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Project FFAB (Fun Fast Activity Blasts): Effect of a novel school-based high-intensity interval training intervention on cardiometabolic risk markers and physical activity levels in adolescents

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Table of contents

List of tables	4
List of figures	5
Scientific output	6
Conference communications	6
Publications	6
Acknowledgments	6
Abstract	7
Chapter 1: Introduction	9
Introduction	9
Thesis structure	12
Chapter 2: Literature review	13
Cardiometabolic health.....	13
The metabolic syndrome.....	13
Defining the paediatric metabolic syndrome	13
Prevalence of the metabolic syndrome in children and adolescents.....	18
The association between cardiorespiratory fitness and physical activity and the paediatric metabolic syndrome	20
Summary	22
High-intensity interval training	23
Low-volume high-intensity interval training	25
The effects of HIT on health outcomes in adults.....	30
Summary	37
The effects of HIT on health and fitness outcomes in children and adolescents.....	38
Effects of Low-Volume High-Intensity Interval Training (HIT) on Fitness in Adults: A Meta-Analysis of Controlled and Non-Controlled Trials	50
Chapter 3: Programme framework.....	63
Programme setting.....	63
Programme framework and overview	64
Chapter 4: Key elements of a school-based low-volume high-intensity interval training intervention from an adolescent perspective: The development of Project FFAB (Study 1)	69
Introduction	69
Methods	70
<i>Participants</i>	70
<i>Focus group sessions</i>	71

<i>Data analysis</i>	72
Results	73
<i>Perceptions of vigorous-/high-intensity physical activity</i>	73
<i>Intervention activities</i>	74
<i>Intervention timing</i>	75
<i>Intervention Setting</i>	75
<i>Intervention leaders</i>	76
<i>Intervention feasibility and acceptability</i>	76
Discussion	77
Limitations.....	81
Conclusions	81
Chapter 5: Heart rate and perceived exertion responses to three types of low-volume high-intensity exercise in adolescent females: Pilot data from Project FFAB (Study 2)	83
Introduction	83
Methods	86
<i>Participants</i>	86
<i>Study design and exercise session structure</i>	86
Outcome measures	88
Results	92
Heart rate and perceived exertion responses.....	92
Subjective feedback	95
Discussion	96
Limitations.....	100
Conclusions	101
Chapter 6: Project FFAB: The effect of a novel school-based low-volume high-intensity interval training intervention on cardiometabolic risk markers and physical activity levels in adolescents (Study 3)	101
Introduction	101
Methods	103
Participants.....	103
Design	104
Outcome measures	106
Intervention protocol.....	123
Statistical Analysis.....	126
Results	128
Descriptive statistics	128
Post-intervention effects	132
3-month follow-up effects	135

Discussion	137
Limitations.....	143
Conclusions	144
Chapter 7:Evaluating the intervention fidelity of Project FFAB through mixed linear modelling and focus groups (Study 4)	145
Introduction	145
Methods	147
Design and Participants	147
Heart rate analysis.....	147
Focus groups	148
Results	149
Heart rate analysis.....	149
Focus groups	154
Discussion	159
Conclusions	164
Chapter 8: Discussion and conclusions.....	164
General summary	164
Summary of individual study findings	165
Study 1	165
Study 2	166
Study 3	168
Study 4	171
Overall conclusions and implications for future research	172
References	174

List of tables

Table 1. Individual study aims	12
Table 2. Definitions of the paediatric metabolic syndrome published prior to 2007.....	16
Table 3. The International Diabetes consensus definition of the metabolic syndrome in children and adolescents (Zimmet et al., 2007)	17
Table 4. Baseline (PRE), post-intervention (POST) and change values from AIT and low-volume HIT studies examining body composition	33
Table 5. Baseline (PRE), post-intervention (POST) and change values from AIT and low-volume HIT studies examining blood pressure.....	34
Table 6. Baseline (PRE), post-intervention (POST) and change values from AIT and low-volume HIT studies examining blood lipids	36
Table 7. Study and participant characteristics of trials examining the effects of high-intensity interval training on young people	40
Table 8. School level descriptive statistics	71
Table 9. School level descriptive characteristics	86
Table 10. Exercise blast drill examples.....	88
Table 11. Participants' feedback on the exercise blast sessions	95
Table 12. School level descriptive characteristics	103
Table 13. Further examples of exercise blast activities	124
Table 14. Number of measurements collected for each outcome variable at baseline, post-intervention and 3-month follow-up	129
Table 15. Participants' baseline characteristics	131
Table 16. Mean post-intervention values adjusted for sex, baseline value and maturity offset from an ANCOVA analysis	134
Table 17. Mean 3-month follow-up values adjusted for sex, baseline value and maturity offset from an ANCOVA analysis	136

List of figures

Figure 1. Key elements of the MRC development and evaluation process, reproduced from Craig et al., (2008)	65
Figure 2. Overview of the sequential phases and time course of Project FFAB	65
Figure 3. Children's OMNI-walk/run scale of perceived exertion. Reprinted from Utter et al. (2002)	91
Figure 4. Mean peak heart rate responses to each exercise blast, across the three activity modes (Weeks 1 to 3) (Values are mean \pm SD)	94
Figure 5. Mean peak heart rate responses to each exercise blast during the combination session (Values are mean \pm SD)	94
Figure 6. Illustrations of a selection of the exercise blast activities.....	125
Figure 7. Mean heart rate responses averaged over each 45-s exercise blast (Intervention school 1).....	151
Figure 8. Mean peak heart rate response for each 45-s exercise blast (Intervention school 1)	151
Figure 9. Mean heart rate response averaged over each 45-s exercise blast (Intervention school 2).....	153
Figure 10. Mean peak heart rate response for each 45-s exercise blast (Intervention school 2)	153

Conference communications

1. **Taylor, K.L.**, Azevedo, L.B., Bock, S. & Batterham A.M. Using young peoples' attitudes, beliefs, and opinions to design a school-based physical activity intervention. 1st Knowledge Exchange in Public Health Conference, Durham, UK. April 2011. Oral presentation.
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Publications

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Abstract

Whilst high levels of cardiorespiratory fitness and physical activity may protect against cardiometabolic risk factor clustering, evidence suggests these outcomes are below optimal in English youths. Adolescence is a key stage in health behaviours development, and thus represents an opportunity for interventions aiming to improve the cardiometabolic health, fitness and activity levels of this population. Recently, there has been growing interest in the efficacy of low-volume high-intensity interval training (HIT) as a time efficient way of improving health and fitness outcomes in adults. Contrastingly, the effects of low-volume HIT in adolescents remains relatively unknown. The first aim of this programme therefore was to develop a novel school-based low-volume HIT intervention. The second was to determine the effectiveness of this model for improving the cardiometabolic health, cardiorespiratory fitness and physical activity levels of adolescents.

Study one examined adolescents' views towards high-intensity exercise, and the proposed low-volume HIT intervention. This data was used to design the novel low-volume HIT model. In Study 2, participants' heart rate and perceived exertion responses to three prototype prescriptions of low-volume HIT, based on boxing, dance and football were examined. Here, it was indicated that these activities were capable of eliciting a high-intensity training response (~90% of maximum heart rate). Study 3 incorporated the main intervention, which examined the effect of a 10-week multi-activity low-volume HIT intervention (named Project FFAB [Fun Fast Activity Blasts]) on various health and fitness outcomes in adolescents. Here, beneficial effects were detected in the intervention participants compared to the controls for triglycerides, waist circumference, lipid accumulation product and daily moderate-to-vigorous physical activity. Study 4 assessed the fidelity of the intervention, and found that this had been largely upheld. Collectively therefore, it appears that Project FFAB represents a viable strategy for improving aspects of cardiometabolic health and physical activity levels in adolescents.

Introduction

In some individuals, cardiometabolic risk factors cluster as a constellation of abnormal metabolic, lipid and non-lipid variables (Camhi & Katzmarzyk, 2010). The metabolic syndrome exemplifies this clustering, and is characterised by a combination of abdominal obesity, hypertension, glucose intolerance, elevated triglycerides and decreased high-density lipoprotein [HDL] cholesterol levels (Grundy et al., 2004). While each of these is an independent risk marker for cardiovascular disease and type 2 diabetes mellitus (Graham et al., 2007), clustering can confer additional risk beyond the level predicted by individual components (Golden et al., 2002). In adults, several large prospective studies have demonstrated that metabolic syndrome presence doubles the risk of atherosclerotic cardiovascular disease events (e.g. Isomaa et al., 2001; Malik et al., 2004; Hunt et al., 2004) and is associated with a near seven-fold increased risk of developing type 2 diabetes mellitus (Wilson et al., 2005). Initially the syndrome was only reported in adults, however it is now frequently observed in young people, particularly in the overweight and obese (De Ferranti & Osganian, 2007). Indeed, it is well accepted that cardiovascular risk factors have their origins in childhood and can track into adulthood (Andersen et al., 2004; Camhi & Katzmarzyk, 2010). This is concerning, as the occurrence of multiple risk factors may accelerate the development of atherosclerosis in young people (Berenson et al., 1998). Accordingly, whilst the risk of mortality through cardiovascular disease in younger life is extremely low; early and continued exposure to an unfavourable cardiometabolic profile may heighten the risk of premature death (Andersen et al., 2004; Buchan et al., 2011a).

Physical inactivity, poor cardiorespiratory fitness and obesity (in particular abdominal obesity) appear to mediate the development of cardiometabolic risk factors and the paediatric metabolic syndrome (Brage et al., 2004; Weiss et al., 2004; Després & Lemieux, 2006; McMurray & Andersen, 2010; Nadeau et al., 2011) In England overweight and obesity prevalence figures are updated annually via the Health Survey for England; using the 85th and 95th percentiles, respectively, of the 1990 body mass index reference curves for the UK (Cole, Freeman & Preece, 1995). According to the latest report (Health Survey for England, 2012) youth obesity levels peaked at ~18% in 2004 and now appear to be levelling off at ~14%, though it is too early to confirm whether this is an ongoing trend (Ryley, 2013). In spite of this possible plateau, it appears that waist circumferences of English adolescents have substantially increased over the last 35 years (McCarthy et al., 2004; Mindell et al.,

2012). Several studies have also shown that the cardiorespiratory fitness levels of English youths is declining (Stratton et al., 2007) by around 8% per decade (Sandercock et al., 2010) and at twice the rate of other developed countries (Tomkinson & Olds, 2007). Perhaps not surprisingly therefore, the 2012 Health Survey for England (Scholes & Mindell, 2013) found that adherence to the youth physical activity guidelines was well below optimal. In this survey physical activity was measured via a 7-day recall questionnaire, which was completed by the parent/guardians of those aged 2 to 12 years and independently by participants aged 13 to 15 years. In respondents aged 5 to 15 years (n= ~1300), only 21% of boys and 16% of girls met the Chief Medical Officer's recommendations of accruing at least 60 minutes of moderate-to-vigorous intensity physical activity (MVPA) per day (Department of Health, 2011). Physical activity levels also declined with age; 24% of boys and 23% of girls aged 5 to 7 years met the guidelines, however in 13 to 15 year olds this dropped to 14% and 8% of boys and girls, respectively. These findings support the common observation that the onset of adolescence marks a sharp decline in physical activity (e.g. Sallis, Prochaska & Taylor, 2000; Troiano et al., 2008), and when viewed alongside the unfavourable changes in cardiorespiratory fitness levels and waist circumference, represents serious concern. Adolescence is a key stage in the development of health behaviours (Dumith et al., 2011); therefore the need for interventions to improve the cardiometabolic health, fitness and activity levels of this population is clear. School-based interventions are widely regarded as the most universally applicable and effective way to reverse these poor figures, though debate remains over the best way to intervene (Kriemler et al., 2011). Indeed, despite extensive scientific investigation, the optimal intensity and volume of exercise required to accrue maximal health benefits remains elusive and there is no clear consensus on guidelines for the prevention of inactivity-related disorders and disease (Gibala et al., 2012; Tjønnna et al., 2013). Largely, youth physical activity recommendations and programmes have focused on activity duration (e.g. 60 minutes per day), and the accumulation of exercise that is of moderate-to-vigorous intensity (e.g. Department of Health, 2011). Low levels of adolescent physical activity has however led to suggestions that this population may have difficulty and perhaps little interest in engaging in activity of this kind (Buchan et al., 2011b). Accordingly, determining whether novel, "non-traditional" exercise interventions can improve the fitness and cardiometabolic profile of UK adolescents is timely. For this to be achieved, it may also be necessary to engage with and understand the needs of the target population prior to intervening.

One example of “non-traditional” exercise is low-volume high-intensity interval training (HIT), which is characterised by brief, intermittent bouts of intense exercise, alternated with periods of rest or low intensity active recovery (Fox, 1973). This is often performed at an “all-out”/ maximal effort intensity (i.e. $\geq 90\%$ of peak oxygen uptake [VO_{2peak}]) (Gibala et al., 2012), which therefore necessitates short interval durations (~30 to 60 s) and longer recovery periods. Whilst forms of HIT have historically been used by athletes to improve sporting performance (Laursen & Jenkins, 2002a) the brief, maximal effort exercise bursts may appeal to adolescents, as these may better resemble their activity patterns compared with longer, less intense bouts (Chia & Armstrong, 2007). Over the last decade, there has been a surge of scientific interest in the efficacy of low-volume HIT as a time efficient way of improving health and fitness outcomes in non-athlete populations (e.g. Babraj et al., 2009; Whyte et al., 2010; Weston et al., 2014). Consequently, there is now accumulating evidence that, in adults at least, low-volume HIT can stimulate physiological remodelling comparable with continuous moderate-intensity training (Gibala & McGee, 2008). In comparison, the effects of low-volume HIT on children and adolescents remains relatively under researched, with only a handful of studies conducted to date. The initial findings from these are promising however, with authors reporting substantial improvements in cardiorespiratory fitness and systolic blood pressure post-intervention (Buchan et al., 2011a; de Araujo et al., 2012). These findings are in line with the adult-based literature, despite differences in the exercise protocol employed. The majority of low-volume HIT studies involving adults have utilised a training model which incorporates repeated 30-s Wingate tests, each interspersed with ~4 minutes recovery (Burgomaster et al., 2005). The use of this protocol in youths and those unaccustomed to intense exercise could be deemed unfeasible however, since Wingate tests demand high levels of participant motivation and may not be safe, tolerable or appealing for some individuals (Gibala et al., 2012). As such, youth studies have tended to shun the “extreme” Wingate model, and instead devised novel programmes based on dance (Boddy et al., 2010) or running (Buchan et al., 2011a; de Araujo et al., 2012). These innovative protocols have also enabled the effectiveness of low-volume HIT to be explored in “real-life” settings such as schools, since they do not require expensive laboratory based equipment such as cycle ergometers. Given the small number of studies conducted to date however, the effect of low-volume HIT on young people has yet to be fully determined. It also remains unknown whether such interventions are engaging and appealing to this population; or whether a programme requiring intense bursts of exercise can effectively be delivered under real life conditions with non-athlete participants. Accordingly, the first objective of this programme of work (named Project FFAB [Fun Fast Activity Blasts]) was

to develop a novel school-based low-volume HIT intervention that was engaging and acceptable to the participants. The second was to determine whether this intervention was an effective model for improving the cardiometabolic health profile, cardiorespiratory fitness and physical activity levels of adolescent school students from the Tees Valley region of North East England.

Thesis structure

This thesis contains eight chapters. It begins with a general introduction (Chapter 1) detailing the rationale and specific aims of the research. This is followed by a review of the cardiometabolic health and high-intensity interval training literature (Chapter 2). Chapter 3 details the framework for this PhD programme. Four studies are presented in Chapters 4 to 7, each containing a study specific introduction, methodology, results and discussion section. Lastly, Chapter 8 discusses the main findings from the four studies and offers future recommendations for research in the area. The main aims for each study are detailed in Table 1.

Table 1. Individual study aims

Study	Aims
1	(1) To explore the attitudes, beliefs and opinions of school pupils (aged 13 to 15 years) towards high-intensity physical activity and a proposed school-based low-volume HIT intervention. (2) To use the collected data to inform the design and implementation of a school-based low-volume HIT intervention for 13 to 15 year olds.
2	(1) To assess the heart rate and perceived exertions responses of adolescent school pupils to three prototype prescriptions of low-volume HIT, based on boxing, dance and football drills. (2) To trial the proposed intervention under “real-life” school conditions, and gain insight into whether such a programme would be accepted and appealing to 13 to 15 year olds.
3	To determine the impact of a novel school-based, low-volume HIT intervention on cardio-metabolic risk markers and physical activity levels in 13 to 15 year olds.
4	(1) To demonstrate how mixed linear modelling can be used to evaluate the intervention fidelity of Project FFAB. (2) To explore the intervention participants’ experiences of taking part of Project FFAB

Cardiometabolic health

The metabolic syndrome

The concept of cardiometabolic risk factor clustering dates back to 1923 when Kylin described a syndrome incorporating hypertension, hyperglycaemia and hyperuricaemia (Cameron, Shaw & Zimmet, 2004). The current paradigm of the metabolic syndrome and the role of insulin resistance and hypertension in type 2 diabetes and cardiovascular disease were identified by Reaven in 1988. Here, the disorder was called Syndrome X which described the co-existence of multiple metabolic disturbances including hyperinsulinaemia, glucose intolerance, hypertension, decreased levels of high density lipoprotein (HDL) cholesterol and elevated levels of triglycerides (Reaven, 1988). Besides cardiovascular disease and type 2 diabetes, the metabolic syndrome is associated with many other conditions including chronic low-grade inflammation, oxidative stress, hepatic steatosis and non-alcoholic fatty liver disease, obstructive sleep apnoea, vascular dementia and Alzheimer's disease, and certain forms of cancer (Reaven, 1988; Cornier et al., 2008). The syndrome has been referred to as a "master of disguise" (Eckel et al., 2005), owing to the various ways it can appear and the different components that constitute it. Whilst the disorder itself is well accepted, controversy exists on how it is diagnosed (Weiss, Bremer & Lustig, 2013). In adults, definitions have been proposed by five leading health groups (World Health Organisation [WHO] 1998 [Alberti & Zimmet 1998]; European Group for the Study of Insulin Resistance [Balkau & Charles, 1999]; National Cholesterol Education Programme [NCEP] Adult Treatment Panel III, 2001; American Association of Clinical Endocrinologists [Einhorn et al., 2003]; International Diabetes Federation, 2006 [Alberti, Zimmet & Shaw, 2006]). With the exception of Einhorn et al. (2003) there is agreement across the definitions that the essential components of the syndrome are glucose intolerance, abdominal obesity, hypertension, low levels of HDL cholesterol and high circulating triglycerides.

Defining the paediatric metabolic syndrome

Since the publication of various adult definitions, research on the metabolic syndrome has accelerated (Ford & Li 2008). Controversy remains however on the exact cut points for each risk factor, the number of factors needed to evidence the syndrome, the underlying mechanisms and the usefulness of the syndrome to predict cardiovascular events in a manner

superior to other well described risk factors (Kahn et al., 2005; De Ferranti & Osganian, 2007; Weiss et al., 2013). Nonetheless, there does appear to be agreement on the specific risk markers with regards to adults; whereas a unified consensus on detection and diagnosis in young people has yet to be reached (McMurray & Andersen, 2010). This was illustrated in the review article by Ford & Li (2008), where 40 unique metabolic syndrome definitions were found across 27 publications examining the disorder in youths. Diagnosis in children and adolescents is also complicated by several other factors. Firstly, since young people do not routinely suffer from cardiovascular events, relating the risk factor criteria to a health outcome can be problematic (McMurray & Andersen, 2010). This links to the ongoing debate on the strength of risk factor tracking (e.g. the stability and predictive ability of a variable measured in an individual at different time points [Twisk et al., 1994]) from childhood to adulthood. Generally, adiposity and cholesterol components tend to have greater tracking stability than blood pressure (e.g. Kemper et al., 1990; Katzmarzyk et al., 2001), glucose and triglyceride levels (Pagnan et al., 1982). In addition to these individual variables, evidence from a recent systematic review indicates that risk marker clustering may also be stable from childhood through to adulthood (Camhi & Katzmarzyk, 2010). This is concerning as cardiovascular disease tends to result from high levels of multiple risk factors over many years, rather than high levels of one individual factor (Kannel & Gordon, 1987; Andersen et al., 2004).

There are several other methodological and physiological limitations that can confound metabolic syndrome diagnosis in young people. For example, normal lipid levels vary by age, sex and ethnicity (Dai et al., 2009) and during puberty young people can develop transient physiologic insulin resistance (Hannon, Janosky & Arslanian, 2006; Moran et al., 2008). Furthermore, the use of fasting bloods prevents the utilisation of a post-glucose load sample to detect impaired glucose tolerance, which is a superior marker of peripheral insulin resistance in this age group (Weiss et al., 2013). Detection is further complicated by a lack of standardised abdominal obesity cut-points linked to obesity morbidity or metabolic syndrome in youths (Steinberger et al., 2009); and the fact that many of the associated metabolic perturbations are usually moderate in paediatric populations (Weiss et al., 2013). There are also concerns that by diagnosing the clustering of risk factors on a dichotomous scale (e.g. suffering from metabolic syndrome, or not), important information on the values of the key risk components could be lost. This view is shared by the American Diabetes Association and the European Association for the Study of Diabetes (Kahn et al., 2005), who instead advocate that the identification of one risk marker should simply prompt a search for

others. They go on to recommend that investigators should evaluate and attempt to treat all apparent risk factors, regardless of whether an individual meets the criteria for metabolic syndrome. A proposed solution to the issues associated with dichotomous diagnosis is to assess the risk markers as continuous variables and then sum z scores for each component to quantify the risk (Eisenmann, 2008). However, whilst this approach holds promise, its proponents have acknowledged that it may be better suited as a research tool rather than for clinical practice. Another method which may aid detection of the metabolic syndrome is the calculation of lipid accumulation (Kahn, 2005). This was developed in light of observations that in the current climate of increasing obesity, attempts should be made to define and measure lipid accumulation specifically in those contexts where it may represent a physiological danger (Schaffer, 2003; Unger, 2003a). Accordingly, Kahn proposed an index called the lipid accumulation product (LAP), which is calculated using waist circumference and triglyceride measurements. To date, the usefulness of this tool for recognising cardiovascular disease, diabetes and metabolic syndrome risk has only been reported in adults (Kahn, 2005; Kahn 2006; Taverna et al., 2011). The appropriateness of the index for young people is therefore unknown and warrants further investigation.

Despite ongoing debate, there is evidence supporting the existence of metabolic syndrome in childhood and adolescence (De Ferranti & Osganian, 2007). Over the last decade several definitions of the paediatric version of the syndrome have been proposed in the literature. Generally, these have been modified from adult criteria using age- and sex-specific normative values where available (Weiss et al., 2013). Whilst there is general agreement that the paediatric definition should contain the same risk factors as the adults, uncertainty remains over the appropriate risk factor thresholds for young people (Cook et al., 2003; De Ferranti et al., 2006). Five of the most well-known paediatric definitions published prior to 2006 are shown in Table 2. In these, metabolic syndrome is identified when an individual displays three or more risk factors. In four cases (Cook et al., 2003; Cruz et al., 2004; De Ferranti et al., 2004; Ford, Ajani & Mokdad, 2005) waist circumference cut-offs were anchored around the age- and/or sex-specific percentiles from the Third National Health and Nutrition Examination Survey (NHANES III) which took place in the United States (US) between 1988 and 1994 (Ford, Giles & Dietz, 2002). Two studies (Cruz et al., 2004; Weiss et al., 2004) used the American Diabetes Association criterion for impaired glucose tolerance (American Diabetes Association, 2002). With regard to triglycerides, two publications used age-specific cut-offs adapted from the NCEP adult definition (NCEP, 2001) and the NCEP adult definition values for HDL cholesterol (Cook et al., 2003; Ford et al., 2005); whereas

others were based on age- and sex- and race-specific distributions and trends from either the NHANES III (Cruz et al., 2004) or the National Growth and Health Study (Weiss et al., 2004). For blood pressure, all but De Ferranti et al., (2004) referenced the National High Blood Pressure Education Programme age-, sex- and height-specific cut-points (Falkner et al., 1996). Inevitably however, this use of varying data sources has led to differing threshold values, which is clearly evident in Table 2. This further complicates risk factor identification, particularly for the triglyceride and HDL cholesterol components.

Table 2. Definitions of the paediatric metabolic syndrome published prior to 2007

Study (year)	Risk factor component				
	Central Obesity	Glucose	Triglycerides	HDL cholesterol	Blood pressure
Cook et al., (2003)	WC $\geq 90^{\text{th}}$ percentile	Fasting glucose ≥ 6.1 mmol/L	Triglycerides ≥ 1.2 mmol/L	HDL Cholesterol ≤ 1.03 mmol/L	Blood pressure $\geq 90^{\text{th}}$ percentile
De Ferranti et al., (2004)	WC $> 75^{\text{th}}$ percentile	Fasting glucose ≥ 6.1 mmol/L	Triglycerides ≥ 1.1 mmol/L	HDL Cholesterol < 1.3 mmol/L	Blood pressure $> 90^{\text{th}}$ percentile
Cruz et al., (2004)	WC $\geq 90^{\text{th}}$ percentile	Plasma glucose ≥ 7.7 mmol/L and less than 11.1 mmol/L at 2-hours post- glucose challenge	Triglycerides $\geq 90^{\text{th}}$ percentile	HDL Cholesterol $\leq 10^{\text{th}}$ percentile	Blood pressure $> 90^{\text{th}}$ percentile
Weiss et al., (2004)	BMI – z score ≥ 2.0 (age- and sex- specific)	Plasma glucose ≥ 7.7 mmol/L and less than 11.1 mmol/L at 2-hours post- glucose challenge	Triglycerides $> 95^{\text{th}}$ percentile	HDL Cholesterol $< 5^{\text{th}}$ percentile	Blood pressure $> 95^{\text{th}}$ percentile
Ford et al., (2005)	WC $\geq 90^{\text{th}}$ percentile	Fasting glucose ≥ 6.1 mmol/L (additional analysis with ≥ 5.5 mmol/L)	Triglycerides 1.2 mmol/L	HDL Cholesterol ≤ 1.03 mmol/L	Blood pressure $\geq 90^{\text{th}}$ percentile

WC = waist circumference

The confusion created by the varying risk factor thresholds further emphasised the need for a single, consistent set of criteria. Accordingly, in 2007 the International Diabetes Federation (IDF) released a consensus definition of the metabolic syndrome in children and adolescents (Zimmet et al., 2007). In an attempt to unify previous paediatric guidelines and simplify diagnosis, this report was partly based on the adult IDF definition (Alberti et al., 2006) and built on earlier paediatric metabolic syndrome work. Within this new guidance, young people are divided into three age groups (6 to < 10 years, 10 to 16 years, and > 16 years) to account for the developmental challenges presented by the age-related differences (Zimmet et al., 2007). No specific guidelines were proposed for children under the age of 10 years and diagnosis using the adult IDF criteria was recommended for those aged over

16 years. The definition for those aged 10 to 16 years was based on the presence of central adiposity, and at least two of the other four risk factors. Across the ages, central obesity (assessed via waist circumference) was the “*sine qua non*” for diagnosis. The rationale for this was multi-faceted. Firstly, it has been evidenced that insulin resistance and central obesity are significant causative factors in the development of the metabolic syndrome in adults (Anderson et al., 2001; Eckel et al., 2005) and a similar relationship has been described in young people (Goodman et al., 2004; Rosenberg, Moran & Sinaiko, 2005). Furthermore, elevated waist circumference is also a strong cardiovascular risk factor in children (Savva et al., 2000) and adults (Yusuf et al., 2005); and an independent predictor of insulin resistance, lipid levels and blood pressure (Flodmark, Sveger & Nilsson-Ehle, 1994; Hirschler et al., 2005; Lee et al., 2006; Bacha et al., 2006). In contrast to the adult IDF definition however, the paediatric guidelines used percentiles rather than absolute waist circumference values to allow for ethnicity and the different degrees of development in the youth population (Zimmet et al., 2007). Since four of previous paediatric definitions used the 90th percentile as a cut-off for waist circumference, the IDF also used this with the intention of reassessing this threshold when more outcome data becomes available. They also elected to use the same absolute values described in their adult guidance for the four remaining risk factors until definitive evidence on the optimal thresholds in youths are published. Their criteria, along with further information for each age group classification are shown in Table 3.

Table 3. The International Diabetes consensus definition of the metabolic syndrome in children and adolescents (Zimmet et al., 2007)

Age group	Central obesity	Risk factor component			
		Glucose	Triglycerides	HDL Cholesterol	Blood pressure
6 to under 10 years	≥90 th percentile	The metabolic syndrome cannot be diagnosed, but further measurements should be made if there is family history of metabolic syndrome, type 2 diabetes, dyslipidaemia, CVD, hypertension and/or obesity.			
10 to 16 years	≥90 th percentile, or adult cut-off if lower	≥5.6 mmol/L (If ≥5.6 mmol/L, or known type 2 diabetes, recommend an oral glucose tolerance test)	≥1.7 mmol/L	<1.03 mmol/L	Systolic ≥130 mmHg Diastolic ≥85 mmHg
Over 16 years (IDF adult criteria, 2006)	≥94cm for Europid men ≥80cm for Europid women	≥5.6 mmol/L (If ≥5.6 mmol/L, or known type 2 diabetes, recommend an oral glucose tolerance test)	≥1.7 mmol/L	<1.03 mmol/L for males <1.29 for females	Systolic ≥130 mmHg Diastolic ≥85 mmHg, or previously diagnosed hypertension

Since its release, the IDF consensus has been widely referenced; a Google Scholar search performed in January 2014 evidenced over 600 citations. Furthermore, the guidelines have been lauded as a “valuable attempt” at unifying the diagnosis of the metabolic syndrome in young people (Marcovecchio & Chiarelli, 2013). They are not however, without limitations. Indeed, the use of waist circumference in youths is hindered by reference values only existing for some populations. This is problematic, since elevated waist circumference is the pre-requisite for diagnosis. The large variability of absolute values within waist circumference percentiles across countries further complicates matters. For example, in the US the 90th percentile for a 14-year old male is 91.6 cm (Fernández et al., 2004); whereas the corresponding percentile value in the UK is 76.1cm (McCarthy, Jarrett & Crawley, 2001). Similarly, the 90th percentile values for Canadian and Australian 14-year old males are also lower than the US equivalent, at 77.6cm and 79.9cm respectively (Katzmarzyk, 2004; Eisenmann, 2005). This hinders efforts of establishing the global prevalence of the syndrome in youths. To facilitate valid comparisons, authors should therefore explicitly specify which reference data they use. A further limitation of the IDF report is the statement that the metabolic syndrome is not definable in children aged <10 years (Marcovecchio & Chiarelli, 2013). This conflicts with a large body of work that demonstrates that many of the metabolic abnormalities and cardiovascular complications of obesity are already apparent in pre-pubertal children (Sinha et al., 2002; Marcovecchio et al., 2006; D’Adamo et al., 2008).

Prevalence of the metabolic syndrome in children and adolescents

Undoubtedly, the lack of unified criteria for paediatric metabolic syndrome has hindered global attempts in estimating the true prevalence (Marcovecchio & Chiarelli, 2013). Indeed, it appears that despite the release of the paediatric IDF report, debate remains over which definition is most appropriate (Tailor et al., 2010). In two recent systematic reviews (Tailor et al., 2010; Friend, Craig & Turner, 2013), it was reported that the majority of studies use the youth versions of the IDF, NCEP or WHO definitions (Zimmet et al., 2007; NCEP, 2001 and Alberti & Zimmet, 1998, respectively). It is therefore unsurprising that paediatric metabolic syndrome prevalence varies greatly, with rates of between 0% and 60% reported depending on the definition and the population studied (Golley et al., 2006). To date, only one study has attempted to determine prevalence in obese UK youths (Viner et al., 2005). Here a modified version of the 1998 WHO criteria was used, thus describing levels of insulin resistance syndrome rather than the metabolic syndrome. In this sample (103 obese youths aged 12 to 18 years) 33% were diagnosed with insulin resistance syndrome. The usefulness

of these data for estimating whole population prevalence in UK youths is greatly limited however by the small sample size and the fact that only obese participants were included. Furthermore, since the analysis was conducted on data collected between 1999 and 2002 the prevalence figures reported may now be well out of date.

Several US prevalence studies have sampled NHANSES youth data from 1999 to 2004 (e.g. Kranz, Mahood & Wagstaff, 2007; Cook et al., 2008; Ford et al., 2008). Here, incidence of paediatric metabolic syndrome ranged from 2.0% (Kranz et al., 2007) to 9.4% (Cook et al., 2008). In the study by Ford et al. (2008) prevalence was estimated for different age groups using the 2007 IDF definition. In a sample of 2014 adolescents (aged 12 to 18 years) the overall incidence was ~4.5%. Prevalence also increased with age, with 1.0%, 5.2% and 7.1% of those aged 12, 14 and 16 to 17 years, respectively, meeting three or more of the syndrome criteria. A similar pattern was observed in the systematic review by Friend et al. (2013) where the median prevalence in whole populations was 3.3%. In younger children (aged ~11 years) this decreased to 2.9%, whereas in older children (aged 12 to 19 years) the median incidence was 5.6%. These data therefore suggest that metabolic syndrome occurs more frequently in adolescents than younger children. Although the use of multiple definitions makes this observation difficult to confirm, this highlights the need to engage adolescents in cardiometabolic health improvement programmes if attempts to reverse this trend before adulthood are to be made. Epidemiological studies have also found that metabolic syndrome prevalence is higher in overweight and obese youth (Cruz & Goran, 2004; Bitsori & Kafatos, 2005). This was also confirmed in the systematic reviews by Taylor et al. (2010) and Friend et al. (2013). In the former, prevalence ranged from ~2% amongst normal weight children and young people, to ~32% in overweight and obese youths. From this, the authors suggested that the odds of having the metabolic syndrome is around 15 times higher in overweight and obese youths compared with their leaner counterparts. Since abdominal obesity is a central component of the syndrome however, this finding is perhaps not surprising.

Despite the variation in prevalence rates, evidence to date strongly indicates that the paediatric metabolic syndrome is a genuine phenomenon, particularly in obese youth (Marcovecchio & Chiarelli, 2013). There is also evidence that prevalence is higher in boys than girls, however this finding is not universal (Friend et al., 2013). This male preponderance has also been documented in adults; however this sex gap may be narrowing (Regitz-Zagrosek et al., 2006). In earlier reviews, concerns over the rise in metabolic

syndrome prevalence in parallel with increases in childhood obesity were clear (De Ferranti & Osganian, 2007). Currently however, there is insufficient evidence to determine whether the prevalence is indeed changing over time (Friend et al., 2013). This is largely due to the fact that research on the paediatric syndrome is still relatively new, with the first publication (Cook et al., 2003) using data from 1988. Any changes in prevalence prior to 1988 are therefore undetectable, and insufficient time may have since passed to ascertain a subsequent rise (Friend et al., 2013).

The association between cardiorespiratory fitness and physical activity and the paediatric metabolic syndrome

Aside from debates on syndrome prevalence and definitions, early cardiometabolic risk factor management in youth is worthwhile as it may potentially reduce premature death from cardiovascular disease or type 2 diabetes (Morrison et al., 2008). In young people it appears that obesity, in particular abdominal obesity, is the key factor relating to syndrome development (e.g. Weiss et al., 2004; De Ferranti & Osganian, 2007) and is linked to all of the individual risk components (e.g. Twisk et al., 1997; Katzmarzyk et al., 2001; Chen et al., 2005; Cruz et al., 2004). Both obesity and metabolic syndrome risk in young people have been also associated with systemic inflammatory markers, in particular raised serum C-reactive protein (CRP) levels (Hiura et al., 2003; Lambert et al., 2004). Two other factors thought to influence the development of the metabolic syndrome in youths are cardiorespiratory fitness and, to a lesser extent, habitual physical activity. Often these terms are used synonymously which is incorrect. Rather, physical activity defines any bodily movement produced by skeletal muscles that results in substantial increases in energy expenditure, whereas cardiorespiratory fitness is a physiological trait (Eisenmann, 2007). In the context of the paediatric metabolic syndrome, this distinction is particularly important as it has been shown that physical activity and cardiorespiratory fitness have independent effects on syndrome components and therefore should be examined separately (Brage et al., 2004; Andersen et al., 2006; McMurray & Andersen, 2010).

Habitual physical activity

In adults, associations between metabolic syndrome prevalence and low physical activity levels have been found (Lakka et al., 2003; Rennie et al., 2003). Studies examining this relationship in young people however are inconclusive. This may be due to the methods used to collect youth physical activity data; some studies have used self-report instruments whereas others have used accelerometry (McMurray & Andersen, 2010). Generally,

findings have been more consistent when activity was objectively measured via accelerometers. In the study by Brage et al. (2004) physical activity data were collected via uniaxial accelerometers (Actigraph MTI) from 589 Danish children (aged 9.6 ± 0.4 years; mean \pm standard deviation [SD]). Cardiorespiratory fitness was assessed via a maximal cycle ergometer test and metabolic syndrome risk score obtained using the z score method (Eisenmann, 2008). Here it was found that as physical activity levels decreased, metabolic syndrome risk z score increased. Whilst this relationship weakened after adjustment for cardiorespiratory fitness, there was a significantly positive interaction between physical activity and fitness. From this the authors concluded that physical activity was inversely associated with metabolic risk. Based on the positive interaction between physical activity and fitness, they also suggested that the potentially beneficial effect of physical activity may be greatest in those with low cardiorespiratory fitness. A similar association was reported in the study by Andersen et al. (2006) which utilised a composite cardiometabolic risk factor z score and accelerometry for physical activity measurement. Compared with the most active quintile, odds ratios for risk factor clustering for ascending quintiles of PA were 3.29 (95% confidence interval [C.I.]; 1.96 to 5.52), 3.13 (1.87 to 5.25), 2.51 (1.47 to 4.26) and 2.03 (1.18 to 3.50). As such, individuals in the two least active categories were over three times more likely to display risk marker clustering than those in the most active group. Whilst these data are potentially useful, another study found weak correlations between total, moderate and vigorous activity and metabolic syndrome scores (Holmes et al., 2008), albeit in a favourable direction. As such although the relationship between physical activity and paediatric metabolic syndrome is unconfirmed, the associations are nonetheless in the expected direction (McMurray & Andersen, 2010).

