotein, glucose, adiponectin, C-reactive protein, may also indicate relative cardiometabolic risk in children from smoking and non-smoking homes.

Finally, the mechanism by which SHS exposure is detrimental to CRF cannot be determined via a cross-sectional, observational study. There are over 5000 chemical components in tobacco smoke, and therefore 5000 candidates for toxicological impact on CRF. Findings of the present study indicate the parental smoking is associated with reduced CRF in children, but not through impacts on PA or respiratory health. Using the principles of toxicology in the 21st century (Tox21) future work could utilise adverse outcome pathways (AOPs) and AOP networks (Roper & Tanguay, 2020), to elucidate the potential pathways and mechanisms by which exposure to the components in SHS is detrimental the adverse outcome of reduced CRF in children.

6.6. Personal Reflection

Looking back on the previous four and a half years, I have developed many new skills, met some wonderful and impressive individuals, and my confidence as a researcher has grown tremendously. I expected a PhD to be academically challenging, which it has been, but it has been demanding in many more ways than intellectually. I have developed skills which I never would have anticipated needing to complete the PhD.

Prior to this PhD research, I had undertaken a BSc in Biological Sciences and an MSc in Environmental and Biochemical Toxicology, and as a result, the most complicated organisms I had research experience with were algae, human cell cultures, and invertebrates. Although I had experience with human physiology, this was never in a research setting, and so the world of research ethics and the process of gaining ethical approval, was a new experience for me. The original research plan, which involved understanding children's perceptions of smoking, was not originally approved by the University Research Ethics Committee, due to the potential anxiety and psychological stress for children who realise parental smoking could be causing them harm. The research ultimately gained ethical approval when discussion of smoking was removed from the research plan. Research with children has required me to be extra vigilant with regard to their health and safety, and I now feel well equipped to ensure the safeguarding of children in a research setting, whether in a physiology laboratory or elsewhere.

A major obstruction, which led to a significant delay, was the sheer difficulty of recruiting schools to take part in the project. There was a point where not a single school had agreed to take part after months of attempted recruitment and I thought the project would never get off the ground. The nature of the research meant that some schools felt the topic too contentious and others were far too busy to take part. Eventually, with a change of tactic by better demonstrating how the project could benefit the school and students, and a broader target area, I finally managed to recruit four schools. In hindsight, whilst I am not thankful for the delay it caused, the obstacle has better armed me as a researcher, and I have developed skills in participant recruitment and problem solving as a result.

Once schools had agreed to take part, the project gained momentum. However, the process of data collection was not without challenges. The level of logistical planning that was required to coordinate the data collection was nothing short of a military operation. From scheduling school visits, procuring transport and equipment, and driving said transport full of children through Liverpool city centre, ensuring children are returned to school on time, to training my data collection assistants, and organising rotas for laboratory assistance, this PhD venture has been more than just academically challenging.

The mixed-methods nature of the research has been a steep learning curve, having to learn multiple new research techniques and procedures from cardiopulmonary testing to focus group facilitation. Coming from a pure science and quantitative background, this PhD has opened my eyes to the value and merit of qualitative research and the social sciences, challenging my pre-conceived views of qualitative research. What surprised me the most during this PhD journey, was how much I enjoyed conducting qualitative research. Having discussions with insightful children about their views of physical activity and fitness, as well as being able to give children from smoking homes a platform to share their opinions and perceptions, was a particular highlight of my PhD.

In contrast to the days of data collection, where there was barely a moment to sit down, thesis writing has been a longer, more solitary process. Writing my thesis through the Covid-19 pandemic, and several national and regional lockdowns, has added to the challenge of completing the PhD. Like many others adapting to working from home, I was eventually able to be disciplined enough to stick to 'office hours' at home; writing the majority of this thesis at my bedroom dressing table, with only my cat for company.

Overcoming the various challenges and obstacles has made completing the PhD all the more worthwhile and has greatly contributed to my advancement as a researcher. Under the supervision of a team of experts, I have not only developed professionally as a researcher, but I have grown in strength of character. I have learned that completing a PhD requires a high level of knowledge and skill, but mostly it is a test of resilience and perseverance. Finally, I would like to end with a quote from one of my supervisors, Greg, which neatly summarises the PhD journey, that is: 'Nothing good comes easy' (Whyte, 2015).

6.7. Conclusion

The aim of this work was to use a mixed-methods approach to, quantitatively and qualitatively, explore the association between second-hand smoke exposure and cardiorespiratory fitness, physical activity, and respiratory health in children, and children's attitudes to physical activity, fitness, and exercise. This thesis has provided an original and unique insight into the physical and psychological impacts of household tobacco smoking, based on a sample of 9-11-year-old boys and girls from Merseyside, UK, with the strength of a mixed-methods approach.

Study 1 has quantitatively demonstrated the association between second-hand smoke exposure, measured by the number of cigarettes smoked by the household, and CRF. This study also demonstrated that overall PA and PA enjoyment, as measured by PAQ-C and PACES were not impacted by household smoking. Additionally, whilst spirometry measures FEV_1 and FVC were associated with SES, household smoking was not associated with spirometry or FeNO. This is the first study to examine the association between SHS and children's CRF using direct measurement of $\dot{V}O_{2peak}$.

Study 2 has provided unique insight into the thoughts, feelings, and perceptions of children from smoking and non-smoking homes surrounding physical activity and fitness. To the author's knowledge, this work is the first to explore and compare the perceptions of children from smoking and non-smoking households regarding physical activity and fitness.

The case study chapter uses a mixed-methods design to provide rich, contextual insight into the behaviours and perceptions surrounding PA and CRF for children from smoking and non-smoking homes. The case studies reflect the variation and heterogeneity of the sample, including examples of the extremes and exceptions to the trend. The findings illuminate the complexities and interactions of the socioecological factors that contribute to an individual's perceptions and behaviours surrounding PA and CRF. The value of the case study chapter is that a single data point in the quantitative study becomes a story as a case study.

The research has implications for children's health, especially for children who are exposed to SHS. Familial interventions that incorporate elements of behaviour change techniques, as well as education of the health harms of active and passive smoking, could be used to decrease SHS in the home. Such strategies could be used in combination with strategies that aim to increase PA and CRF, in family wide interventions focused on improving CRF. This thesis makes an original contribution to the body of research concerning children's health, fitness, and physical activity, in relation to household smoking and second-hand smoke exposure. The studies included have provided a unique insight into the physical and psychological impacts of household tobacco smoking on children. Further research is now needed to explore in depth, the behaviours, exposures, psychological factors, and possible mechanisms that contribute to the findings in this research.

Chapter 7
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Appendices

Appendix 1 - Ethical Approval

Approved - Parnell

From: MW

Thu 3/9/2017, 11:29 AM

Parnell, Melissa;

Research Ethics Proportionate Review;

Gee, Ivan;

Foweather, Lawrence

Dear Melissa

With reference to your application for Ethical Approval:

16/PBH/001 - Melissa Parnell, PGR - The impact of second-hand smoke exposure on children's exercise performance. (Ivan Gee/Lawrence Foweather)

The University Research Ethics Committee (UREC) considered the above application by proportionate review. I am pleased to inform you that ethical approval has been granted and the study can now commence.

Approval is given on the understanding that:

- any adverse reactions/events which take place during the course of the project are reported to the Committee immediately;
- any unforeseen ethical issues arising during the course of the project will be reported to the Committee immediately;
- the LJMU logo is used for all documentation relating to participant recruitment and participation e.g. poster, information sheets, consent forms, questionnaires. The LJMU logo can be accessed at http://www.ljmu.ac.uk/corporatecommunications/60486.htm

Where any substantive amendments are proposed to the protocol or study procedures further ethical approval must be sought.

Applicants should note that where relevant appropriate gatekeeper / management permission must be obtained prior to the study commencing at the study site concerned.

For details on how to report adverse events or request ethical approval of major amendments please refer to the information provided at http://www.ljmu.ac.uk/RGSO/93205.htm

Please note that ethical approval is given for a period of five years from the date granted and therefore the expiry date for this project will be March 2022. An application for extension of approval must be submitted if the project continues after this date.

MW, Research Support Officer
(Research Ethics and Governance)
Research and Innovation Services

Appendix 2 – Participant Information Infographic

What will taking part involve?

Survey - we would like to know about children's levels and enjoyment of physical activity and exercise*

We will do some breathing tests with the children to measure exhaled gases and lung function*

The children will walk, jog or run on a treadmill so we can see how well their cardiovascular system works during exercise*

*These activities will take place during a visit to Liverpool John Moores University sport science laboratories during the school day.

We may invite some parents for a telephone interview to discuss attitudes toward smoking and exercise

Some children will be invited to focus groups (group discussion, drawing activity) on school premises

Families will be given the option to have air quality monitors in their homes to tell us about the particles in the air

Are there any risks or benefits to taking part?

The study offers the opportunity for children to come and experience the state of the art Sport and Exercise Science laboratories at a world leading institution.

Previously children have enjoyed the challenge of the fitness task and results are eagerly anticipated.

Parents have the opportunity to find out about the child's fitness levels and even the air quality of their home.

Children will experience fast breathing and find it difficult to talk during the treadmill running, but this is similar to what your child experiences when playing for a long time in the playground or taking part in sport.

WIN A £50 VOUCHER

For a sports retailer of your choice

To say thank you for taking part, children will be entered into a prize draw to win £50 worth of vouchers for a sports retailer of their choice!

What should I do now?

If you would like to take part, please read the more detailed participant information sheets provided, and complete the medical and consent forms attached. Please return the forms to your child's school or teacher.

We will then be in touch with information about the next steps.

Should you have any comments or questions regarding this research, you may contact the researchers Melissa Parnell (M.J.Parnell@2016.ljmu.ac.uk) or Dr Ivan Gee (I.L.Gee@ljmu.ac.uk)

PHI Public Health Institute LIVERPOOL JOHN MOORES UNIVERSITY

LIVERPOOL JOHN MOORES UNIVERSITY

PHYSICAL ACTIVITY EXCHANGE

LIVERPOOL JOHN MOORES UNIVERSITY
PARENT/GUARDIAN
INFORMATION SHEET

Title of Project: Impact of Air Quality on Children's Exercise Performance

Name of Researcher: Miss Melissa Parnell

School/Faculty: This is an inter-faculty project based in the Public Health Institute, Faculty of Education, Health and Community and Physical Activity Exchange, School of Sport and Exercise Sciences.

What is the reason for this letter?
You and your child are being invited to take part in a research study. Before you decide it is important that you understand why the research is being done and what it involves. Please take time to read the following information. Ask us if there is anything that is not clear or if you would like more information. Take time to decide if you want to take part or not.