Cardiorespiratory fitness

Compared to physical activity, more studies have examined the relationship between cardiorespiratory fitness and the metabolic syndrome in youth. When $VO_{2\text{peak}}$ is expressed per kilogram of body mass, the majority of evidence suggests a strong inverse relationship between cardiorespiratory fitness and paediatric metabolic syndrome (e.g. Anderssen et al., 2007; García-Artero et al., 2007; Rizzo et al., 2007; McMurray & Andersen, 2010) and cardiometabolic events later in life (Ruiz et al., 2009). For example, in the study by Anderssen et al. (2007) 2845 European school children aged either 9 or 15 years were assessed for cardiorespiratory fitness via a maximal cycle ergometer test. To examine the degree of cardiometabolic risk factor clustering, measurements of total cholesterol/ HDL cholesterol ratio, plasma triglycerides, insulin resistance, sum of four skinfolds and systolic

blood pressure were also taken. Using the quartile with the highest fitness as reference, the odds ratio for risk factor clustering in the lowest fitness quartile was 13.0 (95% C.I.; 8.8 to 19.1). Even after adjustment for various factors including fatness, sex, pubertal stage and socioeconomic status, this association remained strong. Furthermore, in the study by DuBose, Eisenmann & Donnelly (2007) a high fitness score resulted in a lower metabolic syndrome score in overweight youths, compared with overweight youths with low fitness. This suggests that high cardiorespiratory fitness could possibly attenuate the impact that weight status has on metabolic syndrome manifestation in young people. This observation is bolstered by the seminal work of Professor Stephen Blair where it has repeatedly been shown that within a fatness category, cardiorespiratory fitness attenuates the risk of disease in adults (Lee, Blair & Jackson, 1999; Church et al., 2004; Lee et al., 2005a). The implications of this are two-fold. Firstly, researchers should consider including measures of cardiorespiratory fitness in their cardiometabolic risk assessments. This could provide them a greater understanding of the impact this outcome has on metabolic syndrome development. Perhaps more importantly however, this highlights the need for exercise interventions aimed at improving cardiorespiratory fitness as a means of decreasing metabolic syndrome risk in young people.

Summary

Over the last decade, research on the metabolic syndrome in children and adolescents has gathered pace, fuelled largely by the secular trends in paediatric obesity and the recognition of high syndrome prevalence in adults (Ford & Li, 2008). This has led to the release of paediatric guidelines from various health organisations, and the creation of continuous risk factor scores (e.g. *z* scores [Eisenmann, 2008] and the lipid accumulation product [Kahn, 2005]) to address the limitations of dichotomous categorisation. Despite continued debate over how best to define the disorder in young people, there appears to be consensus over the key risk markers (obesity [namely abdominal obesity], hypertension, elevated triglycerides, decreased HDL cholesterol levels and glucose intolerance). There have also been calls to include low levels of cardiorespiratory fitness in the syndrome definition (McMurray & Andersen, 2010); given the strong inverse relationship between this variable and paediatric metabolic syndrome development (e.g. Anderssen et al., 2007; McMurray et al., 2008). Whilst the potential mechanisms underpinning this are largely unknown, several metabolic and endocrine pathways have been suggested (McMurray & Andersen, 2010). Contrastingly, the association between habitual physical activity and cardiometabolic risk factor clustering remains unclear, which may be complicated by the use of different physical

activity measurement tools across studies. This potential relationship is intriguing however and warrants further study. Recently, the association between muscular fitness, a term used to represent muscular strength, local muscular endurance and muscular power, and health status has received increased attention in the scientific literature (Smith et al., 2014). Whilst research on the independent association of muscular fitness with individual cardiometabolic risk factors and clustered metabolic risk in youth is gathering pace (e.g. Steene-Johannessen et al., 2009; Artero et al., 2011), many of these studies are cross-sectional so causality cannot be inferred (Artero et al., 2011). Indeed, in a recent systematic review on the topic, the authors acknowledged that the putative mechanisms linking muscular fitness and cardiometabolic risk remains unknown (Smith et al., 2014). Furthermore, they also highlighted that a reliable standard assessment battery for the testing of muscular fitness in youth populations does not yet exist. For these reasons and others (time and equipment restrictions during the main trial) muscular fitness was not assessed in the current programme of work, and is therefore not discussed further within this review. Given the uncertainties described, it is perhaps not surprising that, despite mounting evidence that exercise can positively influence various cardiometabolic risk factors, no optimal exercise prescription exists. Recently, there has been growing interest in the efficacy of high-intensity interval training (HIT) as a time efficient way of improving various health and fitness outcomes. This training form will be the focus of the next review section, with particular emphasis placed on HIT trials involving young people.

High-intensity interval training

Activity guidelines in the UK and the US recommend the accumulation of MVPA, performed between 50 to 70% of maximum heart rate (US Department of Health and Human Services, 2008 [USDHHS]; Department of Health, 2011). Such endurance-type exercise can elicit numerous morphological and metabolic adaptations in skeletal muscle, including mitochondrial biogenesis and an increased capacity to oxidise fuels such as glucose and fats (Holloszy & Booth, 1976; Holloszy, 1967). Notwithstanding these benefits, traditional endurance training requires a significant time commitment which may be incompatible with the “time poor” culture of today’s society (Palmer, 2010). Indeed, perceived lack of time remains the most frequently cited barrier to regular exercise in adults and young people alike (Dishman et al., 1982; Booth et al., 1997; Allison et al., 2005; Dwyer et al., 2005). Furthermore, although the beneficial effects of MVPA for adolescents are widely acknowledged (e.g. Janssen & LeBlanc, 2010; Andersen et al., 2011), low levels during

adolescence suggests that this form of activity may not be engaging or appealing to this population (Buchan et al., 2011b).

Recently there has been renewed interest in the benefits of vigorous intensity exercise, in light of suggestions that health improvements could be achieved in a more time-efficient manner by replacing some MVPA with more intense exercise (USDHHS, 2008; Department of Health, 2011). Indeed, one prospective cohort study with an 18-year follow-up found that a single weekly bout of vigorous physical activity was associated with the prevention of cardiovascular mortality among men and women without known cardiovascular disease at the study on-set (Wisløff et al., 2006). These findings support the prevailing concept that the effects of exercise depend on the intensity; and the higher the intensity, the greater the benefit (Shephard et al., 1968; Barinaga; 1997). They also suggest that provided exercise is performed at a vigorous intensity, it may be possible to reduce cardiovascular risk with substantially less activity than is generally recommended. As such, over the last ten years there has been growing interest in the efficacy of HIT for improving cardiometabolic risk factors. This training form is characterised by repeated brief bursts of intense exercise interspersed with periods of rest or low intensity active recovery (Fox, 1973). Depending on the intensity, a single repetition may last from a few seconds up to several minutes (Gibala & McGee, 2008). Part of the appeal of HIT is that it offers the possibility to maintain intense exercise for longer periods than continuous exercise, thus eliciting a greater training stimulus (Guiraud et al., 2012). The use of HIT by athletes has been common practice for several decades, with sports such as soccer (Weston et al., 2004), handball (Buchheit et al., 2010), tennis (Fernandez-Fernandez et al., 2012) and cycling (Laursen et al., 2002b; Laursen, Blanchard & Jenkins, 2002c) utilising it as an effective training tool. Away from elite sport however, HIT was generally viewed as unsafe and unfeasible for less “fit” populations (MacDonald & Currie, 2009). This standpoint has been strongly challenged in recent years, in light of growing evidence demonstrating that HIT can be a safe and time-efficient exercise tool (Kessler, Sisson & Short, 2012) which may be as effective as continuous moderate intensity exercise at eliciting physiological remodelling (Gillen & Gibala, 2013). Furthermore, forms of HIT have been shown to improve a number of health markers in various “non-athlete” populations, including heart failure patients (Wisløff et al., 2007), metabolic syndrome sufferers (Tjønnå et al., 2008), type 2 diabetics (Little et al., 2011), sedentary individuals (e.g. Whyte et al., 2010), school students (e.g. Buchan et al., 2011a) and recreationally active adults (e.g. Sandvei et al., 2012). Original trials from this body of work will be discussed within this review, which culminates with a meta-analytical review

on the effects of low-volume HIT on fitness in adults. The impact of HIT on other cardiometabolic risk factors in adults and young people will also be examined. Whilst the effects of HIT on performance outcomes such as repeated sprint ability and time trial performance have also been extensively studied, these were considered beyond the scope of this review and are not covered. As such, only measures related to the outcomes assessed in the current PhD programme are discussed herein.

Low-volume high-intensity interval training

The basic principle of interval training is that the high-intensity bouts are alternated with lower intensity recovery periods, thus enabling the exerciser to reengage with the next high-intensity section (Kemi & Wisløff, 2010). Across trials the exact application of HIT varies infinitely, with the degree of the specific physiological adaptations determined by a multitude of factors relating to the precise nature of the exercise stimulus (Gibala et al., 2012). These include the exercise mode, the intensity, the interval duration, the number of intervals performed, and the activity performed during recovery periods. Currently, the forms of HIT generating the most scientific interest from a health and disease prevention perspective are aerobic interval training (AIT) and low-volume HIT. The term HIT has been used to collectively describe all forms of high-intensity training in the literature, however for purposes of clarity, protocols utilising intervals of 30 to 60 s will be described as low-volume HIT herein. Models incorporating longer intervals (>60 s) are referred to as aerobic interval training (AIT); the term used by several influential studies on this topic (e.g. Wisløff et al., 2007; Tjønnå et al., 2008). Due to the majority of youth-based HIT trials favouring low-volume HIT over AIT, the focus of this review is the former with AIT discussed only briefly. Whilst it is acknowledged that successful low-volume HIT models utilising intervals of <10 s exist (e.g. Trapp et al., 2008; Metcalfe et al., 2012) these will not be covered. The reason for this is twofold. Firstly, exercise repetitions lasting less than 10 s are considered more anaerobic dependent (Linossier et al., 1993; Linossier et al., 1997; Bogdanis et al., 1998) compared to longer bouts (Bogdanis et al., 1995; Bogdanis et al., 1996), and earlier studies utilising such short bouts reported no improvements in mitochondrial enzyme markers of muscle oxidative capacity (Linossier et al., 1993; Dawson et al., 1998). Although a model devised by Trapp et al. (2008) (60 × 8 s cycling repetitions, interspersed with 12 s recovery) did induce improvements in VO_{2peak} , it is questionable whether a high-intensity workload could be maintained for 60 repetitions. As the authors did not provide any training data in the form of heart rate files or equivalent, this casts further doubt over whether the protocol can be labelled as HIT. In the context of the current PhD programme, a model

dictating such tight changeovers between work and recovery periods would not be feasible in a school where external time pressures are commonplace. Whilst such a rigid structure could easily be controlled in a laboratory with adults, it would be naïve to assume the same would occur with adolescents in a school sports hall.

When compared on a “matched work” basis, there is accumulating evidence that AIT can serve as an effective and sometimes superior alternative to traditional endurance training in healthy and diseased individuals. The most widely used AIT model originated from work led by Professor Ulrik Wisløff in Norway (e.g. Rognum et al., 2004; Wisløff et al., 2007; Tjønnå et al., 2008). This protocol incorporates four 4-minute intervals of uphill treadmill walking/running at 85 to 95% of peak heart rate, interspersed with 3 minutes recovery. In a meta-analysis by Hwang, Wu and Chou (2011) it was reported that this form of AIT significantly increased VO_{2peak} by $3.6 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (95% C.I.; 2.3 to $4.9 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) compared to continuous moderate intensity exercise in adults with cardiometabolic disorders. Less is known about the effects of low-volume HIT however, which requires a substantially shorter time commitment and reduced total training volume than endurance and AIT models (Gibala & McGee, 2008). Various low-volume HIT protocols have been proposed, the most common being the repeated 30-s Wingate model. This was popularised by the low-volume HIT trials performed by Professor Martin Gibala (e.g. Burgomaster et al., 2005; Gibala et al., 2006; Burgomaster et al., 2008). These built on the work of Parra et al. (2000) and Rodas et al. (2000) who observed significant increases in VO_{2peak} and maximal activity of citrate synthase (a mitochondrial enzyme marker of muscle oxidative capacity) in active males, following 2-weeks of daily sprint training on a cycle ergometer. These intriguing findings challenged the view that, compared to endurance exercise, brief bouts of very intense activity had little effect on aerobic energy metabolism (Kubukeli, Noakes & Dennis, 2002). However, what remained unknown was whether these effects were maintained if the number of training sessions decreased. Accordingly, in the seminal paper by Burgomaster et al. (2005), eight participants (two women; aged 22 ± 1 years; mean \pm SD) undertook six sessions of “all-out” sprints on a cycle ergometer over 2-weeks. This was performed against a resistance equivalent to 0.075 kg/kg body mass. Participants completed 30-s sprints separated by ~ 4 min recovery, during which they either rested or cycled at a low cadence ($<50 \text{ rpm}$). Sessions took place three times a week, with the number of Wingates increasing from four to seven across the study duration. Eight men (aged 25 ± 2 years) served as controls and completed a VO_{2peak} test and a cycle endurance capacity test (cycling to volitional exhaustion at a workload designed to elicit $\sim 80\%$ of VO_{2peak}) ~ 2 weeks apart

with no training intervention. Post-training, despite no changes in $\text{VO}_{2\text{peak}}$, cycle endurance capacity increased by 96% in the sprint group (51 ± 11 min vs 26 ± 5 min; $p < 0.05$), whereas no changes were observed in the controls. Extensive familiarisation trials by the sprint group strengthened the authors' belief of the generalizability of their findings. Furthermore, the maximal activity of citrate synthase significantly increased by 38% (5.5 ± 1.0 vs 4.0 ± 0.7 $\text{mmol} \cdot \text{kg} \text{ protein}^{-1} \cdot \text{h}^{-1}$) in the training group. This was in line with Rodas et al. (2000) and several other authors who had reported increases in citrate synthase activity following maximal effort sprint programmes (e.g. Jacobs et al., 1987; MacDougall et al., 1998). As such, this trial was the first to demonstrate that as little as ~16 minutes of "all-out" low-volume HIT could greatly improve endurance capacity during a fixed-workload test in which the majority of cellular energy was derived from aerobic metabolism. This research group then extended their findings via a series of studies (Burgomaster, Heigenhauser & Gibala, 2006; Gibala et al., 2006; Burgomaster et al., 2007; Burgomaster et al., 2008); two of which compared their low-volume HIT model to traditional endurance training. Whilst these primarily focused on cellular adaptations to skeletal muscle; one examined changes in $\text{VO}_{2\text{peak}}$ (Burgomaster et al., 2008). Here participants ($n = 20$; 10 females; aged 23 ± 1 years) performed an incremental $\text{VO}_{2\text{peak}}$ test before and after 6-weeks of either low-volume HIT or endurance training. The former protocol mirrored that used by Burgomaster et al. (2005); the only difference being that the number of repetitions increased every two weeks rather than every two sessions. Endurance group participants completed 90 to 120 min cycling at ~65% $\text{VO}_{2\text{peak}}$. The exercise time commitment over the training period was therefore ~2.5 hours for the low-volume HIT group and ~10.5 hours for the endurance arm. Post-intervention, $\text{VO}_{2\text{peak}}$ had significantly improved by 7.3% (41 ± 6 $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ vs 44 ± 6 $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) and 9.8% (41 ± 6 $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ vs 45 ± 6 $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) in the low-volume HIT and endurance training group, respectively. No significant difference was observed between the groups, despite the total exercise volume being ~90% lower for those who completed low-volume HIT. This further demonstrated the potency of low-volume HIT as a time efficient strategy to induce adaptations normally associated with endurance training. As such, this low-volume HIT model is the most widely used to date. Studies examining the effect of this model on health and fitness parameters in adults are discussed later in this chapter.

Modified low-volume high-intensity interval training protocols

Whilst the findings of Burgomaster and others are promising from a human physiological perspective, their applicability for the general population is questionable (Metcalf et al.,

2012). Indeed, Wingate tests require a specialised cycle ergometer, high levels of motivation and may be perceived as too demanding for sedentary individuals (Hawley & Gibala, 2009). In response to these criticisms a “practical” model of low-volume HIT was developed (Little et al., 2010), which remained time efficient but had wider application to different populations. To ensure training time remained low, the absolute intensity of the intervals and recovery time decreased but interval duration increased. This model therefore incorporated 10×60 -s cycling efforts, with 60-s recovery between bouts (Little et al., 2011). The efficacy of this protocol was first examined by Little et al. (2010). Here, seven males (aged 21 ± 0.4 years) completed six exercise sessions. These consisted of 8 to 12 efforts at $\sim 100\%$ of peak power elicited during a ramp $\text{VO}_{2\text{peak}}$ test, each separated by 75-s recovery. Post-training there were significant improvements in several markers/mediators of muscle oxidative capacity and mitochondrial biogenesis; namely maximal activity of citrate synthase ($\sim 16\%$), protein content of peroxisome proliferator-activated receptor α co-activator (PGC-1 α) ($\sim 24\%$) and mitochondrial transcription factor A (Tfam) ($\sim 37\%$), and total content of silent information regulator T1 (SIRT1) ($\sim 56\%$). Although changes in $\text{VO}_{2\text{peak}}$ were not examined, the authors concluded that the model was an effective stimulus for increasing skeletal muscle mitochondrial capacity. They also reported that the participants tolerated the protocol well and did not describe any feelings often associated with “extreme” Wingate tests (e.g. dizziness, light-headedness or nausea). Notwithstanding these promising findings, it is questionable whether cycling at 100% of peak power is actually “practical” for untrained individuals. Indeed, although Little’s participants were classified as “recreationally active” rather than athletes, the mean (\pm SD) $\text{VO}_{2\text{peak}}$ was $46 (\pm 2) \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. When this is compared to normative $\text{VO}_{2\text{peak}}$ values for males aged 20 to 29 years provided by the American College of Sports Medicine (ACSM), the group falls in the “good” fitness category (65th percentile) (ACSM, 2013). This casts doubt over whether individuals with lower fitness levels could fully comply with the protocol. It is therefore unsurprising that subsequent trials utilising this model were not performed at 100% of peak power. Instead, in the study by Hood et al. (2011) seven sedentary adults (three women; aged 45 ± 5 years) completed six sessions of “practical” low-volume HIT, but this time at 60% of peak power. This elicited average heart rate responses of 80% of heart rate reserve at the end of the first interval, which climbed to 95% of heart rate reserve by the tenth. Whilst the outcomes for this study were mechanistic measures beyond the scope of this review, it is noteworthy that participants completed all of the prescribed exercise bouts. Accordingly, in the 2011 paper by Little et al. exercise intensity was defined as $\geq 90\%$ of maximal heart rate, rather than as a percentage of peak power. Here, eight type 2 diabetics (aged 63 ± 8 years)

completed two weeks of “practical” low-volume HIT. The mean heart rate across the intervals was $88 \pm 3\%$ of maximum, which ranged from $\sim 80\%$ during the first bout to $\sim 93\%$ by the tenth. The average whole session rating of perceived exertion (RPE) was 6.4 ± 1.3 ; with individual interval RPEs ranging from ~ 4.5 (first interval) to ~ 8 (tenth interval). Post-intervention, maximal activity of citrate synthase significantly increased by 20% and a significant reduction in average 24-hour blood glucose concentration (7.6 ± 1.0 vs 6.6 ± 0.7 mmol/L) was also observed. Furthermore, the participants’ perceived enjoyment of low-volume HIT was high. This was assessed via a 9-point Likert scale which ranged from 1 (not enjoyable at all) to 9 (very enjoyable). Post-intervention, participants were asked how enjoyable they would find continuing 1) a single bout of “practical” low-volume HIT and 2) “practical” low-volume HIT at least three times per week for the next four weeks. Here, a single session scored 8.1 ± 1.0 , with three sessions scoring 7.9 ± 1.0 . Whilst the small pilot study nature is acknowledged, this trial illustrates the promise of “practical” low-volume HIT. From a physiological perspective, it shows that ~ 10 minutes of exercise performed at $\geq 90\%$ of maximal heart rate can rapidly induce adaptations in skeletal muscle and improve glucose control in type 2 diabetics. The protocol also remains relatively time efficient, with a single session lasting ~ 25 minutes when the warm-up, recovery periods and cool down are included. Moreover, the training stimulus was manageable, as evidenced through the participants’ RPE and enjoyment scores. In conjunction with the findings from Hood et al. (2011), this suggests that an exercise intensity of $\sim 90\%$ of maximal heart rate is achievable and acceptable in sedentary and patient groups. This provides further justification for the use of $\sim 90\%$ of maximal heart rate as a practical, non-invasive descriptor of low-volume HIT in non-athlete populations. Whilst laboratory-based studies may use measures such as percentage of $VO_{2\text{peak}}$ or peak power to describe intensity, in field-based investigations the assessment of these may not be possible. As it may be the exercise intensity that gives rise to the training adaptations, it is crucial that this component is accurately assessed. This can be afforded through heart rate monitoring which provides a simple and reliable measure of exercise intensity and physiological stress out with the laboratory setting (Achten & Jeukendrup, 2003). As such, it appears that it is the descriptor used to quantify the exercise intensity that is the most “practical” element of modified low-volume HIT, rather than the training mode or the work/rest ratios. By proposing an intensity parameter that can be accurately assessed with ease, this enables low-volume HIT to move away from the laboratory and into “real-life” settings.

Whilst previous findings demonstrate that forms of low-volume HIT can induce rapid skeletal remodelling, much of the work published prior to 2009 only examined a few muscle specific parameters and markers of fitness and performance (Gibala et al., 2012). Accordingly, it was recommended that future studies examine whether low-volume HIT can induce other physiological adjustments typically associated with endurance training; such as increased maximal capacity for lipid oxidation, changes in blood health status markers and the potential for weight loss (Burgomaster et al., 2008). Additionally, many of the earlier low-volume HIT trials took place over a short timeframe on small groups of young, active participants. The long term effects and the impact on wider populations therefore remain relatively unknown. Although this is now being addressed, the evidence is far from conclusive. Findings of low-volume HIT studies are discussed in the following sections; which begins with a summary of the adult-based trials before focusing on the HIT investigations which have utilised youth populations. For clarity, results from the adult studies are grouped by outcome measure, whereas findings from the youth trials are each discussed individually. It should be highlighted however that data between trials often cannot be directly compared, due to the use of differing exercise protocols, study populations and measurement techniques. For further information of the participant and design characteristics of studies discussed, please see the relevant table. This is shown in brackets after the trial is cited for the first time.

The effects of HIT on health outcomes in adults

Body composition

Body composition analysis is often used as an umbrella term to capture a wide range of anthropometric measurements. In this review, body composition refers to assessments of body mass, waist circumference, percentage body fat and lean body mass. Baseline and post-intervention values from studies examining one or more of these outcomes are shown in Table 4, which includes data for intervention (low-volume HIT or AIT), active comparator and control groups. Whilst there are many other anthropometric variables, only the four listed above will be discussed as they encompass the assessments included in the PhD programme.

Body mass, percentage body fat and lean body mass

As shown in Table 4, body mass is the most commonly assessed anthropometric variable in low-volume HIT investigations. Across these, body mass remained largely unchanged post-training (average effect -0.4 kg; (range -1.1 to +0.3 kg), regardless of the trial duration,

exercise model or population tested. No body mass data were provided for three low-volume HIT trials (MacDougall et al., 1998; Hazell et al., 2010; Trilk et al., 2011 (all Table 1; meta-analysis); instead the authors simply reported that no significant changes had occurred. Only three low-volume HIT studies have included percentage body fat and/or lean body mass assessments, which may be due to equipment and time restrictions. Nonetheless, the measurement of body mass alone cannot detect individual changes in the fat or lean mass components. The inclusion of these additional measurements in training studies is therefore warranted since they provide information on anthropometric changes that may otherwise be missed. For example, in the 6-week study by MacPherson et al. (2011) (Table 1; meta-analysis) body fat percentage significantly decreased by 1.8 percentage points in low-volume HIT group and lean mass significantly increased by 0.6 kg. This was despite only a small change in body mass (-1.1 kg). A similar pattern was observed in the active comparator group (endurance training). Here, lean mass significantly increased by 0.6 kg and body fat percentage decreased by 1.1 percentage points, with an overall change in body mass of 0.3 kg. Accordingly, the authors concluded that six weeks of low-volume HIT could induce changes in lean and fat mass that were similar, possibly even superior, to that observed from endurance training, despite the smaller training time commitment. This was the first study to demonstrate that low-volume HIT could impact aspects of body composition, yet had the investigators purely relied on body mass this finding would have been overlooked. The effects of low-volume HIT on fat and lean mass remains unclear however, with subsequent studies producing conflicting results. In the trial by Sandvei et al. (2012) (Table 1; meta-analysis) negligible changes in percentage body fat were observed after an 8-week low-volume HIT intervention; whereas reductions of 2.2 percentage points were seen after a similar 6-week trial by Tong et al. (2011) (Table 1; meta-analysis). This may be partly explained by the populations utilised. Whilst both groups were described by the respective authors as non-exercisers, the average baseline body fat percentage reported in Tong's trial was 7.5 percentage points higher than in Sandvei's. Thus, a ceiling effect may have been evident, with the fact that Tong's participants had more body fat to lose possibly explaining the larger effect. Nonetheless, participants in MacPherson's study had considerably less to lose (baseline percentage body fat $18.4 \pm 6.2\%$), yet still displayed a reduction. It therefore appears that the effect of low-volume HIT on aspects of body composition remains unclear, with factors such as differing equipment, testing procedures and diet likely to further confound this.

Waist circumference

To date, one AIT and one low-volume HIT trial have included waist circumference as a study outcome, both of which reported significant reductions post-training. In the former, a reduction of 5 cm was observed following 16 weeks of AIT (Tjønnå et al., 2008). Given that a significant decrease in body mass (-2.3kg) also occurred in this trial, these findings are perhaps unsurprising as one reduction may reflect the other. The more intriguing decrease was found by Whyte et al. (2010) (Table 1; meta-analysis). Here, 10 sedentary and overweight/ obese men completed six sessions of the low-volume HIT model devised by Burgomaster et al. (2005). Despite body mass remaining largely unchanged (-1 kg post-intervention), waist circumference reduced on average by 2.4 cm ($p = 0.004$). These findings demonstrate the potential potency of low-volume HIT for eliciting decreases in waist circumference and possibly in turn, visceral fat. Given that both outcomes are strong cardiometabolic risk markers (Kuk et al., 2006); this is particularly promising from a disease prevention perspective. Although the external validity of Whyte's findings are limited by factors such as the lack of a control group and the short trial duration, they are nonetheless intriguing and warrant further investigation with a larger sample and a robust study design. Whilst the mechanisms underlying the potential HIT-induced fat loss effect remain unclear, they may include enhanced exercise and post-exercise fat oxidation (Thackray, Barrett & Tolfrey, 2013) and suppressed post-exercise appetite (Boutcher, 2011). It has also been suggested that the high levels of catecholamines produced by HIT may underpin its ability to reduce visceral fat (Heydari et al., 2012); as catecholamines have been shown to drive lipolysis in animal models and are mainly responsible for fat release from visceral fat stores (Issekutz, 1978).

Table 4. Baseline (PRE), post-intervention (POST) and change values from AIT and low-volume HIT studies examining body composition

Study (year)	Group ¹	Mass (kg) (PRE)	Mass (kg) (POST)	Δ (kg)	WC (cm) (PRE)	WC (cm) (POST)	Δ (cm)	BF (%) (PRE)	BF (%) (POST)	Δ (percentage points)	LBM (kg) (PRE)	LBM (kg) (POST)	Δ (kg)
Allemieier et al. (1994)	L-V	76.7 ± 7.4	77.0 ± 7.4	+0.3	-	-	-	13.5 ± 5.6	12.5 ± 4.1	-1	67.3 ± 6.9	67.3 ± 5.9	0
	Con	92.7 ± 14.3	91.8 ± 12.6	-0.9	-	-	-	18.0 ± 8.1	17.4 ± 7.4	-0.6	73.8 ± 6.8	74.2 ± 6.4	+0.5
Dalleck et al. (2010)	L-V	69.1 ± 10.6	69.3 ± 10.5	+0.2	-	-	-	-	-	-	-	-	-
	L-V	67.7 ± 7.5	67.6 ± 7.7	-0.1	-	-	-	-	-	-	-	-	-
Iaia et al. (2009)	L-V	73.1 ± 2.7	73.2 ± 2.7	+0.1	-	-	-	-	-	-	-	-	-
	Con	72.6 ± 2.9	73.2 ± 2.8	+0.6	-	-	-	-	-	-	-	-	-
Little et al. (2011)	L-V	93 ± 19	92 ± 18	-1	-	-	-	-	-	-	-	-	-
MacPherson et al. (2010)	L-V	76.0 ± 15.0	74.9 ± 13.6	-1.1	-	-	-	18.4 ± 6.2	16.6 ± 7.3	-1.8*	62.3 ± 14.5	62.9 ± 14.9	+0.6*
	A-C	68.8 ± 9.5	68.5 ± 9.1	-0.3	-	-	-	20.8 ± 9.7	19.7 ± 9.1	-1.1	54.9 ± 12.2	55.5 ± 12.0	+0.6*
Sandvei et al. (2012)	L-V	70.2 ± 3.5	69.8 ± 3.3	-0.4	-	-	-	23.8 ± 1.8	23.6 ± 1.4	-0.2	-	-	-
	Con	72.2 ± 3.7	71.6 ± 3.3	-0.6	-	-	-	23.8 ± 1.8	23.3 ± 1.8	-0.5	-	-	-
Tjønnå et al. (2008)	AIT	91.8 ± 5.3	89.5 ± 4.9	-2.3*	105.5 ± 4.1	100.5 ± 3.6	-5*	-	-	-	-	-	-
	A-C	91.2 ± 6.9	87.6 ± 6.5	-3.6*	105.1 ± 5.3	99.1 ± 5.0	-6*	-	-	-	-	-	-
	Con	96.4 ± 4.0	96.2 ± 4.9	-0.2	114.3 ± 2.7	112.0 ± 3.4	-2.3	-	-	-	-	-	-
Tong et al. (2011)	L-V	-	-	-	-	-	-	31.3 ± 5.7	29.1 ± 5.6	-2.2*	-	-	-
	A-C	-	-	-	-	-	-	29.9 ± 3.0	29.8 ± 2.9	-0.1	-	-	-
Whyte et al. (2010)	L-V	93.9 ± 12.6	92.9 ± 13.3	-1	101.3 ± 8.5	98.9 ± 9.8	-2.4*	-	-	-	-	-	-

Δ = change

¹ L-V= low-volume high-intensity interval training; Con= control; AIT= aerobic interval training; A-C= active comparator

WC = waist circumference

BF = body fat

LBM= lean body mass

* significantly different from baseline (p<0.05)

Blood pressure

Baseline and post-intervention systolic and diastolic blood pressure values from two AIT studies and one low-volume HIT trial are shown in Table 5. Here it can be seen that forms of HIT have the potential to reduce systolic blood pressure (range -9 to -3 mmHg), with less clear effects shown for diastolic blood pressure (range -9 to +1 mmHg). These findings are far from conclusive however, as they are based on relatively small trials utilising specific populations and, in one case, lack a control group. Furthermore, decreases in systolic blood pressure were transient in the study by Whyte et al., (2010). Here, reductions were displayed 24-hours post-exercise (-6 mmHg; $p = 0.020$) but had diminished by the 72-hour time point (-2 mmHg; $p = 0.197$). Nevertheless, although it is well known that a single exercise bout can lower blood pressure (Kenney & Seals, 1993); this was the first study to suggest that low-volume HIT can elicit this also. A slightly higher reduction (-8 mmHg) was observed in 16-week AIT trial by Tjønnå et al. (2008). Whilst this should not be directly compared to Whyte's due to differing exercise protocols and trial duration, it provides further evidence that forms of HIT may positively impact blood pressure. The exact mechanisms for this have yet to be fully elucidated however, with Whyte et al. stating that it is likely to be a combination of reduced sympathetic nervous activity (Halliwill, Taylor & Eckberg, 1996) and increased nitric oxide-mediated vasodilation (Halliwill, 2001).

Table 5. Baseline (PRE), post-intervention (POST) and change values from AIT and low-volume HIT studies examining blood pressure

Study (year)	Group ¹	Systolic BP (mmHg) (PRE)	Systolic BP (mmHg) (POST)	Δ (mmHg)	Diastolic BP (mmHg) (PRE)	Diastolic BP (mmHg) (POST)	Δ (mmHg)
Rognmo et al. (2004)	AIT	140 ± 20	137 ± 11	-3	72 ± 11	73 ± 10	+1
	A-C	146 ± 19	145 ± 29	-1	79 ± 10	79 ± 14	0
Tjønnå et al. (2008)	AIT	144 ± 5	135 ± 5	-9*	95 ± 3	89 ± 3	-6*
	A-C	131 ± 6	121 ± 5	-10*	88 ± 4	82 ± 5	-6*
	Con	146 ± 6	141 ± 5	-5	95 ± 5	96 ± 4	+1
Whyte et al. (2010)	L-V	127 ± 3	121 ± 3	-6*	80 ± 3	71 ± 2	-9

Δ = change

¹AIT= aerobic interval training; A-C= active comparator; Con= control; L-V= low-volume high-intensity interval training
BP = blood pressure

* significantly different from baseline ($p < 0.05$)

Blood lipids

Data from trials examining the effects of HIT on blood lipids can be found in Table 6. Of these, three AIT and two low-volume HIT studies included triglyceride measurements. One reported reductions of ~24% post-training in AIT participants (Wisløff et al., 2007), with a further three observing decreases of ~10% in AIT and low-volume HIT groups (Helgerud et al., 2007; Whyte et al., 2010; Sandvei et al., 2012). Although none of these findings reached statistical significance, they may yet be clinically important and the emerging downward trend of a key risk marker justifies further study. It is important to acknowledge however that the average intra-individual biological variation for triglycerides is ~22.5% (Smith et al., 1993). This arises from physiological variation and instrumental variation (Atkinson & Nevill, 1998) and should be used to aid the interpretation of blood analysis findings (National Institute for Health and Care Excellence [NICE], 2008). With regards to HDL cholesterol, the impact of HIT is unclear. Of the six studies (four AIT) detailed in Table 6, the effects on HDL range from decreases of ~8% (Wisløff et al., 2007), to no change (e.g. Nybo et al., 2010), to increases of 22% (Tjønnå et al., 2008). Whilst these conflicting results could be partly explained by the average biological variation for HDL (7.5%, Nazir et al., 1999), it is likely that the differing trial durations and study populations also play a role. Moreover, it is widely recognised that changes in blood lipids tend to manifest over months, rather than weeks (National Heart, Lung and Blood Institute, 2002; NICE, 2008). A similarly inconclusive picture can be seen for total cholesterol (TC) and LDL cholesterol. Of the three studies (two low-volume HIT) that evaluated TC, post-training reductions of ~5% were observed. In the trial by Sandvei et al., (2012), TC significantly decreased by 7%, which reflects the 10% drop in LDL cholesterol that was also observed. As the respective biological variation for TC and LDL are 7.2% and 9.5% (Smith et al., 1993; Nazir et al., 1999) however, it is unclear whether these represent “true” changes, or are merely reflective of individual variation. Whilst the precision of blood lipid values can be increased by repeated measurements, it is recognised that in practice performing serial replicate readings is often not feasible.