What is the purpose of this study?
We would like to know if there is a link between air quality and children's ability to exercise. We are also interested in whether or not pollution, tobacco smoke and e-cigarette vapour impacts fitness and attitudes towards exercise. This is the first study of its kind and the data collected might contribute to the health and wellbeing of Merseyside children and help us to give better advice to support parents.

Do we have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part, please carefully read this information, and then sign the consent forms below. You and your child are still free to withdraw at any time and without giving a reason.

What will taking part involve?
We are looking for both smoking and non-smoking families to take part in this research. Firstly, parents are asked to complete a questionnaire about outdoor and indoor air pollution, including smoking and vaping habits. Next, children will be invited to visit the laboratories within Liverpool John Moores University (LJMU) – School of Sport and Exercise Sciences to undertake various activities for half a school day between 18th Sept and 6th Oct.

Children will be transported to LJMU by an experienced driver and member of the research team in a LJMU insured vehicle with other children in the project. Children will need to change into their sports kit before being collected from school on the morning or afternoon of the visit to the LJMU and returned to school before lunch or home-time (exact dates and times will be confirmed with the school and yourself).

Activities will include:

1) **Body measurements** such as height, weight, sitting height, waist, and hip girth
2) **Running**: children will be asked to run on a treadmill whilst wearing a mouthpiece and heart rate monitor that is connected to a computer. The speed of the treadmill will start at a walking pace and then get faster every 3 minutes. We encourage the children to continue running for as long as they can. They are in complete control at all times and can stop the test at any time. Previously, children have really enjoyed this challenge and often want to do it again!
3) **Lung function** activities: children will be asked exhale as hard as they can into a respiratory analyser. This will allow us to assess their lung function.
4) **Levels of exhaled gases** such as carbon monoxide and nitric oxide will also be measured by breathing into a gas analyser (like a breathalyser).

During the visit, children will also complete a survey to assess their level of participation and enjoyment of physical activity. Following on from the results, children will be invited to focus groups to explore attitudes toward physical activity and exercise, and parents will be invited for a telephone interview to discuss similar themes. Focus groups will last for around 30 minutes and take place on school premises with a member of school staff present, at a day and time agreed by the school.

In addition, some families will be invited to take part in a study to measure small particles in the air of the home. This will involve placing air monitors in various rooms in the house for approximately one week to gather information about where air particles are most abundant in the home. You can still take part in the other aspects of the study if you do not wish to be involved in the air quality research.

In the past, visits to the labs by schools have generated excitement and enthusiasm in the children and the results have been eagerly anticipated. Parents may find the information beneficial in terms of assessing their child's health and fitness status, although receiving the results back is optional. If any results indicate a health issue with your child, you will be informed either way and advised to talk to a GP. Furthermore, the experience of the testing may stimulate interest in the health and fitness field and promote the adoption of a healthy lifestyle and an interest in the sciences.

Are there any risks or benefits involved?

Children will experience fast breathing during the treadmill activity. This is similar to what they experience when playing for a long time in the playground or playing sport. A harness will prevent any falls and the children will be well warmed up before any exercise.

By taking part, you will receive information about how fit your child is, as well as information about their lung function. To say thank you for taking part, your child will also be entered into a prize draw to win a £50 worth of sports retailer vouchers.

Will our taking part in the study be kept confidential?

Yes. Data will be stored on a password protected computer, and will only be accessible to the researchers and the project supervisor. In the event of your withdrawal from the study, any data concerning you and your child will be permanently removed. However, if the study was to be published, then data used shall remain anonymous.

What should I do now?

To take part, child participants must be in year 5 or 6, and have no known motor coordination problems or injuries that limit their ability to walk or run on a treadmill. If you are happy for you and your child to take part in this study, please sign both consent forms, fill out the medical form and your child must sign the child consent form. Please also complete and return the attached questionnaire.

Should you have any comments or questions regarding this research, you may contact the researcher **Melissa Parnell (**M.J.Parnell@2016.ljmu.ac.uk, 07429251490).

This study has received ethical approval from LJMU's Research Ethics Committee (Ref: 16/PBH/001, 02/03/17)

Contact Details of Academic Supervisor:
Dr Ivan Gee
Senior Lecturer in Public Health
I.L.Gee@ljmu.ac.uk
0151 231 4300

If you have any concerns regarding your involvement in this research, please discuss these with the researcher in the first instance. If you wish to make a complaint, please contact researchethics@ljmu.ac.uk and your communication will be re-directed to an independent person as appropriate.

Checklist of forms to return to school:

- ☐ Form A – Parental consent for child
- ☐ Form B – Parental consent for parent
- ☐ Form C – Medical questionnaire
- ☐ Form D – Child consent
- ☐ Completed questionnaire

If you have any concerns or need any assistance regarding smoking, more information, help and advice can be found at ASH or FagEnds Liverpool (www.roycastle.org/how-we-help).

FORM A

LIVERPOOL JOHN MOORES UNIVERSITY

PARENTAL CONSENT FORM FOR CHILD

Impact of Air Quality on Children's Exercise Performance

Melissa Parnell

Public Health Institute and Physical Activity Exchange

Please tick/cross the relevant boxes below:

1. I confirm that I have read and understand the information provided for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. [1]

2. I understand that my child's participation in the research is voluntary and that I am free to withdraw him/her at any time, without giving a reason and that this will not affect my legal rights. My child can also withdraw consent should they wish to. [2]

3. I understand that any personal information collected during the study will be anonymised and remain confidential. [3]

4. I give permission for photographs/video to be taken of my child during the project, which may be used for subsequent academic/promotional purposes associated with LJMU. [4]

5. I give permission for the research team to transport my child with other children to LJMU [5]

6. I understand that parts of our conversation may be used as quotes in future publications or presentations but that such quotes will be anonymised. [6]

7. I agree for my child to take part in the above study. [7]

PLEASE COMPLETE IN BLOCK CAPITALS

Name of Child ____

Name of Parent/Guardian: ____

Signature: ___________________________________ **Date:** __________________

I, Melissa Parnell, certify that the details of this project have been fully explained and described in writing to the carer/parent/guardian named above and have been understood by him/her.

FORM B

LIVERPOOL JOHN MOORES UNIVERSITY

ADULT PARTICIPANT CONSENT FORM

Impact of Air Quality on Children's Exercise Performance

Melissa Parnell

Public Health Institute and Physical Activity Exchange

Please tick/cross the relevant boxes below:

1. I confirm that I have read and understand the information provided for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. 1

2. I understand that my own participation in the research is voluntary and that I am free to withdraw at any time, without giving a reason and that this will not affect my legal rights. 2

3. I understand that any personal information collected during the study will be anonymised and remain confidential. 3

4. I understand that parts of our conversation may be used as quotes in future publications or presentations but that such quotes will be anonymised. 4

5. I agree to take part in the above study. 5

PLEASE COMPLETE IN BLOCK CAPITALS

Name of Participant ____

Signature: ____ **Date:** ____________________

I, Melissa Parnell, certify that the details of this project have been fully explained and described in writing to the participant named above and have been understood by him/her.

ID code (researcher use only):_______________________________

PHI Public Health Institute LIVERPOOL JOHN MOORES UNIVERSITY

FORM C

PHYSICAL ACTIVITY EXCHANGE

CHILD'S MEDICAL HISTORY FORM

This form should be completed as accurately as possible by the parent/guardian. All information will remain confidential. The form is designed to ensure that your child has no medical condition/illness that might compromise their safety to take part in the project. It will also be used in case of emergency. Please complete in BLOCK CAPITALS.

Name of child:____

Date of Birth: ____________________

Home Address: ____

__________________________________**Post Code**: _____________

Doctors Address ____

Home Tel No.___________________ **Parent/Carer Mobile No**. _________________

Emergency contact name & relation to child_______________________________

Emergency Tel No. ________________

	YES	NO
Has your child ever had any surgery?		
Has your child ever suffered from any injuries?		
Has your child recently suffered from any illness?		
Has your child been involved in any major accidents?		
Is your child currently being treated by your doctor?		
Is your child on any long term medication?		
Could your child be pregnant?		
Does your child have problems with:		
• hearing		
• vision		
• bones/joints		
• co-ordination		
• diabetes		
• epilepsy		
• respiratory problems		
• heart problems		
Is your child allergic to any medication?		
Does your child carry any medication in case of emergency?		
Is there any history of heart disease in the Childs family?		
Is there any history of high cholesterol in the Childs family?		
Is there any history of high blood pressure the Childs family?		
Is there any family history of unexplained sudden death?		
If you have answered YES to ANY questions please provide relevant detail OR anything else that may be relevant i.e. any other medical conditions/issues;		

FORM D

LIVERPOOL JOHN MOORES UNIVERSITY

ASSENT FORM FOR CHILDREN / OTHER DEPENDENTS

(to be completed by the child participant)

The impact of Air Quality on Children's Exercise Performance

Melissa Parnell
Public Health Institute and Physical Activity Exchange

Child (or if unable, researcher on their behalf) / young person to circle all they agree with:

1. Have you read (or had read to you) information about this project? Yes / No
2. Has somebody else explained this project to you? Yes / No
3. Do you understand what this project is about? Yes / No
4. Have you asked all the questions you want? Yes / No
5. Have you had your questions answered in a way you understand? Yes / No
6. Do you understand it's OK to stop taking part at any time? Yes / No
7. Are you happy to take part? Yes / No

If any answers from questions 1-6 are 'no' or you **don't** want to take part, don't sign your name!

If you **do** want to take part, you can write your name below.

Your name ______________________________________

Date ____________________

The researcher who explained this project to you needs to sign too.

Print Name: _________________________________

Signed: ____________________________________

Date: ________________________

ID code (researcher use only):_____________________________

Appendix 4 – Parental Survey

Public Health Institute
LIVERPOOL JOHN MOORES UNIVERSITY

PHYSICAL ACTIVITY EXCHANGE

Parent/guardian Questionnaire

We are trying to find out about physical activity in children as well as air pollution and household smoking habits. We may be able to see if air quality has any effect on exercise performance so we can develop advice for parents.

Remember:

1. This is not a test - there are no right or wrong answers
2. Please answer as honestly and accurately as you can
3. Try to answer all of the questions but you may leave a question blank if you do not wish to answer
4. All answers given will remain confidential and will be anonymous once each participant has been given a specific participant ID code

If you have any questions about this questionnaire or the study, do not hesitate to contact a member of the research team who will be happy to help (contact details at the bottom).

Please tick to indicate you are happy to take part in this study:

I have read the information sheet provided and I am happy to participate. I understand that by completing and returning this questionnaire I am consenting to be part of this research study and for my data to be used as described in the information sheet provided. ☐

Please return this form to school

ABOUT YOU

We first need some information about you so that we may get in contact to invite you to the next stages of the study. Only the main researcher will access this information to contact you, after which each participant will be given an identification code and any personal information such as address, school, and full name, will be kept separate. All personal information will be destroyed when we no longer need to contact you.