Table 6. Baseline (PRE), post-intervention (POST) and change values from AIT and low-volume HIT studies examining blood lipids

Study (year)	Group ¹	TG mmol/L (PRE)	TG mmol/L (POST)	Δ mmol/L	TC mmol/L (PRE)	TC mmol/L (POST)	Δ mmol/L	HDL mmol/L (PRE)	HDL mmol/L (POST)	Δ mmol/L	LDL mmol/L (PRE)	LDL mmol/L (POST)	Δ mmol/L
Helgerud et al. (2007)	AIT	1.04 ± 0.43	0.94 ± 0.61	-0.10	-	-	-	1.32 ± 0.35	1.26 ± 0.31	-0.06	2.84 ± 0.52	2.84 ± 0.50	0
	A-C	0.94 ± 0.48	0.80 ± 0.24	-0.14	-	-	-	1.18 ± 0.22	1.23 ± 0.23	+0.05	2.86 ± 0.81	2.77 ± 0.95	-0.07
Sandvei et al. (2012)	L-V	0.88 ± 0.15	0.81 ± 0.09	-0.07	4.5 ± 0.3	4.2 ± 0.3	-0.30*	1.3 ± 0.1	1.3 ± 0.1	0	3.2 ± 0.3	2.9 ± 0.3	-0.3*
	A-C	0.70 ± 0.07	0.77 ± 0.07	+0.07	4.1 ± 0.2	4.0 ± 0.2	-0.10	1.4 ± 0.1	1.3 ± 0.1	-0.10	2.7 ± 0.2	2.7 ± 0.2	0
Tjønnå et al. (2008)	AIT	1.65 ± 0.20	1.70 ± 0.19	+0.05	-	-	-	0.69 ± 0.07	0.84 ± 0.10	+0.15	-	-	-
	A-C	1.47 ± 0.45	1.67 ± 0.38	+0.20	-	-	-	0.74 ± 0.09	0.80 ± 0.08	-	-	-	-
	Con	1.84 ± 0.40	2.00 ± 0.54	+0.16	-	-	-	0.62 ± 0.05	0.58 ± 0.08	-	-	-	-
Whyte et al. (2010)	L-V	1.28 ± 0.54	1.13 ± 0.47	-0.15	4.89 ± 0.92	4.66 ± 0.98	-0.23	1.07 ± 0.25	1.02 ± 0.22	-0.05	-	-	-
Wisløff et al. (2007)	AIT	2.1 ± 1.2	1.7 ± 0.7	-0.40	-	-	-	1.2 ± 0.4	1.3 ± 0.3	+0.10	-	-	-

Δ = change

¹ AIT= aerobic interval training; A-C= active comparator; Con= control; L-V= low-volume high-intensity interval training

TG= triglycerides

TC= total cholesterol

HDL= HDL cholesterol

LDL= LDL cholesterol

* significantly different from baseline (p<0.05)

Insulin sensitivity and blood glucose

To date, several studies have shown that low-volume HIT may be capable of increasing insulin sensitivity. In the trial by Babraj et al., (2009), 16 young males (aged 21 ± 2 years) completed six sessions of Burgomaster's 2005 low-volume HIT model. Post-training, insulin sensitivity (measured by the Cederholm index [Cederholm & Wibell, 1990]) had significantly improved by 23%. A similar increase was observed in overweight and obese males in the trial by Whyte et al., (2010). Here, insulin sensitivity was calculated using the homeostasis model assessment (HOMA) method described by Matsuda & DeFronzo (1999) and a significant post-training increase of 23.3% was reported. This was only observed for 24-hours after the last exercise session however, whereas in Babraj's trial this improvement was apparent for 48 to 72 hours post-training. The latter was also seen in the 2-week low-volume HIT study by Richards et al. (2010) (Table 1; meta-analysis), where insulin sensitivity was assessed using the gold standard hyperinsulinemic euglycemic clamp method. Furthermore, Hood et al. (2011) observed a 35% increase in insulin sensitivity (via the HOMA method) in a sample of sedentary adults following six sessions of the 10×60 -s modified low-volume HIT model. Fasting glucose concentration also tended to decline post-training (4.9 ± 0.3 mmol/L vs 4.3 ± 0.5 mmol/L), though this did not reach statistical significance. These findings are particularly encouraging however, as they suggest that improvements in insulin sensitivity can be achieved through "practical" HIT models that may be more feasible and appealing to the public.

Summary

Whilst far from definitive, there is growing evidence that forms of HIT can positively impact aspects of cardiometabolic health in adults. From a weight-loss perspective, low-volume HIT does not appear to be particularly effective; however this is perhaps unsurprising given the low energy expenditure associated with these protocols. Nonetheless, there is data to suggest that low-volume HIT could induce changes in percentage body fat (e.g. Tong et al., 2011), lean body mass (e.g. MacPherson et al., 2010) and waist circumference (Whyte et al., 2010.) The last outcome is of particular importance, given the strong link between elevated waist circumference and metabolic syndrome risk. With regards to blood lipids, a downward trend in triglycerides following HIT is beginning to emerge (e.g. Wisløff et al., 2007; Whyte et al., 2010). Whilst the findings from these trials have been deemed statistically insignificant, they may still have real-world relevance. This example cautions against relying purely on null-hypothesis testing, which can often be misleading depending on the sample size, error measurement and magnitude of the outcome statistic (Batterham &

Hopkins, 2006). It is therefore recommended that researchers consider adopting a magnitude-based inferences approach (Hopkins et al., 2009) which is a more intuitive and practical framework and based directly on the true value of the outcome statistic (Batterham & Hopkins, 2006).

At this stage, the effects of HIT on components of blood cholesterol are unclear. This may be confounded by individual biological variation and the fact that many HIT studies are relatively short-term. To date, only one trial has examined the effects of low-volume HIT on physical activity levels in adults (Sandvei et al., 2012). Here however activity was only assessed during the intervention itself and for one day pre- and post-training; which does not provide an accurate representation of participants' normal physical activity habits. This is therefore an area that requires further research, given the world-wide public health agenda to increase physical levels. There is also growing scientific and public interest on the effects of HIT on insulin sensitivity and maximal/ peak oxygen uptake (VO_{2max} / VO_{2peak}). Indeed, several studies have shown the beneficial effects of low-volume HIT on insulin sensitivity (e.g. Babraj et al., 2009; Hood et al., 2011), albeit in specific population groups. Whilst the exact mechanisms are unknown, Sandvei et al., (2012) suggested that observed increases in muscle oxidative capacity and protein GLUT4 expression following HIT (MacDougall et al., 1998; Burgomaster et al., 2005) may underpin these changes, since both are markers of whole body insulin sensitivity (Bruce et al., 2003). With regards to fitness, the effects of HIT on VO_{2max} were reviewed by Hwang et al. (2011) as previously discussed. A meta-analysis on the effects of low-volume HIT on fitness in adults, produced as part of an international research collaboration with colleagues in the School of Health and Social Care and the School of Social Sciences and Law at Teesside University, and AUT University, New Zealand was published in *Sports Medicine* in July 2014. This can be found in this last section of this chapter.

The effects of HIT on health and fitness outcomes in children and adolescents

Compared to adults, HIT is far less studied in youths as it is often dismissed as unsafe or unfeasible for them to undertake (Buchan et al., 2011a). Nonetheless, brief maximal intensity exercise may actually better resemble the activity patterns of adolescents compared with longer, less intense bouts (Chia & Armstrong, 2007); therefore interventions mirroring the former may be appealing. As such, scientific interest on the effectiveness of HIT for improving the health and fitness of young people is increasing. Investigations to date (study and participant characteristics shown in Table 7) have been performed in hospitals and

schools and have based their low-volume HIT models around running or dance. Given this novel approach, each trial will be individually discussed with regards to the study design, the exercise intervention and the practical relevance of the findings.

Table 7. Study and participant characteristics of trials examining the effects of high-intensity interval training on young people

Study (y)	Design ¹	Participants	Group ²	Intensity	Age (y)	Sample size	Maleness	Duration (weeks)	Total no. of sessions	Mode	Total no. of reps	Rep duration (min)	Work / Rest ratio	Outcome measures
Boddy et al. (2010)	C	School students	L-V	>80% HR _{max}	11.8	8	0	3	12	Dance	72	0.5	0.67	VO _{2peak} , BP, CIMT, body composition, and PA
			Con	-	11.8	8	0	-	-	-	-	-	-	
Buchan et al. (2011a)	C	School students	L-V	Maximal	16.7	17	0.89	7	21	Running	108	0.5	1.0	CRF, BP, body composition, blood lipids and glucose and CRP
			A-C	70% VO _{2max}	16.2	16	0.77	7	21	Running	-	20	-	
			Con	-	16.3	24	0.83	7	-	-	-	-	-	
de Araujo et al. (2012)	C	Obese	L-V	100% V _{peak}	10.7	15	0.34	12	24	Running	108	1	0.34	VO _{2peak} , body composition, BP, blood lipids and glucose
			A-C	80% HR _{peak}	10.4	15	0.27	12	24	Walking/running	-	0.5 to 1	-	
Tjønnna et al. (2009)	C	Overweight/obese	AIT	90 to 95% HR _{peak}	13.9	28	0.50	12	24	Walking/running	96	4	1.34	VO _{2max} , body composition, blood lipids and glucose, BP and PA.
			MTG	?	14.2	26	0.47	12	3	?	-	-	-	

¹ C = controlled trial² L-V= low-volume high intensity interval training; Con = control; A-C active comparator; MTG= multi-treatment group

y = years

HR_{max/peak} = maximal/ peak heart rateVO_{2max} = maximal oxygen uptakeV_{peak} = peak velocity attained during baseline incremental VO_{2peak} test

To date, only one trial has utilised AIT as a means of improving cardiovascular risk factors in overweight adolescents (Tjønnå et al., 2009). Unlike subsequent youth studies, this used a pre-existing AIT model (the 4 × 4 minutes AIT protocol [Rognmo et al., 2004]). This was compared to a multidisciplinary intervention, with follow-up testing occurring at 3- and 12-months. Participants randomised to AIT completed 3-months at a Norwegian Hospital in a near identical manner to the adult-based AIT studies (e.g. Tjønnå et al., 2008). Following 3-month data collection, participants were encouraged to perform at least two home or gym-based AIT sessions a week. They also continued one hospital-based session every fortnight for 6-months, which reduced to one monthly session in the 3-months before the 12-month follow-up testing. Multidisciplinary treatment participants attended hospital meetings every fortnight which consisted of activity sessions and group conversations. This continued throughout the 12 months; with attendance criteria for inclusion in the 3-month analysis set at >80% for both groups. Prior to 3-month follow-up, 12 participants (8 AIT) dropped out, with an additional 15 (7 AIT) withdrawing by 12-month follow-up. Analysis was completed at the within-group level only, with the authors citing the relatively small sample size as the reason for not completing between-group analyses. By not directly comparing the two groups however, this questions the external validity of the data. Indeed, the effectiveness of an intervention should always be judged relative to non-intervention/comparator, since it is the relative change in means for both groups that evidences an effect (Hopkins et al., 2000). Withstanding this, percentage body fat significantly decreased in the AIT group by 1.3% at 3-months and a further 0.7% at 12-months. Lean body mass increased by 2 kg at 3 months and a further 0.9 kg at 12 months, with the former reaching statistical significance. Significant reductions in waist circumference were apparent at 12-months follow-up (-7.2cm), which may indicate some form of maintenance effect from the AIT. Systolic and diastolic blood pressure also significantly decreased post-training (-9 mmHg and -5 mmHg at 3-months, respectively). Maximal oxygen uptake was assessed via a treadmill ramp test and expressed both in ml·min⁻¹·kg of body weight and ml·min⁻¹·lean body mass^{-0.75}, with the latter used to ensure that any changes were due to improved fitness and not changes in body weight (Bergh et al., 1991). When expressed as the latter, VO_{2max} in the AIT group significantly increased by 10.6% after 3-months (145.9 ± 20.1 ml·min⁻¹·lean body mass^{-0.75} vs 161.4 ± 4.4 ml·min⁻¹·lean body mass^{-0.75}) and a further 2.1% at 12-month follow-up. Compared to baseline, there was a significant decrease in fasting blood glucose at 3- and 12-months (5.8%) and a 10% increase in HDL cholesterol at 3-months with no further increase at 12-months. Triglycerides reduced by 13% and 8% at 3- and 12-months, respectively.

Despite the effects of AIT being limited to within-group comparisons only, the findings from this trial are promising. Indeed, 3-months of AIT was shown to improve several well-known risk factors in overweight adolescents; namely VO_{2max} , HDL cholesterol, systolic and diastolic blood pressure and fasting blood glucose. Non-significant but favourable changes were also observed for triglycerides and body composition. Furthermore, the authors reported non-significant increases in physical activity levels post-training (assessed via pedometer counts), though did not provide data on this outcome. It is encouraging that majority of the positive changes observed at 3-months were also evident at 12-months, despite the marked decrease in training volume. This suggests some form of maintenance effect, which should be explored in future trials. Despite these promising findings however, it is doubtful that such a model could be implemented in schools. This largely relates to equipment limitations, in that it is unlikely that schools would have access to multiple treadmills over a long time period. Moreover, the AIT dropout rate of almost 30% by the 3-month data collection point is concerning and may suggest that such an intervention is not appealing or acceptable for youth populations.

In 2010 Boddy et al. presented the findings of a 3-week dance-based low-volume HIT intervention, which remains the only HIT trial to date to utilise an exercise mode other than cycling or running. The study took place over five weeks in one English secondary school; with participants (Year 7 pupils) randomised either the intervention or control group. All participants attended baseline and post-intervention testing in weeks 1 and 5, respectively. The intervention took place during the morning form time in the school's dance studio where participants performed six 30-s bouts of high-intensity activity based on dance and aerobics moves, each followed by 45-s recovery. Polar Team System heart rate monitors (Polar Electro, Kempele, Finland) were worn throughout, with collected data at 5-s intervals. The participants' average peak heart rate for each week was expressed as a percentage of maximum heart rate and used to quantify the exercise intensity. Mean peak heart rate values of 94.2%, 93.7% and 96.8% of maximum heart rate were achieved for intervention weeks 1, 2 and 3, respectively. As the authors' criterion for high-intensity exercise was >80% of maximum, these values suggest that at the week-to-week group level, a high-intensity workload was maintained. Whilst this attempt at intervention quantification is rare and commended, no data on the between- and within-participant heart rate variability is presented. It is therefore unclear whether all of the participants consistently complied with the high-intensity nature of the exercises. This then questions the fidelity of the intervention since there is no evidence confirming that it was delivered as intended to the entire sample

(Bellg et al., 2004). In terms of session attendance however, adherence was high with only one participant withdrawing.

Post-intervention, small non-significant improvements in body mass (-0.7 kg), waist circumference (-0.5 cm), VO_{2peak} (+1.33 ml·kg⁻¹·min⁻¹, assessed via an incremental treadmill protocol) and MVPA (+2.97 minutes, assessed via uniaxial accelerometers [Actigraph, Model 7164]) were reported in the intervention group. Additionally, there were increases in systolic and diastolic blood pressure of 10.1 mmHg and 5.9 mmHg respectively, with the latter reaching statistical significance. The clinical relevance of this is questionable however, since the post-intervention diastolic score (64.6 ± 4.9 mmHg) is still well below the value associated with hypertension and/or metabolic syndrome (≥ 85 mmHg; Zimmet et al., 2007). In the control group, there were non-significant increases in body mass (+0.8 kg), waist circumference (+0.5 cm) and VO_{2peak} (+2.1 ml·kg⁻¹·min⁻¹); and non-significant reductions in systolic and diastolic blood pressure of 1.4 mmHg and 4.1 mmHg. Post-intervention data on MVPA were not available for the control group, as only three participants reached the minimum inclusion criteria of ≥ 2 days of 10-hours wear time. In both groups, carotid-artery intima-media thickness remained unchanged. Like Tjønnå et al., (2008) however, it appears that analyses were completed at the within-group level only, with differences in the groups at baseline not controlled for.

Whilst this study primarily assessed the intervention effect on health and fitness measures, compliance was cited as a secondary outcome. In light of evidence of decreasing physical activity and cardiorespiratory fitness levels among adolescents (Grieser et al., 2006; Stratton et al., 2007; Sandercock et al., 2010), it is crucial that interventions attempting to reverse this trend are adhered to and accepted by their target population. As such, assessing and reporting intervention compliance alongside the main effects is essential. Unfortunately this is often not the case, with authors providing little to no information on whether the participants completed the intervention as intended. In this study however, the authors provided week-to-week heart rate data confirming the high-intensity nature, and the mean completed exercise time was 78% (28.1 minutes) of the total provided. This suggests that the participants adhered to the intervention, in terms of session attendance at the very least. Accordingly, this time-efficient programme may represent an effective method for future low-volume HIT studies in girls. It remains unknown however whether adolescent boys would engage, given the strong dance element.

With the exception of the unexplained increase in diastolic blood pressure, this trial did not find substantial changes in any outcome post-intervention. Given the short study duration however this is perhaps unsurprising. It is also important to note that the changes observed in the intervention group for waist circumference, body mass, VO_{2peak} and MVPA were in a positive direction. Thus although the trial may have been too short to detect any meaningful effects, it was not harmful in the sense that participants' cardiovascular health worsened as a result. Furthermore, the authors acknowledged that their small sample size greatly limited the trial, in terms of assessing the intervention impact and extrapolating the findings to other populations. They also suggested that their outcomes may have been unsuitable for detecting intervention effects and future trials should include measures such as lipid profiling. With regards to physical activity levels, it is unfortunate that low compliance hindered the interpretation. The impact of low-volume HIT on youth physical activity therefore remains unknown, which necessitates further investigation. Overall however, this trial provided an excellent example of how low-volume HIT can be implemented in a novel and engaging way in a "real-life" setting. It also evidenced that activities such as dance and aerobics can elicit a heart rate response indicative of high-intensity work, therefore low-volume HIT need not be limited purely to cycle ergometry and running.

Findings from a second school-based low-volume HIT intervention were published across two articles in 2011 (Buchan et al., 2011a; Buchan et al., 2011b). The first of these described the intervention effects on novel and established cardiovascular risk factors; with the second reporting changes in performance markers including counter-movement jump and agility. Given the health focus of the current PhD programme, only findings from the first publication are discussed. The 7-week trial took place in one low socio-economic status school in Scotland, thus the data presented in both manuscripts are from the same sample. Participants were recruited from two PE classes in the Secondary 5 (S5) and Secondary 6 (S6) year group; of which the English equivalent is Year 12 and 13, respectively. The S5 group acted as controls, with S6 pupils randomly assigned to either low-volume HIT or moderate intensity exercise. Control group participants were instructed not to change their lifestyle habits during the trial. Those in the low-volume HIT arm completed 30-s maximal effort sprints within a 20-m distance. During interventions weeks 1 and 2 this was completed four times, increasing to five and six during weeks 3 and 4, and weeks 5 and 6, respectively. In week 7 participants performed six repetitions, but this time with 20-s recovery. The moderate intensity group ran steadily for 20 minutes at an intensity designed to elicit 70% of VO_{2max} . From the information provided, it appears that both groups performed their

respective training at the same time, within the same area. As such, it can be assumed that the groups were aware of what the other was doing, which could have induced contamination problems such as compensatory rivalry or resentful demoralisation (Cook & Campbell, 1979). A manifestation of this may well have occurred, since the total exercise time for low-volume HIT participants was $\leq 30\%$ of that completed by the moderate intensity group. This difference would have been clear, as those in the moderate intensity arm may still be exercising when other group had finished. This could have led to the former perceiving they were in the less desirable of the groups. They then may then not have tried as hard (resentful demoralisation), or contrastingly worked harder than the prescribed intensity (compensatory rivalry). Post-intervention, this could also have led to bias in the fitness measurements which, unlike blood or anthropometric outcomes, are controlled by the participants' effort. Had the groups been unaware of what the other was doing however, this potential source of bias could have been avoided.

Withstanding this potential design issue, mean \pm SD attendance across all intervention participants was 17.7 ± 4.2 of a possible 21 sessions, indicating a high adherence rate. Whilst this is encouraging, a breakdown of attendance for each group would have been more informative. The authors reported mean heart rate responses over the 7-week programme in both groups, with weekly averages ranging from 174.3 to 178.2 beats \cdot min $^{-1}$ in the low-volume HIT participants; and 174.1 to 178.9 beats \cdot min $^{-1}$ in the moderate intensity group. As these were not presented as a percentage of maximum heart rate, it is not possible to confirm the exercise intensity via commonly used heart rate criteria (e.g. $\sim 90\%$ of maximum; Little et al., 2011). Nonetheless, if the mean heart rate responses were expressed as a percentage of age-predicted maximum heart rate (using the Fox, Naughton & Haskell [1971] equation of $220 - \text{age} [\text{years}]$ and an age of 16) the average heart rate response for both groups was $\sim 85\%$ of age-predicted maximum. Although this value appears to confirm the intense nature of the intervention for the low-volume HIT participants, it questions the appropriateness of the moderate intensity label used to define the exercise performed by the second training group. As moderate intensity activity is more commonly associated with heart rate zones of $\sim 70\%$ of maximum, the term "vigorous intensity" (70 to 85% of maximum; Centres for Disease Control and Prevention, 2013) may have been a more accurate descriptor. This issue aside, significant post-intervention improvements were found for cardiorespiratory fitness (assessed indirectly via the 20-m multistage fitness test; Léger et al., 1988) in both the low-volume HIT group (82.00 ± 25.8 shuttles vs 88.78 ± 26.4 shuttles) and the moderate intensity group (73.56 ± 21.8 shuttles vs 93.25 ± 23.2 shuttles), with no changes detected in the control

group. Whilst these values indicate a greater improvement in the moderate intensity group, their mean baseline score was ~9 runs less than the low-volume HIT group, which equates to nearly one level in the fitness test. This does not appear to have been controlled for in the analysis, therefore the effect may be slightly inflated. There was an improvement in systolic blood pressure across the groups post-intervention (112 ± 10 mmHg vs 106 ± 11 mmHg [low volume HIT group], 112 ± 11 mmHg vs 108 ± 12 mmHg [moderate intensity group] and 113 ± 10 mmHg vs 109 ± 11 mmHg [control group]), however only the change in the low-volume HIT arm was deemed statistically significant. Diastolic blood pressure contrastingly remained unchanged, as did body mass. In the moderate intensity group, percentage body fat significantly decreased ($19.73 \pm 8.6\%$ vs $17.64 \pm 6.5\%$), whereas in the control and low-volume HIT groups remained largely unchanged. There were no statistically significant reductions in LDL cholesterol across the groups; however a downward trend was evident in the low-volume HIT and moderate intensity groups (1.91 ± 0.84 mmol/L vs 1.45 ± 0.58 mmol/L, and 2.20 ± 0.92 mmol/L vs 1.96 mmol/L, respectively). These changes equate to 31% and 12%, respectively, which could be clinically relevant. Whilst individual biological variation must also be acknowledged, this further exemplifies the need to interpret results on their clinical and practical significance. With regards to HDL cholesterol, non-significant increases of 6%, 20% and 42% were observed in the moderate intensity, low-volume HIT and control groups, respectively. Here however, the variability in the post-training measures was much higher than baseline in the low-volume HIT and control groups (1.52 ± 0.51 mmol/L vs 1.83 ± 1.41 mmol/L and 1.55 ± 0.62 vs 2.20 ± 1.46 mmol/L) which may partly account for these otherwise unexplained findings. Plasma triglycerides significantly increased by 65% and 43% in the low-volume HIT and moderate intensity groups, respectively. A 28% increase was also observed in the controls, although this did not reach statistical significance. This was surprising, given that exercise interventions have been documented to have a beneficial effect on plasma triglycerides in young people (Strong et al., 2005; Kelly et al., 2007). Nonetheless, the authors highlighted that this increased response is typical during growth and maturation (Dai et al., 2009), which may explain their findings. They also suggested that exercise may only positively influence plasma triglycerides in those presenting with abnormally high levels at baseline (Kelley & Kelley, 2007). Serum C-reactive protein (CRP) also increased by 51% (controls) and 34% (moderate intensity and low-volume HIT groups). The authors were unable to offer an explanation to this, as information on the effects of exercise interventions of differing intensities in non-obese adolescents is not available for this variable. Lastly, glucose levels remained largely unchanged post-intervention in the control and moderate intensity groups;

however a statistically non-significant decrease of 10% was evident in the low-volume HIT arm.

Overall, this study demonstrated that both low-volume HIT and a moderate intensity running protocols had distinct cardioprotective effects on adolescents. Participants completing 7-weeks of low-volume HIT exhibited significant improvements in cardiorespiratory fitness, systolic blood pressure and HDL cholesterol. Non-significant downward trends were also observed for LDL cholesterol and glucose, which are encouraging. Whilst potentially harmful post-intervention increases were observed for triglycerides and CRP, these occurred across the three groups which suggests that they did not happen as a result of the exercise interventions *per se*. Collectively, the findings support the use of low-volume HIT as a means of improving health and fitness profiles of young people, albeit from a relatively small sample. In a separate editorial piece however (Buchan et al., 2012), problems with recruitment and retention during a second unpublished phase of the trial are discussed. It appears the authors attempted to replicate their intervention in a second school, however experienced a 40% attrition rate during the first two days of the exercise sessions. Whilst this does not in any way undermine the success of the study at the first school, it does highlight the problems that can be encountered when low-volume HIT ventures out of the laboratory into the “real world”. It also questions the appropriateness of adolescent-targeted programmes based exclusively on one exercise mode, given the wide range of activities available for young people in today’s society.

The latest youth-based low-volume HIT study was described by de Araujo et al. (2012). This compared the effects of a 12-week hospital-based low-volume HIT programme to endurance training. Participants (aged 8 to 12 years) were recruited from obesity clinics in Brazil and randomised to either a low-volume HIT or endurance training group. Inclusion criteria were BMI $\geq 95^{\text{th}}$ percentile and non-participation in regular exercise programmes for at least six months prior to the trial. Those in performing low-volume HIT performed three 60-s treadmill running efforts at 100% of the peak velocity they attained during the baseline $\text{VO}_{2\text{peak}}$ test, interspersed with 3-min recovery at 50% of the peak velocity. Training progression was applied by adding one running repetition every three weeks. Endurance group participants performed continuous walking/ running exercise throughout, with training progression applied by increasing the duration by 10 minutes every three weeks. To ensure participants trained at the prescribed intensity, the authors reported that heart rate was continuously monitored. They provide no data to support this however and it appears that

heart rate was not assessed in the low-volume HIT group at all, which questions whether they were working at a high-intensity. In terms of session attendance, adherence was similar between the groups (86.9% and 85.5% for the low-volume HIT and endurance groups, respectively). Nine participants (4 low-volume HIT) withdrew prior to the 12-week follow-up.

Post-intervention, the authors described increases in absolute and relative $\text{VO}_{2\text{peak}}$ in the low-volume HIT (19.0% and 14.6%, respectively) and the endurance training groups (26.0% and 13.1%, respectively). In their manuscript however this is presented through figures rather than numerical data. Although this format is preferred by some, the scales chosen in this instance were too large to allow the values to be extracted with confidence. For example, in the figure displaying the changes in relative $\text{VO}_{2\text{peak}}$ the scale increases in increments of $10 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, which makes the detection of changes smaller than this near impossible. Furthermore, as the authors do not report baseline values for $\text{VO}_{2\text{peak}}$, there are no clear anchor values from which the reported improvements can be assessed. As such, whilst these apparent fitness improvements are promising, the shortcomings in the data reporting question the integrity of the findings. Post-training, percentage body fat remained largely unchanged in both groups. Fat-free mass remained stable in the endurance group, whereas a 3 kg decrease was observed in the low-volume HIT participants. Whilst this finding is not significant from a null-hypothesis perspective ($p = 0.280$), the authors reported an effect size of 0.473. According to the thresholds suggested by Cohen (0.2, 0.5 and 0.8 for small, moderate and large effects, respectively; Cohen, 1988), this indicates a near moderate effect. This further exemplifies the problems associated with over-relying on null-hypothesis significance testing. The reporting of effect sizes contrastingly, allows the practical significance of an effect to be assessed. Unfortunately, there were several other instances of disagreement between the statistical and practical significance of the trial outcomes. This was evident for waist circumference in the endurance group (effect -7cm; $p = 0.08$; effect size = 0.610) and the low-volume HIT group (effect -3cm; $p = 0.290$; effect size 0.280). It was also the case for total cholesterol (effect +5%; $p = 0.400$; effect size = 0.300) and LDL cholesterol (effect +8%; $p = 0.560$; effect size = 0.270) in the endurance group; and for triglycerides in the low-volume HIT arm (effect -9%; $p = 0.750$; effect size = 0.350). For HDL cholesterol, the disagreement was apparent for both groups (effect +10%; $p = 0.710$; effect size = 0.210 [endurance training]; effect +10%; $p = 0.730$; effect size = 0.370 [low-volume HIT]). No attempts were made by the authors to interpret their effect sizes however, instead all effects with p -values of >0.05 were simply referred to as “unchanged”.

Frustratingly, this approach is surprisingly common. These examples therefore highlight the need for researchers to use effect sizes alongside p-values to evaluate the practical significance of an effect; rather than purely using them to “back up” statistically significant findings. The largest effect in this trial was observed for systolic blood pressure in the low-volume HIT group (115 ± 10 mmHg vs 106 ± 10 mmHg; $p = 0.020$; effect size = 0.896). This variable remained constant in the endurance group and for the diastolic component reductions of 5 mmHg (effect size = 0.532) and 4mmHg (effect size = 0.462) were reported for the endurance and low-volume HIT groups, respectively. Lastly, body mass in the endurance participants remained largely unchanged (-1 kg), whereas a small statistically significant effect was observed in the low-volume HIT group (74 ± 10 kg vs 72 ± 10 kg; $p = 0.030$; effect size 0.182). This more likely reflects the decrease in fat free mass rather than fat mass compartments however.

Withstanding the shortcomings in the $VO_{2\text{peak}}$ reporting and the intervention quantification; this study adds to the growing support for the efficacy of low-volume HIT in youth people. Statistically significant changes were observed post-intervention for systolic blood pressure and $VO_{2\text{peak}}$ in the low-volume HIT group, with non-significant but practically relevant positive effects also found for waist circumference, triglycerides, HDL cholesterol and diastolic blood pressure. A small reduction in fat free mass was also described; however the mechanisms behind this are unclear. As similar changes were observed in the endurance trained group, the authors concluded that both programmes were equally effective in promoting health-related effects. They emphasised however that the time-efficient nature of the low-volume HIT may heighten its appeal over endurance training. It was also highlighted that whilst this trial confirms the work of others, much is still unknown about low-volume HIT in young people. Here it was questioned whether the efficacy of this training form holds true on a long-term basis and whether young people prefer low-volume HIT to endurance training. It is therefore clear that whilst the youth HIT studies support and even go beyond the findings of the adult trials, many issues relating to the widespread use of HIT have yet to be answered. Nonetheless, it is encouraging that youth investigations appear to be leading the way in terms of moving HIT from the laboratory to the “real world”.

Effects of Low-Volume High-Intensity Interval Training (HIT) on Fitness in Adults: A Meta-Analysis of Controlled and Non-Controlled Trials

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SYSTEMATIC REVIEW

Effects of Low-Volume High-Intensity Interval Training (HIT) on Fitness in Adults: A Meta-Analysis of Controlled and Non-Controlled Trials

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Abstract

Background Low-volume high-intensity interval training (HIT) appears to be an efficient and practical way to develop physical fitness.

Objective Our objective was to estimate meta-analysed mean effects of HIT on aerobic power (maximum oxygen consumption [VO_{2max}] in an incremental test) and sprint fitness (peak and mean power in a 30-s Wingate test).

Data Sources Five databases (PubMed, MEDLINE, Scopus, BIOSIS and Web of Science) were searched for original research articles published up to January 2014. Search terms included 'high intensity', 'HIT', 'sprint', 'fitness' and ' VO_{2max} '.

Study Selection Inclusion criteria were fitness assessed pre- and post-training; training period ≥ 2 weeks; repetition duration 30–60 s; work/rest ratio < 1.0 ; exercise intensity described as maximal or near maximal; adult subjects aged > 18 years.

Data Extraction The final data set consisted of 55 estimates from 32 trials for VO_{2max} , 23 estimates from 16 trials for peak sprint power, and 19 estimates from 12 trials for mean sprint power. Effects on fitness were analysed as

percentages via log transformation. Standard errors calculated from exact p values (where reported) or imputed from errors of measurement provided appropriate weightings. Fixed effects in the meta-regression model included type of study (controlled, uncontrolled), subject characteristics (sex, training status, baseline fitness) and training parameters (number of training sessions, repetition duration, work/rest ratio). Probabilistic magnitude-based inferences for meta-analysed effects were based on standardized thresholds for small, moderate and large changes (0.2, 0.6 and 1.2, respectively) derived from between-subject standard deviations (SDs) for baseline fitness.

Results A mean low-volume HIT protocol (13 training sessions, 0.16 work/rest ratio) in a controlled trial produced a likely moderate improvement in the VO_{2max} of active non-athletic males (6.2 %; 90 % confidence limits ± 3.1 %), when compared with control. There were possibly moderate improvements in the VO_{2max} of sedentary males (10.0 %; ± 5.1 %) and active non-athletic females (3.6 %; ± 4.3 %) and a likely small increase for sedentary females (7.3 %; ± 4.8 %). The effect on the VO_{2max} of athletic males was unclear (2.7 %; ± 4.6 %). A possibly moderate additional increase was likely for subjects with a $10 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ lower baseline VO_{2max} (3.8 %; ± 2.5 %), whereas the modifying effects of sex and difference in exercise dose were unclear. The comparison of HIT with traditional endurance training was unclear (-1.6 %; ± 4.3 %). Unexplained variation between studies was 2.0 % (SD). Meta-analysed effects of HIT on Wingate peak and mean power were unclear.

Conclusions Low-volume HIT produces moderate improvements in the aerobic power of active non-athletic and sedentary subjects. More studies are needed to resolve the unclear modifying effects of sex and HIT dose on aerobic power and the unclear effects on sprint fitness.

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1 Introduction

High-intensity interval training (HIT), which involves alternating bouts of intensive exercise with low-intensity recovery periods [1], is considered one of the most effective means of improving cardiorespiratory and metabolic function [2]. Athletes and coaches have historically used HIT to improve exercise performance, but the effectiveness of HIT to improve health-related outcomes has recently generated new interest [3]. In recent reviews, there appears to be a consensus for the benefit of high-intensity aerobic interval training in patient populations [3–6]. Weston et al. [6] meta-analysed ten studies and reported that high-intensity aerobic interval training, typically performed at 85–95 % maximal heart rate ($\%HR_{max}$), increased cardiorespiratory fitness by almost double that of moderate-intensity continuous training in patients with lifestyle-induced chronic disease. In contrast, HIT of similar intensity elicits improvements in maximal oxygen uptake (VO_{2max}) slightly greater than is typically reported with continuous training in healthy, active adults [7].

HIT can encompass a considerable range of exercise intensities. For example, Buchheit and Laursen [8] recently defined HIT as “either repeated short (<45 s) to long (2–4 min) bouts of rather high- but not maximal-intensity exercise, or short (<10 s, repeated-sprint sequences) or long (>20–30 s, sprint interval session) all-out sprints, interspersed with recovery periods.” As such, maximal, all-out sprint training is classified as a form of high-intensity training at the highest end of the intensity spectrum [9, 10]. Here, the repeated bouts of relatively brief all-out (maximal) intermittent exercise necessitate shorter interval durations and longer recovery periods than those of traditional high-intensity aerobic interval programming, and the total weekly volume (duration) of exercise is therefore lower. There is accumulating evidence supporting improved aerobic exercise performance following this form of training. Kessler et al. [3] reviewed five studies with exercise intensity described as all-out and concluded that it was an effective means of improving VO_{2max} . Sloth et al. [10] meta-analysed standardized effects of low-volume all-out interval training on VO_{2max} in 13 studies and reported an overall moderate effect (standardised change in the mean of 0.63). However, their meta-analysis did not account for the modifying effects of study and subject characteristics, or studies with reference groups representing traditional endurance training, rather than no training. Using similar inclusion criteria (e.g. 30-s all-out sprints) Gist and colleagues [11] meta-analysed 16 randomized controlled trials and reported a moderate effect (0.69) of HIT on VO_{2max} in comparison with no-exercise control groups and a trivial effect (0.04) when compared with endurance-training controls. However, effects on

physical performance should be meta-analysed in percent units before assessment via standardization [12]. Gist et al. [11] reported no significant effects of initial fitness, intervention length, inclusion of additional training or mode of training in response to HIT, but they did not report the effect of sex or work to rest ratio. The magnitude of the benefit of low-volume HIT on aerobic power, therefore, has still to be summarised adequately.

Low-volume HIT may also have the potential to improve sprint power, as it increases enzymatic activities of anaerobic metabolism [13]. Most sporting activities depend upon the expression of power for short or sustained periods of time [14]. Furthermore, many basic daily activities are dependent on the ability to generate force at high velocity, and power training can improve mobility-related outcomes in the elderly [15] as well as increasing self-efficacy, satisfaction with physical function and overall life satisfaction [16]. A meta-analysis of the effect of HIT on sprint power is therefore timely. Our aim for this review was to use a mixed-model meta-analysis to provide estimates of the effect of low-volume HIT on fitness (VO_{2max} , 30-s Wingate power) along with the modifying effects of study and subject characteristics.

2 Methods

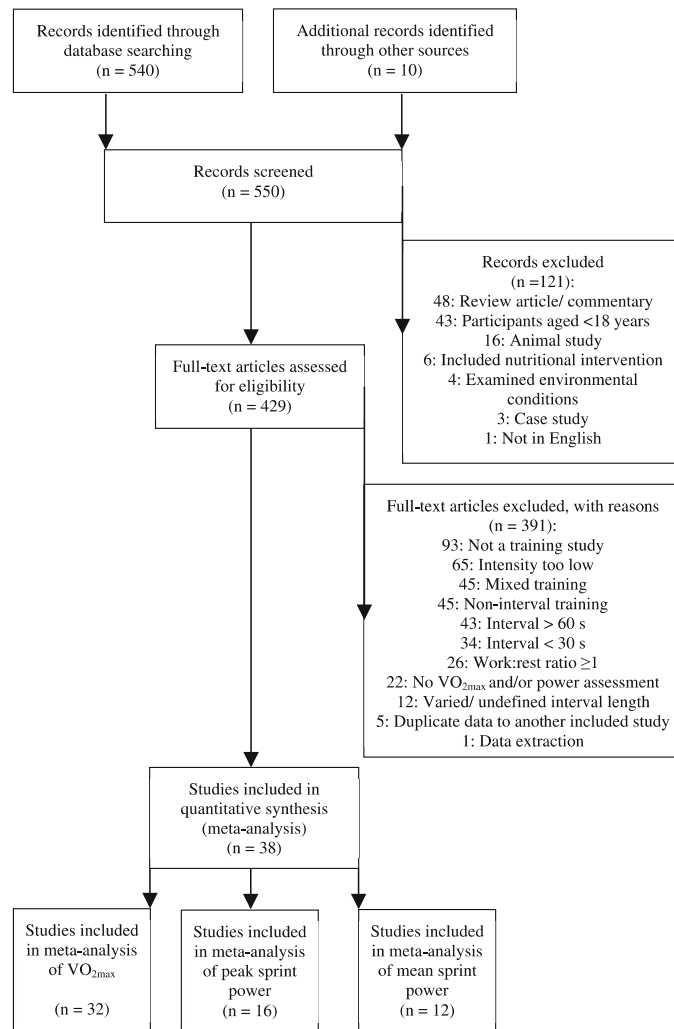
2.1 Literature Search

A search of five databases (PubMed, MEDLINE, Scopus, BIOSIS and Web of Science), along with the reference lists of original research and review articles published in English up to January 2014 was conducted by two of the authors (KT, MW). Our independent variable search terms were ‘aerobic high intensity’, ‘high intensity’, ‘HIT’, ‘intervals’, ‘intensive’, ‘sprint’, ‘repeated sprint’, and the dependent variable search terms were ‘fitness’, ‘aerobic fitness’, ‘anaerobic fitness’, ‘ VO_{2max} ’, ‘performance’, ‘endurance’ and ‘adaptations’. Independent variable search terms were combined with dependent variable search terms, giving a total of 49 combinations.