CHILD		**PARENT/GUARDIAN**	
Full Name		**Full name**	
Date of Birth		**Date of Birth**	
Ethnicity		**Ethnicity**	
Sex	Male / Female (please circle)		
Primary School			
School Year			
Home address			
Postcode			
Contact number of parent			
Email address of parent (optional)			
ID Code (Researcher use)			

A - OUTDOOR AIR QUALITY

1. **What kind of road or street do you live on?**
   a) A quiet residential street (only residential traffic)
   b) A road that sometimes gets busy
   c) Quite a busy road with lots of traffic
   d) Other: ________________________

2. **On a scale of 1-5, how concerned are you about the air quality in your area?**

Not concerned at all 1 2 3 4 5 Very concerned

3. **How does your child get to school?**
   a) Car
   b) Bus
   c) Train
   d) Walk
   e) Cycle
   f) Other:_______________________

4. **How long does the journey to school take? (Hours and/or minutes)**

   ____

B - TOBACCO AND E-CIGARETTE QUESTIONNAIRE

This section of the questionnaire is interested in tobacco smoking and e-cigarette habits and should be completed by a parent/guardian of smoking and non-smoking households. Again, there are no right or wrong answers and it is very important that you try to answer as honestly and as accurately as possible.

1. How many members of your household smoke a) tobacco products?	
b) e-cigarettes	
2. How many rooms does your house have?	
3. In how many of these rooms is a) tobacco smoking allowed?	
b) e-cigarette use allowed?	

4. In which rooms of your house do people smoke tobacco in? Tick all that apply.

☐ None, not even outside the house
☐ Outside only (e.g. garden/patio)
☐ Kitchen
☐ Living rooms (e.g. lounge, dining room etc.)
☐ Adult's bedroom
☐ Children's bedroom
☐ Other: ____________________

5. Which of these statements is true for the rooms you have selected for <u>tobacco smoking</u>? (Tick 'Not applicable' if you selected 'None' or 'Outside only' for question 5). Tick one.

☐ Smoking is allowed at any time in these rooms, without restriction
☐ Smoking is generally only allowed with a window open
☐ Smoking is not generally allowed but people smoke in the house anyway
☐ Not applicable
☐ Other: ______________________

5. In which rooms of your house do people use <u>e-cigarettes</u>? Tick all that apply.

☐ None, not even outside the house
☐ Outside only (e.g. garden/patio)
☐ Kitchen
☐ Living rooms (e.g. lounge, dining room etc.)
☐ Adult's bedroom
☐ Children's bedroom
☐ Other: ____________________

6. Which of these statements is true for the rooms you have selected for <u>e-cigarette use (vaping)</u>? (Tick 'Not applicable' if you selected 'None' or 'Outside only' for question 5). Tick one.

☐ Vaping is allowed at any time in these rooms, without restriction
☐ Vaping is generally only allowed with a window open
☐ Vaping is not generally allowed but people vape in the house anyway
☐ Not applicable
☐ Other: ______________________

Please complete for each member of the household that smokes tobacco. If you require more space please contact the research team.				
	1	2	3	4
7. Relation to the child participant? (e.g. mother, father, sister, not related, etc.).				
8. Typical number of cigarettes smoked in 1 day				
9. How long has this person smoked for (years, months)?				
10. Type of cigarette smoked (e.g. packet cigarettes, roll-ups)				
11. Does this person have a preferred brand? If yes, what is it?				
12. At what time does this person normally smoke at home? (Tick all that apply).	○ Morning ○ Afternoon ○ Evening	○ Morning ○ Afternoon ○ Evening	○ Morning ○ Afternoon ○ Evening	○ Morning ○ Afternoon ○ Evening
13. When is this person most likely smoke at home? (Tick all that apply).	☐ After waking ☐ Whilst preparing food ☐ After eating ☐ With friends and family (socially) ☐ When drinking alcohol ☐ Whilst eating ☐ Whilst relaxing (watching TV, on PC, reading) ☐ Before bed ☐ Other: ________________ ________________	☐ After waking ☐ Whilst preparing food ☐ After eating ☐ With friends and family (socially) ☐ When drinking alcohol ☐ Whilst eating ☐ Whilst relaxing (watching TV, on PC, reading) ☐ Before bed ☐ Other: ________________ ________________	☐ After waking ☐ Whilst preparing food ☐ After eating ☐ With friends and family (socially) ☐ When drinking alcohol ☐ Whilst eating ☐ Whilst relaxing (watching TV, on PC, reading) ☐ Before bed ☐ Other: ________________ ________________	☐ After waking ☐ Whilst preparing food ☐ After eating ☐ With friends and family (socially) ☐ When drinking alcohol ☐ Whilst eating ☐ Whilst relaxing (watching TV, on PC, reading) ☐ Before bed ☐ Other: ________________ ________________

14. Does this person smoke in the car? (Tick one).	☐ Yes ☐ Yes, but not with a child present ☐ Yes, but only with the window open (child present) ☐ Yes, but not with a child present, and only with the window open ☐ Never	☐ Yes ☐ Yes, but not with a child present ☐ Yes, but only with the window open (child present) ☐ Yes, but not with a child present, and only with the window open ☐ Never	☐ Yes ☐ Yes, but not with a child present ☐ Yes, but only with the window open (child present) ☐ Yes, but not with a child present, and only with the window open ☐ Never	☐ Yes ☐ Yes, but not with a child present ☐ Yes, but only with the window open (child present) ☐ Yes, but not with a child present, and only with the window open ☐ Never

Please complete for each member of the household that <u>uses e-cigarettes</u> or <u>vapes</u>. If you require more space please contact the research team.				
	1	2	3	4
15. Relation to the child participant? (e.g. mother, father, sister, not related, etc.).				
16. Approximately how much e-cigarette fluid does this person use per day? (e.g. amount in mL can be found on e-fluid bottle).				
17. How long has this person used an e-cigarette?				
18. What is this person's preferred e-fluid nicotine concentration (found on e-fluid bottle)?				
19. Does this person have a preferred brand or type? If yes, what is it?				
20. At what time does this person normally use e-cigarettes <u>at home</u>? (Tick all that apply).	○ Morning ○ Afternoon ○ Evening	○ Morning ○ Afternoon ○ Evening	○ Morning ○ Afternoon ○ Evening	○ Morning ○ Afternoon ○ Evening
21. When is this person most likely to use e-cigarettes <u>at home</u>? (Tick all that apply).	☐ After waking ☐ Whilst preparing food ☐ After eating ☐ With friends and family (socially) ☐ When drinking alcohol ☐ Whilst eating ☐ Whilst relaxing (watching TV, on PC, reading) ☐ Before bed	☐ After waking ☐ Whilst preparing food ☐ After eating ☐ With friends and family (socially) ☐ When drinking alcohol ☐ Whilst eating ☐ Whilst relaxing (watching TV, on PC, reading) ☐ Before bed ☐ Other: ________________	☐ After waking ☐ Whilst preparing food ☐ After eating ☐ With friends and family (socially) ☐ When drinking alcohol ☐ Whilst eating ☐ Whilst relaxing (watching TV, on PC, reading) ☐ Before bed ☐ Other: ________________	☐ After waking ☐ Whilst preparing food ☐ After eating ☐ With friends and family (socially) ☐ When drinking alcohol ☐ Whilst eating ☐ Whilst relaxing (watching TV, on PC, reading) ☐ Before bed

	☐ Other: ________________ ________________	________________	________________	☐ Other: ________________ ________________
22. Does this person use e-cigarettes in the car? (Tick one).	☐ Yes ☐ Yes, but not with a child present ☐ Yes, but only with the window open (child present) ☐ Yes, but not with a child present, and only with the window open ☐ Never	☐ Yes ☐ Yes, but not with a child present ☐ Yes, but only with the window open (child present) ☐ Yes, but not with a child present, and only with the window open ☐ Never	☐ Yes ☐ Yes, but not with a child present ☐ Yes, but only with the window open (child present) ☐ Yes, but not with a child present, and only with the window open ☐ Never	☐ Yes ☐ Yes, but not with a child present ☐ Yes, but only with the window open (child present) ☐ Yes, but not with a child present, and only with the window open ☐ Never
23. Any other comments or information you think will be helpful. E.g. previous smoker (last 10 years), smoke tobacco and use e-cigarettes,).				
24. Reason for e-cigarette use? (e.g. replacement of tobacco, like the flavours, for the nicotine etc.)				

Parent/Guardian Demographics

i) **What is your gender?**
- o Male
- o Female

ii) **What is the highest level of education you have completed?**
- o No formal education
- o High School
- o College / sixth form
- o Bachelor's degree
- o Master's degree or higher
- o Other: ___________________

iii) **What is your marital status?**
- o Single
- o Married
- o Divorced
- o Living with another
- o Separated
- o Windowed

iv) **What is your employment status?**
- o Unemployed
- o Employed full-time
- o Employed part-time
- o Self employed
- o Other

  ____

v) **What do you do for a living? (e.g. homemaker, teacher, driver, retired).**

____

Finally, would you be interested in having an indoor air quality monitor in your home? We are particularly interested to know how tobacco smoke and e-cigarette 'vapour' particles behave in the home, but non-smoking households can take part too. There is absolutely no obligation to have the air quality monitors, you can still take part in the other aspects of the study.

☐ Yes (please ensure you have left a phone number or email contact)
☐ No

Thank you for taking the time to complete this questionnaire. Please hand your completed questionnaire back to your school who will then pass them on to the research team. We will be in contact shortly to invite you and your child to the next stages of the study.

If you have any questions, please feel free contact the research team.