2.2 Study Selection

The most common model employed in low-volume HIT studies consisted of four to six 30-s ‘all-out’ efforts separated by ~4 min of recovery, for a total of two to three minutes of intense exercise during a single training session. As such, our study selection criteria were VO_{2max} or 30-s Wingate power assessed pre- and post-training, training period ≥ 2 weeks, repetition duration 30–60 s, work/rest ratio <1.0, exercise intensity described as maximal or near maximal, and adult subjects aged >18 years. No inclusion

Fig. 1 Flow diagram of study selection. VO_{2max} , maximum oxygen consumption



criteria were used for participant fitness. Using the subject characteristic information provided by each study, participants were assigned to one of three groups: sedentary, active non-athletic or athletic.

The selection of studies for our meta-analysis was confined to studies predominantly utilizing the classic

Wingate protocol. In doing so, we acknowledge the exclusion of a large body of laboratory- and field-based HIT research utilizing longer interval durations (1–4 min) performed at high, but not maximal intensity, and with a work:rest ratio ≥ 1.0 [8]. Furthermore, by selecting VO_{2max} as our measure of aerobic fitness, we excluded field-

Table 1 Study and subject characteristics for maximum oxygen consumption estimates included in the meta-analysis

References	Study design	Subjects	Mean age, y	Sample size	Proportion of males	Duration (weeks)	Total sessions	Group	Exercise intensity ^a	No. of reps		Rep duration (s)	Work/rest ratio	Effect on VO _{2max} (%)		
										Start	End					
Rakobowchuk et al. [20]	NC	Non-ath	23.1	11	0.36	6	18	HIT	100 %P _{max}	20	27	420	30	0.50	15.4	2.8
Siahkouchian et al. [21]	NC	Non-ath	19.1	12	1.00	8	24	HIT	All-out	6	7	191	30	0.13	13.9	3.0
Siahkouchian et al. [21]	NC	Ath	19.4	12	1.00	8	24	HIT	All-out	6	7	191	30	0.13	7.3	3.0
Triuk et al. [22]	C	Sed	30.1	14	0.00	4	12	HIT	All-out	4	7	66	30	0.13	13.4	2.5
Triuk et al. [22]	C	Sed	31.4	14	0.00	4	-	CON	-	-	-	-	-	-	-0.5	2.5
Allemeyer et al. [23]	C	Non-ath	22.7	11	1.00	6	15	HIT	All-out	3	3	45	30	0.03	12.5	2.8
Allemeyer et al. [23]	C	Non-ath	24.0	6	1.00	6	-	CON	-	-	-	-	-	-	-0.7	3.8
McKenna et al. [24]	NC	Non-ath	20.9	8	1.00	7	21	HIT	All-out	4	10	174	30	0.14	12.5	3.3
Maepherston et al. [25]	NC	Non-ath	24.3	10	0.60	6	18	HIT	All-out	4	6	90	30	0.13	11.5	2.9
Maepherston et al. [25]	NC	Non-ath	22.8	10	0.60	6	18	END	65 %VO _{2max}	-	-	-	2,700	-	12.5	2.9
Esfandiari et al. [26]	NC	Non-ath	24.5	8	1.00	2	6	HIT	95-100 %VO _{2max}	8	12	60	60	0.8	11.1	3.7
Esfandiari et al. [26]	NC	Non-ath	25.6	8	1.00	2	6	END	65 %VO _{2max}	-	-	-	6,300	-	4.5	3.7
Dunham and Harms [27]	NC	Non-ath	20.2	8	?	4	12	HIT	90 %P _{max}	5	5	60	60	0.33	9.6	3.7
Dunham and Harms [27]	NC	Non-ath	21.3	7	?	4	12	END	60-70 %P _{max}	-	-	-	2,700	-	5.5	4.0
Bayatti et al. [28]	C	Non-ath	25.0	8	1.00	4	12	HIT	All-out	3	4	48	30	0.13	9.6	4.0
Bayatti et al. [28]	C	Non-ath	25.0	8	1.00	4	12	HIT	125 %P _{max}	6	8	96	30	0.25	9.7	4.1
Bayatti et al. [28]	C	Non-ath	25.0	8	1.00	4	-	CON	-	-	-	-	-	-	-0.9	5.5
Whyte et al. [29]	NC	Sed	32.1	10	1.00	2	6	HIT	All-out	4	6	30	30	0.11	9.5	3.2
Hazell et al. [30]	C	Non-ath	24.0	12	0.73	2	6	HIT	All-out	4	6	30	30	0.13	9.3	2.7
Hazell et al. [30]	C	Non-ath	24.0	12	?	2	-	CON	-	-	-	-	-	-	0.2	1.7
Jacobs et al. [31]	NC	Non-ath	27.0	16	1.00	2	6	HIT	100 %P _{max}	8	12	60	60	0.8	8.9	3.6
Sharp et al. [32]	NC	Non-ath	25.5	8	1.00	8	32	HIT	All-out	8	8	256	30	0.13	8.3	3.3
Barnett et al. [33]	C	Non-ath	21.2	8	1.00	8	24	HIT	All-out	3	6	108	30	0.17	8.2	1.5
Barnett et al. [33]	C	Non-ath	21.2	8	1.00	8	-	CON	-	-	-	-	-	-	4.1	1.4
Harmer et al. [34]	C	Non-ath	24.0	7	0.57	7	21	HIT	All-out	4	10	174	30	0.14	8.2	3.5
Harmer et al. [34]	C	Non-ath	25.0	8	0.63	7	21	HIT	All-out	4	10	174	30	0.14	2.4	3.3
Shepherd et al. [35]	NC	Non-ath	22.0	8	1.00	6	18	HIT	All-out	4	6	90	30	0.11	7.6	3.7
Shepherd et al. [35]	NC	Non-ath	21.0	8	1.00	6	30	END	65 %VO _{2max}	-	-	-	3,000	-	15.6	3.7
Burgomaster et al. [36]	NC	Non-ath	24.0	10	0.50	6	18	HIT	All-out	4	6	90	30	0.11	7.3	2.9
Burgomaster et al. [36]	NC	Non-ath	23.0	10	0.50	6	30	END	65 %VO _{2max}	-	-	-	3,000	-	9.8	2.9
Bailey et al. [37]	C	Non-ath	21.0	8	0.63	2	6	HIT	All-out	4	7	35	30	0.13	7.1	3.3
Bailey et al. [37]	C	Non-ath	21.0	8	0.63	2	6	END	90 %GET	-	-	-	1,200	-	0.0	3.3
Bailey et al. [37]	C	Non-ath	21.0	8	0.63	2	-	CON	-	-	-	-	-	-	-2.1	3.3

Table 1 continued

References	Study design	Subjects	Mean age, y	Sample size	Proportion of males	Duration (weeks)	Total sessions	Group	Exercise intensity ^a	No. of reps		Total reps	Rep duration (s)	Work/rest ratio	Effect on $\dot{V}O_{2max}$ (%)
										Start	End				
MacDougall et al. [38]	NC	Non-ath	22.7	12	1.00	7	21	HIT	All-out	4	10	174	30	0.15	6.9 2.7
Tong et al. [39]	NC	Sed	22.9	8	0.25	6	18	HIT	120 %P _{max}	20	20	360	30	0.50	6.6 3.3
Esfarjani and Laursen [40]	NC	Ath	19.0	6	1.00	10	20	HIT	130 %vVO _{2max}	7	12	190	30	0.11	6.2 3.8
Esfarjani and Laursen [40]	NC	Ath	19.0	5	1.00	10	40	CON	75 %vVO _{2max}	-	-	-	3,600	-	2.1 4.1
Burgomaster et al. [41]	NC	Non-ath	22.0	8	1.00	2	6	HIT	All-out	4	7	30	30	0.13	5.5 3.2
Astorino et al. [42]	C	Non-ath	25.3	20	0.55	2	6	HIT	All-out	4	6	30	30	0.10	5.5 2.1
Astorino et al. [42]	C	Non-ath	22.8	9	0.55	2	-	CON	-	-	-	-	-	-	1.6 3.1
Sandvei et al. [43]	NC	Non-ath	25.2	11	0.36	8	24	HIT	All-out	5	10	189	30	0.17	5.1 2.8
Sandvei et al. [43]	NC	Non-ath	25.2	12	0.33	8	24	END	70-80 %HR _{max}	-	-	-	2,700	-	3.8 2.7
Rowan et al. [44]	NC	Ath	19.5	7	0.00	5	10	HIT	All-out	5	5	25	30	0.13	4.7 4.0
Rowan et al. [44]	NC	Ath	19.5	6	0.00	5	10	END	80 %VO _{2max}	-	-	-	2,400	-	3.3 4.3
Stadhis et al. [45]	NC	Non-ath	22.1	8	0.75	7	21	HIT	All-out	3	10	153	30	0.13	4.2 3.3
Barnes et al. [46]	NC	Ath	24.9	5	1.00	6	12	HIT	110 %vVO _{2max}	8	16	74	40.5	0.33	3.6 4.7
Laursen et al. [47]	C	Ath	25.0	10	1.00	4	8	HIT	175 %P _{max}	12	12	96	30	0.11	3.1 2.9
Laursen et al. [47]	C	Ath	25.0	10	1.00	4	-	CON	-	-	-	-	-	-	0.8 2.9
Harmer et al. [48]	NC	Non-ath	22.0	7	1.00	7	21	HIT	All-out	4	10	174	30	0.13	2.9 1.3
Laursen et al. [49]	C	Ath	23.5	7	1.00	2	4	HIT	100 %P _{max}	20	20	80	60	0.25	2.3 3.5
Laursen et al. [49]	C	Ath	23.5	7	1.00	2	-	CON	-	-	-	-	-	-	-0.8 3.5
Dalleck et al. [50]	NC	Non-ath	21.1	10	0.45	6	6	HIT	110-120 %P _{max}	6	8	42	30	0.14	-0.7 2.9
Dalleck et al. [50]	NC	Non-ath	21.1	10	0.45	6	12	HIT	110-120 %P _{max}	6	8	84	30	0.14	-0.6 2.9
Iaia et al. [51]	C	Ath	33.9	9	1.00	4	13.6	HIT	93 %V _{max}	8	12	124	30	0.17	-2.4 3.1
Iaia et al. [51]	C	Ath	33.9	8	1.00	4	16	CON	-	-	-	3,138	-	-	0.5 3.3

Studies are sorted from the largest to the smallest effects on $\dot{V}O_{2max}$ in the intervention group
 Ath athlete, C controlled study, CON control group, END endurance training group, GET gas exchange threshold (determined from a cluster of ventilatory measurements taken during a pre-training incremental test), HIT low-volume high-intensity interval training group, NC non-controlled study, Non-ath non-athlete, Rep repetition, SE standard error, Sed sedentary, $\dot{V}O_{2max}$ maximum oxygen uptake, %HR_{max} intensity corresponding to a percentage of maximal heart rate (determined via a pre-training incremental test), %V_{max} intensity corresponding to a percentage of maximum running velocity (determined via a pre-training 30-s all-out sprint run [51]), %VO_{2max} intensity predicted to elicit a percentage of $\dot{V}O_{2max}$ (on a treadmill [25] or on a cycle ergometer [26, 36]), determined via a pre-training incremental test, %vVO_{2max} percentage of the running speed predicted to elicit $\dot{V}O_{2max}$ (determined during a pre-training incremental test [40, 46]), - indicates not applicable, ? indicates data not available

^a All-out: encompasses intensities described by the authors as “maximal” [24]; “near maximal” [43]; “sprints” [33]; “maximum efforts” [38, 44]; “supramaximal” [23]; “sprint training at the highest resistance maintained for 90 rpm” [32]; or “all-out” [21, 22, 25, 28-30, 34-37, 41, 42, 45, 48]; %P_{max} encompasses intensities described as either a “percentage of peak watt workload” [50]; a “percentage of the highest 30 s power output completed” [47]; a “percentage of peak work rate” [20, 39]; a “percentage of final completed work rate maintained for 10 s” [28, 49]; a “percentage of peak power output” [31]; a “percentage of their final workload” [27] (all determined via a pre-training incremental test)

Table 2 Study and subject characteristics for peak power output included in the meta-analysis

References	Study design	Subjects	Mean age, y	Sample size	Proportion of males	Duration (weeks)	Total sessions	Group	Exercise intensity ^a	No. of reps		Rep duration (s)	Work/rest ratio	Effect on peak power (%)	
										Start	End				
Stathis et al. [45]	NC	Non-ath	22.1	8	0.75	7	21	HIT	All-out	3	10	153	30	0.13	17.1
Burgomaster et al. [52]	NC	Non-ath	22.0	8	0.75	2	6	HIT	All-out	4	7	30	30	0.25	15.7
Siakhouhian et al. [21]	NC	Non-ath	19.1	12	1.00	8	24	HIT	All-out	6	10	191	30	0.13	14.4
Forbes et al. [53]	NC	Non-ath	21.0	7	0.57	2	6	HIT	All-out	4	6	30	30	0.13	11.4
MacDougall et al. [38]	NC	Non-ath	22.7	12	1.00	7	21	HIT	All-out	4	10	174	30	0.13	10.6
Bayatti et al. [28]	C	Non-ath	25.0	8	1.00	4	12	HIT	All-out	3	4	48	30	0.13	10.3
Bayatti et al. [28]	C	Non-ath	25.0	8	1.00	4	12	HIT	125 %P _{max}	6	8	96	30	0.25	7.5
Bayatti et al. [28]	C	Non-ath	25.0	8	1.00	4	12	CON	–	–	–	–	–	–	–0.4
Harmer et al. [48]	NC	Non-ath	22.0	7	1.00	7	21	HIT	All-out	4	10	174	30	0.14	9.4
Barnett et al. [33]	C	Non-ath	21.2	8	1.00	8	24	HIT	All-out	3	6	108	30	0.17	7.7
Barnett et al. [33]	C	Non-ath	21.2	8	1.00	8	–	CON	–	–	–	–	–	–	8.9
Siakhouhian et al. [21]	NC	Ath	19.4	12	1.00	8	24	HIT	All-out	6	10	191	30	0.13	7.9
Richards et al. [54]	NC	Non-ath	29.0	12	0.42	2	6	HIT	All-out	4	7	30	30	0.13	6.9
McKenna et al. [24]	NC	Non-ath	20.9	8	1.00	7	21	HIT	All-out	4	10	174	30	0.14	5.8
Esbjörnsson Lijedahl et al. [55]	NC	Non-ath	25.0	10	0.00	4	12	HIT	All-out	3	3	27	30	0.03	5.6
Richards et al. [54]	NC	Non-ath	25.0	11	0.27	2	6	HIT	All-out	4	7	30	30	0.13	5.5
Burgomaster et al. [41]	NC	Non-ath	21.0	8	1.00	2	6	HIT	All-out	4	7	30	30	0.13	5.4
Whyte et al. [29]	NC	Sed	32.1	10	1.00	2	6	HIT	All-out	4	6	26	30	0.11	4.7
Allemeyer et al. [23]	C	Non-ath	22.7	11	1.00	6	15	HIT	All-out	3	3	45	30	0.03	3.0
Allemeyer et al. [23]	C	Non-ath	24.0	6	1.00	6	–	CON	–	–	–	–	–	–	3.0
Jansson et al. [56]	NC	Non-ath	27.0	7	1.00	4	10	HIT	All-out	3	3	30	30	0.03	2.4
McKenna et al. [57]	NC	Non-ath	18.8	6	1.00	7	21	HIT	All-out	4	10	174	30	0.13	2.3
Esbjörnsson Lijedahl et al. [55]	NC	Non-ath	26.0	6	1.00	4	12	HIT	All-out	3	3	27	30	0.03	1.4

Studies are sorted from the largest to the smallest effects (intervention group) on peak power output
Ath athlete, *C* controlled study, *CON* control group, *HIT* low-volume high-intensity interval training group, *NC* non-controlled study, *Non-ath* non-athlete, *Rep* repetition, *SE* standard error, *Secd* sedentary, *%P_{max}* percentage of the final completed work rate maintained for 10 s during a pre-training incremental test [28], – indicates not applicable
^a All-out: encompasses intensities described as either “maximal” [24, 53, 55, 57]; “sprints” [33]; “maximum efforts” [38]; “supramaximal” [23]; and “all-out” [21, 28, 29, 41, 45, 48, 52, 54, 56]

relevant performance measures, which may limit the application of our findings to athletic populations and sports performance. The recent meta-analysis by Bacon et al. [7] has, to an extent, addressed this gap in the literature. However, the number of studies excluded from the present study on interval duration, intensity and other measures of aerobic fitness (e.g. velocity at VO_{2max} , speed at lactate threshold, running economy and sports-specific tests) underscores the need for a dedicated review of studies using longer intervals at lower intensities.

To select relevant papers, all titles were initially screened by two authors (KT, MW) during the electronic searches to exclude studies that were beyond the scope of this meta-analysis. Following this initial selection process, there were 550 potentially eligible studies (Fig. 1). All study titles and abstracts were then screened independently by the same authors. Full-text versions of the remaining papers that met each of the eligibility criteria were then reviewed by these authors to determine final inclusion in the meta-analysis. Any disputed studies were taken to a third reviewer (AMB) for resolution. The final dataset for VO_{2max} consisted of 55 estimates from 32 trials, 11 of which were controlled trials. For peak sprint power, the final dataset consisted of 23 estimates from 16 trials, three of which were controlled trials. For mean sprint power, the dataset consisted of 19 estimates from 12 trials, three of which were controlled trials.

2.3 Data Extraction

Graph digitizer software (Digitizeit, Germany) was used to obtain data values in studies where only plots were published. Accuracy was confirmed via intra- and inter-individual reassessments of data extraction. Mean effects on VO_{2max} , peak and mean sprint power in training and control groups were converted to a percentage change. For each converted effect, standard errors were calculated to indicate the level of imprecision. In studies where exact p values were given (VO_{2max} $n = 7$; peak power $n = 4$; mean power $n = 5$), standard errors were calculated directly via the corresponding t statistic and its degrees of freedom. Under the assumption that studies with similar test protocols and subject characteristics would have similar typical errors of measurement, the typical errors from these studies were then averaged (via the weighted mean variance) and assigned to the studies that did not report an exact p value. The standard error was then calculated via the relationship between typical error and standard error [17, 18]. Descriptive statistics for studies included in the meta-analysis for VO_{2max} , peak and mean sprint power are shown in Tables 1, 2 and 3, respectively.

2.4 Publication Bias and Outliers

To investigate the extent of publication bias, we examined the standard error against the t value for each predicted effect for each outcome, and inspected the plot for signs of asymmetrical scatter [12]. Such a plot is an improved version of the funnel plot, as the scatter of the effects is adjusted for any uncertainty in the estimates and for the contribution of study covariates. Examination of these plots revealed no evidence of the asymmetrical scatter associated with publication bias.

2.5 Meta-Analytic Model

The general linear mixed-model procedure (Proc Mixed) in the Statistical Analysis System (Version 9.2, SAS Institute, Cary, NC, USA) was used to perform the meta-analysis. Fixed effects in the model included type of study (controlled, uncontrolled), study-level subject characteristics (sex, training status, baseline VO_{2max} , peak and mean sprint power) and training parameters (number of training sessions, repetition duration, work/rest ratio). We determined the predicted effect of reference training conditions on VO_{2max} , peak and mean sprint power using mean values of baseline fitness, number of sessions and work/rest ratio from all eligible studies. Performance effects were then calculated as the predicted effect under these reference training conditions. The modifying effects of predictors were also calculated, either as differences between levels of a nominal covariate (i.e. male/female, non-athletic/sedentary) or as the effect of approximately two standard deviations (SDs) of a numeric covariate (i.e. a typically high value minus a typically low value) [12]. Random effects in the model were the usual between-subject random effects and a novel within-study random effect to account for within-study repeated measurements (a control treatment and/or more than one training treatment). The residual was set to unity to properly weight the estimates by the inverse of the square of their standard errors. Unexplained true variation within and between studies was estimated by combining the variances for the random effects and was expressed as an SD. The SD was doubled before interpreting its magnitude with the scale used to interpret fixed effects [19], for the same reason that the magnitude of the effect of a linear covariate is evaluated with two SDs of the covariate [12].

2.5.1 Outcome Statistics

We expressed the uncertainty in the estimates of effects on fitness as 90 % confidence limits (CL) and as probabilities that the true value of the meta-analysed effect was trivial, beneficial or harmful in relation to threshold values for

Table 3 Study and subject characteristics for mean power output included in the meta-analysis

References	Study design	Subjects	Mean age, y	Sample size	Proportion of males	Duration (weeks)	Total sessions	Treatment group	Exercise intensity ^a	No. of reps		Rep duration (s)	Work/rest ratio	Effect on mean power (%)		
										Start	End			Mean	SE	
Siahkhoulian et al. [21]	NC	Non-ath	19.1	12	1.00	8	24	HIT	All-out	6	10	191	30	0.13	17.5	3.1
Bayati et al. [28]	C	Non-ath	25.0	8	1.00	4	12	HIT	All-out	3	4	48	30	0.13	17.2	6.1
Bayati et al. [28]	C	Non-ath	25.0	8	1.00	4	12	HIT	125 %P _{max}	6	8	96	30	0.25	11.2	6.7
Siahkhoulian et al. [21]	NC	Ath	19.4	12	1.00	8	24	HIT	All-out	6	10	191	30	0.13	11.1	3.1
Stathis et al. [45]	NC	Non-ath	22.1	8	0.75	7	21	HIT	All-out	3	10	153	30	0.13	10.7	3.8
Estbjörnsson Liljedahl et al. [55]	NC	Non-ath	25.0	10	0.00	4	12	HIT	All-out	3	3	27	30	0.03	10.1	2.9
Burgomaster et al. [41]	NC	Non-ath	21.0	8	1.00	2	6	HIT	All-out	4	7	30	30	0.13	8.7	2.9
Barnett et al. [33]	C	Non-ath	21.2	8	1.00	8	24	HIT	All-out	3	6	108	30	0.17	7.1	1.6
Barnett et al. [33]	C	Non-ath	21.2	8	1.00	8	24	CON	All-out	3	6	108	30	0.17	7.1	1.6
McKenna et al. [24]	NC	Non-ath	20.9	8	1.00	7	21	HIT	All-out	4	10	174	30	0.14	6.1	3.8
Allemeier et al. [23]	C	Non-ath	22.7	11	1.00	6	15	HIT	All-out	3	3	45	30	0.03	5.0	3.2
Allemeier et al. [23]	C	Non-ath	24.0	6	1.00	6	6	CON	All-out	3	3	45	30	0.03	5.0	3.2
Forbes et al. [53]	NC	Non-ath	21.0	7	0.57	2	6	HIT	All-out	4	6	30	30	0.13	4.5	1.3
Richards et al. [54]	NC	Non-ath	25.0	11	0.27	2	6	HIT	All-out	4	7	30	30	0.13	3.9	3.2
Whyte et al. [29]	NC	Sed	32.1	10	1.00	2	6	HIT	All-out	4	6	26	30	0.11	3.6	1.5
Jansson et al. [56]	NC	Non-ath	27.0	7	1.00	4	10	HIT	All-out	3	3	30	30	0.03	2.8	4.1
Estbjörnsson Liljedahl et al. [55]	NC	Non-ath	26.0	6	1.00	4	12	HIT	All-out	3	3	27	30	0.03	1.4	3.7
Richards et al. [54]	NC	Non-ath	29.0	12	0.42	2	6	HIT	All-out	4	7	30	30	0.13	1.1	3.1

Studies are sorted from the largest to the smallest effects (intervention group) on mean power output

Ath athlete, C controlled study, CON control group, HIT low-volume high-intensity interval training group, NC non-controlled study, Non-ath non-athlete, Rep repetition, SE standard error, Sed sedentary, %P_{max} percentage of the final completed work rate maintained for 10 s during a pre-training incremental test [28], - indicates not applicable

^a All-out: encompasses intensities described as either "maximal" [24, 53, 55]; "sprints" [33]; "supramaximal" [23]; and "all-out" [21, 28, 29, 41, 45, 54, 56]

benefit and harm. Probabilities were then used to make a qualitative probabilistic inference about the effect [12]. Given that improved aerobic functioning and power output have clinical application [3–7, 15, 16], main treatment effects were considered unclear if the chance of benefit (improved fitness) was high enough to warrant use of the intervention but with an unacceptable risk of harm (reduced fitness). An odds ratio of benefit to harm of <66 was used to identify such unclear effects. This ratio corresponds to a borderline possibly beneficial effect (25 % chance of benefit) and a borderline most unlikely harmful effect (0.5 % risk of harm). All other effects were deemed clinically clear and inference made via estimation of the probability that the true magnitude of the effect was at least as large as our pre-specified thresholds. In the absence of robust anchors for the smallest worthwhile clinical and practical effect on VO_{2max} and sprint power, our inferences were based on standardized thresholds for small, moderate and large changes of 0.2, 0.6 and 1.2 SDs, respectively [12], and derived by averaging appropriate between-subject variances for baseline VO_{2max} , peak and mean sprint power. For VO_{2max} , magnitude thresholds were 3.2, 9.6 and 19.2 % for sedentary subjects, 1.4, 4.1 and 8.1 % for active non-athletic subjects, and 1.4, 4.2 and 8.4 % for athletic subjects. For peak and mean sprint power, thresholds were 1.7, 5.1 and 10.3 and 1.7, 5.2 and 10.5 %, respectively, for male subjects. The chance of the true effect being trivial, beneficial or harmful was interpreted using the following scale: <0.5 % most unlikely; 0.5–5 % very unlikely; 5–25 % unlikely; 25–75 % possibly; 75–95 % likely; 95–99.5 % very likely; >99.5 % most likely [12]. Modifying effects were evaluated non-clinically and deemed unclear if the 90 % CL overlapped the thresholds for the smallest worthwhile positive and negative effects [12].

3 Results

3.1 Maximum Oxygen Consumption

The meta-analysed effects on VO_{2max} of an average low-volume HIT protocol in a controlled trial are shown in Table 4. When compared with control, moderate improvements in VO_{2max} were likely for active non-athletic males and possible for sedentary males and active non-athletic females. A small improvement in VO_{2max} was likely for sedentary females. The effect on athletic males was unclear. With the exception of a possible moderate additional increase in VO_{2max} for subjects with a lower baseline value, the effects of all modifiers were unclear. The comparison of HIT with endurance training was unclear (-1.6 %; 90 % CL ± 4.3 %). Unexplained variation expressed as a between-study SD was 2.0 % (± 2.7).

3.2 Sprint Power

The meta-analysed effects of low-volume HIT on 30-s Wingate peak and mean sprint power in a controlled trial are shown in Tables 5 and 6, respectively. With the exception of a possibly moderate improvement in the peak sprint power of controls, all mean effects on sprint power were unclear. There were possibly moderate and likely small improvements in mean and peak sprint power, respectively, following a threefold increase in the number of training sessions. A moderately beneficial improvement in peak sprint power with a greater work/rest ratio was possible and a small additional increase in mean sprint power was possible for subjects with a lower baseline value. All other modifying effects were unclear. Unexplained variation between studies was 2.4 (± 2.5) and 1.0 (± 2.9) % for peak and mean sprint power, respectively.

4 Discussion

In the previous meta-analyses of Sloth et al. [10] and Gist et al. [11], low-volume HIT improved aerobic fitness and Wingate sprint power, but the effects on different subject groups and other modifying effects were either not analysed or not presented. Our meta-analysis broadens the scope of these previous reviews, as it is the first to include study and subject characteristics in the analysis. Our data revealed HIT to have an apparent adaptive effect on VO_{2max} that favours the less fit. Despite HIT effectively representing repeated Wingate tests, there was no clear effect on measures of performance in the test.

We found that a mean protocol of 13 HIT sessions with a work/rest ratio of 0.16 led to moderate improvements in the VO_{2max} of sedentary and non-athletic males and females. This main finding is consistent with the recent work of Sloth et al. [10], Gist et al. [11] and Bacon et al. [7], who reported standardized moderate effects on VO_{2max} for HIT and high-intensity aerobic interval training, respectively. A combination of central and peripheral adaptations promoting an enhanced availability, extraction and utilization of oxygen may explain such improvements following intensive interval-training protocols. However, mechanisms responsible for increased VO_{2max} following HIT were not the focus of our review. Comprehensive reviews of the possible underlying mechanisms are available elsewhere [9, 10].

Gibala et al. [58] reported low-volume HIT to be a time-efficient strategy for rapid physiological and performance improvements that are comparable to improvements following traditional endurance training. The random effects component of our mixed model enabled us to include studies where the reference group was traditional

Table 4 Effects of low-volume high-intensity interval training on maximum oxygen consumption following reference training, with modifying effects for study characteristics, subject characteristics and training parameters

	Effect on VO_{2max} (%)		Inference
	Mean	$\pm 90\%$ CL	
Effect on treatment groups ^a			
Sedentary males	10.0	± 5.1	Possibly moderate \uparrow
Sedentary females	7.3	± 4.8	Likely small \uparrow
Active non-athletic males	6.2	± 3.1	Likely moderate \uparrow
Active non-athletic females	3.6	± 4.3	Possibly moderate \uparrow
Athletic males	2.7	± 4.6	Unclear
Controls	1.2	± 2.0	Unclear
Modifying effects			
Baseline VO_{2max} lower by 10 mL·kg ⁻¹ ·min ⁻¹	3.8	± 2.5	Possibly moderate \uparrow
Athlete vs. active non-athlete	2.4	± 5.7	Unclear
Threefold increase in work/rest ratio	-0.3	± 2.0	Unclear
Threefold increase in no. of sessions	-0.3	± 2.0	Unclear
Uncontrolled study	-0.7	± 2.3	Unclear
Sedentary vs. active non-athlete	-2.2	± 5.7	Unclear
Females	-2.5	± 4.1	Unclear
Replacement of training (male athletes only)	-2.9	± 5.3	Unclear

Effects on treatment groups are presented as intervention minus control

Reference training: a controlled study of 13 low-volume HIT sessions with a work/rest ratio of 0.16 (0.14 for sedentary females)

CL confidence limit, *HIT* low-volume high-intensity interval training, VO_{2max} maximal oxygen uptake, \uparrow indicates increase

^a Active non-athletic males: baseline VO_{2max} adjusted to 45 mL·kg⁻¹·min⁻¹. Sedentary males: baseline VO_{2max} adjusted to 30 mL·kg⁻¹·min⁻¹. Active non-athletic females: baseline VO_{2max} adjusted to 45 mL·kg⁻¹·min⁻¹. Sedentary females: baseline VO_{2max} adjusted to 30 mL·kg⁻¹·min⁻¹. Athletic males: baseline VO_{2max} adjusted to 60 mL·kg⁻¹·min⁻¹

endurance training rather than no training. Here, the comparison between the two types of training was unclear. This finding is consistent with that of Gist et al. [11], who reported a trivial effect of HIT on VO_{2max} when compared with endurance training controls. More studies are therefore required to examine the effectiveness of HIT versus traditional endurance training for training-induced endurance gains. The effect of HIT on VO_{2max} was greater for the less fit, which is consistent with training in general having greater effects on the less fit [59]. For already highly trained athletes who replaced their usual training

Table 5 Effects of low-volume high-intensity interval training on 30-s Wingate peak sprint power following reference training, with modifying effects for study characteristics, subject characteristics and training parameters

	Effect on peak power (%)		Inference
	Mean	$\pm 90\%$ CL	
Effect on treatment groups ^a			
Males	1.8	± 5.0	Unclear
Controls	4.5	± 3.8	Possibly moderate \uparrow
Modifying effects			
Fivefold increase in work/rest ratio	5.7	± 3.5	Possibly moderate \uparrow
Threefold increase in sessions	2.9	± 3.5	Likely small \uparrow
Females	2.0	± 6.3	Unclear
Baseline peak power lower by 5 W/kg	1.6	± 3.2	Unclear
Uncontrolled study	-1.0	± 3.7	Unclear

Effects on treatment groups are presented as intervention minus control

Reference training: a controlled study of 12 low-volume HIT sessions with a work/rest ratio of 0.10

CL confidence limit, *HIT* low-volume high-intensity interval training, \uparrow indicates increase

^a Males, with baseline peak power output adjusted to 11.5 W/kg

with HIT, as opposed to adding the HIT, the effect on VO_{2max} was unclear. This finding also indicates the need for more research, providing that elite athletes can be convinced to experiment with their normal training programmes [9]. Despite reporting no analytical data for the potentially modifying effect of training duration, Sloth et al. [10] and Gist et al. [11] reported no clear effects of the length of HIT intervention on the magnitude of VO_{2max} improvement. The data presented in our more extensive meta-analysis have still not resolved this issue.

On the basis of the CLs, low-volume HIT had an unclear effect on peak and mean sprint power that could at most be a moderate beneficial or a small harmful effect. These results contrast with those of Sloth et al. [10], who reported enhanced peak and mean power following HIT. Their assertion was based on nine studies [24, 28–30, 33, 36, 41, 42, 52], without a meta-analysis of the mean effect and its uncertainty. Three of these studies [30, 36, 42] were excluded from our analysis, owing to difficulties in obtaining precise baseline and post-intervention data during the data extraction process. An enhanced sprint power following HIT was expected, given that all-out training increases enzymatic activity related to anaerobic metabolism [13]. Furthermore, studies showing strong similarities between testing and training routines are more likely to

Table 6 Effects of low-volume high-intensity interval training on 30-s Wingate mean sprint power following reference training, with modifying effects for study characteristics, subject characteristics and training parameters

	Effect on mean power (%)		Inference
	Mean	±90 % CL	
Effect on treatment groups ^a			
Males	2.2	±10.3	Unclear
Controls	2.8	±8.2	Unclear
Modifying effects			
Threefold increase in sessions	6.2	±3.9	Possibly moderate ↑
Baseline mean power lower by 4 W/kg	2.3	±3.7	Possibly small ↑
Fivefold increase in work/rest ratio	1.5	±3.7	Unclear
Females	-0.1	±6.9	Unclear
Uncontrolled study	-2.3	±4.3	Unclear

Effects on treatment groups are presented as intervention minus control

Reference training: a controlled study of 14 low-volume HIT sessions with a work/rest ratio of 0.09

CL confidence limit, *HIT* low-volume high-intensity interval training, ↑ indicates increase

^a Males, with baseline mean power output adjusted to 7.6 W/kg

show training improvements [60]. However, when measured relative to controls, the meta-analysed effect of HIT on sprint power was unclear. Improvements of 4.5 % in peak sprint power and 2.8 % in mean sprint power of control subjects may have represented a learning effect on the Wingate test or provide some evidence of compensatory rivalry (e.g. greater effort by controls). There was some evidence of a dose–response relationship and a greater effect for the less fit. The finding of a possibly moderate enhancement in peak sprint power with a fivefold increase in repetition work/rest ratio could be explained by greater phosphocreatine resynthesis in the recovery phase [61, 62].

There was considerable uncertainty in the SDs representing the residual between-study variation in the mean effect of the treatment on the three measures of fitness, but in this sample of studies the observed magnitudes (after doubling the SDs) were small to moderate, depending on the measure of performance and the subject group. This SD needs to be added to and subtracted from the main effect to evaluate the magnitude of the HIT treatment in a specific setting. For example, the mean effect of HIT on VO_{2max} for active non-athletic males (6.2 %; moderate) in any given

setting could be anywhere from 4.2 % (very likely small) to 8.2 % (possibly large). Such differences between the effects of training in the different studies presumably reflect differences in subject characteristics and training protocols that are not properly accounted for by the published data. Some data may also have been analysed or reported erroneously.

We propose several areas for future research, along with suggestions for those publishing research in this area. Given that the age of participants included within our meta-analysis was mainly young adults, it is evident that research is required to clarify the effects of low-volume HIT in older populations. Moderating effects of changing the exercise dose on VO_{2max} were unclear, as was the replacement of athletes' usual aerobic training with HIT, indicating that more research is necessary to investigate these predictors. However, we do recommend that modifying effects are interpreted with slight caution, as when a covariate is a subject characteristic averaged over study subjects, the observed meta-regression relationships might not hold at the individual study level [63]. The practicality of low-volume HIT warrants further investigation, given that repeated bouts of maximal exercise require high levels of motivation [9]. Adherence to unsupervised training also needs investigation [29]. We concur with the need to test the effectiveness of low-volume HIT via large-scale, multi-centre, randomized clinical trials in various clinical populations and on long-term clinical outcome measures [64]. Of further benefit would be the reporting of full inferential statistics, such as SD of change scores or exact *p* values in training and control groups, to enable meta-analysis of the magnitude of individual responses. Finally, the findings of a training study are of very little or no value without precise information of the training itself [65]. We therefore encourage authors to report physiological responses during HIT sessions, as this practice will help to demonstrate that the fidelity of an intervention has been upheld for all subjects.