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Appendix 5 – Survey for Children's Physical Activity and Enjoyment

ABOUT YOU

Name:

Age:

School:

Year group:

ID Code (researcher use only):

Please tick to indicate you are happy to take part in this study:

I have read the information sheet provided and I am happy to participate. I understand that by completing and returning this questionnaire I am consenting to be part of this research study and for my data to be used as described in the information sheet provided ☐

---

1. **Which of these activities do you enjoy and which do you not enjoy? If you have never tried an activity, or you don't know, tick 'Don't know'.**

Activity	Like	Don't know	Dislike
Walking or hiking			
Jogging or running			
Playing in the playground at school			
Cycling			
Swimming			
Football (soccer)			
Rugby			
Netball or basketball			
Hockey			
Tennis			
Badminton			
Dance			
Gymnastics			
Martial arts			
Aerobics			
Track athletics – running and hurdles			
Field athletics – throwing and jumping			
Rounders or cricket			
Horse riding			
Climbing			
Table-tennis (ping-pong)			
Archery or shooting			
Kayaking or canoeing			

2. **Have you done any of the following activities in the past 7 days? If so, how many times? (Tick one box per row). You may use the additional space to add any activities not listed.**

	Times per week				
Activity	None	1-2	3-4	5-6	7 or more
Walking or hiking for exercise					
Jogging or running					
Skipping					
Cycling					
Swimming					
Football (soccer)					
Rugby					
Cricket					
Netball					
Hockey					
Tennis or badminton					
Dance					
Gymnastics					
Martial arts					
Climbing					
Other (please state):					

3. **Overall, do you enjoy being physically active in your spare time?**

☐ No
☐ Sometimes
☐ Yes

4. **In the last 7 days, during physical education (PE) or games classes, how often were you very active (e.g. running, jumping, throwing). Tick one.**

☐ I don't do PE or games
☐ Hardly ever
☐ Sometimes
☐ Often
☐ Always

5. **On a scale of 1-5, how much do you enjoy your PE or games lessons? (1=dislike very much, 5=enjoy very much) Circle one.**

1 2 3 4 5

6. **In the last 7 days, what did you do most of the time at *break time*? (Tick one).**

    ☐ Sat down (talking, reading, doing schoolwork)
    ☐ Stood around or walked around
    ☐ Ran or played a little bit
    ☐ Ran around and played quite a bit
    ☐ Ran and played hard most of the time

7. **In the last 7 days, what do you normally do *at lunch* (besides eating lunch)? (Tick one).**

    ☐ Sat down (talking, reading, doing schoolwork)
    ☐ Stood around or walked around
    ☐ Ran or played a little bit
    ☐ Ran around and played quite a bit
    ☐ Ran and played hard most of the time

8. **In the last 7 days, on how many days *right after school* (e.g. after-school clubs), did you do sports, dance, or play games in which you were very active? (Tick one).**

    ☐ None
    ☐ 1 time last week
    ☐ 2 or 3 times last week
    ☐ 4 times last week
    ☐ 5 times last week

9. **In the last 7 days, on how many *evenings* did you do sports, dance, or play games in which you were very active? (Tick one).**

    ☐ None
    ☐ 1 time last week
    ☐ 2 or 3 times last week
    ☐ 4 or 5 times last week
    ☐ 6 or 7 times last week

10. ***On the last weekend*, how many times did you do sports, dance, or play games in which you were very active? (Tick one).**

    ☐ None
    ☐ 1 time
    ☐ 2-3 times
    ☐ 4-5 times
    ☐ 6 or more times

11. **Which of the following describes you best for the past 7 days? (Tick one)**

- ☐ All or most of my free time was spent doing things that involve little physical effort
- ☐ I sometimes (1-2 times last week) did physical things in my free time (e.g. went running, played sports, bike riding, aerobics).
- ☐ I often did physical things in my free time (3-4 times last week)
- ☐ I quite often did physical things in my free time (5-6 times last week)
- ☐ I very often did physical things in my free time (7 or more times last week)

12. **Mark how often you did physical activity (like playing sports, games, doing dance etc.) for each day last week (Tick one box in each row).**

	None	A little bit	Often	Very often
Monday				
Tuesday				
Wednesday				
Thursday				
Friday				
Saturday				
Sunday				

13. **How did you get to and from school last week, and how long does the journey take? (Tick all that apply, and write in minutes the time taken).**

- ☐ Walked __________________
- ☐ Cycled ___________________
- ☐ By car ___________________
- ☐ By bus ___________________
- ☐ By train __________________
- ☐ Other (____________) _________________

14. **I do physical activities because… (Tick all that are true for you).**

- ☐ I don’t do any physical activities
- ☐ It keeps me fit and healthy
- ☐ It is fun
- ☐ I am told to by my parents
- ☐ I am told to by my teachers
- ☐ I get to see my friends / make new friends
- ☐ I like to compete with other people
- ☐ Because I am good at it
- ☐ I like being physically active
- ☐ My parents and teachers are proud of me when I do it
- ☐ I like to be in a team or club
- ☐ Any other reasons: ____

15. **How much do you agree with the following statements? Tick one per row.**

When I am physically active…					
	Strongly agree	**Agree**	**Neither agree or disagree**	**Disagree**	**Strongly disagree**
I enjoy it					
I feel bored					
I dislike it					
I find it pleasurable					
It's no fun at all					
It gives me energy					
It makes me sad					
It's very pleasant					
My body feels good					
I get something out of it					
It's very exciting					
It frustrates me					
It's not at all interesting					
It gives me a strong feeling of success					
It feels good					
I feel as though I would rather be doing something else					

16. **Were you sick last week, or did anything prevent you from doing your normal physical activities? (Tick one).**

☐ No
☐ Yes
If Yes, what prevented you?
____

Thank you for taking the time to complete this survey!

Appendix 6 – Focus Group Guide

Focus Groups for Second-hand Smoke and Fitness Study

Five children from the cohort will be selected from both smoking and non-smoking households (two groups, from the most and least male and females from each year group). The teacher will be consulted to ensure the groups will work well together. The focus groups will be semi-structured, and both groups will perform the same tasks, be asked the same questions, and in the same order.

Focus groups will aim to address the following PhD project objective:

Utilise qualitative and creative methodologies to explore a purposeful subsample of the cohorts' (n=30 children) attitudes to fitness and physical activity, and examine the relationship between their physical activity and perceptions of cardiorespiratory fitness.

Research Questions

RQ1. What are a child's reasons for being physically active?

RQ2. What are children's attitudes and beliefs towards physical activity, exercise and fitness?

RQ3. What factors limit or facilitate a child's ability to be physically active?

RQ4. What factors influence a child's perception of their own fitness and physical ability?

Focus Group Guide

1) Introduction
2) Ice breaker activity
3) Main set of focus group questions
4) Wrap up

1) Introductions and overview

"*Hi, for those of you that don't remember, my name is Melissa, and I'm doing some research at John Moores University. After all your excellent efforts during the fitness challenge at the sports labs, I'd like to talk to you about physical activity, fitness, and exercise. For this part of the project I'm looking at what things affect children's fitness, including your own fitness, and the fitness of other children. For some of the activities you will write, or look at some pictures and tell me what you think, and at other times we will have a group discussion to share what we all think. This should only take 30 minutes.*

There are no right or wrong answers, and please show respect to everyone in the group by letting them speak their own opinions and we will do this one at a time - try not to talk over each other. If someone is speaking and you want to say something next put your hand up and I will say your name so as to then have your turn We won't use your name or others names when we write about this. You can stop taking part at any time.

If it is OK, I'd like to tape record the conversation, so I can remember what we've said. That's what this clever device is for here I'm the only person that will listen to the recordings.

You have all signed forms which say that you would like to take part is everybody still happy to take part? (Get confirmation from all participants).

Under your chair you'll find some paper and pens but don't touch them just yet, we will use those later. Remember to put your hand up when you want to say something. Also, relax and have fun. This is not a test, I just want to know what all of you think and feel about physical activity and exercise."

2) Ice breaker – What is physical activity?

"Before we talk about physical activity, we first need to explore what it is. Under your chair you will find a sticky note, and a pen. Write down on the sticky note <u>*three*</u> *words that you think describe physical activity. For example, if I wanted three words to describe spring time, I might put 'flowers, lambs and Easter'. When you've got your three words, come and sticky your note on the board."* Read out all words and highlight those which are accurate.

Define physical activity in child friendly manor: *"Scientists and doctors would say that physical activity is 'any body movement with our muscles that uses energy'".*

3) Main set of focus group questions

Use statements such as 'That was great, thank you everyone for listening to each other and taking turns, that's helped me to understand. So now we have done X, let's move on to Y', to move from each question.

3a) Physical Activity

Focus group question	Probe	Justification
How much activity do you think you need to do each day? In minutes/hours.	-How hard should we work (e.g. get out of breath)? - Why do you think you should be active?	Gage children's understanding on how much PA they should be doing, and why.
I'm going to ask you to have a think, then choose which physical activity you enjoy the most and tell me why.	-What did you enjoy about the activity? Why? - Why do you like about taking part in physical activity and sport? - What don't you like about taking part in physical activity and sport?	RQ1: What are children's reasons for being physically active RQ2: What are children's attitudes towards physical activity, exercise and fitness?
[Activity] Think aout what things help you to be physically active, and what things might stop you. Take it in turns to come and something that help or stop you from being active	-Use pens and flipchart. Green post-it note for 'helps' and red for 'stops'.	RQ3: What factors limit or facilitate a child's ability to be physically active?
Do any adults who live with you, care for you, help you to be active? How?	- Encouragement - Financial - Logistical - Co-participation - Modelling - Does your family do anything that stops you from being active?	RQ3. Family facilitators and barriers

3b) Fitness

What does fitness mean? (Then researcher define)	-Good health and strength achieved through exercise - Ability of heart, blood vessels and lungs to supply blood with oxygen during physical activity -How can we tell if someone is fit/unfit (e.g. do they get out of breath easily, want to stop, what do they look like, etc.) - being able to keep going for a long time without getting tired	Orientating question to define fitness correctly before following Qs.
Is it important to be physically fit? Why? Is it important to you?	Personal reasons vs what parents and teachers say	RQ1, RQ2
How physically fit do you feel, on a scale of 1-10? With 1 being not very fit at all, 10 being the fittest you could be.	-Use of visual aid, e.g. ladder of fitness you are? you know how fit	RQ4: What factors influence a child's perception of their own fitness and physical ability?
What sort of things do you think affect your fitness?	-Things you can change, can't change	Knowledge and understanding of fitness
Can you improve your fitness? What kind of things can you do to help you to improve your fitness. You can have a moment to think about this, and pick one or two main ideas.	-Things you can do yourself -Things your parents/guardians can help with -Teachers and after-school clubs	RQ4, RQ2

3c) Exercise task – *"Look at this scale showing how hard an exercise is, with the easiest level of work at the bottom, and the hardest at the top, you might remember it from the fitness challenge. I'm going to give you some pictures of children doing various activities or sports and I'd like you to decide how hard you would find each activity. When you're ready, come and place the pictures on the scale, showing how hard you would find each activity."*

-Borg scale blown up large to allow children to stick pictures of various activities on.

Why would that activity be hard/easy for you?	-Would you not be able to do it for very long? -Would it cause you to become out of breath quickly?	RQ2, RQ4
At which level of activity would you choose to work at? Why?	-Why would you prefer that intensity? -How easy/difficult do you find that activity? -How do you feel working that hard/easy?	RQ2

How did you feel during the fitness challenge?	-Did you stop when it got very hard, or carry on a little more? -Do you normally work that hard? -Would you like to work that hard very often? - What were some of your thoughts and feelings during the challenge?	RQ2, RQ4.

4. **Closing questions:**

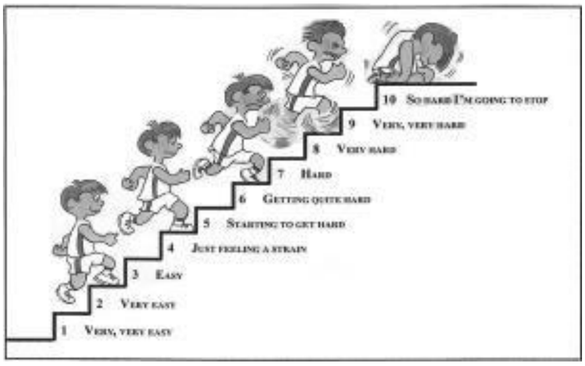
- After our discussion, how do you feel about physical activity and exercise? Has your opinion changed in any way from when we started to now
- Do you have anything that you would like to add?
- Are there any questions about what we have discussed?

Signpost to online and school health resources relevant to physical activity and health.

Thank participants for taking part, explain how the research findings will be used. Remind participants of researcher contact details.

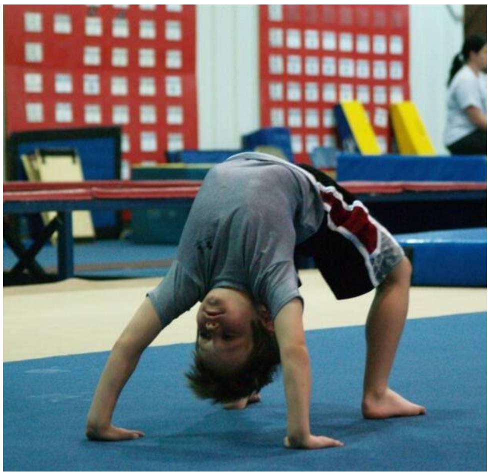
Picture Samples

Borg Scale (Exertion scale for part 3c)



Playing on apparatus or monkey bars

Gymnastics (a 'crab')

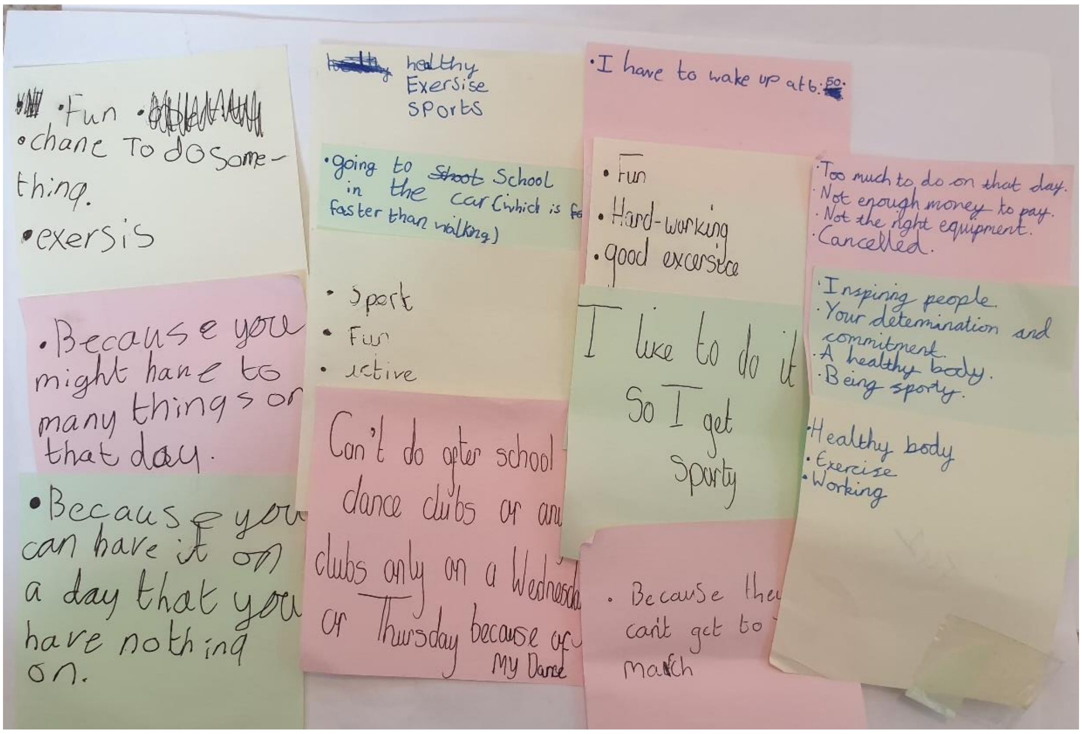


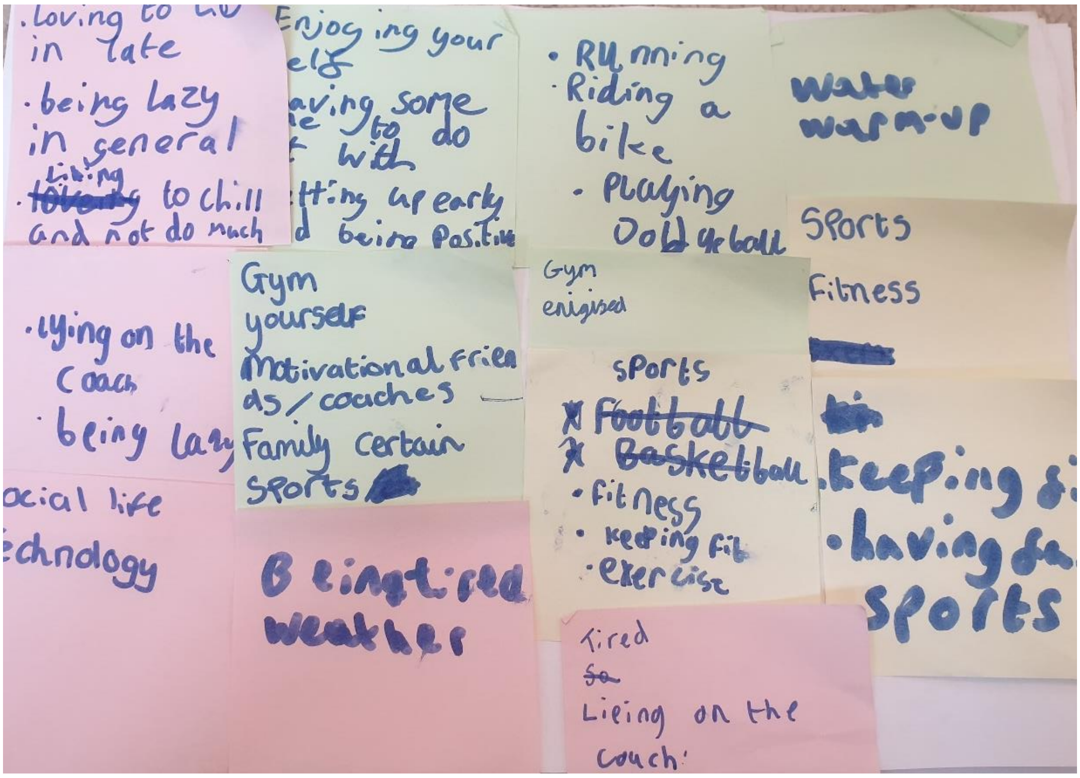
Running or sprinting

Walking (to school, shop, etc.)

Swimming

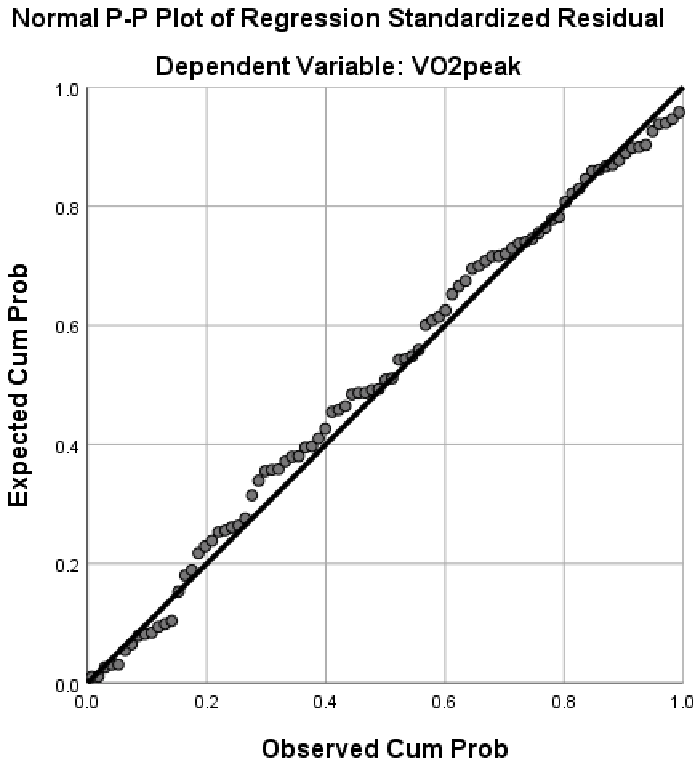
Appendix 7 – Example Responses from Focus Groups