5 Conclusions

Low-volume HIT is increasingly being used for aerobic adaptations previously achieved with traditional endurance training. Our meta-analysis provides evidence of substantial improvements in the endurance fitness of sedentary and non-athletic subjects following repeated bouts of brief maximal intermittent exercise. The effect of HIT on sprint power should be determined with more studies.

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Chapter 3: Programme framework

Programme setting

Project FFAB (Fun Fast Activity Blasts) was carried out in three of the five unitary authorities in the Tees Valley region of North East England (Middlesbrough; Redcar and Cleveland; and Stockton-on-Tees). According to the 2011 Health Profiles, deprivation and overall health in Middlesbrough, Redcar and Cleveland and Stockton-on-Tees are markedly worse than the English average (Network of Public Health Observatories, 2011). Across these areas, life expectancy for both men and women is lower than the national average and over 27,000 children live in poverty. Additionally, despite the apparent flattening of youth obesity levels nationwide, the percentage of obese Year 6 children (aged 10- to 11-years) in these authorities is higher than the English Year 6 average of 18.7% (Middlesbrough 21.6%; Redcar and Cleveland 20.6%; and Stockton-on-Tees 20.1%). When assessed using the English Index of Multiple Deprivation 2007 (Noble et al., 2008), levels of deprivation in these areas are also much higher than the English average (19.9%), with levels of over double the national mean reported for Middlesbrough (56.3%). This is a further cause for concern, as a recent survey conducted in Scottish children found that waist circumference was significantly associated with deprivation, such that the greatest values were found in youths in the most deprived quintile (Masson et al., 2012). When these findings are viewed alongside the nationwide declines in youth physical activity and cardiorespiratory fitness levels, the implementation of cardioprotective exercise programmes for youths in the Tees Valley region is both timely and justified.

School-based interventions have long been regarded as the most universally applicable and effective way to reverse low physical activity and cardiorespiratory fitness trends, though debate remains over the optimal way to intervene (Kriemler et al., 2011). Much of the appeal of the school setting lies in it enabling access to a large, ethnically and socioeconomically diverse population of young people (Lobstein & Swinburn, 2007), who will spend between 6 to 12 years of their lives within the school environment (St Leger et al., 2007). This therefore creates an extended window of opportunity to explore the impacts of various forms of physical activity to all young people, regardless of their life circumstances (Naylor & McKay, 2009). In the context of the current programme of work, the school setting may provide the ideal environment to examine the effects of low-volume HIT in young people when delivered under “real world” conditions. Indeed, the main aim of an effectiveness trial is to ascertain whether an intervention works among a broadly defined population (Glasgow,

Lichtenstein & Marcus, 2003). This can be afforded through the school setting, where diverse practices and student populations are commonplace (St Leger et al., 2007; Franks et al., 2007; Buchan et al., 2012).

Programme framework and overview

Project FFAB was developed using the Medical Research Council's (MRC) guidance for developing and evaluating complex interventions (Craig et al., 2008). Here, complex interventions are viewed as those containing several interacting components. This can relate to the number and variability of outcome measures, the behaviours required by those delivering and/or receiving the intervention, the number of groups targeted by the intervention, interactions between components within the experimental and control groups, and the degree of flexibility permitted within the intervention itself (Craig et al., 2008). Project FFAB can be described as a complex intervention in several ways. Firstly, the setting for all of the studies within this programme was secondary schools in the Tees Valley region. Schools are dynamic, busy places (Franks et al., 2007; St Leger et al., 2007) which can create unique problems to the researcher that would not be apparent in standardised laboratory settings. Furthermore, the main trial of Project FFAB incorporated a 10-week low-volume HIT intervention and the collection of 11 outcome measurements from 101 Year 9 students from four schools across three time points. Each school presented different challenges, including time restrictions, access to students and competing priorities. This therefore necessitated that the project adopted a flexible structure, whilst still attempting to maintain high intervention fidelity. This approach is supported by the MRC and others (WHO European Working Group on Health Promotion Evaluation, 1998; Hawe, Shiell & Riley, 2004) who have warned against overly standardising interventions based in "real-life" settings. The authors of the MRC framework recommend that interventions are developed by testing the best available evidence and appropriate theory via a phased approach. These tend to begin with a series of pilot studies, which are followed by an exploratory investigation and culminate with a definite trial. These main stages and key activities are summarised in Figure 1.

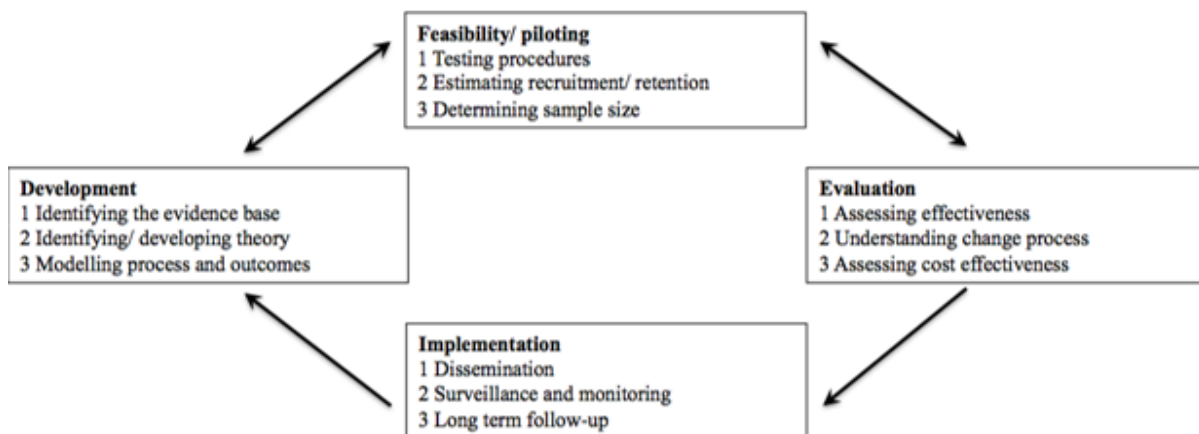


Figure 1. Key elements of the MRC development and evaluation process, reproduced from Craig et al., (2008)

Notwithstanding the usefulness of Figure 1 for illustrating each step of the development and evaluation process, often these stages will not follow a linear or even cyclical sequence (Campbell et al., 2007). Indeed, a criticism of the earlier MRC framework (Campbell et al., 2000) was that it lacked flexibility (Dieppe, 2006) and did not give due weight to the intervention development phase. With this in mind, the programme of work encompassing Project FFAB was developed using a sequential mixed methods design (Creswell et al., 2003). As such, Study 1 contained the majority of the intervention development work; Study 2 piloted the feasibility of the proposed intervention; Study 3 incorporated the main exploratory trial, and in Study 4 the fidelity of the main intervention was assessed using both quantitative and qualitative methods. Qualitative data was collected in Study 1, 2 and 4, and quantitative data collected in Study 2, 3 and 4. These phases and the programme time course are summarised in Figure 2.

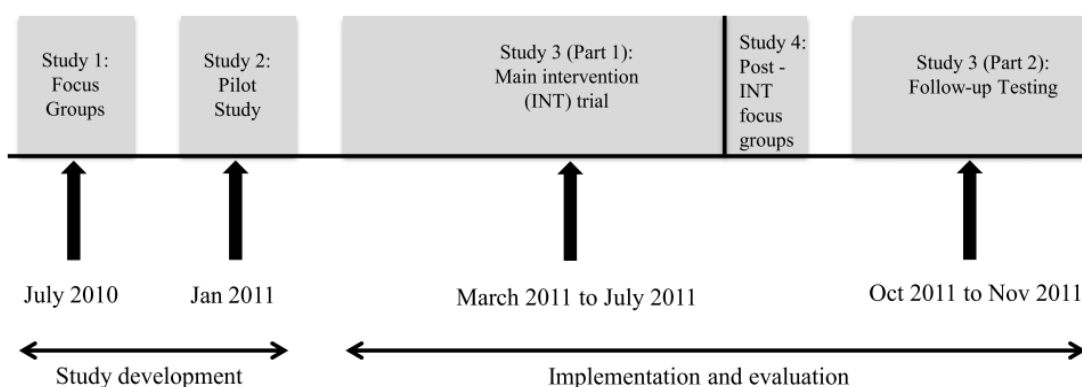


Figure 2. Overview of the sequential phases and time course of Project FFAB

Study 1 comprised of in-depth qualitative work with individuals representative of the target population for the main trial. Focus groups were chosen as the most appropriate methodology for exploring the participants' thoughts and opinions on vigorous-/high-intensity exercise and the proposed school-based low-volume HIT intervention. This form of data collection was chosen over individual semi-structured interviews for a number of reasons. Firstly, focus groups can create a permissive environment which encourages participants to share their perceptions, motivations, concerns and opinions (Krueger & Casey, 2000); thereby generating data through group interaction (Kitzinger, 2008). Furthermore, it has been suggested that the group context facilitates openness and disclosure, which is contrary to the common assumption that individuals will be inhibited by the presence of their peers (Wilkinson, 1998). Perhaps most importantly in the context of adolescents, focus groups provide insight to the participants' own language and concepts, as they tend to talk mainly to each other rather than the researcher (Slater & Tiggemann, 2010). This is particularly relevant for teenage participants who may use very different language from adult researchers.

During the focus groups, small groups of pupils were asked a series of open-ended questions by the lead researcher who had completed an "Introduction to Focus Groups" course at the University of Surrey in March 2010. This approach is recommended in the MRC guidance as a means of understanding facilitators and barriers to participation in an intervention. Previously, the views of potential participants have been largely overlooked (Hesketh et al., 2005). This is surprising, given that most health promotion theories suggest that gaining a comprehensive understanding into important determinants should be the first step in developing such interventions (Bartholomew et al., 2001). This can be afforded through focus group methodology, and is deemed imperative in the design of successful intervention trials (Allender, Cowburn & Foster, 2006). Furthermore, this approach, often referred to as formative research, has been shown to effectively inform several other physical activity interventions (e.g. Young et al., 2006; Mackintosh et al., 2011). Generally, this method has been more commonly used to develop behaviour change trials, rather than health outcome interventions like Project FFAB. Nonetheless, this approach was considered appropriate for the development of the project, given its pragmatic nature.

In line with the MRC guidance, Study 2 piloted the feasibility and appropriateness of the key concepts identified in Study 1, in the context of a school-based low-volume HIIT

intervention. Previous research suggests that this vital preparatory work is often skimmed (Eldridge et al., 2004), which can lead to problems of acceptability (Armstrong, Winder & Wallis, 2006), compliance, delivery of the intervention and recruitment and retention (McDonald et al., 2006; Bower, Wilson & Mathers, 2007). Although a pilot study need not be a “scale model” of the main trial, it should test key procedures and address any uncertainties in the intervention model (Craig et al., 2008). As such Study 2 examined adolescent females’ responses to three prototype prescriptions of low-volume high-intensity exercises, which were based on the most popular activities cited in Study 1. This was assessed both quantitatively, through heart rate and rating of perceived exertion responses; and qualitatively via participant feedback forms. Accordingly, this allowed the appropriateness of the proposed intervention to be addressed from a physiological/ training perspective and an enjoyment and acceptability standpoint. These findings underpinned the refinements to the intervention protocol prior to the main exploratory trial.

The main trial of Project FFAB took place between February 2011 and November 2011. As displayed in Figure 2; Study 3 encompassed two distinct parts. The first incorporated the baseline measurements, the 10-week low-volume HIT intervention and the post-intervention measurements. The second part took place after the summer break. Here, the data collection procedures were repeated for a third time which enabled 3-month follow-up measurements to be obtained. During the planning phase, it was envisaged that the trial would follow a cluster randomised control trial design. This was not possible however; as one of the participating schools disclosed that they would only be able to take part if they were assigned to the control condition, due to time restrictions and timetabling pressures. As such, the trial utilised a cluster controlled before-and-after study design, where outcomes were compared between participants who had received the intervention with those who had not. Here however, the allocation of groups to the intervention or control condition is no longer randomised, which can lead to several sources of bias (selection, performance, attrition and detection bias). Of these, Deeks et al. (2003) cites selection bias, where systematic differences in groups arise at baseline, as the greatest threat to internal validity in observational studies. This can be introduced when participants selected for an intervention have different characteristics from those allocated to the control arm. This scenario may have existed in Project FFAB, as participants came from four different schools. Whilst this limitation was not possible to entirely overcome, it was partly controlled for by including the participants’ baseline values for each study outcome in the statistical analysis. Furthermore, the intervention and control schools were matched on factors such as Index of

Multiple Deprivation (Noble et al., 2008), school speciality and number of hours offered for PE per week. The trial was also reported using the Template for Intervention Description and Replication (TIDieR) checklist (Hoffman et al., 2014) and the Transparent Reporting of Evaluation with Non-randomised Designs (TREND) statement (Des Jarlais, Lyles & Crepaz, 2004). These guidelines place emphasis on the description of the intervention; including its theoretical base, description of the control condition, full reporting of outcomes, the extent to which fidelity was upheld and inclusion of study design information which will allow possible biases in the outcome data to be assessed. This information could aid assessments of the external validity of Project FFAB and avoids the common intervention “black box” scenario (Armstrong et al., 2008). As the findings of an exercise study are of very little use without precise, thorough and in-depth information about the training itself (Mujika, 2013), the fidelity of Project FFAB intervention was assessed throughout the main trial period and reported in Study 4. Intervention fidelity refers to the methodological practices used to monitor and enhance the reliability and validity of a study (Bellg et al., 2004), and is based on three main components: intervention delivery; receipt and enactment (Moncher & Prinz, 1991; Lichstein, Riedel & Grieve, 1994). Delivery examines whether the intervention was delivered as intended to all of the participants, throughout the trial time period. Receipt assesses whether participants have understood the intervention, learned new information or are able to perform a new behaviour; and enactment establishes whether they are able to apply this information and/or behaviours to their daily life (Bellg et al., 2004; Resnick et al., 2011). Within Project FFAB, intervention delivery was objectively assessed via participants’ heart rate responses to the low-volume HIT trial, with intervention receipt explored through semi-structured post-intervention focus groups. Here, on completion of the intervention all participants were invited to attend focus groups to discuss their experiences of the project. This approach is recommended by the MRC, and can be particularly important in explaining the complexities of school-based interventions (Young et al., 2008).

Chapter 4: Key elements of a school-based low-volume high-intensity interval training intervention from an adolescent perspective: The development of Project FFAB (Study 1)

Introduction

Over the last decade there has been a rise in the number of school-based interventions specifically targeting the enhancement of physical activity levels and health outcomes in young people (Kriemler et al., 2011). In a recent systematic review it was reported that numerous school-based programmes have positively impacted psychological determinants, physical activity and health outcomes in young people (Demetriou & Höner, 2012). The only health outcomes included in this however were BMI and motor control, therefore the impact of school-based exercise programmes on cardiovascular risk factors remains relatively unclear. Furthermore, the effectiveness of school-based interventions for eliciting sustained improvements in physical activity and health outcomes is not universally agreed, with several topical reviews reporting equivocal findings (e.g. van Sluijs et al., 2007; Durant et al., 2009). This could be due to researchers failing to understand the needs and behaviours of their target population prior to intervening (Hesketh, et al., 2005). This may hold particular relevance for secondary school-based interventions, since adolescence is characterised by a shift towards independent decision making that is strongly influenced by peers, technology and the mass media (Gibbons & Naylor, 2007). As such, the needs and attitudes of this population group may be instrumental in an intervention's success or failure, in terms of adherence and acceptability. This, and other complex issues such as variations in school timetables and facilities, must be acknowledged during the early phases of intervention development, as what may work in one school or age group may not be appropriate for another. Moreover, consulting and engaging with potential intervention participants within the context of their community is now deemed a fundamental stage in the intervention development process (Allender, Cowburn & Foster, 2006; NICE, 2007; Craig et al., 2008). This has commonly been achieved through semi-structured individual interviews and/or focus groups; with the merits of the latter discussed in Chapter 3. In the context of intervention development, both these methods can be used to explore individuals' beliefs, perceptions, behaviours, and the environmental structures that may enhance or inhibit a trial's effectiveness, thereby enabling researchers to plan interventions better suited to local conditions (Gittelsohn et al., 1995).

Whilst focus groups and interviews have commonly been used to inform the design of physical activity promotion trials (e.g. MacIntosh et al., 2011), these methods have yet to be used to inform the design of a novel school-based low-volume HIT intervention. This is perhaps unsurprisingly, given that low-volume HIT has only begun to feature prominently in the literature over the last decade. Furthermore, few low-volume HIT studies have been carried out in young people, with only two conducted in school settings (Boddy et al., 2010; Buchan et al., 2011a). Of these, trials utilising running as a training mode have demonstrated the greatest post-intervention benefits (Buchan et al., 2011a; de Araujo et al., 2012). It is however highly questionable whether a low-volume HIT intervention based exclusively on running would be appealing and sustainable for wider population groups, in particular adolescent girls (Motl et al., 2001; Young et al., 2006). The difficulty of recruiting and retaining adolescents to a low-volume HIT trial was highlighted by Buchan et al. (2012) who, after the success of their first low-volume HIT trial, attempted to replicate their study at a second school site. Here however the attrition rate was 40% after only two days of the 7-week programme, leading the authors to deem the trial a failure in terms of expected adherence. They went on to suggest that had they involved members of the school community in the trial planning, the intervention may have been more successful. This further highlights the importance of gaining insights from those within the school when developing such a trial. Furthermore, whilst previous studies have used qualitative data to tailor physical activity promotion programmes for adolescents (e.g. Moe et al., 2006); how this data is actually used in the development process is seldom reported (Young et al., 2006). The aims of this study therefore were to (1) explore the attitudes, beliefs and opinions of secondary school pupils aged 13 to 15 years towards vigorous-/high-intensity physical activity, and a school-based low-volume HIT intervention; and (2) detail how these data were used to inform the design and implementation of a novel school-based low-volume HIT intervention for 13 to 15 year olds.

Methods

Participants

Approval for this study was granted by the Teesside University School of Health & Social Care Research Governance and Ethics Committee in May 2010 (study number 048/10). One secondary school in the Redcar and Cleveland area (characteristics shown in Table 8) was then invited to take part via email correspondence and a face-to-face meeting. After gaining informed consent from the head teacher 50% (280 pupils) of the Year 9 and 10 student cohort (aged 13 to 15 years) were invited to take part in the study through presentations in their PE

lessons, with a target sample size of 50 participants. No clear advice exists regarding the pertinent number of focus groups required for qualitative research (Stewart, Shamdasani & Rook, 2007). A sample size of 50 permitted seven to nine focus groups to be held. This was expected to provide sufficient insight into the wide-ranging opinions of this population group and the sample size was similar to that of previous qualitative studies investigating adolescents' opinions on physical activity (Slater & Tiggemann, 2010). Generally, recruitment is viewed as the single most common source of failure in focus group research (Morgan, 1995). To maximise the chances of achieving the desired sample size therefore, a greater number of students than actually required were initially targeted. All pupils that attended the study presentation received information packs, and were asked to return parental consent and participant assent forms if they were interested in taking part. Every pupil that provided parental consent and participant assent met the inclusion criteria of speaking and understanding English. The total number of participants was 51 (aged 14.1 ± 0.7 years; mean \pm SD), of which 43 (25 females) went on to complete the study. Seven participants were absent on the day of their focus group, and one participant changed their mind about taking part. All participants that attended their session received a certificate of attendance as a thank you for taking part.

Table 8. School level descriptive statistics

No. of pupils	Sex on entry	Age range (y)	IMD rank ^a (1= most deprived)	Free school meals eligibility ^b (%)	School specialism	PE (hours per week)
1258	Mixed	11-16	12521	12.4	Sport	2

IMD = Index of Multiple Deprivation

y = years

^aSource: <http://dclgexamples.mywebcommunity.org/imd/imd-explorer-v0.html>

^bSource: <http://www.education.gov.uk/cgi-bin/schools/performance/school.pl?urn=111724>

Focus group sessions

It has been suggested that focus group size should be dictated by age (Gibson, 2007), and in youths aged over 10 years groups of up to eight are possible (Horner, 2000). In the present study, there was a maximum of seven participants per group. Where possible, the groups were also split by sex, following the recommendations by Heary and Hennessy (2002). The sessions were led by the lead researcher, who also acted as the time keeper. In addition, another researcher took field notes, readdressed any points they felt needed more discussion, and provided a session summary. The focus groups took place during the participants' PE lessons in one of school staff meeting rooms. The use of schools as a focus group setting for students is viewed favourably in the literature, as participants are then "insiders", which

may therefore reduce the power imbalance between participants and researchers (Morgan et al., 2002; Hill, 2005). During the sessions, the lead researcher sat amongst the participants around a large circular table, which can help create a non-authoritarian climate (Gibson, 2007). The interview scripts were informed by relevant literature and key social marketing principles (Grier & Bryant, 2005) which have been successful in engaging underserved adolescents in physical activity previously (Bush et al., 2010). This approach suggests that an intervention should centre on the wants and needs of the priority population and that subsequent decisions made by the researcher should reflect these. It is also highlighted that in the trial development phase, care should be taken to identify and reduce potential barriers for the participants, and that the specific needs of various population segments should be taken into account. Accordingly, conversations in the current study began with a general discussion about physical activity, and then moved on to specific questions and dialogue relating to the proposed intervention. In the first instance, participants were asked broad questions including what physical activity meant to them, what they knew about physical activity and young people and what opportunities were there for them to be active. Participants were then asked for opinions on vigorous-/high-intensity physical activity, which marked the start of discussions about the proposed low-volume HIT intervention. Here, participants were questioned on what activities they would like the intervention to include, and who the sessions should be run by. They were also asked to discuss where the intervention should be held and when it should take place. Lastly, participants were questioned on potential barriers to participation in the intervention, and how it should be run to ensure that it was engaging and fun for everyone involved. Each group also created mind maps of their discussions and ideas which were retained for analysis. The sessions lasted ~30 minutes, after which participants were invited to help themselves to juice and biscuits which were provided by the researcher. All of the sessions were recorded using a digital recorder (Edirol R-09HR; Roland), and were transcribed verbatim by the lead researcher for further analysis.

Data analysis

The raw transcription data were analysed using thematic content analysis (Burnard, 1991) which involves identifying, analysing and reporting patterns within the data (Braun & Clarke, 2006). This creates a detailed and systematic recording of the themes and issues that are discussed; and allows the themes across groups to be linked together under a reasonably exhaustive system (Burnard, 1991). This type of analysis is particularly useful for informing intervention development (Braun & Clarke, 2006) and aids the generation of unanticipated

insights (Bélanger et al., 2011). Despite its widespread use however, there is no clear guidance on how thematic analysis should be executed (Attride-Stirling, 2001; Tuckett, 2005). In the current study therefore, the widely cited analysis framework by Burnard (1991) was used. Briefly, this involved reading the transcripts and mind maps and making notes on the general themes within them. After this, the transcripts were reread and a list of headings that described all of the content was made. This stage is known as “open coding” (Berg, 1989). Headings from the list were then grouped together under broader themes. Finally, each transcript was worked through and “coded” according to the list of categories and sub-headings.

Results

In total, eight focus groups (five with Year 9 pupils and three with Year 10) were conducted. Accordingly, the qualitative data consisted of the groups’ mind maps and eight transcripts that resulted in 178 pages of raw transcription data. The findings and emerging themes from the main intervention related discussions are summarised below, with illustrative quotes provided where appropriate. Findings from the first section of questions on general physical activity are not displayed, as these served as ice breaker questions and were not specific to the intervention.

Perceptions of vigorous-/high-intensity physical activity

When asked to define vigorous-/high-intensity physical activity, the participant replies centred on bodily responses and feelings, and examples of specific types of exercises. In the Year 9 discussions, at least one participant per group was unsure of what vigorous-/high-intensity activity meant. Generally, the participants viewed it as harder than normal exercise and something that would take place over a long period of time. Activities synonymous with high-intensity exercise included circuit training and prolonged running. Participants also described it as difficult, exhausting, and something that would use a lot of energy. One participant summarised it as:

“Anything where you have to put all your effort in, and you’re really tired after”.

(Female Year 10 student; Focus group 6)

Several female participants across the groups expressed concerns that high-intensity exercise would make them go red and sweaty. This was viewed negatively and highlighted as a

potential barrier for participation. Conversely, some participants spoke positively about the term, and felt that high-intensity exercise could teach them to try harder, work “beyond their limits” and get fitter.

Intervention activities

The question on which activities the intervention should include prompted the widest variety of responses within and across the groups. The most popular activity suggested by both the males and females was football, with several girls noting that they never got to play it in PE. Dance and gymnastics were frequently suggested by the females; however these were also cited as an activity that may put people off. This was viewed as a potential problem, as described below.

“If it (the intervention) had dance in it, some people wouldn’t do it, but on the other hand if it was all certain sports without dancing, some people wouldn’t do it.”

(Male Year 10 student; Focus group 8)

Ball games such as basketball, netball and volleyball were also popular, as were circuit and fitness training. Although running and sprinting were suggested, they provoked a mixture of positive and negative responses. Boxing was also highlighted frequently by the males as something that was popular but not available in school. This was also the case with swimming. Across the groups, it was apparent that the attitudes of the males and females differed. Generally, the females reported specific likes and dislikes, whereas the males reported a willingness to try out different activities, whether they liked them or not. Regardless of the exercise mode suggested, the strongest theme to emerge was the desire to have an element of choice in the interventions activities. This view was uniform across the groups, and is illustrated in two participants’ responses below.

“Do three options, so that you’ve got a range of activities. So that everybody has something they at least partly like”.

(Male Year 10 student; Focus group 7)

“Let people choose the sports they want. Like something new and interesting, or something that you don’t do like football and hockey. Yeah you could get given a list or something.”

(Female Year 9 student; Focus group 2)

Intervention timing

When asked when the intervention should be held, the participants responded with a variety of conflicting opinions. The idea of holding the sessions during PE lessons was popular across the groups. Here, participants explained that if the intervention took place on a school day that already included PE, they were more likely to remember their kit. The participants also suggested that sessions could be run during lessons other than PE; however they acknowledged that their teachers would probably not permit this. The majority of participants felt that another convenient time was straight after school; however some disagreed as they had prior commitments. Lunchtime sessions were also frequently discussed, but were generally viewed as inconvenient, as explained by one participant;

“I think more after school, cause people don’t really like spending their dinner times doing more stuff when they’re just having a break from all their lessons”.

(Female Year 10 student; Focus group 6).

Some felt that holding sessions at the weekends would be a good idea, particularly for those that did not have anything else on. Others voiced concerns over this however, citing transport issues or wanting to have a break. For example, one participant said;

“During a PE lesson (would be best), cause my parents work. I mean I could (do it at other times), but my dad wouldn’t be able to pick me up, and I’ve have to get someone else to pick me up”.

(Female Year 9 student; Focus group 4).

Intervention Setting

The participant’s views on where the intervention should take place did not vary greatly across the groups, with the majority saying it should be held in the school. Reasons for this related largely to convenience. Participants said that the school was close by for everyone, would require minimal effort to get to, and was somewhere that felt familiar. For example, one participant explained;

“If it’s done right after school (at the school), it’ll be really easy to get there, you don’t have to go anywhere, you really just have to go the changing room and get changed and then you’re there”.

(Male Year 10 student; Focus group 7)

Some participants suggested leisure centres and community halls as potential settings, as these would provide a change of scenery and could allow them to meet new people. Again

however the issue of transport was highlighted, as was the proximity of such venues to their homes.

Intervention leaders

When asked who they would like to lead the intervention sessions, the participants' responses largely focused around personality attributes and qualities, as opposed to specific people. Nonetheless, the majority said they would prefer someone from outside the school to lead the sessions, with some strongly opposed to the PE teachers delivering the intervention. In contrast, the male Year 10 students said they would prefer the PE teachers to lead the sessions, as they were familiar and knew the pupils' names and skill level. Generally, the participants wanted someone who was fun, young and would engage with them and the activities. They did not want someone who would embarrass them, or was too strict. This is shown in two of the participants' responses below.

"I like someone who could get involved with it as well. Someone who's not stood telling us what to do."

(Female Year 9 student; Focus group 2)

(I'd like) *"Someone that pushes you, and they're like, really really nice to you, and doesn't act clever"*.

(Male Year 9 student; Focus group 5).

Intervention feasibility and acceptability

Lastly, the participants were asked if there was anything they considered crucial to the success of the proposed intervention that had not already been considered. Again, the notion of choice and variety was reiterated as a key element to success. Several participants also stated that they would like the opportunity to add their input to the intervention activities through, for example, making up their own dance routine. Opinions were split over whether the sessions should be mixed or separated by sex. Generally, the boys did not mind participating with the girls. Conversely, some of the girls said that they would prefer gender specific activities, and would not take part in activities they perceived as male-oriented. The participants felt that this could be overcome however, if they were allowed a choice in what they were doing. For example, one participant reasoned.

(If) *“Everyone’s said they’d like to do boxing, we could do that together. But, if the boys wanted to do something like tennis, hockey, stuff like that and the girls don’t want to, they want to do dance or something. They could go do that, and the boys go do what they want”*.

(Male Year 9 student: Focus group 1).

Lastly, when asked about competing interests, such as other school-based exercise projects and programmes, there were complaints across the groups about the lack of activities available for students in Year 9 and above. Generally, it seemed that school and teacher led sports clubs and activities predominantly targeted Year 7 and 8 pupils, and that there were fewer opportunities for females than males.

Discussion

The first aim of this study was to explore the views of Year 9 and Year 10 secondary school students on vigorous-/high-intensity physical activity and specific aspects of a proposed school-based low-volume HIT intervention. This builds on earlier findings which have largely focused on young peoples’ perceptions towards physical activity in general, rather than specific exercise intensities (e.g. Bélanger et al., 2011). Given the heightened interest of HIT in the scientific literature and the media over recent years, providing insight into the publics’ perception of this training form using an established qualitative method is timely. Earlier physical activity studies that have used qualitative methods to tailor intervention development have often failed to clearly demonstrate how their findings actually shaped their subsequent exercise programme. Indeed, whilst questions around barriers to participation and enjoyment are commonplace on interview scripts (e.g. MacIntosh et al., 2011), these are often generalised to all physical activity forms and not discussed in the context of the intervention itself. Contrastingly in the current study, participants were questioned on how a low-volume HIT intervention could be implemented within their school setting. This ensured that their responses related specifically to the proposed trial, and not physical activity and promotion/ exercise programmes in general. The second aim of this study was to demonstrate how the focus group data informed the design and implementation of a novel low-volume HIT intervention for adolescent school pupils. Such procedures are often under reported, therefore documenting these may help guide other academic groups and practitioners during the development phase of their interventions (Young et al., 2006).

The first key discussion in the focus groups centred on the participants' definition and understanding of the term vigorous-/high-intensity physical activity. Whilst approximately one participant per group was unsure of what this meant, the phrase was generally viewed negatively. Indeed, it is was often associated with pain, discomfort and sweating; all of which may be barriers to physical activity participation. This was potentially problematic, as the entire programme of work had been named the VIEWS study (Vigorous Intensity Exercise Within Schools) by the lead researcher. Furthermore, the high-intensity nature of the exercise intervention was a novel and vital component to the overall work. Due to the emergence of these negative associations however, it was imperative that the intervention name was altered at this early development phase. Previous work has consistently identified enjoyment as a motivator for physical activity participation (MacIntosh et al., 2011; Enright & O'Sullivan, 2010), with girls in particular preferring fun-filled, non-competitive activities such as dance and aerobics (Crocker, Ekelund & Kowalski, 2000; Motl et al., 2001; Young et al., 2006). With this in mind, the programme was renamed Project FFAB (Fun Fast Activity Blasts). This was chosen to place greater emphasis on the enjoyment element of the activities, and to capture the brevity of the exercises that would be performed.

When participants were questioned on which activities the low-volume HIT intervention should include, the strongest emerging theme was that they should have an element of choice in the exercises they performed. This opinion was uniform across the groups and may reflect the participants' desire to make decisions by themselves, rather than always being told what to do by their teachers or intervention leaders. This shift towards independent decision making during adolescence was described earlier (Gibbons & Naylor, 2007) and was also evident in a large-scale participatory action research project in Ireland (Enright & O'Sullivan, 2010). This 3-year study aimed to identify and transform barriers associated with PE engagement and physical activity participation in adolescent girls by altering the school PE curriculum. Here, participants were highly critical of the hierarchical and institutional power they felt their teachers embodied. When these pupils then discussed altering their PE curriculum, accountability for their own actions and decisions frequently emerged as a theme. From this, the authors suggested that this negotiation process and the associated feelings of choice provided the participants with autonomy, which allowed them to fully engage with decisions relating to the changed curriculum. With this, and data from the current study in mind, participants in the main trial of Project FFAB will be provided with a menu of activities to choose from. It is hoped that this increased autonomy could heighten the participants' ownership of the study, which in turn may have a positive impact

on session adherence and compliance. This exercise menu will include football, dance and non-contact boxing drills. Football was chosen due to its popularity amongst the male and the female participants and because it was cited as an activity that girls did not often get to do in normal PE lessons. Dance was also included owing to its popularity amongst females in both the current study and previous work (e.g. Young et al., 2006; Boddy et al., 2010). Boxing was chosen as the final activity as it was frequently discussed in the focus groups and the participants disclosed that such an activity was unavailable within the school setting. By incorporating it therefore, this may aid recruitment as potential participants may consider it a novel activity that they may not have tried before. Additionally, the capability of boxing drills for engaging adolescent females has already been demonstrated in the study by Enright & O’Sullivan (2010). Here, after completing a taster session, participants regarded it as something they wanted their PE lessons to include because of its individual and non-competitive nature. The three activities were also chosen due to the ease in which exercise drills associated with them could be manipulated and modified to elicit a high-intensity training stimulus. This may not have been possible for other popular activities such as gymnastics, which is generally performed at lower intensities, or volleyball where a minimum skill level is required. Furthermore, the chosen activities could also be performed in a variety of settings without much need for specialised equipment or facilities.

With regards to the intervention timing, there was not a clear consensus on when the low-volume HIT sessions should take place, although the idea of holding them predominately during PE lessons was frequently discussed. This is in agreement with previous work, where PE has been described as the ideal setting for implementing exercise interventions (Buchan et al., 2012). In line with previous low-volume HIT studies (e.g. Burgomaster et al., 2005; Burgomaster et al., 2008; Buchan et al., 2011a), it had been projected that the proposed intervention would take place three times per week. Due to school timetabling restrictions, it may therefore be unfeasible for low-volume HIT sessions to take place exclusively during PE lessons. Indeed, at the school participating in the current study, PE was only scheduled for one 2-hour lesson a week. This is not uncommon, and therefore necessitated that additional time slots outside of school hours were also discussed. The majority of the participants felt that all of the sessions should take place within the school premises, as it was familiar and easy to get to. Although some participants did suggest other venues such as local community halls, this was met with a number of concerns relating to transport and accessibility. This was slightly surprising, given that the NICE guidelines for promoting physical activity in children and young people recommend a “school plus community

approach” (NICE, 2009), where exercise sessions take place in both the school and the participants’ local areas. Notwithstanding these recommendations, this inconsistency highlights that a “one size fits all” physical activity model for schools does not exist, and that the needs of potential participants must be considered. Accordingly, it was decided that two of the three low-volume HIT sessions would take place during the PE lesson, either as two single sessions on separate days, or as one double session with a 15-minute break in between. This flexible structure would therefore enable the main trial to adapt to the potentially complex demands of the schools in the intervention arm, without compromising its fidelity. The third session would take place either straight after school or at lunchtimes, with this decision made by the trial participants and PE teachers.

In accordance with the focus group data, the main intervention trial will be led by the head researcher and observed by one of the school PE teachers. This would therefore ensure that the participants were able to engage with someone new, whilst still being overseen by someone familiar. As requests for the intervention leader to get involved with the activities were continually reinforced in the focus groups, an external teacher would be sought for dance related activities, as this was outside the expertise of the lead researcher. Agreement on whether the sessions should be split by sex could not be reached. This factor could however be largely determined by individual school’s circumstances during the main trial, therefore was not a concern at this stage. Throughout the discussions, there were complaints surrounding the lack of exercise opportunities available for students in Year 9 or above. This further warrants targeting this age group for the main trial. After discussions with both the participants and the PE teachers however, it was decided that the main intervention would involve Year 9 students only. This was due to concerns relating to unwanted timetable disruptions in the lead up to the Year 10 pupils’ GCSE exams. To summarise therefore, it is proposed that Project FFAB will encompass low-volume HIT sessions that will take place three times per week; twice during a PE lesson and once after school or at lunchtimes. The sessions, led by the lead researcher where appropriate, would be available to Year 9 students (aged ~14 years) and would involve football, dance and boxing drills that were capable of eliciting a high-intensity training stimulus (~90% of an individual’s maximum heart rate). Factors such as when the third session took place, whether the sessions were split by sex, and whether any additional activities were added to the exercise menu would be determined at the individual school level.