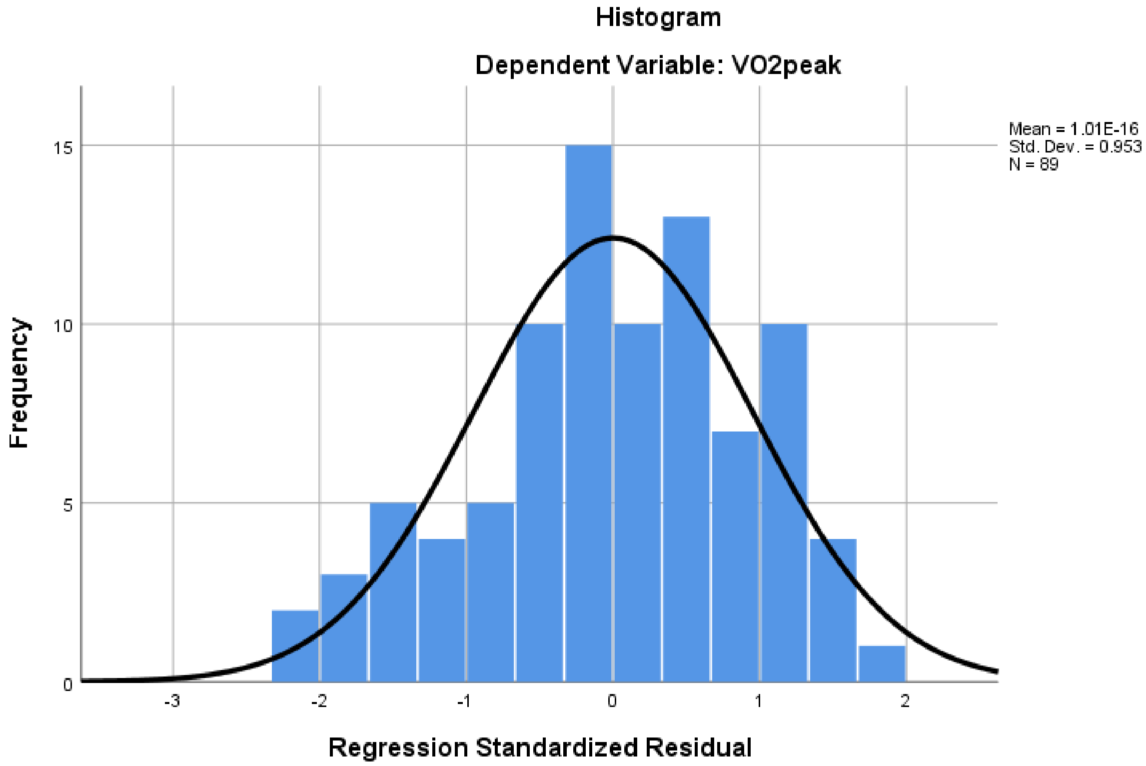




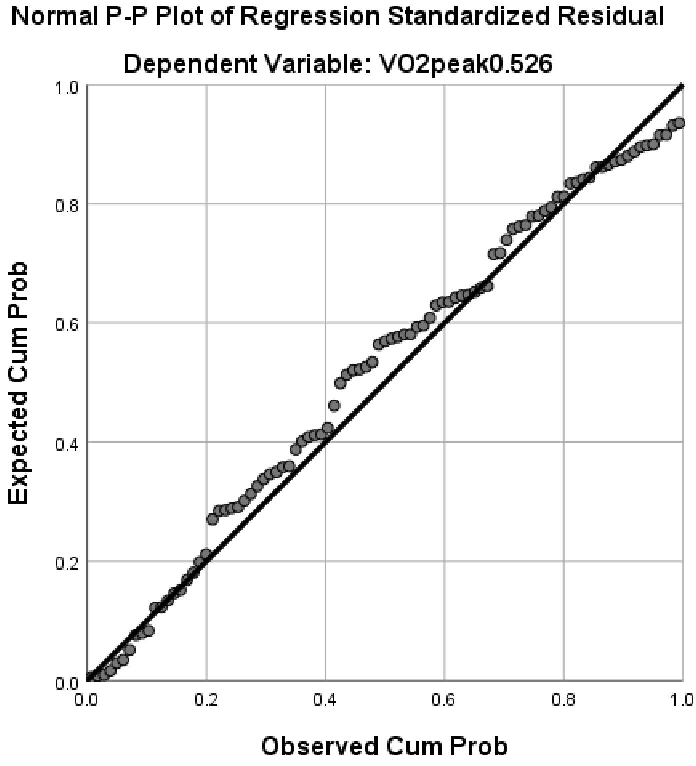
Appendix 8 – Statistical Analysis - Assumption of Normality testing

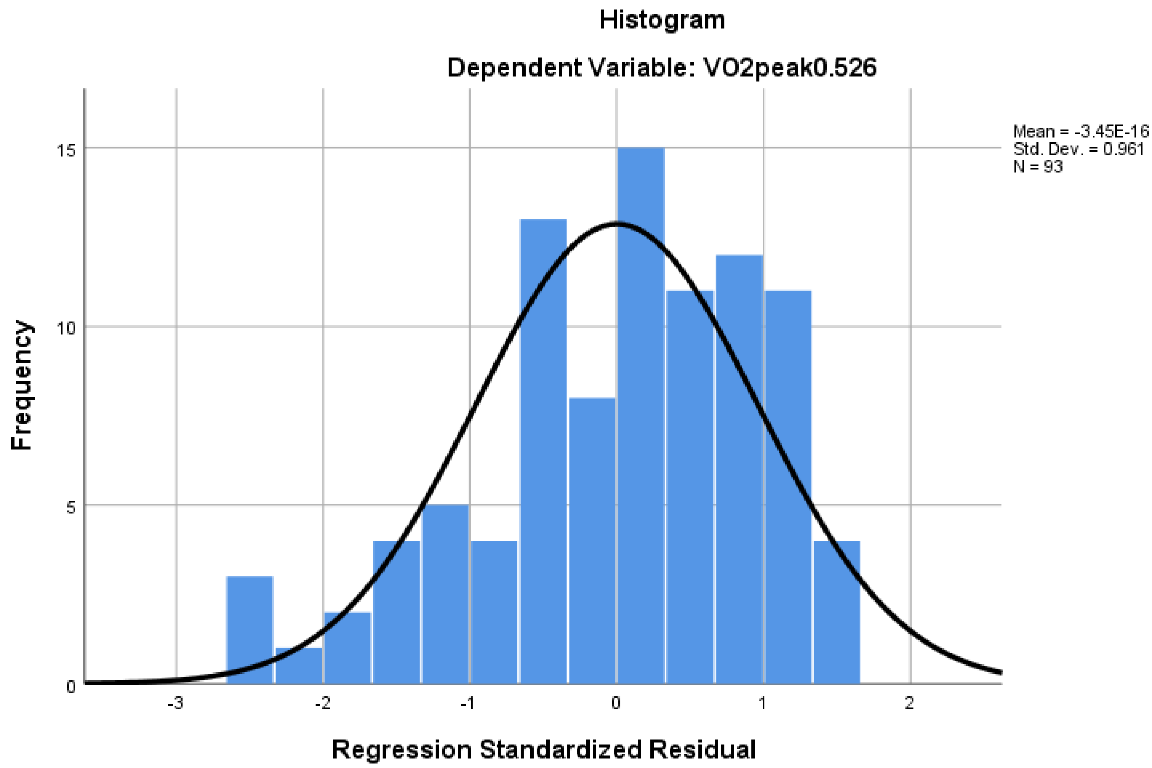
Appendix 8.1. P-P plot and histogram for linear regression of absolute $\dot{V}O_2$peak.



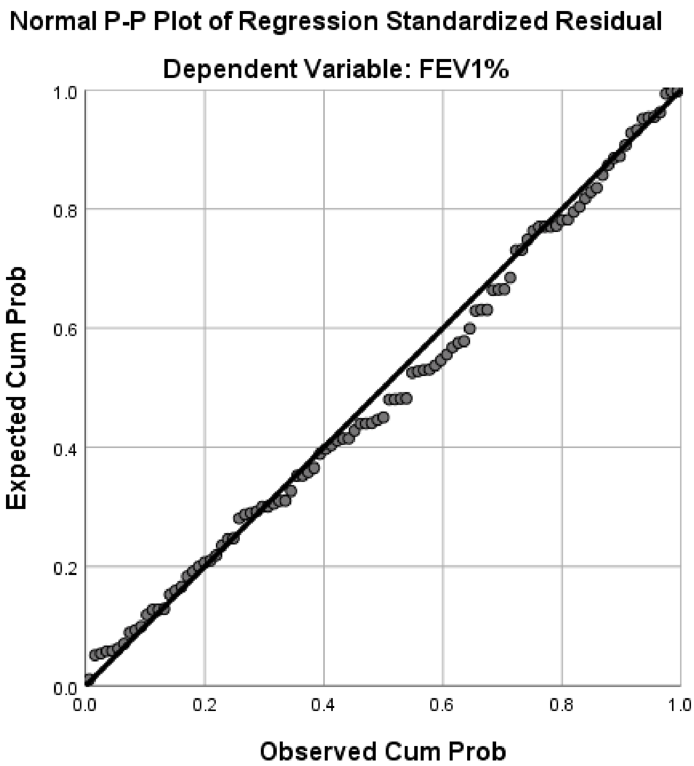


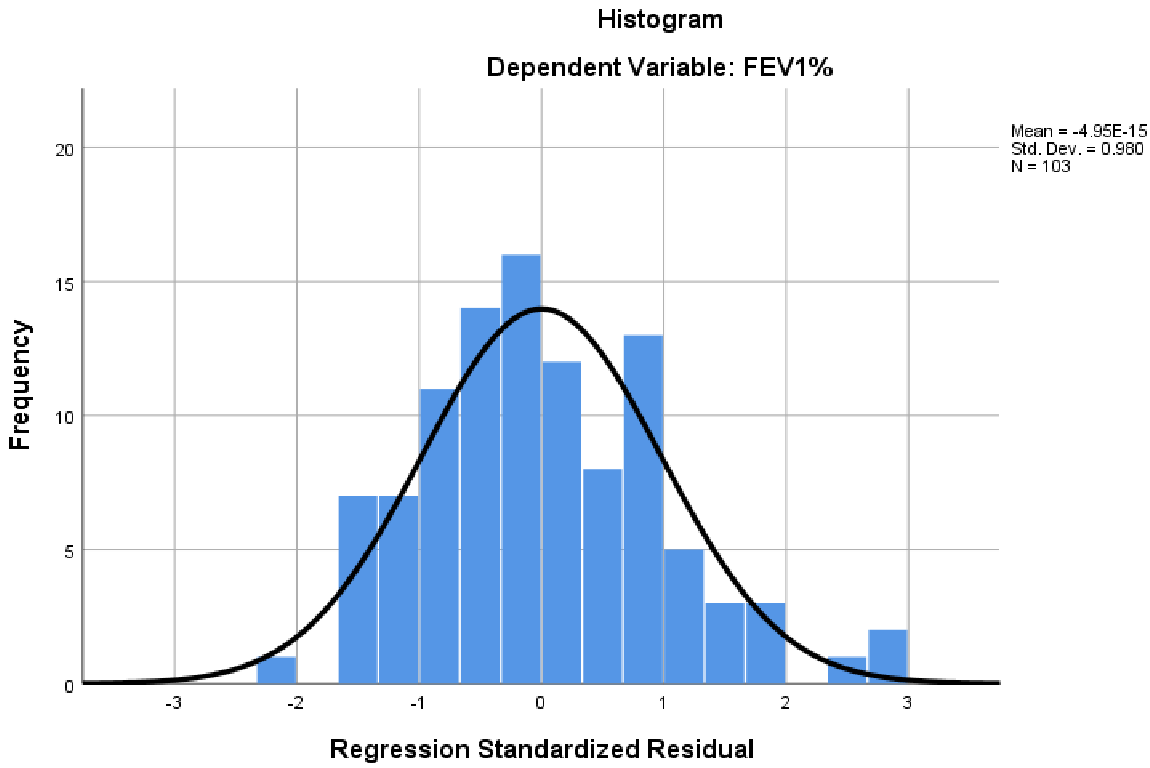
Appendix 8.2. P-P plot and histogram for linear regression of allometrically scaled $\dot{V}O_2$peak.



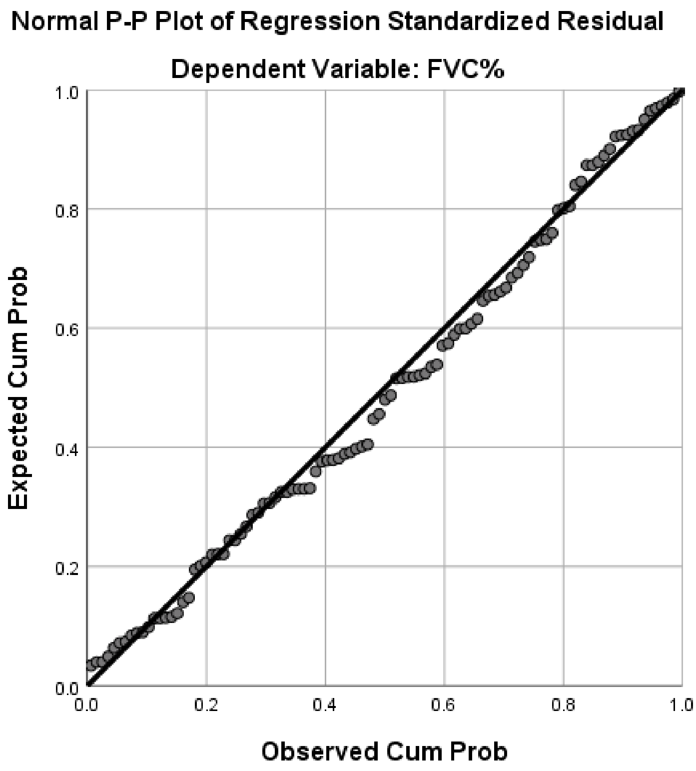


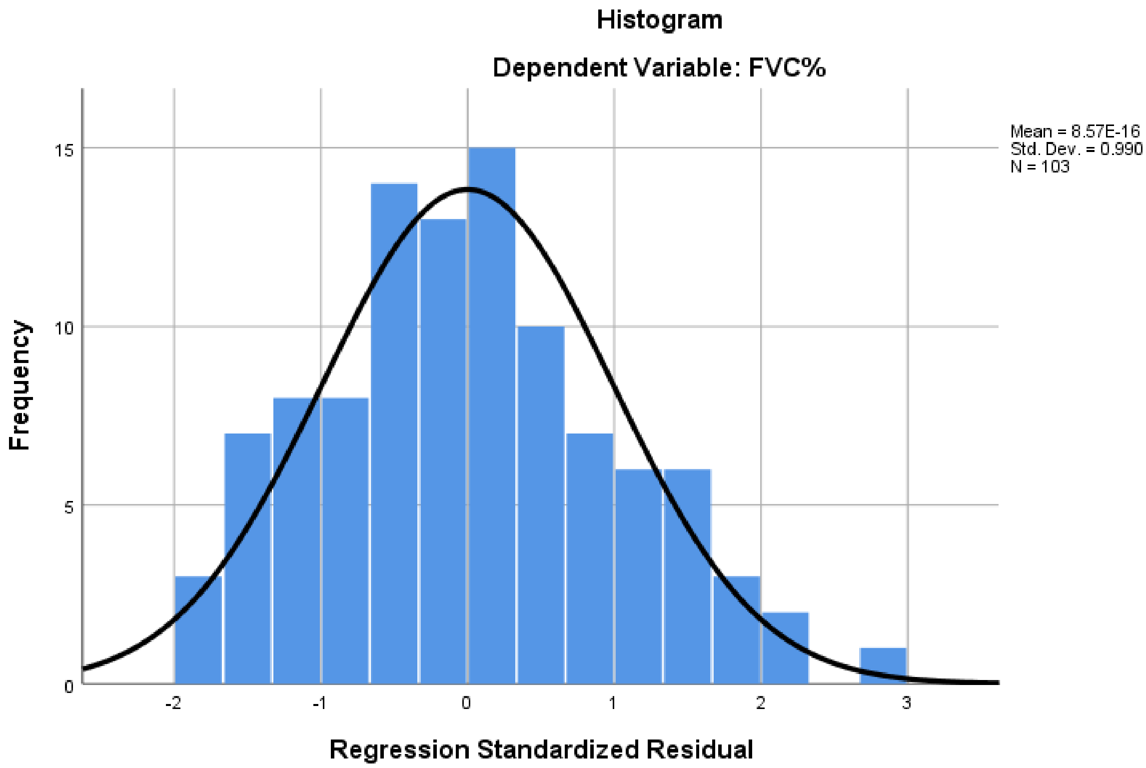
Appendix 8.3. P-P plot and histogram for linear regression of FEV_1.



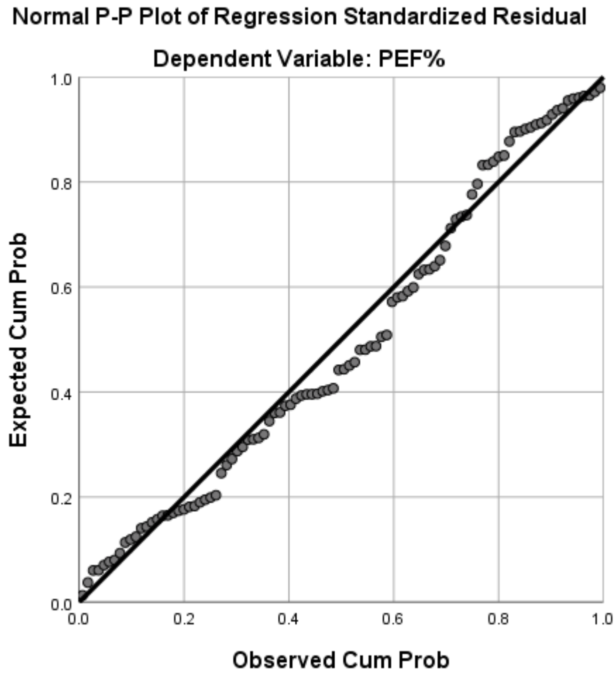


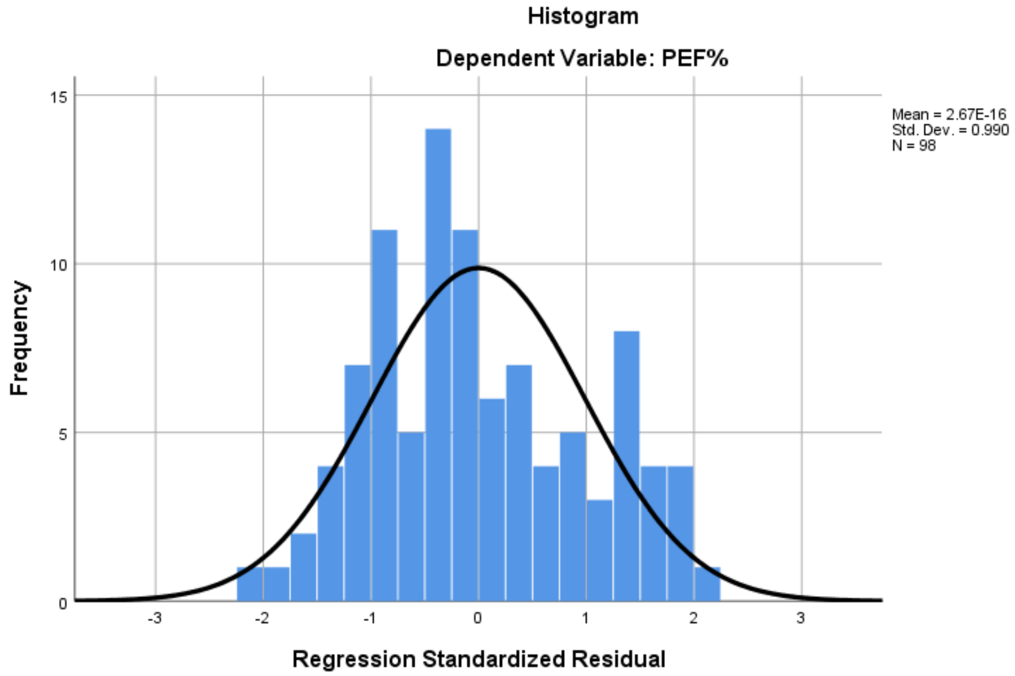
Appendix 8.4. P-P plot and histogram for linear regression of FVC.