Limitations

Although this study has provided important insights into specific ways in which a novel school-based low-volume HIT intervention could be developed, it is not without limitations. The sample was drawn from one school in the Tees Valley region; therefore caution should be taken when generalising these findings to broader adolescent communities. Additionally, as the specialism of the school was sport, the participants' feelings towards the proposed exercise intervention and physical activity in general may be positively skewed. It should also be noted that the participants in this study would be unlikely to take part in the main intervention, as they will have moved into the next school year. They are however representative of population that will take part in the trial, therefore the appeal and appropriateness of the intervention should not be questioned. Although informal discussions about the main programme frequently occurred between the lead researcher and the school PE teachers, these were not documented using established methods which may have introduced bias. It would therefore have been inappropriate to shape the intervention predominantly around this anecdotal dialogue, despite the useful information it contained. With this in mind, future studies on developing school-based interventions should consider including focus group sessions for the PE teachers, and where appropriate the pupils' parents/ guardians. The latter was intended for the current study; however, due to a lack of interest, this did not occur. Lastly, given the surge in public and media interest in low-volume HIT, the participants' perceptions of this training form could have been explored in more depth. The aims of this study did however centre on developing a novel and engaging school-based low-volume HIT intervention, rather than participants' opinions of low-volume HIT *per se*. Consequently, a detailed exploration of individuals' attitudes, perceptions and experiences of low-volume HIT was beyond the scope of this study. Given the importance of enjoyment as a facilitator for exercise, a qualitative examination of the perceived facilitators and barriers to low-volume HIT should be considered in the near future.

Conclusions

Despite the documented limitations, this study is the first to provide detailed adolescent insights on how a school-based low-volume HIT intervention could be implemented. It has also reported how these data were used to tailor the proposed trial; with thorough consideration given to what the programme should include, where it should take place and when, and who should lead it. Additionally, by involving adolescents at the early stage of the development process, this may increase the likelihood of the subsequent intervention

being accepted and enjoyed by their counterparts. Accordingly, it is now necessary to pilot these ideas in a representative adolescent sample, which will allow any “fine-tuning” of the intervention to occur prior to a larger exploratory study.

Chapter 5: Heart rate and perceived exertion responses to three types of low-volume high-intensity exercise in adolescent females: Pilot data from Project FFAB (Study 2)

Introduction

Low-volume HIT studies in adults and young people have tended to utilise exercise models based on cycle ergometry and running (e.g. Burgomaster et al., 2008; Buchan et al., 2011a; Barnes et al., 2013). In Study 1 of Project FFAB however, participants indicated a preference for exercise challenges relating to boxing, dance and football. This suggests that a low-volume HIT programme based exclusively on one activity may not be engaging for an adolescent population. Previous school-based interventions aimed at improving cardiovascular risk factors in young people have utilised multi-activity programmes (e.g. circuits, dance and games) (Henaghan et al., 2008; McWhannell et al., 2008), however these have generally been performed at a moderate-to-vigorous intensities (~70% of maximum heart rate), rather than high-intensity (~90% maximum heart rate). As such, whilst a school-based trial centred on pupil chosen activities may increase levels of adherence, enjoyment and study ownership; it is unclear whether drills based on boxing, dance and football can elicit a high-intensity stimulus similar to that observed in earlier low-volume HIT studies (e.g. ~90% maximum heart rate; Little et al., 2011). Furthermore, as a multi-activity low-volume HIT intervention has not yet been conducted, the feasibility and acceptability of such a novel programme is unknown.

There is a small amount of data indicating that basic dance and aerobic moves performed as part of low-volume HIT are capable of producing a high-intensity workload in young females (aged ~11 years) (Boddy et al., 2010). Conversely, there are no low-volume HIT trials that have incorporated football or boxing. There is however field data to suggest that drills based on these activities may be capable of producing an intense workload similar to that observed in previous low-volume HIT work. In these field-based studies, physiological stress is often assessed via heart rate monitoring, which is a popular, simple and reliable measure of exercise intensity (Achten & Jeukendrup, 2003). These data are then often expressed as a percentage of maximal heart rate. In football, the heart rate responses of players and referees performing short-duration activity specific training has been extensively analysed (e.g. Bangsbo, 1994; Hoff et al., 2002; Weston et al., 2004; Hill-Haas et al., 2011). A variety of training structures have been assessed, including movement specific sessions (Weston et al., 2004) and small-sided games (Hoff et al., 2002). In the study by Weston et

al. (2004), the effectiveness of football pitch and running track based sessions at eliciting high-intensity work (defined as $\geq 85\%$ of maximum heart rate) were examined. Here, 18 football referees undertook 16-months of intermittent high-intensity training which consisted of a combination of pitch and running track based sessions. As it was not envisaged that the activities performed during the main trial of Project FFAB would take place on a running track, only the pitch sessions devised by Weston et al. (2004) are described here. Participants completed three running circuits, clockwise around a diagonal course. This was performed in pairs, with partners exchanging roles once each set of runs were finished. The sequence (3 sets, 2 sets, 1 set, 1 set, 2 sets and 3 sets) was repeated until each pair had completed twelve 150 m runs (~ 1800 m in total). After 2 to 3 minutes recovery, the runs were repeated in a counter clockwise direction. Throughout the circuits, participants' heart rate data were collected at 5-s intervals using Polar S610 monitors (Polar Electro, Kempele, Finland). The mean session heart rate reported was $86.4 \pm 2.9\%$ of maximum (mean \pm SD), which indicates that this form of activity-specific training was successful at imposing a load deemed as high-intensity by the authors. Accordingly, similar drills could be appropriate for use in the current study. The inclusion of small-sided football games (played on a reduced pitch area and involving smaller number of players) may also be warranted, based on reports that these can elicit heart rate responses indicative of high-intensity work in elite (Hoff et al., 2002) and youth players (Sampaio et al., 2007). Furthermore, small-sided games are popular training drills for players of all ages and levels (Hill-Haas et al., 2011). These could be more appealing than simple running training, as the presence of the ball can allow improvements in technical and tactical skills, and increase player motivation (Flanagan & Merrick, 2002). In Norwegian players, 4-minute group play (5 versus 5) was shown to elicit heart rate responses of 91.3% of maximum (Hoff et al., 2002). Slightly lower values were reported in youth players participating in 2 versus 2 games (percentage of maximum heart rate = $81.2 \pm 3.5\%$; mean \pm SD) (Sampaio et al., 2007), however the duration of these plays were not clear. Indeed, not all small-sided game formats provide sufficient internal stress (Hill-Haas et al., 2011) which may be a concern in the current study, given the pre-specified high-intensity nature. Furthermore, the duration of the exercise bouts in all of these studies (~ 4 minutes) is markedly longer than the repetition time in the recent low-volume HIT work (~ 30 to 60 s). The ability of such activities to elicit a high-intensity stimulus in non-football specialists, over only an eighth to a quarter of the previous time frame is therefore unknown.

Similar uncertainties exist with regards to the use of boxing as a form of low-volume HIT. Indeed, whilst heart rate training data is available for adult fitness and amateur boxers, data on adolescents with no boxing experience is lacking. Nonetheless, the findings from the adult studies are intriguing, and warrant further exploration. In the trial by Kravitz et al. (2003), fitness boxers ($n = 18$; 6 women; aged 22.0 ± 2.8 years) completed six randomised trials of 2-minutes of contact punching against a commercial device. Each trial was performed at a different tempo (60, 72, 84, 96, 108 and $120 \text{ beats}\cdot\text{min}^{-1}$) followed by 5-minutes recovery. The boxing movements included a self-selected combination of alternating right and left jabs, hooks and straight punches. Here, participants' responses ranging from 167.4 to $182.2 \text{ beats}\cdot\text{min}^{-1}$ (~85 to 93% of maximum heart rate) and higher boxing speeds ($>96 \text{ beats}\cdot\text{min}^{-1}$) were significantly associated with an increased heart rate response. Slightly lower values were found in the study by Arseneau, Mekary and Léger (2011). Here, nine male amateur boxers (age 22.0 ± 3.5 years) performed three 2-minute rounds with 1-minute standing rest in between, which elicited a mean percentage of maximum heart rate of $83.6 \pm 6.3\%$. As such, although the applicability of these studies may be limited to those experienced in boxing, the exercise mode does appear to hold promise as a high-intensity training tool. Additionally, few low-volume HIT trials have assessed participants' ratings of perceived exertion (RPE) during sessions. This is surprising, given that this widely used measurement tool is a simple and accurate means of monitoring exercise intensity (Borg, 1982). Furthermore, adolescents' perceptions of effort during low-volume HIT have not yet been examined. Such information could indicate how tiring individuals find high-intensity exercise bouts; which may influence session adherence and compliance in the main trial. Lastly, as a multi-activity low-volume HIT programme has not been conducted before, it is imperative to trial the various exercise sessions in the setting that the main trial will take place. This will allow feedback to be gained from those within the school and highlight any unforeseen practical issues. Accordingly, the first aim of this pilot study was to assess the heart rate and perceived exertion responses of female Year 9 students (aged ~14 years) to three prototype prescriptions of low-volume HIT, based on boxing, dance and football drills. The second aim was to trial the main intervention under "real-life" school conditions to gain insight into whether it would be acceptable and appealing to Year 9 students.

Methods

Participants

On receiving ethics approval from the Teesside University School of Health & Social Care Research Governance and Ethics Committee in November 2010 (study number 263/10), one secondary school in the Stockton-on-Tees area (characteristics shown in Table 9) was invited to take part in the study via email correspondence. A face-to-face meeting was then arranged; here the head teacher and the lead PE teacher received information on the study and were each given a detailed information sheet. After gaining full informed consent from the head teacher, 28 female Year 9 students (aged 13 to 14 years) from one PE class were invited to take part in the study through a presentation in their PE lesson. All pupils received study information packs, and asked to return parental consent, participant assent and exercise and physical activity readiness assessment forms if they were interested in taking part. Exclusion criteria were symptoms of or known presence of heart disease or major atherosclerotic cardiovascular disease, condition or injury or co-morbidity affecting their ability to undertake exercise, diabetes mellitus, early family history of sudden cardiac death, and pregnancy or likelihood of pregnancy. Participants reporting that they were asthmatic were allowed to participate with medical clearance and instructed to carry their bronchodilator medication and use it when required. Every pupil that provided written and parental consent was free from the exclusion criteria; therefore the total number of study participants was 24 (aged 13.6 ± 0.5 years; mean \pm SD). All of these participants went on to complete the study, and received a thank you pack containing a certificate, a tub of hand cream and a Sportsister magazine after the final exercise session.

Table 9. School level descriptive characteristics

Number of pupils	Sex on entry	Age range (y)	IMD rank ^a (1= most deprived)	Free school meals eligibility ^b (%)	School specialism	PE (hours per week)
1459	Mixed	11-18	29437	5.9	Performing arts; Science & Mathematics	2

IMD – Index of Multiple Deprivation

y = years

^aSource: <http://dclgexamples.mywebcommunity.org/imd/imd-explorer-v0.html>

^bSource: <http://www.education.gov.uk/cgi-bin/schools/performance/school.pl?urn=111724>

Study design and exercise session structure

The study ran over four weeks commencing in January 2011, and took place at the same time every Monday during the one hour PE lesson. The exercise mode changed on a weekly basis; participants engaged in boxing drills during the first session, dance in the second and football in the third. For the fourth session (referred to herein as the combination session)

participants took part in their favourite of the three activities, thus during this there were three sessions running concurrently. The purpose of this was to assess the feasibility of running different activities in a single session. The boxing, dance and combination sessions were held in the school sports hall, and the football session outside on the school playing fields. Prior the start of each session, all participants were fitted with a heart rate monitor, which they wore for the remainder of the session. Detailed information on this can be found in a later section (*Outcome measures; Heart rate monitoring*). All sessions began with a 5-minute warm up which contained pulse raising exercises relevant to the session activity. This was followed by four 45-s maximal effort exercise blasts, with 60-s rest in between each bout. During each bout, participants were verbally encouraged to work at an “all out” intensity throughout, and aim to reach as high a heart rate as possible. The volume and intensity of the bouts were similar to those described in earlier low-volume HIT studies (Burgomaster et al., 2005; Boddy et al., 2010; Little et al., 2011). In addition, the exercise blasts were simple and did not require any specific skillsets or past experience. This was to ensure that the intensity of the blasts was not compromised, as skill is synonymous with the minimum outlay of time and energy (Knapp, 1963). It could therefore be assumed that the less skilful or experienced the participant, the slower their movements. This could be particularly problematic if the drills were complex, as it could decrease the intensity of the bout. Attempts to counteract this were made in a number of ways. During the boxing drills, participants repeated only one move (either a jab, hook, straight punch or upper cut) per exercise blast. Additionally, as higher heart rates were observed during the faster punching tempos in the study by Kravitz et al. (2003), participants were encouraged to punch as hard and as fast as possible through each 45-s blast. In the dance session, in line with Boddy et al. (2010) only one dance move was performed for each 45-s blast. These were completed to popular chart music, and the dance moves devised by combining the dance teachers’ expertise with the study objectives. In the first football session the 2 versus 2 games were trialled as an exercise blast activity, however these were not included in the combination session. The first boxing session and both the football sessions were led by the lead researcher. The dance sessions were led by two dance teachers, with input from the lead researcher. As such, the first dance session used moves from Zumba®; whereas the second session, completed during the combination week, was based around modern and jazz dance. The second boxing session, also completed as part of the combination week, was devised and led by a separate Teesside University researcher. This involved an exercise video game which incorporated boxing moves. Further information on the content of the exercise blasts can be found in Table 10.

Table 10. Exercise blast drill examples

Activity	Example drills
Boxing	Ten jabs on the focus pads, followed by running to the end of the sports hall and back. Ten hooks on the focus pads, followed by five squat thrusts Fast upper cuts on the focus pads Ten jabs on the focus pads, followed by five star jumps
Dance	<i>Zumba</i> Full star jumps Tuck jumps Stationary high knees runs Jumping with one hand in the air <i>Modern/ jazz</i> High leg kicks Fast side kicks Fast side to side twists
Football	Ten toe touches, followed by running to a cone and back. Running back and forth to a partner to receive and return a football pass Jumping up to head the ball ten times, followed by five burpees Sprinting around cones in the sports hall

Outcome measures

Heart rate monitoring

Equipment validation

Accurate heart rate monitoring is essential for determining and evaluating exercise intensity (Karvonen & Vuorimaa, 1988). The use of an electrocardiogram (ECG) is the gold standard for measuring heart rate (Engström et al., 2012), however this method is too costly and complex to use in the field (Laukkanen & Virtanen, 1998). A more common method is the detection of heart rate via a chest belt, which is then recorded by a unit worn on the wrist. In the current study, the participants' heart rates were assessed at 5-second intervals throughout the exercise blast sessions using Polar RS400 monitors and the Polar Team₂ Pro System (both Polar Electro, Kempele, Finland). When using the Polar RS400s, heart rate was detected and stored through the use of a chest belt and wrist watch, whereas the Team₂ Pro System worked independently of a watch and instead stored the heart rate data on the receiver belt. The Team₂ Pro System also enables heart rate to be monitored in real-time, rather than being limited to retrospective analysis (Alexandre et al., 2012). The Polar RS400 detects heart rate in the range of 15 to 240 beats·min⁻¹, and in a recent validation study (Engström et al., 2012) was shown to have good criterion-related validity and test-retest repeatability versus ECG over a series of cycling tests. Here, 10 participants (seven females) aged between 19 and 34 years performed cycle ergometer tests where they completed 15-mins of exercise at three different loads (50W, 100W and 150W; each for 5-minutes). Heart rate was measured via ECG and the Polar RS400 and after at least one hour of rest the test was repeated. Statistically significant linear relationships between heart rate measurements

derived from the ECG and the Polar RS400 were found at the three different power levels for each of the repeated tests, with correlation coefficients ranging from 0.97 to 1.00. The authors then assessed the repeatability of the recorded heart rate by plotting the differences of the mean heart rate recorded from the Polar RS400 and the ECG respectively, based on the recommendations of Bland and Altman (1999). The repeatability coefficients, defined as 2 standard deviations (2SD) were then calculated. In the repeated test, the mean difference in heart rate between the test 2 and test 1 $\pm 2SD$ was 3.2 ± 11.9 beats \cdot min $^{-1}$ for the ECG, and 2.6 ± 14.2 beats \cdot min $^{-1}$ for the Polar RS400, but these differences were not significant. From this, the authors concluded that the Polar RS400 was suitable for recording heart rate during physical activity and exercise training. Whilst similar validation data is not currently available for the Team₂ Pro System, the equipment is widely used for collecting heart rate data in team sports such as football (e.g. Kelly & Drust, 2009; McMillan et al., 2005) therefore was considered an appropriate data collection method in the current study.

Prediction of maximum heart rate and heart rate zones

The participants' maximum heart rate was predicted using the equation developed by Tanaka et al. (2001); $208 - 0.7 \times (\text{age; years})$. Generally, heart rate prediction equations are derived from studies involving adults and therefore may not be applicable to paediatric populations. The Tanaka equation might be more suitable for use in young people, as the age-related decline in the equation is comparable to what may occur in children and adolescents (Washington et al., 1994). Compared to the $220 - \text{age}$ prediction equation (Fox et al., 1971), the Tanaka equation has also shown to better predict mean maximum heart rate in 7 to 17 year olds during a graded treadmill exercise test (Mahon et al., 2010). Here, absolute differences between measured and predicted maximum heart rate were 8 ± 5 beats \cdot min $^{-1}$ and 10 ± 8 beats \cdot min $^{-1}$ (mean \pm SD) for the Tanaka and Fox equations respectively, though individual variations were apparent. In the current study, the mean age of participants was 13.6 years. For use in the Tanaka equation, this was rounded down to 13; therefore the age-predicted maximum heart rate for the study sample was ~ 199 beats \cdot min $^{-1}$. This value is similar to that observed by Voss and Sandercock (2009) in 208 adolescents (aged 11 to 16 years) following the 20 m multistage fitness test. Here, the average peak rate was 196 beats \cdot min $^{-1}$ (range 194 to 198 beats \cdot min $^{-1}$). Consistent with previous literature (e.g. Little et al., 2011; Boddy et al., 2010) $\geq 90\%$ of the age-predicted maximum heart rate was used as the criterion for low-volume HIT, which equated to ~ 179 beats \cdot min $^{-1}$. In line with Boddy et al., (2010), heart rate was used to confirm the intensity of the exercise in the current study, rather than prescribe it. As such, activities that elicited heart rate values of ≥ 179 beats \cdot min $^{-1}$

¹ were classed as high-intensity. Given the exploratory nature of the trial however, the participants were not made aware of this value, and were simply asked to work maximally.

Heart rate data processing and reduction

Prior to data collection, the lead researcher received training on the extraction and analysis of heart rate data. This was provided by a Teesside University researcher who has extensive experience and expertise in the use of heart rate data to monitor the training loads of professional soccer referees (Weston et al., 2004; Weston et al., 2006). After each exercise blast session, the heart rate files from participants using the Polar RS400 monitors were downloaded onto a laptop computer using the Polar ProTrainer software (Polar Electro, Kempele, Finland). Participants' data from the Team2 Pro system was observed on a laptop screen in real-time during the sessions, and then downloaded using the Polar ProTrainer software. All of the raw heart rate values and traces were retained and visually inspected after each session. If during this inspection values appeared to be recorded outside of the normal physiological range ($> 220 \text{ beats} \cdot \text{min}^{-1}$ or $< 40 \text{ beats} \cdot \text{min}^{-1}$), data were corrected using the error correction function within the Polar ProTrainer software. Following this procedure, if the data still displayed uncharacteristic spikes or plateaux, the values for the associated exercise bout were omitted from the analysis due to its lack of validity (Weston et al., 2004).

Perceived exertion

Protocol validation

Perception of effort, also known as perceived exertion is widely used to monitor and prescribe exercise intensity (Borg, 1982; Noble & Robertson, 1996). In this study, the participants' perception of effort was assessed using the Children's OMNI Scale of Perceived Exertion (Children's OMNI-walk/run Scale) (Utter et al., 2002). In adult populations, the Borg 6 to 20 rating of perceived exertion (RPE) scale (Borg, 1982) is often used; however the applicability of this in youth populations is unclear (Lamb & Eston, 1997). Indeed, such adult formatted scales can pose methodological and semantic limitations when applied to young people (Robertson & Noble, 1997). These include observations that some youths, particularly those aged under 11 years, cannot consistently assign numbers to words or phrases that describe exercise-related feelings (Williams et al., 1994). Furthermore, younger children may struggle to interpret certain verbal scale descriptors that are not semantically consistent with their vocabulary (Robertson et al., 2000). In response to these concerns, the Children's OMNI scale was devised by Robertson et al. (2000), which incorporates a developmentally indexed category format containing both pictorial and verbal

descriptors along a numerical response range of 0 to 10. As such, the scale displays a series of images of a child riding a bicycle, which were used to ensure that the “exertional meaning” of each pictorial descriptor was consistent with its verbal descriptor (Robertson et al., 2000). When correlated against VO_2 and heart rate, the scale demonstrated acceptable validity over a range of cycle ergometer exercise intensities in 80 African American and white children aged 8 to 12 years ($r = 0.85$ to 0.94) (Roberston et al., 2000). Nonetheless, the generalizability of the scale to other exercise modes and/or young people of different ages could be limited. In an attempt to address this, a modified version of the Children’s OMNI scale was validated using a graded treadmill protocol, and termed the Children’s OMNI-walk/run scale (Utter et al., 2002). In this modification, the pictorial descriptors display a child at various levels of exertion walking/running up an incline, as shown in Figure 3. This version was evaluated using 63 children (aged 6 to 13 years) during a graded exercise test on a treadmill. The tool was assessed against heart rate, VO_2 and percentage of maximal oxygen uptake ($\% \text{VO}_{2\text{max}}$). Here the strongest correlations were found between OMNI scale responses and $\% \text{VO}_{2\text{max}}$ ($r = 0.41$ to 0.60), and heart rate ($r = 0.26$ to 0.52). These correlations were weaker than those reported for the OMNI cycle scale, which the authors suggested could be due to differences in exercise mode, walk/run transition, exercise stage-time, and/or maturation stage. Despite this, they concluded that the walk/run scale is a valid tool for measuring perceived exertion in young people, which may have greater application than the cycle pictorial scale in exercise interventions where activities involving walking and running are core elements.

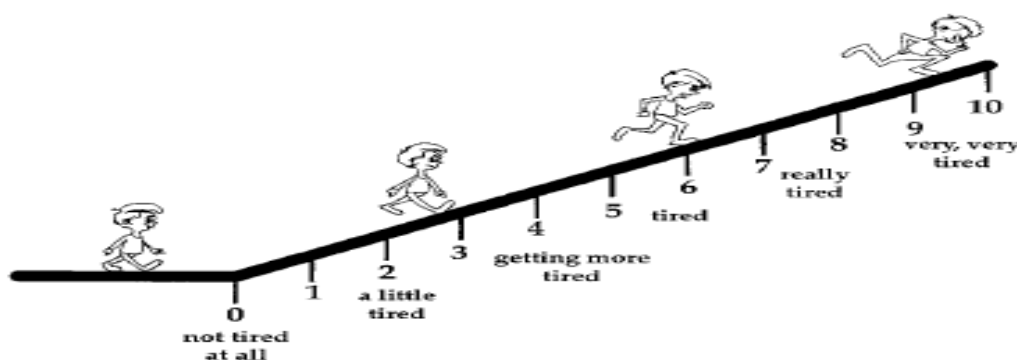


Figure 3. Children's OMNI-walk/run scale of perceived exertion. Reprinted from Utter et al. (2002) *Measurement protocol*

At the end of each session, participants were asked to record how tired their body had felt during the activities by circling a number on their copy of the Children’s OMNI-walk/run Scale. When assessing perceived exertion after interval-style training, it has been suggested that ratings should be secured 30-minutes after exercise, so that particularly difficult or easy segments towards the end of the session do not dominate the participant’s rating (Foster et

al., 2001). This was adhered to as closely as possible in the current study; however, due to external time pressures within the school, this was not always permitted.

Participant feedback forms

Measurement protocol

To gain subjective feedback of the participants' opinions towards the exercise blasts, each received a feedback sheet to complete at the end of every session. Here participants were asked to indicate whether they liked, neither liked or disliked, or disliked the session, by circling their chosen response. They were also asked to provide written feedback on what they liked and did not like about the sessions, what they would keep the same and what they would change.

Data analysis

Individual heart rate files were examined to obtain the peak heart rate value for each exercise blast within a session. This was determined as the highest 5-s value observed during each exercise bout. Participants' peak heart rates for each exercise bout across the sessions (expressed in absolute terms and as a percentage of age-predicted maximum heart rate) were then inputted into an Excel spreadsheet. The mean peak heart rate response for every exercise blast across the four weeks was then calculated by averaging the corresponding peak heart rate values for each activity. These values were recorded for each bout during the intervention on a week-to-week basis in absolute terms ($\text{beats}\cdot\text{min}^{-1}$) and as percentage of age-predicted maximum heart rate. The participant feedback forms were analysed using frequency statistics and thematic analysis (Burnard, 1991). Here, each individual response was coded and then grouped into categories to summarise the content of the data. This approach provided a systematic framework for identifying the major and minor themes among the responses. This was undertaken by the lead researcher; and the themes then confirmed by another researcher.

Results

Heart rate and perceived exertion responses

Across the four exercise blast sessions, 78 of a possible 96 individual heart rate files were collected and analysed. Of these, 20 were collected during the boxing session, 24 in the dance, 8 in the football, and 24 in the combination session. Missing data files were due to participant absence, invalid data or equipment failure. During the combination session in

Week 4, four participants chose boxing as their favourite activity, with 13 and 7 choosing dance and football, respectively. The mean peak heart rate responses, shown as a percentage of age-predicted maximum heart rate, for each exercise blast across the three activities are displayed in Figures 4 and 5, respectively. These show the mean peak heart rate for each 45-s exercise bout across the three different activity sessions in Weeks 1 to 3 (Figure 4), and the mean peak heart rate for each exercise blast performed during the combination session in Week 4 (Figure 5). From Figure 4, it can be seen that the mean peak heart rate for every exercise blast performed during weeks 1 to 3 was ~90% of age-predicted maximum. In absolute terms, the overall session mean \pm SD peak heart rate values were 189 ± 15 beats \cdot min $^{-1}$ ($95 \pm 8\%$ of age-predicted maximum heart rate) for boxing, 192 ± 9 beats \cdot min $^{-1}$ ($96 \pm 5\%$ of maximum) for dance, and 188 ± 7 beats \cdot min $^{-1}$ ($91 \pm 4\%$ of maximum) for football, respectively. Figure 5 shows that during the combination session the mean peak heart rate responses were slightly lower during the boxing and dance sessions (~85% of maximum heart rate), whereas the mean peak heart rate responses during each football-based blast was ~95% of maximum heart rate. In this session, the overall mean peak heart rate for boxing was 174 ± 26 beats \cdot min $^{-1}$ ($84 \pm 15\%$ of age-predicted maximum heart rate), 169 ± 13 beats \cdot min $^{-1}$ ($82 \pm 6\%$ of maximum) for dance, and 193 ± 8 beats \cdot min $^{-1}$ ($94 \pm 4\%$ of maximum) for football. The mean overall perceived exertion scores for the exercise sessions completed during Weeks 1 to 3 were as follows: boxing 5.9 ± 1.4 (verbal descriptor “tired”); dance 6.6 ± 1.4 (verbal descriptor just above “tired”); and football 3.9 ± 1.7 (verbal descriptor “getting more tired”).

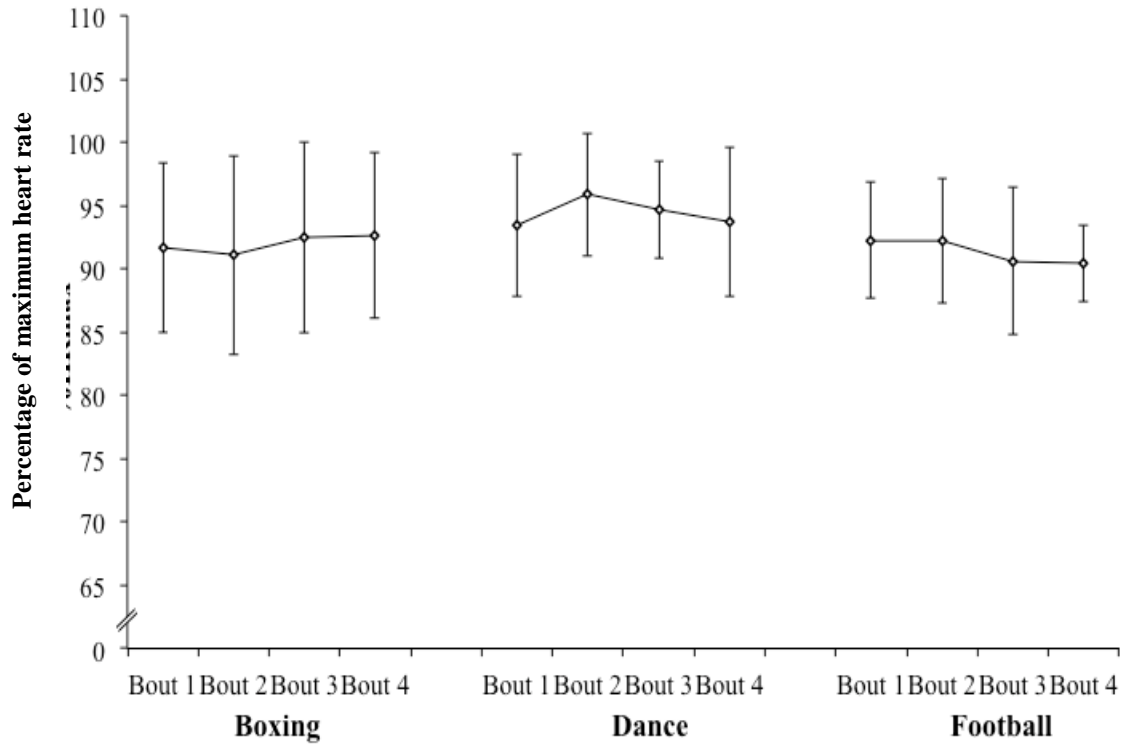


Figure 4. Mean peak heart rate responses to each exercise blast, across the three activity modes (Weeks 1 to 3). Values are mean \pm SD

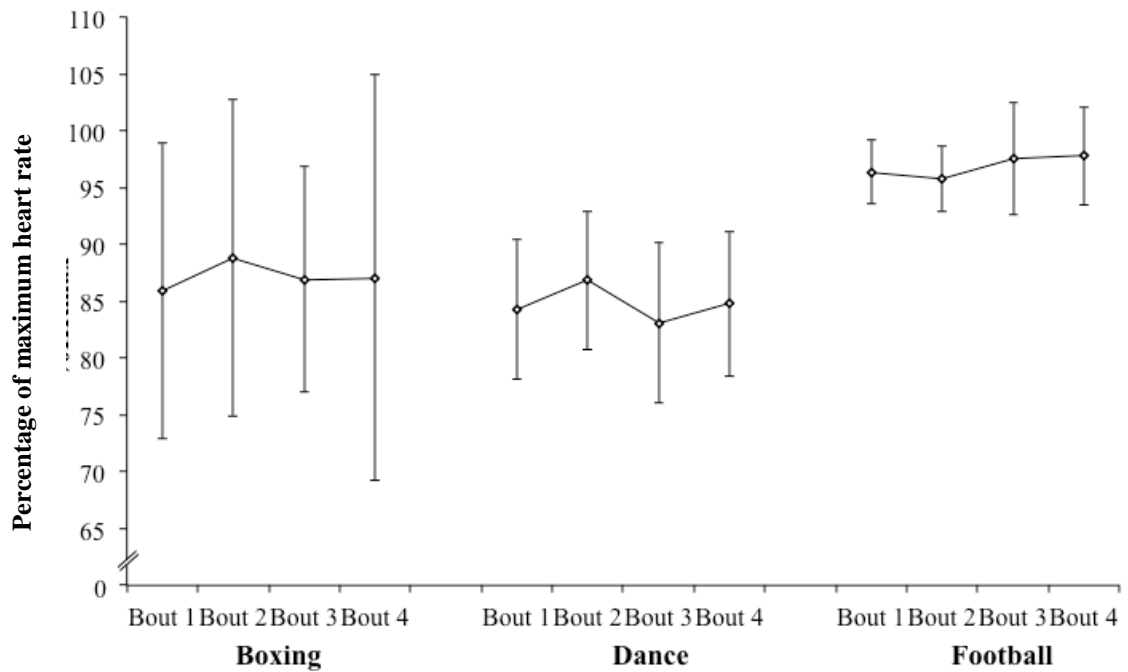


Figure 5. Mean peak heart rate responses to each exercise blast during the combination session. Values are mean \pm SD.

Subjective feedback

Across the trial, when asked “*What did you think about the session?*” $\geq 70\%$ of participants reported that they liked the exercise sessions; with dance cited as the most popular activity (Table 11). The emerging themes from the participants’ responses to each of the other feedback questions (*what did you like; what did you not like; what would you keep the same and what would you change*) are described below.

Table 11. Participants’ feedback on the exercise blast sessions

What did you think about the session?	Number of responses		
	(Number expressed as a % of the total sample [n=24])		
	Boxing	Dance	Football
Liked it	17 (71%)	18 (75%)	16 (71%)
Neither liked or disliked it	1 (4%)	3 (13%)	4 (17%)
Disliked it	0 (0%)	1 (4%)	0 (0%)
Left blank	2 (8%)	2 (8%)	2 (8%)
Absent from session	4 (17%)	0 (0%)	1 (4%)
Total	24 (100%)	24 (100%)	24 (100%)

Boxing

Twelve of the participants reported that there was nothing that they did not like about the boxing blasts, and that they would keep everything about the session the same. Issues were raised regarding the equipment and the timing of the bouts; two participants had difficulty getting the boxing gloves on, and four felt that there was not enough time to change over. Three participants reported disliking wearing the heart rate monitors as they kept slipping down. Nine liked that the session was fun, and something different from normal PE. The benefits of the exercise were also cited as a reason for enjoyment. One participant reported liking it because “*it got my heart pumping to get me fit*”, whilst another enjoyed “*seeing how my heart rate was after the session*”. Specific activities were also highlighted; three participants did not like the blast that involved squat thrusts, and cited it as something they would change. Generally, the variety of the exercises available was viewed very positively, and was something that should remain the same in future sessions.

Dance

Nine participants reported they would keep everything about the dance blasts session the same and did not dislike anything. Five however, did not like the amount of jumping, specifically the number of tuck jumps, and a further five did not like the blasts at all. Two of these five then reported that they would not change anything about the sessions, whereas

the others, and a further three participants, suggested a longer rest period. Six participants stated they would keep the warm up the same, and eight liked the dance moves and the music. Two however disliked the dancing style and suggested adding in more moves. Specific references were also made to the exercise intensity. One participant reported that she “*liked the dancing and how hard it was*”, and two others described the session as “*fun, tiring and energetic*”.

Football

Fourteen participants reported that they would keep everything about the football blasts the same, whereas three suggested changing the warm up section, and three recommended including more activities. Ten participants liked the 2 versus 2 games, though five thought that they were too short. Three participants like the session because they do not normally get to play football in PE. One participant said “*it was really fun, and is a new skill*”, and another “*liked how enjoyable it was*”. A further four enjoyed the fast running and scoring goals, whereas three participants did not like the blasts that involved burpees or heading the ball. Nine participants felt that there was nothing about the session that they did not enjoy, however three did not like that the session took place outside, and cited the cold weather as a negative aspect.

Discussion

The first aim of this pilot study was to assess the heart rate and perceived exertion responses of female Year 9 pupils to three prototype prescriptions of low-volume HIT based on boxing, dance and football drills. Previous field-based investigations have suggested that boxing and football drills may be capable of eliciting a high-intensity stimulus (e.g. Kravitz et al., 2003; Weston et al., 2004), however the duration of the activity bouts in these trials was typically longer than that performed during low-volume HIT (~30 to 60 s). Furthermore, these studies used adult participants with prior experience or expertise in the tested exercise mode. Contrastingly, participants in the current study were non-sport specialist adolescent females, of whom the physiological and psychological responses to low-volume HIT are largely unknown.

During the low-volume HIT sessions, participants performed four 45-s repetitions of “all out” exercise blasts based on boxing, dance or football, followed by 60-s rest. The criterion for high-intensity exercise was a mean peak heart rate of $\geq 90\%$ of age-predicted maximum; in line with earlier laboratory and field-based low-volume HIT trials (Boddy et al., 2010;

Little et al., 2011). The heart rate responses achieved during Weeks 1 to 3 indicate that the exercise blasts were indeed high-intensity, with mean peak heart rate values (expressed as a percentage of age-predicted maximum heart rate) of $95 \pm 8\%$, $96 \pm 5\%$ and $91 \pm 4\%$ for boxing, dance and football, respectively. These values are similar to those observed in the dance-based low-volume HIT study by Boddy et al., (2010), who reported mean peak heart rate of 94.2%, 93.7% and 96.8% of maximum, across Weeks 1 to 3 of their programme respectively. Boddy's study however fell short of providing evidence that high-intensity exercise was maintained for every activity bout throughout their intervention. Contrastingly in the current study, participants' mean peak heart rate reached ~90% of age-predicted maximum, on average, during every exercise blast across the trial (Figure 4).