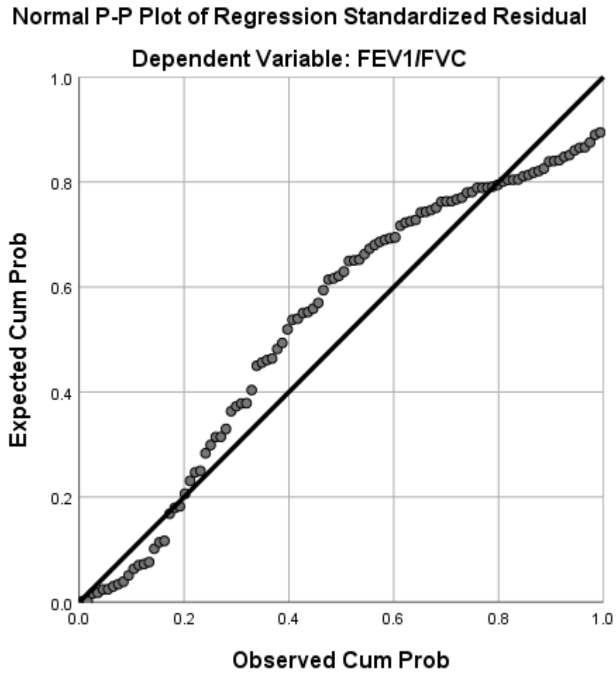


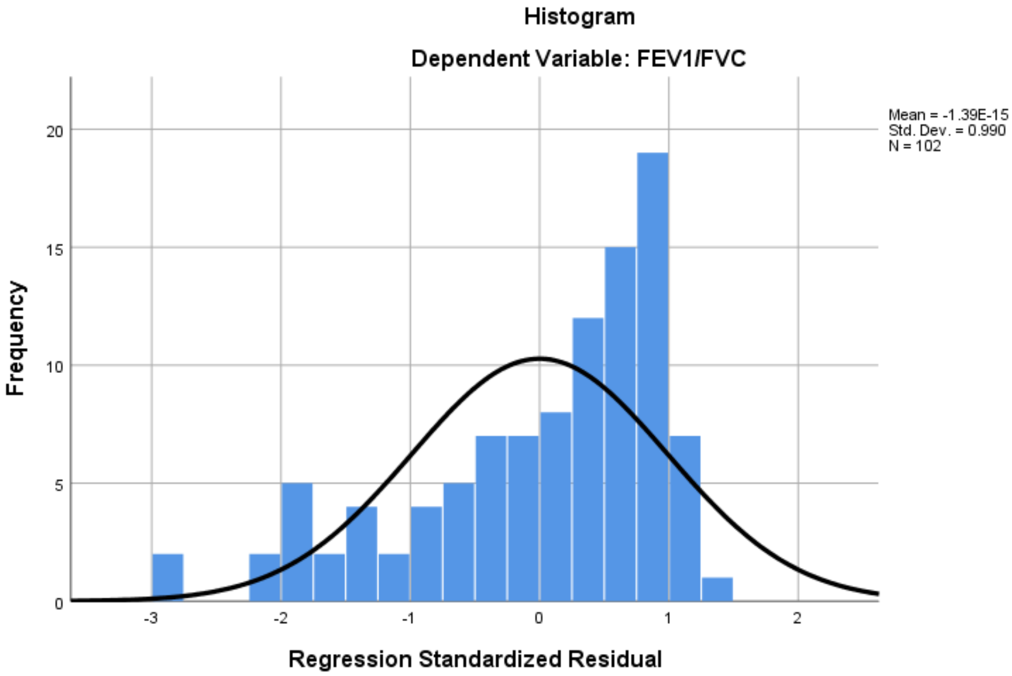
Appendix 8.5. P-P plot and histogram for linear regression of PEF



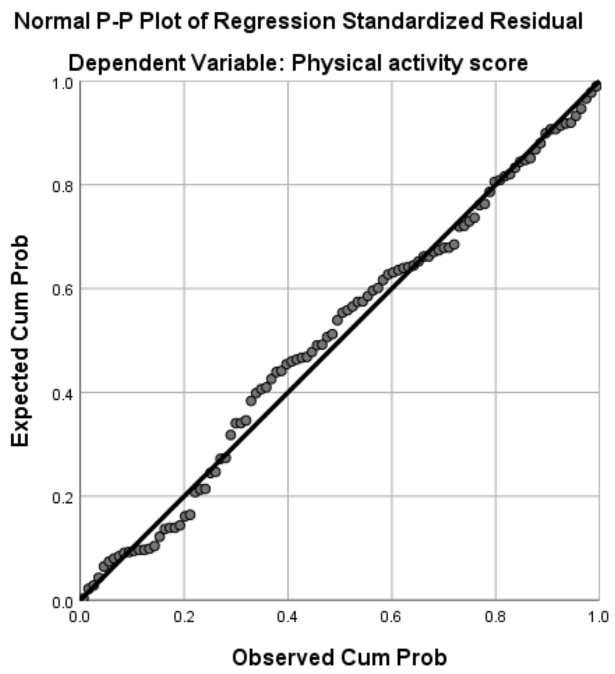


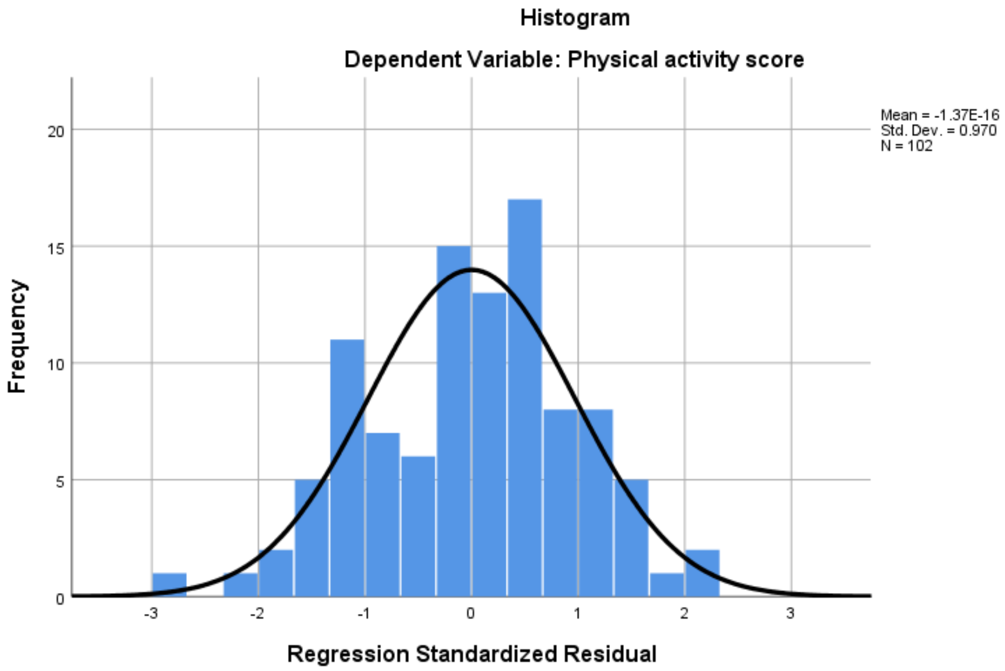
Appendix 8.6. P-P plot and histogram for linear regression of FER



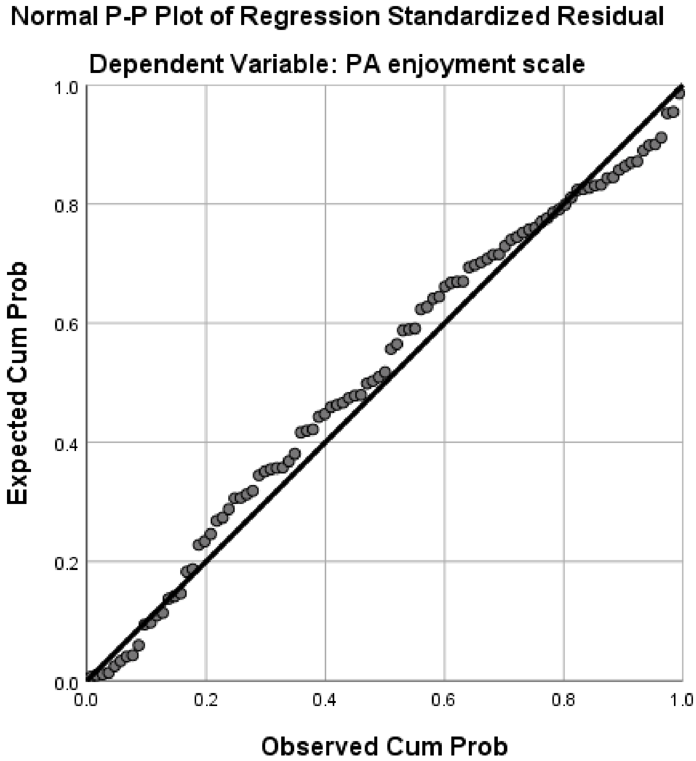


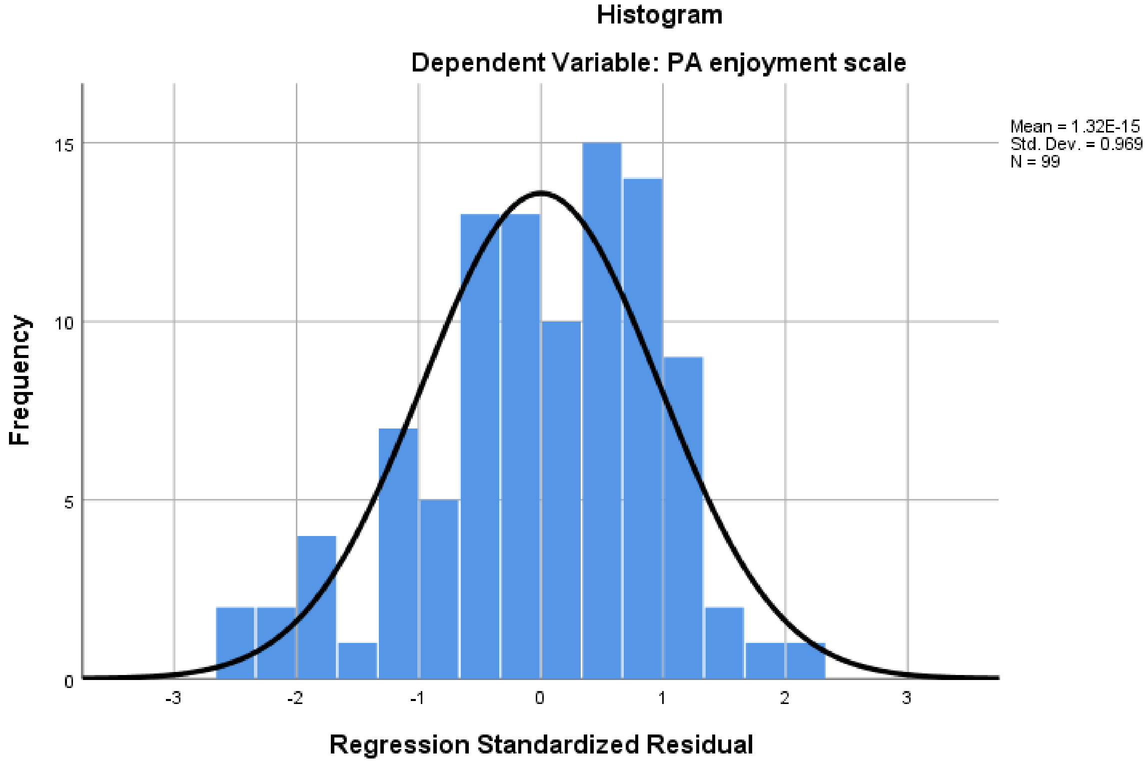
Appendix 8.7. P-P plot and histogram for linear regression of physical activity





Appendix 8.8. P-P plot and histogram for linear regression of physical activity enjoyment





Appendix 9 - ANOVA for assessing differences between smoking exposure groups.

	ANOVA		Tukey post hoc *p*		
Variable	df	*p*	Non-smoking and smoking	Non-smoking and e-cigarette	E-cigarette and smoking
Allometrically scaled VO_{2peak}	2, 91	0.082	0.352	0.379	0.084
Ratio scaled VO_{2peak}	2,91	0.001	**0.013**	0.150	**0.001**
PA	2,100	0.316	0.987	0.328	0.308
PA enjoyment	2,100	0.888	0.918	0.926	0.991
FEV_1%	2,100	0.923	0.988	0.944	0.916
FVC%	2,100	0.246	0.311	0.475	0.965
PEF%	2,100	0.154	0.999	0.150	0.163
FER	2,101	0.044	0.093	0.145	0.829