Due to multiple problems with the Polar Team₂ system, heart rate data were only collected from only 8 of the 23 participants during the football session. Intensity inferences for this session should therefore be made with caution, since the data is based on only 35% of the sample. Nonetheless, the heart rate values from this session were not dissimilar to that observed during the football section of the combination session. Here, the mean peak heart rate for the seven participants that opted to perform football-based exercise blasts was $94 \pm 4\%$ of age-predicted maximum heart rate. In direct contrast, the mean peak heart rates from the boxing and dance sections of the combination week were markedly lower than the individual session data. For boxing, the mean peak heart rate (expressed as a percentage of age-predicted maximum) dropped by 11 percentage points. A similar decrease was observed for dance, where the mean peak heart rate response fell from 96% of age-predicted maximum, to 82%. Furthermore, in the second boxing session the standard deviation of the mean heart rate response increased from 8% to 15%, indicating a large amount of variability in the data. This was also evident on a bout-to-bout basis, as shown in Figure 5. Although this could be partly due to the low number of participants in the second boxing session ($n=4$), this inconsistency may also be explained by two other factors. During the first boxing session participants performed a combination of upper and lower body movements, such as punching a target then running to the end of the sports hall and back. In the second session however, participants were only required to move their arms in a straight punching movement in time to music on a boxing video game. Whilst the participants were wearing hand and waist devices fitted with resistance bands designed to increase the amount of effort needed to perform the punching movements, it was clear that such an activity was not capable of consistently providing a high-intensity stimulus in this population. As such, it was decided that this activity would not form part of the main trial. Additionally, it was

noted that during the second boxing and dance sessions, the instructors did not appear to fully engage with the participants and in particular a lack of verbal encouragement was noted. Since adhering to low-volume HIT can require high levels of participant motivation (Little et al., 2010; Gibala et al., 2012), it could be that individuals not used to performing such intense training may need external motivation in the form of encouragement or other sources. At present however, this observation is purely speculative with no empirical data to evidence this.

Across the exercise blast sessions, the mean perceived exertion responses ranged from 3.9 ± 1.7 for football, to 6.6 ± 1.4 for dance. The verbal descriptors for these were “getting more tired” (football) and just above “tired” (dance). This was somewhat surprising, given the intense nature of the activities that the participants performed. Nonetheless, similar patterns have been observed in other HIT studies utilising the modified 10×60 -s cycling protocol (Little et al., 2011), and a 6×3 -mins running model devised by Bartlett et al. (2011). In the former, the mean RPE score for six sessions of HIT was 6.4 ± 1.3 (assessed on the 0 to 10 Borg scale [Borg, 1982]), thus describing the training as between “hard” and “very hard”. Similarly in the study by Bartlett et al. (2011), mean RPE was 14 ± 1 ; therefore between “somewhat hard” and “hard”. These data suggest that despite the participants performing at near maximal levels in terms of heart rate, this was not reflected in their perceived exertion responses. This is surprising, as a strong relationship between RPE and markers of exercise intensity including heart rate has consistently been evidenced (Foster et al., 2001). It is possible that these lower than expected scores may be linked to enjoyment (Bartlett et al., 2011; Raedeke, 2007), or represent the participants’ perceived effort towards the whole session, including the warm up and cool down, rather than the exercise blasts alone. Largely however, the reasons underlying these inconsistencies are unknown and warrant further investigation.

The second aim of this pilot study was to trial the main intervention under “real life” school conditions to assess the feasibility and acceptability of such a programme by Year 9 students. This was aided by the practical experiences of the exercise blast sessions and the participants’ feedback. During the first football session, it was clear that due to differing skill levels amongst the participants, the small sided games were not capable of consistently delivering a high-intensity stimulus. As such, the small sided games were not included in the football section of combination session. Comparison of the heart rate responses from the football sessions in Figures 4 and 5 justifies this decision. Here, it can be seen that the bout-

to-bout variability in heart rate is smaller for the combination session; and that the overall intensity is higher (~95% of age-predicted maximum heart rate vs ~90% of maximum observed in the individual session). In the first football session, there were also technical issues with the Polar Team₂ system, possibly due to the outside location. Additionally, there were a number of occasions where these monitors displayed unfeasibly high heart rates of ~231 beats·min⁻¹. This occurred sporadically, which necessitated that every 5-s of data collected across the study was re-examined to ensure that all of these anomalies had been removed. Accordingly, it was decided that only the Polar RS400 monitors would be used in main trial. This decision was bolstered by the participants reporting that they liked seeing their heart rate on their watch after each exercise blast. The participants' views on the session content and structure also provide useful insights into the practicalities of a novel low-volume HIT programme. For example, several participants reported that the rest period in between exercise blasts was too short, especially during the boxing activities where they had to swap gloves with their partner in between each bout. Such an issue could influence compliance to the required exercise intensity, therefore it was decided that for the main trial, the rest period would increase from 60-s to 90-s. As both the warm-up track during the Zumba® dance session and the small sided football games were popular amongst the participants, these were retained as activity-specific warm-ups for the main trial.

The combination week session provided the greatest insight into the feasibility of implementing a multi-activity low-volume HIT intervention into a school environment. During this, it was clear from a practical standpoint that having multiple activities running concurrently would not be possible for various reasons. From an exercise intensity perspective, it was much harder to ensure that all participants were consistently reaching heart rates indicative of high-intensity work. This is evidenced by the decrease in heart rates responses, and increased bout-to-bout heart rate variability in Figure 5. This was particularly true for the boxing and dance sessions in the combination week. It was also deemed unrealistic that over a 10-week intervention, access to multiple facilities and equipment would be possible on a near daily basis. Furthermore, as it was projected that the head researcher would lead the majority of the exercise sessions in the main trial, running multiple activities alone would be unrealistic. As such, it was decided that whilst the participants would still choose which activity they performed, this would be decided on a week-by-week basis, rather than at the individual session level. This ensured that the participants could still maintain an element of ownership and choice over the intervention activities, but that this was executed in a feasible manner.

Limitations

As it was not possible to gauge each participants' individual maximum heart rate through an exhaustive incremental $\text{VO}_{2\text{peak}}$ test prior to the exercise blast sessions, the major limitation of this study was that heart responses were expressed as a percentage of age-predicted maximum heart rate, rather than individual. This is potentially problematic as inter-individual variability for this measure is high ($\pm 12 \text{ beats}\cdot\text{min}^{-1}$; [Arena, 2013]). As the high-intensity nature of the exercise blasts was confirmed or denied through the use of this age-predicted value, this may have led to activities being misclassified. Whilst this limitation is acknowledged, the session average mean peak heart rates were consistently $\geq 9 \text{ beats}\cdot\text{min}^{-1}$ higher than the age-predicted 90% of maximum value of $179 \text{ beats}\cdot\text{min}^{-1}$ across Weeks 1 to 3 of the trial. This suggests that despite the caveat of using the age-predicted value for classification, the activities most likely were high-intensity. It has also been proposed that the usefulness of heart rate monitoring for controlling and adjusting the intensity of a low-volume HIT session, rather than a prolonged submaximal one, may be limited (Buchheit & Laursen, 2013). This is largely due to the well-known heart rate lag at exercise onset which, compared to the oxygen uptake response, is much slower (Cerretelli & Prampero, 1971). As such, while heart rate is expected to reach maximal values for exercise at or below the speed/power associated with maximal oxygen uptake, this is not always apparent, particularly for very short ($<30 \text{ s}$) (Midgley et al., 2007) and medium-long intervals (Seiler & Hetlelid, 2005). This may explain why a recent field based low-volume HIT study did not measure participants' heart rate during repeated 30-s high-intensity intervals (Lunt et al., 2014). Notwithstanding this viewpoint, in the current trial the participants' heart rates reached $\sim 90\%$ of age-predicted maximum within a 45-s repetition, despite the acknowledged heart rate lag. The intensity estimates may therefore be conservative, and, as such, further reinforces participant compliance with the required exercise intensity.

A further limitation of the study was that it took place in an affluent state school where levels of deprivation were low. Individuals from a high socio-economic status are thought to be more enthusiastic and aware of the benefits of leading a healthy lifestyle (Hanson & Chen, 2007), therefore the participants' trial feedback may not be typical of Year 9 students across the region. Furthermore, the study sample only included females, therefore the responses of adolescent males to this form of training remains relatively unknown. Nonetheless, adolescent girls are more likely to drop out of exercise opportunities than teenage boys (Craig et al., 2009) and the female participants in Study 1 reported very specific exercise

likes and dislikes. As such, it was imperative to assess the acceptability of a low-volume HIT intervention in a female adolescent population ahead of the main trial. Lastly, although the study assessed responses to a variety of exercise drills across the four weeks, it was not possible to trial all of the activities that may be included in the main intervention.

Conclusions

This pilot study has demonstrated for the first time that novel 45-s second exercise blasts, based on boxing, dance and football can elicit heart rate responses indicative of high-intensity work (~90% of age-predicted maximum heart rate). Such activities were also well received by the study participants, and therefore could be included in a school-based low-volume HIT intervention. The perceived exertion responses to the activities were lower than expected, given the intense nature of the exercise. The underlying reasons for this are unknown, which warrants further investigation. This is the first study to attempt to quantify the intensity of interval-type activities on a bout-by-bout basis in young people. Other school-based low-volume HIT programmes have only provided session mean peak heart rate values to confirm the high-intensity nature of their activities. In the current study however, mean peak heart rate values were provided for each exercise repetition, therefore demonstrating that a high-intensity training stimulus was maintained across all of the exercise blasts throughout the trial. This investigation also allowed key uncertainties in the main study design to be addressed, by trialling it within the proposed setting of a Year 9 PE lesson. From these experiences, it was apparent that the recovery period should be increased to 90-s, and that it would not be possible to run multiple exercise sessions concurrently. The exercise intensity and modes appeared to engage the participants, with session feedback constructive and generally very positive. The next phase of the programme therefore, is to implement a school-based multi-activity low-volume HIT trial for Year 9 students residing in the Tees Valley region.

Chapter 6: Project FFAB: The effect of a novel school-based low-volume high-intensity interval training intervention on cardiometabolic risk markers and physical activity levels in adolescents (Study 3)

Introduction

It is well accepted that the onset of atherosclerosis and cardiometabolic risk factor clustering begins in childhood and adolescence (Berenson et al., 1998; Andersen et al., 2004; De

Ferranti & Osganian 2007). This is concerning as such processes and clustering, often diagnosed as the paediatric metabolic syndrome, can track into adulthood (Camhi & Katzmarzyk, 2010) which may accentuate the risk of early mortality and morbidity (Andersen et al., 2004). It has been shown that high levels of cardiorespiratory fitness and physical activity may offer some form of protection against risk factor clustering in young people (Brage et al., 2004; McMurray & Andersen, 2010), however findings from several studies indicate that both of these variables are in decline in English youths (e.g. Stratton et al., 2007; Sandercock et al., 2010; Scholes & Mindell, 2013). Whilst alarming, this provides strong justification for the development of exercise interventions that target modifiable risk factors in this population.

The popular use of schools as a public health intervention setting was discussed in Chapter 3. Over the last 20 years, many school-based exercise interventions have centred on increasing physical activity levels and tackling obesity (Klakk et al., 2014). In the last decade however, the focus has shifted towards examining the intervention effects on cardiometabolic risk factors (e.g. Henaghan et al., 2008; Reed et al., 2008; Willi et al., 2012). Recently, there has been a surge of scientific research on the efficacy of low-volume HIT as a time efficient way to improve various health and fitness outcomes. Investigations relating to this were extensively examined in Chapter 2. Whilst there is accumulating evidence that low-volume HIT can improve variables such as cardiorespiratory fitness (e.g. Weston et al., 2014), waist circumference (Whyte et al., 2010) and insulin sensitivity (e.g. Babraj et al., 2009), the findings have largely been limited to adult populations. Contrastingly, there are limited low-volume HIT trials that have targeted youths, and specifically adolescents. Of the handful of low-volume HIT studies that have been conducted in young people, substantial post-training improvements in cardiorespiratory fitness and systolic blood pressure have been observed (Buchan et al., 2011a; de Araujo et al., 2012). Although these findings are promising, they are by no means definitive, and much remains unknown about the use of low-volume HIT in youth populations. The impact of low-volume HIT on daily physical activity for example, has yet to be adequately explored. Furthermore, whilst the effects of low-volume HIT on traditional and some novel cardiometabolic risk markers has been examined, no trial to date has assessed its influence on non-invasive disease predictors such as carotid artery intima media thickness and the lipid accumulation product. The majority of low-volume HIT training models are based on cycle ergometry or running, however evidence presented in this thesis suggests that these may not engage adolescents, who reportedly prefer performing a variety of activities. As Study 2 demonstrated that drills

based on boxing, dance and football were capable of eliciting a high-intensity training stimulus, these could form the basis of a novel low-volume HIT programme for adolescents. As such, the aim of this study is to determine the impact of a school-based low-volume HIT intervention based on these activities, on cardiometabolic risk markers and physical activity levels in 13 to 15 year olds.

Methods

Participants

School participation

On receiving approval from Teesside University School of Health & Social Care Research Governance and Ethics Committee in January 2011 (study number 008/11), eight secondary schools in the Middlesbrough, Redcar and Cleveland and Stockton-on-Tees areas were invited to participate in the study, based on their socioeconomic status (assessed through the Index of Multiple Deprivation [Noble et al., 2008]), school specialism and PE provision. Schools were recruited via email and telephone, and a face-to-face meeting then arranged with those who expressed an interest. Of the eight schools, four volunteered to take part (characteristics shown in Table 12) and four declined. The latter cited a lack of time and flexibility in the school timetable and/or disinterest as their reasons for non-participation. To mitigate potential contamination effects between the intervention and control groups (Henaghan et al., 2008), randomisation at the individual level within the schools did not occur. As such, two schools were assigned to the intervention condition and two to the control, matching for school specialism, socioeconomic status, and PE provision. In line with the MRC guidance the study was defined as an exploratory trial, of which one of the key outcomes is securing assumptions about effect size and variability (Craig et al., 2008). Since this information is required for a sample size ‘power calculation’, performing one at this stage was counterintuitive. As such, the target sample size for Project FFAB was 100 Year 9 students (aged 13 to 14 years), consisting of ~25 participants per school. This would then inform a future definitive trial by examining whether the intervention could be delivered as intended, with regards to compliance and retention.

Table 12. School level descriptive characteristics

School	Condition ¹	Study sample size (no. of girls)	No. of pupils on school roll	Sex on entry	Age range (y)	IMD rank ^a (1= most deprived)	Free school meals eligibility ^b (%)	School specialism	PE (hours per week)
1	INT	17 (8)	1258	Mixed	11-16	12521	12.4	Sports	2
2	INT	24 (0)	831	Mixed	11-16	8218	11.2	Science	2

3	CON	23 (15)	952	Mixed	11-16	19697	15.3	Sports	2
4	CON	37 (15)	1059	Mixed	11-18	5376	21.9	Business & Enterprise	2

¹INT = Intervention; CON= Control
IMD – Index of Multiple Deprivation

y = years

^aSource: <http://dclgexamples.mywebcommunity.org/imd/imd-explorer-v0.html>

^bSource: <http://www.education.gov.uk/cgi-bin/schools/performance/school.pl?urn=111724>

Pupil participation

After gaining full informed consent from the schools’ head teachers, Year 9 students (aged 13-14 years) were told about the study. This was done during their PE lessons via a presentation, practical demonstration and question and answer session. All pupils then received study information sheets and asked to return parental consent, participant assent and exercise and physical activity readiness assessment forms if they were interested in taking part. Exclusion criteria were symptoms of or known presence of heart disease or major atherosclerotic cardiovascular disease, condition or injury or co-morbidity affecting the ability to undertake exercise, diabetes mellitus, early family history of sudden cardiac death, condition or disorder which is communicable via blood and pregnancy or likelihood of pregnancy. Asthmatic pupils were allowed to participate with medical clearance and the assurance that they had their bronchodilator medication to use when required.

At intervention school 1, the PE teachers elected to exclude pupils in the top PE group due to GCSE exam commitments. Consequently, the study was introduced to 80 Year 9 students, of which 17 (9 males) volunteered to take part. At intervention school 2, it was only possible to introduce the study to one Year 9 PE class, due to the school timetable. As such, 30 males attended the study presentation of which 24 provided consent. Project FFAB was introduced to 45 and 30 pupils at control schools 1 and 2, respectively, of which 37 (22 males) and 23 (8 males) agreed to take part. All of the volunteers provided written and parental consent and were free from any of the exclusion criteria, therefore at baseline, the total number of participants for Project FFAB was 101 (63 males).

Design

The trial adopted an exploratory controlled before-and-after cluster design and as such, the variance between participants within schools may have been less than the variance for participants between schools (Reed et al., 2008). Due to the small number of clusters within the study (4 schools), it was not possible to use the more common methods designed to

analyse clustered data such as generalised estimating equations or hierarchical linear models (Wears, 2002). To thereby account for the effect of school clusters, a design effect was applied to adjust both the variance used to calculate the t statistic and confidence intervals. It was originally intended that Project FFAB would utilise a cluster randomised control trial design, which is widely regarded as the preferred design for assessing the effectiveness of health interventions (Deeks et al., 2003). When properly implemented, the use of randomisation procedures ensures that the allocation of a participant to one group or another cannot be predicted. During early communications with the school PE teachers however, it became apparent that this would not be feasible. This was due to one PE teacher disclosing that their school's participation was dependent on them being assigned to the control condition because of exam, timetabling and staff pressures. To facilitate this, a cluster controlled before-and-after study design was adopted instead, where outcomes would be compared between participants who had received the intervention with those who had not. In doing this however, the allocation of the schools to the intervention or the control condition was no longer randomised. Utilising this type of observational design may then introduce bias, since randomisation removes the chance of confounding (because of the infinite population assumption) (Shrier et al., 2007). Nonetheless, whilst the superiority of randomised trials over observational designs continues to be debated (Vandenbroucke, 2011); there is little evidence to suggest that observational studies of treatments are widely off the mark (Shrier et al., 2007). To the contrary, four meta-analyses comparing randomised control trials and observational studies of treatment found no large systematic differences (Benson & Hartz, 2000; Concato, Shah & Horwitz, 2000; MacLehose et al., 2000; Ioannidis et al., 2001). As such, the assumption that observational studies are untrustworthy, except when looking at dramatic effects, is actually only based on theory and singular events (Vandenbroucke, 2011) such as the discrepancies in the effects of vitamins (Lawlor et al., 2004). Furthermore, many of the advantages associated with randomised control trials can be achieved through observational designs, provided they are carefully planned and executed (Shrier et al., 2007) and aim to minimise the risk of the four main sources of bias (selection bias, performance bias, attrition bias and detection bias; Higgins, Altman & Sterne, 2011). Of these, it is the potential for selection bias that most clearly differentiates between randomised and non-randomised studies (Deeks et al., 2003). Here, systematic differences in comparison groups arise at baseline, thus participants selected for an intervention have different characteristics from those assigned to the control. This scenario may have existed in Project FFAB since the participants came from four different schools. Whilst this potential source of bias was not possible to entirely overcome, it was partly controlled for

by including the participants' baseline values for each outcome in the statistical analysis. Furthermore, the intervention and control schools were matched on factors including school specialism and socioeconomic status. Accordingly, the trial ran across the four schools between March and July 2011 (Figure 6). This incorporated the baseline testing, the 10-week low-volume HIT intervention, the 2-week school Easter holidays (April 2011), the 1-week mid-term break (June 2011) and the post-intervention testing. The timing and duration of the holidays was uniform across the four schools and occurred after weeks 4 and 9 of the intervention, respectively. At the intervention schools, the post-intervention data collection began within one week of the last exercise session, with all blood measurements completed within those seven days.

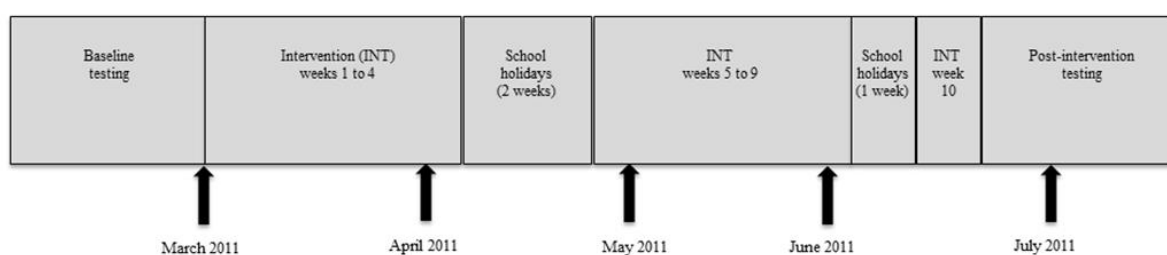


Figure 6. Overview of the trial time line

Outcome measures

Data was collected at three points during the study; baseline (February/March 2011), immediately post-intervention (June/July 2011) and at 3-month follow-up (October/November 2011). The following variables were assessed at these time points, unless otherwise stated; body composition (BMI, body mass, percentage body fat, skeletal muscle mass and waist circumference), systolic and diastolic blood pressure; blood glucose, blood lipids (total cholesterol, HDL cholesterol, LDL cholesterol and triglycerides), high sensitivity C-reactive protein (hsCRP) (measured at baseline and post-intervention only), cardiorespiratory fitness, carotid artery intima-media thickness (cIMT) (measured at baseline and post-intervention only), maturity (age at peak height velocity), lipid accumulation product and physical activity. The variables reflect the criteria set by the IDF (Zimmet et al., 2007) for defining metabolic syndrome in young people (triglycerides, HDL cholesterol, systolic and diastolic blood pressure, glucose and waist circumference), and/or are associated with aspects of cardiometabolic health (body composition, hsCRP, 20 m multi-stage shuttle run test performance (an indirect measure of cardiorespiratory fitness), cIMT, lipid accumulation product and physical activity). Age at peak height velocity was

assessed to allow the effects of maturation to be controlled for in the analysis. Further information on each outcome is detailed below.

Anthropometry and maturity assessments

Body composition

Equipment Validation

The criterion methods for estimating body composition are hydrostatic weighing and dual-energy x-ray absorptiometry (DEXA), with the latter preferred due to its accuracy and precision (Lim et al., 2009). The use of DEXA however is limited in many environments due to high costs, risk of low-dose radiation exposure and inaccessibility (Jensky-Squires et al., 2008). Alternatively, body composition can be assessed using bioelectrical impedance analysis, where detectable electrical signals are sent through the body. The change in impedance in body tissues is measured and from this, the composition of the body estimated. This method has been widely used in clinical, laboratory and school settings (e.g. Malavolti et al., 2003; Kyle et al., 2004; Lubans et al., 2011) as it is relatively low cost, fast and easy to operate, non-invasive and exhibits high inter-observer reproducibility (Anderson, Erceg & Schroeder 2012). During Project FFAB, body composition was measured using multi-frequency bioelectrical impedance analysis via the InBody 720 (Biospace, Gateshead, UK). Here, segmental composition is assessed through eight tactile electrodes; two of which are in contact with the palm and thumb of each hand and two with the anterior and posterior aspects of the sole of each foot (Malavolti et al., 2003). This is achieved by the participant standing barefoot on the InBody device, with their feet and hands on the appropriate electrodes. Segmental impedances are then measured at the right arm, left arm, right leg, left leg and trunk for all frequencies, and the total body impedance value calculated by summing the segmental values (Lim et al., 2009). After approximately two minutes, the device automatically displays various measurements including body mass, skeletal muscle mass and percentage body fat. In previous studies, the precision error of these components was less than 2% (Malavolti et al., 2003; Lim et al., 2009).

Good agreement between bioelectrical impedance analysis and DEXA has been shown in adult studies, (Malavolti et al., 2003; Demura, Sato & Kitabayashi, 2004), yet findings in paediatric populations suggest that the method lacks precision and is not interchangeable with DEXA (Gutin et al., 1996; Goran et al., 1996; Eisenmann, Heelan & Welk, 2004). Nonetheless, Lim et al., (2009) suggested that the discrepancies apparent in previous work were due to small sample size, different ethnicities of study populations and the use of

bioelectrical impedance analysis with single frequency. They also reported that the InBody 720 could be used to measure body composition in young people because of its high precision. Indeed, when compared to DEXA the standard error of the estimate using the InBody was 1.16 kg for fat free mass, 1.34 kg for fat mass and 3.03% for percentage body fat respectively.

Body composition measurement protocol

Prior to each measurement, the electrodes were cleaned using antibacterial InBody Biospace tissues and the participant's height, date of birth and ID code were entered into the device. The participant then stood barefoot on the analyser with their soles in contact with the foot plates, and gripped the hand electrodes whilst holding their arms at their sides. The researcher then ensured that the participant was standing still and that there was full contact between their hands and feet and the electrodes before the measurement was taken. After the output was displayed, the data was saved onto the machine and downloaded at the end of the session.

Assessment of maturity

Protocol validation

From a biological perspective, the effects of a young person's maturation may mask or be greater than the effects associated with exposure to exercise (Baxter-Jones, Eisenmann & Sherar, 2005). It is therefore essential that researchers working with young people attempt to control for maturity by including an assessment of biological age in their study design (Mirwald et al., 2002). Commonly used indicators of biological maturation include skeletal age, somatic maturation and secondary sex characteristics. Skeletal age assessment is considered the single best maturation index (Mirwald et al., 2002; Sherar, Baxter-Jones & Mirwald, 2004; Baxter-Jones et al., 2005). Use in the field however is limited due to cost, the need for specialised equipment and interpretation and radiation safety issues (Baxter-Jones et al., 2005). Although the assessment of secondary sex characteristics is common, this is limited to the adolescent time period and in a nonclinical situation can be seen as personally intrusive by adolescents and their parent/guardians. Additionally, secondary sex characteristics do not reflect the timing of growth (Mirwald et al., 2002). Somatic maturity indicators include age at peak height velocity (the age at which maximum growth rate in stature during adolescence occurs) and predicted age at peak height velocity (Baxter-Jones et al., 2005). The former requires repeated measurements for a number of years surrounding the onset of peak height velocity and is therefore inapplicable in a one-off measurement in

time (Sherar et al., 2004). Age at peak height velocity can however, be accurately predicted using sex-specific multiple-regression equations based on segmental growth patterns that predict the maturity offset parameter. These equations were developed by Mirwald et al. (2002), using measures of height, leg length, body mass and chronological age from a sample of 152 participants aged 8 to 16 years. The use of standing and sitting height in the prediction accounts for the differential timing of the adolescent spurt in body dimensions and also their interactions with chronological age. Using these indicators, maturity offset was estimated within an error of ± 1 year in 95% of the sample. The equations also predict a maturity benchmark that exists in both sexes, therefore allowing for between-sex comparisons (Baxter-Jones et al., 2005). Accordingly, they are now widely recommended for use in youth-based exercise studies (e.g. Sherar et al., 2007; Wickel & Eisenmann, 2007) and were used in the current trial.

Maturity assessment protocol

All measurements were completed with the participants' socks and shoes removed. At each data collection time point, body mass, stature and sitting height were measured to the nearest 0.1 kg and 0.1 cm respectively, using the Leicester Height Measure (Seca, Birmingham, UK) and calibrated scales (Seca, Birmingham, UK). This was completed by one trained researcher who adhered to the International Society for the Advancement of Kinanthropometry standards for anthropometric assessment (Marfell-Jones, Stewart & de Ridder, 2012). In line with Mirwald et al. (2002), two measurements were taken for standing and sitting height. A third was taken if the first two differed by more than 0.4 cm. The two measurements were then averaged, with the median value used if three measurements were taken. Leg length was calculated by subtracting sitting height from stature. Each participant's maturity offset was then estimated by calculating years from attainment of peak height velocity using Mirwald's sex-specific equations.

Waist Circumference

Protocol validation

In lean and obese persons, the majority of adipose tissue (~85% of total adipose tissue mass) is located under the skin (subcutaneous fat), with a smaller amount (~15%) in the abdomen (often described as visceral fat) (Abate et al., 1995). The gold-standard methods for determining the quantity of subcutaneous and visceral fat are magnetic resonance imaging (MRI) and computed tomography (Shen et al., 2004). Their use in field-based interventions however is limited due to issues regarding cost, access and radiation risks. Waist

circumference measurements are often used as an alternative in both adult and youth populations, as they correlate well with both subcutaneous and visceral fat (e.g. Pouliot et al., 1994; Shen et al., 2004 Brambilla et al., 2006). Furthermore, the method is straightforward, requires inexpensive equipment, and is useful for monitoring changes in participants' anthropometrics in response to training interventions.

Waist circumference percentile charts have been developed for UK children aged 5.0 to 16.9 years (McCarthy et al., 2001). These were derived from the measurements of 8355 children (3585 males). Here, waist circumference was taken midway between the tenth rib and the iliac crest (also referred to the natural waist) and recorded to the nearest millimetre. This landmark is the most frequently used site in studies evaluating waist circumference and morbidity and mortality risk (29% of studies) (Klein et al., 2007). Other common sites include the umbilicus (28%), and the narrowest waist circumference (22%). The specific site used for measurement influences the absolute waist circumference value that is obtained (Wang et al., 2003), however there is currently no data evidencing the superiority of one measurement site over another. Given the similarities in the study populations, in Project FFAB participants' waist circumferences were measured using the same technique employed by McCarthy et al. (2001). This therefore allowed accurate use of the percentile curves and facilitates data comparisons.

Measurement protocol

All measurements were taken using a non-elastic Gulick tape measure (G-tape) with a tension device, on the participants' bare midriff midway between the tenth rib and the iliac crest. Prior to measurement, participants stood with their feet together and arms hanging freely. After the researcher ensured that the tape was parallel to the floor the whole way round and that the tape was taut but not pressing against the skin, the participant was asked to fully exhale. The waist circumference measurement was taken at the end of the expired breath and recorded to the nearest 0.1 cm. This was repeated three times, with the average of the first two measures within 1 cm of each other used for analysis. Early in the pre-intervention data collection phase, it became apparent that there were between-researcher differences in the measurements, which is common, and problematic (Ulijaszek & Kerr, 1999). To eliminate this potential source of measurement error, all baseline waist circumferences were reassessed by the lead researcher. Additionally, all measurements taken thereafter were completed by the lead researcher. This may have introduced bias as it was not possible to blind this individual to which group the participants were in.

Nonetheless, the lead researcher adhered fully to the procedures described above, using the spring loaded Gulick tape measure to ensure constant tension using the measurement.

Blood profiling

Equipment validation

Participants' lipid, glucose and hsCRP profiles were assessed using a Cholestech LDX analyser (Cholestech Corporation, Hayward, CA, USA). Using 35 μ L of whole blood, the device measures the following analytes on a dedicated cassette (lipid profile plus glucose panel cassettes): total cholesterol; triglycerides; HDL cholesterol; glucose; estimates of LDL cholesterol; non-HDL cholesterol and the total cholesterol to HDL cholesterol ratio. Results are then displayed on the device screen after ~5 minutes. Participants' hsCRP profiles were measured on a separate cassette using 50 μ L of whole blood, with results displayed after ~7 minutes. The LDX analyser is currently used for the National Health Service Health Checks (Jain et al., 2011) and in various other clinical, community and health promotion settings (Parikh et al., 2009). Compared with gold standard laboratory techniques, one of the key benefits of this method is the rapid generation of test results. This enables immediate feedback to the participant and requires only a small quantity of blood which could promote participant acceptability (Shemesh et al., 2006). Indeed, finger stick measurements have long been considered the most convenient blood sample collection method for young people (Noble, 1993). Various studies (e.g. Shemesh et al., 2006; Parikh et al., 2009) have shown that finger stick measurements assessed using the LDX analyser are a reliable and valid alternative to gold standard methods for cardiovascular risk screening. In these trials the coefficients of variation for total cholesterol, HDL cholesterol and triglycerides met the 1995 NCEP accuracy and precision cut-points for lipid testing ($\leq 3\%$; $\leq 6\%$; $\leq 5\%$, respectively; NCEP, 1995). Both also investigated agreement between the LDX analyser and core laboratory measures in everyday settings and populations. Categorical agreement was assessed by the Kappa statistic (κ) against standardised abnormal cholesterol, glucose and hsCRP concentration cut-points from the NCEP and the American Heart Association and Centres for Disease Control and Prevention (NCEP, 2001; Pearson et al., 2003). In Parikh's study, kappa values of between 0.4 and 0.75 were defined as fair to good agreement and coefficients of >0.75 as excellent. Here, agreement between the two methods for hsCRP was fair ($\kappa = 0.58$) for both the high and above optimal clinical cut-points recommended by Pearson et al. (2003). The trial by Shemesh et al. (2006) reported excellent agreement for glucose at both of the NCEP cut-off values of ≥ 6.1 mmol/L and ≥ 7.0 mmol/L; $\kappa = 0.84$ and

0.95, respectively. For most lipids, agreement was good to excellent in Parikh's study; κ values were 0.69 for LDL cholesterol, 0.75 for total cholesterol and 0.78 for triglycerides. For both HDL cholesterol and hsCRP, agreement was fair ($\kappa = 0.40$ and 0.58 , respectively). These values differ slightly from those reported by Shemesh et al., who found κ coefficients of 0.67, 0.86, and 0.73 for total cholesterol, triglycerides and HDL cholesterol, respectively. Despite these differences, both authors concluded that finger stick analysis using the Cholestech LDX was a reliable and valid alternative to conventional laboratory methods for screening for chronic disease risk. Shemesh et al. also reported agreement between the analyser and laboratory results for the NCEP cut-points using Bland and Altman analysis (Bland & Altman, 1986). Here, statistically significant (but not clinically meaningful) variations in the measurement difference across analyte concentration were found for all measures except total cholesterol. Collectively, these findings confirm the use of the Cholestech LDX analyser as a reliable alternative for lipid and hsCRP testing in diverse settings and populations. In the current study, the LDX analyser was also part of an internal quality control scheme, which further ensured the ongoing accuracy of the device.

The use of non-fasted samples for blood profiling

Current guidelines recommend that lipid profiles are measured when the participant is in a fasted state (>8 hours after their last meal) (NCEP, 2001; De Backer et al., 2004). However, studies both in adults and young people suggest that fasting makes little difference to lipid test results (e.g. Langsted, Freiberg & Nordestgaard, 2008; Steiner, Skinner & Perrin, 2011; Sidhu & Naugler 2012). Fasting recommendations were introduced to reduce variability and achieve consistency in the metabolic states of participants at the time of sampling (Warnick & Nakajima, 2008). They did not however originate from research which consistently demonstrated the superiority of fasted over non-fasted samples for the detection of cardiovascular risk (Ridker et al., 2008). Indeed, evidence from two large prospective cohort studies indicates that abnormal postprandial triglyceride levels may actually better predict future cardiovascular events than abnormal fasted levels (Bansal et al., 2007; Nordestgaard et al., 2007). Moreover, as the majority of humans spend most of their day in a postprandial state (Branchi et al., 2006), non-fasting lipid values may actually be more representative of usual metabolic conditions (Sidhu & Naugler 2012).

Previous work suggests that for most individuals consuming an average sized meal, the overall lipid profile will have a minimal postprandial change (Langsted et al., 2008; Mora et al., 2008). This has been further evidenced in two recent studies, where the association of

fasting duration with lipid levels was examined in a large community-based adult population (n= 209180) (Sidhu & Naugler 2012), and in a nationally representative sample of youths aged 3 to 17 years (n=12744) (Steiner et al., 2011). In the trial by Sidhu and Naugler, mean levels of total cholesterol and HDL cholesterol varied by less than 2% at various fasting times (range 1 to 16 hours), among groups of participants with different fasting intervals. The mean calculated LDL cholesterol and triglyceride levels showed slightly greater variations of up to 10% and 20%, respectively. Similar patterns were found in the Steiner et al. (2011) investigation. Here, fasting had a small positive effect for total cholesterol and LDL cholesterol; resulting in a mean sample value that was 0.05 mmol/L and 0.13 mmol/L higher, respectively after a 12-hour fast compared with a non-fasted sample. For triglycerides, fasting values were on average, 0.18 mmol/L lower, thus demonstrating a negative effect. Although the authors acknowledged these small differences, they concluded that they were not likely to be clinically important and that fasting prior to screening might not be necessary. This was echoed by Sidhu and Naugler, who also suggested that for participants presenting with an initial triglyceride level of higher than ~10 mmol/L, reassessment could be considered. Collectively these findings strengthen the evidence in favour of non-fasted lipid profiling and call into question the added value of fasting before assessment. Indeed, instructing young people to fast prior to blood screening presents several challenges. Compared to adults, the act of fasting may be more difficult and unpleasant for young people, which could decrease participant adherence (Steiner et al., 2011). Additionally, to obtain an >8 hour fasted sample, testing generally needs to take place very early in the morning. In the current study this was not feasible as the school timetables dictated when data collection took place. Continual data collection visits would have been inconvenient and disruptive for both for the participants and the school teachers, which could have led to drop out.

Measurement protocol

All blood measurements were assessed using the Cholestech LDX analyser by one researcher during the three data collection phases. The researcher received training on the analyser and blood sampling techniques by a member of the Alere Cholestech LDX training team in June 2010. Due to time restraints, hsCRP was only measured in 40% of the total study sample at baseline and post-intervention, and was not assessed at 3-month follow-up. Prior to testing the Cholestech LDX lipid panel plus glucose panel and hsCRP cassettes were stored in a refrigerator at Teesside University. The required number of cassettes were then removed before each data collection session and brought to room temperature at least 15

minutes before use. Prior to the start of each session and/or after the analyser had been moved, an optics check was performed. Immediately before sampling, the researcher recorded when the participant had last eaten, then made a firm puncture to the participants' middle finger using a one piece single use finger stick (Unistik 3, Owen Mumford, UK). The first large drop of blood was wiped away using a clean tissue. Moderate pressure was then applied to ensure adequate blood flow until another large drop appeared. Care was taken to avoid vigorous squeezing of the finger which can lead to the collection of interstitial fluid as well as blood (Maw et al., 2000). The sample was drawn into a 35 μ L capillary tube coated with lithium heparin (Cholestech LDX, AR-MED Ltd, Egham, UK) and immediately transferred into a cassette sample well. The cassette was then placed into the device drawer for analysis. Here, the plasma was separated from the total blood and the results displayed after 5 minutes. This process was repeated to obtain the participants' hsCRP profiles, this time using 50 μ L of blood and a dedicated hsCRP cassette. Medical gloves were worn by the researcher at all times and all materials contaminated with blood were disposed of in a biohazardous sharps bin.

Blood Pressure Measurements

Equipment validation

The mercury sphygmomanometer is widely accepted as the gold standard for non-invasive blood pressure measurement (Coleman et al., 2005). Nonetheless, the accuracy of this method can be compromised by various human errors including incorrect eye positioning when reading the manometer scale and applying excessive stethoscope pressure on the brachial artery (Perloff et al., 1993). The precision of the method is also optimised in quiet conditions, which may not be possible within busy school settings. An alternative is to assess blood pressure automatically, which can be auscultatory or oscillometric. The automated oscillometric method avoids the common errors associated with the manual auscultatory process, and is also low cost and easy to use (Christofaro et al., 2009). In the current study blood pressure was measured using the Omron MX3 Plus monitor (Model HEM-742-E; Omron Healthcare UK, Milton Keynes, UK) which displays the systolic and diastolic components on the device's screen. This has been validated for use in adults (Coleman et al., 2005) using the European Society of Hypertension (EHS) International protocol (O'Brien et al., 2002) and for adolescents (aged 10-15 years) (Christofaro et al., 2009) in accordance with the British Hypertension Society (BHS) (O'Brien et al., 1993) and the Association for the Advancement of Medical Instrumentation (AAMI) criteria (AAMI,

1993). As data collection in the current study was limited to the latter, only the work of Christofaro et al. (2009) is discussed here.

Blood pressure monitor validation varies depending on society protocol and is based on the degree of agreement between clinical readings from an automated monitor and those from a mercury sphygmomanometer (Coleman et al., 2005). The BHS criteria specify that for a device to be validated, it must receive a degree of B (O'Brien et al., 1993). For this to be achieved there can be no deviations above 5 mmHg for 50% of the participants; above 10 mmHg in 75% of the participants and above 15 mmHg in 90% of the participants. Using this criteria, the Omron MX3 Plus acquired a degree of A for both systolic and diastolic blood pressure in Christofaro's investigation. Here, no deviations above 5 mm Hg, 10 mmHg and 15 mmHg were found for 66.8%, 88.0% and 96.7% of the study participants, respectively, thus fulfilling the degree A criteria of 60%, 85% and 95%. The device also met the AAMI 1993 validation criteria which stipulate that the difference between averages of measurements with the tested monitor and the mercury column should be ≤ 5 mmHg and that the standard deviation of the differences of the averages is < 8 mmHg (systolic blood pressure average difference \pm SD 2.14 ± 5.15 mmHg; diastolic average difference 0.79 ± 5.27). As such, the device can be considered reliable and valid for clinical practice.

Measurement protocol

Blood pressure measurements were taken by three trained researchers at baseline, post-intervention and 3-month follow-up. For at least five minutes before assessment, participants sat and rested and were asked to remove any tight clothing from around their neck. In line with the Omron MX3 Plus validation study (Christofaro et al., 2009); the standard sized Omron cuff (22 to 32 cm) was placed tightly on the participant's upper right arm. During the measurement participants sat quietly with their arm resting on a table at 90°. Following the recommendations of the American Heart Association (Pickering, 2005), a minimum of two readings were obtained at 1-min intervals, with the average of the two used for analysis. If there was > 5 mmHg difference between the first and the second readings, an additional reading was obtained and the average of the multiple readings recorded.

Cardiorespiratory fitness

Protocol Validation

When assessing cardiorespiratory fitness, represented by peak oxygen uptake (VO_{2peak}), the World Health Organisation recommends laboratory based graded exercise testing to exhaustion as the ‘gold standard’ (Shephard et al., 1968). In large-scale, field-based studies where individual maximal testing is not possible however, the 20 m multi-stage shuttle run test is frequently employed instead. Whilst this test can only offer an indirect measure of cardiorespiratory fitness, it is commonplace within screening programmes at the school level (Boddy et al., 2012). Several variations of the test exist, including the original by Léger et al., (1988), which starts at a speed of 8.5 km/h and increases by 0.5 km/h every minute. Other versions include the protocol used by the Eurofit (Adam, 1988), the Australian Coaching Council (Australian Sports Commission, 1999), the British National Coaching Foundation (Ramsbottom et al., 1988) and the American Progressive Aerobic Cardiovascular Endurance Run (PACER) system (performed as part of the FITNESSGRAM [Meredith & Welks, 2010]). In these, the starting speed is 8.0 km/h, the second stage 9.0 km/h, and the speed then increases by 0.5 km/h each minute thereafter. The Queen’s University of Belfast protocol (Riddoch, 1990) is the third major variant of the test, which starts at 8.0 km/h, and increases by 0.5 km/h each minute.

Over the last two decades, there have been doubts over the appropriateness and reliability of the 20 m multi-stage shuttle run test, with issues such as motivation, perceived worth and competency cited as variables that may influence performance (Rowland, 1995; Naughton et al., 2006). It has also been suggested that secondary school pupils in particular may fail to participate or deliberately produce poor performances (Naughton et al., 2006). Whilst these potential limitations are acknowledged, a recent systematic review concluded that the test is reliable and valid for estimating VO_{2peak} in children and adolescents (Castro-Piñero et al., 2010). The test is also relatively non-invasive, requires limited apparatus and little skill from the participants (Mahoney, 1992). Furthermore, the test is cost-effective, and the scoring method easy to administer and interpret.

Measurement Protocol

Performance in the 20 m multi-stage shuttle run test was assessed using the British National Coaching Foundation protocol (Ramsbottom et al., 1988). In all four schools, assessments were carried out indoors in hard floored sports halls. During the tests, participants’ heart rates were recorded via short-range telemetry using Polar RS400 monitors (Polar, Kempele,

Finland), which recorded data at 5-s intervals. Prior to starting, participants received a standardised set of verbal instructions by the lead researcher and listened to the recorded instructions on the British National Coaching Foundation CD. A 20 m course was marked out using cones and participants were required to complete shuttles between the cones in time with an audible bleep signal. The initial pace (8.0 km/h) required participants to complete each shuttle in ~8.5 s, which is a brisk walk or slow jog for most young people and adults (Sandercock et al., 2012). After 1 minute of shuttles, the audible bleep changed to alert participants of the increase in pace and the beginning of the next level. Participants were encouraged to run for as long as possible and told they would be asked to stop if they failed to maintain the specified pace (missed the bleeps) for two consecutive shuttles. If they missed one, they were encouraged to speed up and finish the next shuttle within the designated time. Participants were also allowed to drop out at their own volition at any time if they felt unable to maintain the required pace. Across the three data collection time points, test termination was most common via volitional exhaustion, which has also been observed in similar recent studies (Sandercock et al., 2012). A team of researchers ensured that the participants completed the full distance of the shuttle within the time limits of each stage. The lead researcher oversaw the running of the test and provided verbal encouragement to all participants throughout. Participants ran in groups of up to twelve, with a maximum ratio of six participants to one researcher. The researchers recorded the final shuttle count at either the point of volitional exhaustion or when the participant failed to maintain the required running speed twice. Following each test, participants' heart rate data files were downloaded into the Polar ProTrainer 5 software (Polar, Kempele, Finland). For each participant, the peak 5 s heart rate value attained during the test was recorded. In the intervention and control group respectively, the average (\pm SD) peak heart was 203 ± 8 beats \cdot min $^{-1}$ and 206 ± 4 beats \cdot min $^{-1}$. To facilitate comparisons with national and international normative data (e.g. Olds et al., 2006; Sandercock et al., 2012), test performance was expressed as the number of shuttles completed, end running speed and predicted $\text{VO}_{2\text{peak}}$ using the equation devised by Leger et al., (1988) Furthermore, each participant was classified as fit (girls >35 ml \cdot kg $^{-1}\cdot$ min $^{-1}$; boys >40 ml \cdot kg $^{-1}\cdot$ min $^{-1}$), or unfit using the sex-specific paediatric cut-offs as recommended by Bell et al., (1986). In the main effects analysis however, 20 m multi-stage shuttle run test performance is reported as number of shuttles only. This was chosen over final running speed, as it has been suggested that this metric may not be sensitive enough to detect small changes in performance (Sandercock et al., 2012).

Carotid artery intima-media thickness

Protocol Validation

Carotid intima-media thickness (cIMT) is defined as the distance between the lumen-intima and the media-adventitia interface (Lakka et al., 1999). The elevation of cIMT is a strong predictor of future cardiovascular events (Negi & Nambi, 2012) and, as such, is increasingly being assessed in paediatric research (e.g. Freedman et al., 2004; Meyer et al., 2006a; Henaghan et al., 2008). The annual change of cIMT is ~0.01 mm, therefore a great deal of precision is required in the measurement (Negi & Nambi, 2012). Despite this potential source of measurement error, the assessment is endorsed by the American College of Cardiology Foundation and the American Heart Association (Greenland et al., 2010) and viewed as a safe, relatively inexpensive procedure well suited for use in large population studies (Lorenz et al., 2007).

Measurement Protocol

One trained ultrasound technician performed all cIMT measurements at baseline and post-intervention. Due to time constraints, data were collected on a sub sample of study population (sampled from one intervention and one control school) and was not assessed at 3-month follow-up. Two-dimensional (B-mode) imaging scans were performed using a standard ultrasound system (MyLab30CV system, ESAOTE, Italy) with a 10 MHz linear phased array transducer. All participants were assessed in the seated position. Ten millimetre segments of the far wall of the right common carotid artery, 1 to 2 cm proximal to the carotid bulb were imaged. Care was taken to generate clear images of the carotid intima media by optimal adjustment of depth, gain and filters. Four images were digitally recorded and analysed off-line (IMT.LAB version 1.1, Pie Medical Equipment, Netherlands) by a single technician blinded to the group condition. The software allowed manual checking of the distance between interfaces of the lumen-intima and media-adventitia and generated data for mean cIMT.

Lipid Accumulation product

Protocol validation

Adipose tissue is increasingly recognised as having complex functions, which may vary according to anatomic region (Lamarche, 1998; Frayn et al., 2003; Ferreira et al., 2004). Attempts have therefore been made to define and measure lipid accumulation specifically in those contexts where it may represent physiological danger (Unger, 2003a). These contexts have been described as lipid overaccumulation (Unger, 2003b). In 2005, a simple tool for

estimating lipid overaccumulation in adults was proposed by Kahn. This novel index - the lipid accumulation product - reflects the combined anatomic and physiologic changes associated with lipid overaccumulation, and is based on a combination of waist circumference (WC) and triglycerides concentration (TG) (Kahn, 2005). Researchers have previously devised dichotomous risk markers such as the hypertriglyceridemic waist (Lemieux et al., 2000), which are also based on waist circumference and triglyceride concentration. Lipid accumulation may not however be adequately described by a dichotomous index (Kahn, 2005), and dichotomising can lead to several problems such as a loss of data (Altman & Royston, 2006). The lipid accumulation product contrastingly, is expressed as a continuous risk function variable, and describes the extent to which a participant has travelled through the route of both increasing waist and triglycerides (Kahn, 2005). In adults, the index has been shown to better predict cardiovascular disease risk (Kahn, 2005) and type 2 diabetes (Kahn, 2006) than BMI, and has been described as a power marker of metabolic syndrome in a healthy adult population (Taverna et al., 2011). The usefulness of the tool for youth populations however remains unknown, and will be applied for the first time in the present study. For adults, lipid accumulation product is defined as $(WC [cm] - 65) \times (TG \text{ concentration [mmol/L]})$ for men, and $(WC [cm] - 58) \times (TG \text{ concentration [mmol/L]})$ for women (Kahn, 2005). The formula includes the minimum waist circumference values Kahn used to define sex-specific origin points that represented a hypothetical state in which triglyceride concentrations were arbitrarily set to zero and the waist circumference comprised primarily lean truncal tissue (65 cm and 58 cm for men and women, respectively).

Measurement protocol

The lipid accumulation product index for each participant was based on their triglyceride and waist circumference values at each of the three data collection time points. As such, if either value was unavailable, the participant's index could not be obtained for that time point. The lipid accumulation product was calculated using the formula devised by Kahn (2005). To avoid non-positive values however, the minimum waist circumference values in Kahn's equation were replaced with values 0.01 cm smaller than the minimum waist circumferences observed in Project FFAB. Accordingly, lipid accumulation product formula was $(WC [cm] - 59.39) \times (TG \text{ concentration [mmol/L]})$ for males and $(WC [cm] - 57.29) \times (TG \text{ concentration [mmol/L]})$.

Physical Activity

Equipment validation

Studies assessing physical activity require reliable, valid and feasible measurement tools (Evenson et al., 2008). Methods include direct observation, self-report and accelerometry. The limitations of self-report methods, such as the under and over reporting of activity are well documented (Troiano, 2007); and observation is often not feasible because of practicality and cost (Evenson et al., 2008). Given these limitations, accelerometry is an attractive alternative for providing an objective measure of physical activity, and is an accurate, reproducible, non-invasive and relatively low cost method that can be utilised with minimal interference in free-living conditions (Toschke et al., 2007). Accordingly, accelerometry has become the most widely used objective measure of physical activity in young people (Robusto & Trost, 2012).

Accelerometers measure the intensity, frequency and duration of physical activity, which can then be used to describe both activity levels and patterns. Several accelerometer models are commercially available; however the Actigraph product (Actigraph, LLC, Pensacola, Florida) is widely used in physical activity measurement research and is one of the most widely used accelerometer-based motion sensors in studies involving young people (Trost, McIver & Pate, 2005). Models of Actigraph currently used in the field include the GT1M, GT3X and GT3X+. Despite multiple technological differences including memory size, sampling frequency, epoch settings and the number of axes measured, researchers often use a combination of the three to collect data within one study (Robusto & Trost, 2012). The present investigation used the small and lightweight ($3.8 \times 3.7 \times 1.8$ cm, 27g) Actigraph GT1M monitors which were updated with firmware version 7.5.0. The GT1M contains a biaxial accelerometer which measures and records time varying accelerations in two axes (vertical and antero-posterior) ranging from 0.05 to 2.0 Gs within a frequency range of 0.25 to 2.5 Hz.

In recent years, it has been questioned whether data from different generations of Actigraphs can be compared. Consequently, several validation studies have been conducted in child (Hänggi, Phillips & Rowlands 2013), adolescent (Robusto & Trost, 2012) and adult populations (Sasaki, John & Freedson, 2011), which have largely found strong agreement between the GT1M and the GT3X (Sasaki et al., 2011; Hänggi et al., 2013) and the GT3X+ monitors (Robusto & Trost, 2012). For the majority of activities assessed in the trial by Hänggi et al. (2013), the mean biases of vertical mean counts per second (cps) were low

(range -1.29 to 1.68 cps) and the 95% limits of agreement narrow, except for slow and medium running. For these, mean bias of vertical counts per second was 8.85 cps (95% limits of agreement -31.63 to 49.33) and 11.95 cps (95% limits of agreement 0.27 to 23.63). These apparent differences did not however impact on classification of activity intensity, thus indicating that the monitors should be comparable for classification of time spent in intensity categories. In the study by Robusto and Trost agreement amongst the GT1M, GT3X and the GT3X+ monitors was evaluated by calculating intraclass correlation coefficients (ICCs). Using the Landis and Koch agreement ratings (Landis & Koch, 1977) almost perfect agreement between the three models was found; ICCs for total vertical axis counts and time spent in MVPA were 0.994 (95% confidence interval (CI) = 0.989 to 0.996) and 0.996 (95% CI = 0.989 to 0.998), respectively. This demonstrated that vertical axis counts and the resultant MVPA estimates provided by the three devices were highly comparable, leading Robusto and Trost to conclude that the models were interchangeable.

Measurement protocol

The ActiLife software Version 5.8.3 was used to initialise the accelerometers and upload the collected data. All devices were fully charged via a computer USB port prior to initialisation. The start date was set as the day and time that the devices were given to the participants and the stop date exactly seven days later. The accelerometers and physical activity logs were distributed to participants after they received information about the tools from the lead researcher. The purpose of the activity log was to gain insight into the types of physical activity being undertaken by the participants. As such, they were also asked to complete the log throughout the 7-day monitoring period. Here they recorded when they put their monitor on and when they removed it for going to bed. They were also asked to detail the type, duration and intensity of all of physical activities they undertook in during the monitoring period. If the accelerometer was removed at any point, the time and reason was also to be noted. Additional information about the monitors was also included within the activity log. The PE teachers were also informed about the procedure and were asked to remind the participants to wear their monitors throughout the data collection period.

To gain a valid representation of physical activity for young people, four to nine days of monitoring are required. In light of this, and observed differences of weekend and weekday physical activity, a seven day monitoring period is suggested (Troost et al., 2005). Based on these recommendations, in the current study data was collected for seven consecutive days, including two weekend days. Studies contrasting different monitor placements options

indicate that devices are best placed on the hip or lower back (Troost et al., 2005). Participants therefore wore an elastic belt containing the monitor on their right hip, and were asked to wear it during all waking hours, except when engaging in water-based activities. To ensure that the accelerometer was worn the correct way round, the top of the device was marked with a sticker and the participants informed that it should be worn with the sticker facing upwards.

Epoch length

Accelerometers detect and sum activity counts over a user-defined epoch. If volume of activity (activity counts over a specified time frame) is the only outcome of interest, epoch length is not an issue (Troost et al., 2005). If however cut points are applied to determine time spent in different physical activity intensities, then the choice of epoch length may affect the study results. Typically, studies using accelerometers to estimate intensity have used cut points based on 1-minute epochs. However, this practice may be problematic when assessing activity in young people as it can obscure the short bursts of activity often exhibited in this population (Troost, 2001). Indeed, in the study by Bailey et al. (1995) the median duration of the participants' high intensity activity was 3 seconds, with 95% lasting for <15 seconds. This suggests that, among young people, the 1-minute epoch is too long, which can result in a smoothing effect and subsequently lead to an underestimation of physical activity (Troost et al., 2005). Thus, in the current trial, accelerometers were initialised to collect data at 10-second epochs. Additionally, the low frequency filter was selected to allow the capture of sedentary behaviours.

Data processing

The data were analysed using ActiLife Version 5.8.3. The software was used to clean and process the raw data files according to non-wear time, invalid data and physical activity intensity categories. Decisions on minimum daily wearing time and number of days required for analysis are critical, as these can substantially change physical activity and sedentary time results (Yıldırım et al., 2011). In line with previous work (e.g. Treuth et al., 2003; Stevens et al., 2007), non-wear time was calculated as periods of 20 minutes or more of consecutive zero accelerometer counts. Further data analyses were then only completed for participants who had worn their accelerometer for at least four days, with a minimum of 10 hours (600 minutes) recorded on each day. These criteria were identical to those used for the processing of the youth accelerometry data in the 2008 Health Survey for England (Craig et al., 2009).

Cut points for physical activity categories

Controversy exists over how best to reduce Actigraph outputs into estimates of physical activity intensity. Currently, at least five sets of youth-specific Actigraph cut points have been published. These differ significantly in magnitude, which can lead to dramatically contrasting reported estimates of physical activity. In an attempt to address this, Trost et al. (2011) compared the classification accuracy of the five sets of youth-specific cut points (Puyau et al., 2002; Treuth et al., 2004; Freedson, Pober & Janz 2005; Mattocks et al., 2007; Evenson et al., 2008), using energy expenditure via indirect calorimetry as the criterion reference. Classification accuracy for each set of cut points was determined by calculating weighted κ statistics, sensitivity, specificity and area under the receiver operating characteristic curve (ROC-AUC). Across the four intensity levels (sedentary, light, moderate and vigorous activity) both the Evenson (Evenson et al., 2008) and Freedson (Freedson et al., 2005) cut points exhibited significantly better agreement ($\kappa = 0.68$ and $\kappa = 0.66$, respectively) than the others ($\kappa = 0.36$ to 0.62). They also showed significantly better classification accuracy for MVPA (ROC-AUC = 0.90, which is considered excellent [Metz et al., 1978]). Only the Evenson cut points provided acceptable classification accuracy across all four levels of physical activity intensity and performed well among young people of all ages. Trost et al. thereby recommended the use of the Evenson cut points, of which sedentary activity is classed as ≤ 100 cpm, light as 101 to 2295 cpm, moderate 2296 to 4011 cpm and vigorous activity as ≥ 4012 cpm. Accordingly, these cut points were applied to the Actigraph data in Project FFAB to estimate the number of minutes per day spent in sedentary, light, moderate, vigorous and moderate to vigorous physical activity.

Intervention protocol

Timescale and protocol design

The exercise intervention took place immediately after the baseline testing was completed and comprised of three ‘exercise blast’ sessions per week. At intervention school 1, PE was timetabled for two hours once a week. Participants therefore completed two of the low-volume HIT sessions during the first hour of this lesson, and the third after school on a Thursday. Prior to the study onset, participants at this school were divided into two intervention groups, based on which day they had their PE lesson. As such, one group (nine participants; three females) completed the PE based sessions on a Tuesday, whilst the second group (eight participants; five females) performed these on a Wednesday. At the second school two one hour PE lessons were timetabled per week (on either Monday and

Wednesdays or Tuesdays and Thursdays); thus two of the low-volume HIT sessions were completed during these. The third took place during the lunch break on a Friday. At both schools, the day and timing of the third session was chosen by the participants, who were encouraged to attend as many sessions as possible. As a means of maximising programme adherence, participants who completed at least 70% of the sessions received a branded sports top at the end of the study. Additionally, those who took part in over 90% of the sessions were entered into a prize draw to win a pair of personalised Nike trainers.

Session structure and content

All of the exercise blast sessions were devised and led by the head researcher and took place in the schools' sports halls. The exception to this was the dance activities. Here, the sessions were jointly devised by the head researcher and a dance teacher, and led by the latter. The exercise mode rotated on a weekly basis at both schools. At the intervention school 1, participants were asked to choose, as a group, between boxing, dancing, football or basketball drills. In the event of the group being unable to reach a unanimous decision, two activities ran concurrently. At the second school, participants chose between boxing, football and basketball, however here it was only feasible to run one activity at a time.

Prior to the start of each PE-based session, participants were fitted with a heart rate monitor. This was enacted to assess the fidelity of the intervention, and will be examined in-depth in Study 4. Every exercise blast session began with a 5-minute warm up which contained pulse raising exercises relevant to the session activity. This was followed by four sets of 45-s maximal effort exercise blasts with 90-s rest in between each set. During these, participants were verbally motivated to provide "all-out/ maximal efforts" throughout. They were also encouraged to try and reach as close to their maximal heart rate as possible. During the PE-based sessions at intervention school 1, the 4 × 45-s exercise sequence was repeated after a 15-minute break. This was enacted to ensure that two exercise blast sessions were completed within the allocated 1-hour time slot. Every session culminated with a 5-minute whole body cool-down. Each exercise blast was first demonstrated by the lead researcher or dance teacher. The sessions included the activities trialled in Study 2 and various other drills; information on which can be found in Table 13. Images of the participants performing some of the exercise blasts are shown in Figure 6.

Table 13. Further examples of exercise blast activities

Activity	Example drills
Boxing	Fast jabs on the focus pads

	Ten side steps dodging the focus pads, followed by running to the end of the sports hall and back
	Five combination punches (hook and jab) on the focus pads, followed by running to the end of the sport hall and back
	Ten of favourite punch action, followed by ten tuck jumps
Basketball	Receiving a returning a chest pass, followed by running to a cone and back
	Running round in a square and receiving and returning a bounce pass on once corner of the square
	Bouncing a ball five times then running to the end of the hall and back
	Receiving a shoulder pass, followed by running to a cone and back
Dance	<i>Cheerleading</i>
	Jumping up and down whilst waving pom poms above the head
	Star jumps whilst waving pom poms.
	High leg kicks whilst clapping pom poms underneath the lifted leg
Football	Kicking a football into a goal then running to end of the sports hall and back.
	Performing fast feet movements through cones then running to end of the sport hall and back
	Jumping up to head a football five times then running to the end of the sports hall and back
	Running around the sports hall following a square or diagonal course



Figure 6. Illustrations of a selection of the exercise blast activities

At the trial onset, it was intended that the number of exercise blasts performed by the participants would increase by one every two weeks to allow for progression. As participants

at intervention school 1 were performing two exercise blast sessions per PE lesson (e.g. a 'double' session), this translated to an increase of two drills every two weeks. During the first two weeks of the intervention however, it was apparent that the participants were struggling with the workload. This may have been heightened by them only receiving a short break in between their first and second blast sessions. In an attempt to alleviate this, the number of drills increased by only one after weeks 2 and 4. From week 6 onwards, the number of drills increased by two every two weeks until the end of the intervention. Accordingly, the number of drills performed during PE sessions at the first intervention school was eight for weeks 1 to 2, nine in weeks 3 to 4, 10 in weeks 5 to 6, 12 in weeks 7 to 8 and 14 in weeks 9 and 10. At the second intervention school, session cancellations due to teacher absence and additional school holidays, necessitated that 'double sessions' were held on several occasions (during weeks 1, 2, 5, 6 and 7). The remaining sessions were singular however and followed the same training progression model as the other intervention school.

Statistical Analysis

Intervention analysis

Statistical package IBM SPSS Version 20 was used to analyse data. Prior to analysis, all blood measures and the lipid accumulation product were log-transformed. For these variables, the descriptive data comprised the back-transformed mean of the log-transform (the geometric mean), and the dispersion shown as \times / \div factor standard deviation (SD) (Hopkins et al., 2009). For all other outcomes, the measures of centrality and dispersion were displayed as arithmetic means \pm SD. Residual plots were created for all outcomes, and inspected to check that the models were correctly specified (uniform variance and normal distribution). With the exception of daily MVPA, there was fewer than 15% missing data for any outcome variable at baseline, therefore a complete case analysis was conducted with no imputation of missing data.

Analysis of covariance (ANCOVA) was conducted to examine the effectiveness of the 10-week intervention. This method was chosen over simple analysis of change scores, despite some claiming that ANCOVA is biased if the groups are not equal as baseline (Chambless & Roebuck, 1993). It has however since been shown that it is not necessarily the case, and that the ANCOVA can provide unbiased estimates of treatment effects (Senn, 2006). Propensity score matching was also investigated as an analytical approach; however the ANCOVA method to adjust for baseline imbalances was preferred (Senn, 2008). Here, the independent variable was the group (intervention or control), with the dependent variable as the change score (post-intervention value minus baseline value for the post-intervention

analysis; and 3-month follow-up value minus baseline value for the follow-up analysis). The general model for this is: $\text{Change} = \text{constant} + a \times (\text{baseline}) + b \times (\text{group}; 0,1)$, where 'group' is coded '0' for the control arm and '1' for the intervention and coefficient 'b' provides the difference between the mean change scores for each arm (intervention minus control) (Vickers & Altman, 2001). The baseline value for the outcome served as the covariate in this analysis to control for any chance imbalances at baseline (Vickers & Altman, 2001). To adjust for differences in maturity offset and sex, baseline values of these variables were also included in the analysis. For blood related outcomes, fasting status (number of hour fasted post-intervention, or follow-up, minus number of hours fasted at baseline) was also included as a covariate, to adjust for differences in fasting time.

A magnitude-based inferences framework (Batterham & Hopkins, 2006) was considered superior to null hypothesis testing (Curran-Everett, Taylor & Kafadar, 1998; Hopkins et al., 2009). This method allows for a more realistic and intuitive approach to inferences and is based on where the confidence interval lies in relation to threshold values for substantial effects rather than the null value (Batterham & Hopkins, 2006). Accordingly, the mean effect of the intervention (versus control) for each outcome measure was presented together with the uncertainty of the estimates expressed as 90% confidence intervals, as suggested by Sterne and Smith (2001). Bonferroni corrections of confidence intervals were not applied, in line with the recommendations of Perneger (1998). Log-transformed variables were back transformed to allow the percent difference to be obtained. The adjusted mean intervention effects were evaluated for their practical significance by pre-specifying the minimum clinically important difference (MCID) (Batterham & Hopkins, 2006). In the absence of a robust clinical anchor, the MCID is conventionally defined using a distribution-based method as a Cohen's d (the difference in change scores between groups) of 0.2 between participant standard deviations (SD) (Cohen, 1988). The weighted SD of the pooled baseline values was used for this purpose, as the post-intervention SD may be inflated by individual differences in responses to the exercise intervention (Henaghan et al., 2008). Using the mean intervention effect for each outcome, together with its uncertainty, the probability (percent chances) that the true population effect was substantially beneficial, harmful (>0.2 SDs), or trivial was then calculated (Froehlich, 1999; Shakespeare et al., 2001; Batterham & Hopkins, 2006). This required the calculation of a t statistic for the intervention effect. The conventional t statistic involves a test against the null hypothesis of zero effect ($t = (\text{mean difference between groups} - \text{zero}) / \text{standard error of the difference}$). When calculating the probability of clinical benefit however, the zero in the formula is replaced by the pre-

specified MCID value; thus $t = (\text{mean difference between groups} - \text{MCID}) / \text{standard error of the difference}$. With the correct degrees of freedom for the comparison, the area under the t distribution curve to the left of the $|t|$ value then returns the probability that the true population effect of the intervention is at least as large as the MCID (Batterham & Hopkins, 2006). This process was completed for each effect using a custom-made spreadsheet designed to derive a confidence interval, mechanistic inference and a clinical inference from a p-value (Hopkins, 2007). In this instance, all outcomes were categorised as clinical inferences. Qualitative probabilistic terms were then assigned to each effect using the following scale; <0.5%, most unlikely or almost certainly not; 0.5 to 5%, very unlikely; 5 to 25%, unlikely or probably not; 25 to 75%, possibly; 75 to 95%, likely or probably; 95 to 99.5%, very likely; >99.5%, most likely or almost certainly (Hopkins, 2007; Hopkins et al., 2009). In line with the recommendations by Hopkins et al., (2009), the current study used the default probabilities of <0.5% (most unlikely) for harm and >25% (possibly) for benefit (Hopkins, 2007) for declaring a clinically beneficial effect. A clinically unclear effect was therefore classified as possibly beneficial (>25%), but with an unacceptable risk of harm (>0.5%). This corresponds to a ratio of ~60 for odds of benefit to odds of harm, which is a suggested default when sample sizes are suboptimal or supraoptimal (Hopkins, 2007).

Design effect analysis

To account for the effect of clustering within the schools, a design effect was applied to adjust both the variance used to calculate the t statistic and confidence intervals. This was calculated as $1 + (m-1) \times \text{ICC}$, where m denotes the adjusted mean cluster size (26) and ICC the intraclass correlation coefficient (Wears, 2002). The ICC summarises the variation between and within clusters of participants, and assesses the clustering effect or lack of independence among participants who make up the cluster (Baskerville, Hogg & Lemelin, 2001). Where possible, a design effect was therefore applied to all variables where the inference of the mean effect was initially at least possibly beneficial/ harmful. The ICC values were selected from published, peer reviewed articles of large trials which had similar participant characteristics and outcomes to the current investigation.

Results

Descriptive statistics

Data on the number of measurements collected for each outcome variables across the three time points are presented in Table 14. Two males declined blood profiling measurements post-intervention and at 3-month follow-up, and one female abstained from body

composition assessment across the three time points. Other missing data was due to participants' absence from school on the data collection days. One female in the intervention group dropped out during week 6 of the programme and one male control relocated during the study. Accordingly, data for these individuals was unavailable post-intervention and at 3-month follow-up. Carotid artery intima media thickness measurements were obtained from 42 participants, drawn from one intervention school (24 males) and one control school (11 males and 7 females). Similarly, hsCRP was assessed in 53 participants, of which 26 attended intervention schools and 27 control schools. Of the 91 participants who received Actigraph physical activity monitors at baseline, 61 met the wear time criteria (≥ 4 days wear time and ≥ 600 minutes recorded each day). This decreased to 32 post-intervention and 24 at 3-month follow-up.

Table 14. Number of measurements collected for each outcome variable at baseline, post-intervention and 3-month follow-up

Outcome Measure	Time point assessed			Number of participants measured (Expressed as a % of the sample at baseline [n=101])		
	<i>Baseline</i>	<i>Post-int</i>	<i>Follow-up</i>	<i>Baseline</i>	<i>Post-int</i>	<i>Follow-up</i>
Maturity	✓	✓	✓	97 (96%)	93 (92%)	99 (98%)
Weight	✓	✓	✓	91 (90%)	94 (93%)	83 (82%)
Body composition	✓	✓	✓	86 (85%)	93 (92%)	83 (82%)
Waist circumference	✓	✓	✓	96 (95%)	90 (89%)	95 (94%)
Blood pressure	✓	✓	✓	96 (95%)	98 (97%)	96 (95%)
20 m multi-stage shuttle run test	✓	✓	✓	91 (90%)	95 (94%)	88 (87%)
Carotid intima-media thickness	✓	✓	-	40 (100%) ^a	40 (100%) ^a	-
Lipid accumulation product	✓	✓	✓	94 (93%)	88 (87%)	92 (91%)
Physical activity	✓	✓	✓	91 (90%)	94 (93%)	72 (71%)
Blood profile (lipids and glucose)	✓	✓	✓	98 (97%)	97 (96%)	95 (94%)
High sensitivity C-reactive protein	✓	✓	-	53 (100%) ^b	51 (96%) ^b	-

Post-int = post-intervention
 - Not sampled at this time point
^a sub sample of total study populations (n=40)
^b sub sample of total study populations (n=53)

Descriptive data of the participants' baseline characteristics are shown in Table 15. These are displayed as either the arithmetic mean \pm SD, or the geometric mean \times/ \div SD for variables log transformed prior to statistical analysis. Using the international cutpoints for body mass index for childhood overweight and obesity by sex (Cole et al., 2000), 8% of participants were underweight, 70% were normal weight and 16% were classified as overweight. This is similar to the Health Survey for England prevalence data for 2012; where 64.8% of youths aged 11 to 15 years were normal /underweight and 16.4% were overweight (Ryley, 2013). Levels of obesity were slightly lower in the current sample compared to the Health Survey for England data, however (18.7% vs 6%). Five intervention and three control group participants met the IDF criteria for paediatric metabolic syndrome (Zimmet et al., 2007) and 35 participants (19 intervention) had a waist circumference higher than the 90th percentile for 14 year old British adolescents (70.6 cm for girls and 76.1 cm for boys; McCarthy et al., 2001). Using the cut-offs for VO_{2peak} recommended by Bell et al., (1986) 12% of the female participants (50% of those in the intervention group), and 17% of the males (21% intervention group) were classified as having 'low fitness' ($<35 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ for girls and $<40 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ for boys).

Table 15. Participants' baseline characteristics

Variable	Control (n=60)	Intervention (n=41)
Arithmetic mean \pm SD		
Sex (male/female)	30/30	33/8
Age (years)	14.1 \pm 0.3	14.1 \pm 0.3
Maturity offset (years)	0.5 \pm 1.3	0.3 \pm 1.0
Height (cm)	163.6 \pm 6.9	165.7 \pm 7.2
Weight (kg)	55.3 \pm 9.2	60.2 \pm 15.3
BMI	20.5 \pm 2.7	21.8 \pm 4.5
Body fat (%)	19.6 \pm 7.8	18.3 \pm 11.1
SMM (kg)	24.3 \pm 4.4	26.7 \pm 5.2
WC (cm)	70.0 \pm 8.8	77.4 \pm 13.7
BP (sys) (mmHg)	117.5 \pm 9.8	121.9 \pm 10.7
BP (dia) (mmHg)	68.0 \pm 7.9	72.4 \pm 9.0
20 m SRT performance (Number of shuttles)	60 \pm 23	49 \pm 22
End running speed in 20 m SRT (km·hr ⁻¹)	11.2 \pm 1.1	10.6 \pm 1.1
Predicted VO _{2peak} from 20 m SRT (ml·kg ⁻¹ ·min ⁻¹)	45.6 \pm 6.0	42.6 \pm 5.9
cIMT (mm)	0.40 \pm 0.05	0.40 \pm 0.05
Daily MVPA (mins)	72.8 \pm 32.5	57.5 \pm 18.2
Geometric mean, \times/ \div SD		
TG (mmol/L)	0.85 \times/ \div 1.6	0.86 \times/ \div 1.6
TC (mmol/L)	3.67 \times/ \div 1.2	3.81 \times/ \div 1.2
HDL (mmol/L)	1.36 \times/ \div 1.4	1.34 \times/ \div 1.5
LDL (mmol/L)	1.37 \times/ \div 1.7	1.33 \times/ \div 1.9

GLU (mmol/L)	5.29 \times/ \div 1.2	5.39 \times/ \div 1.1
hsCRP (mg/L)	0.45 \times/ \div 1.6	0.42 \times/ \div 1.7
LAP	7.00 \times/ \div 4.2	10.5 \times/ \div 4.7

BMI = body mass index
 SMM = skeletal muscle mass
 WC = waist circumference
 BP (sys or dia) = blood pressure (systolic or diastolic)
 20m SRT performance= 20m multi-stage shuttle run test performance
 VO_{2peak} = peak oxygen uptake
 cIMT = carotid intima-media thickness
 Daily MVPA = daily moderate-to-vigorous physical activity
 TG = triglycerides
 TC = total cholesterol
 HDL = HDL cholesterol
 LDL = LDL cholesterol
 GLU = glucose
 hsCRP = high-sensitivity C-reactive protein
 LAP = lipid accumulation product

Post-intervention effects

The total exercise time commitment over the 10-week intervention was 459 minutes, inclusive of warm-up and cool-down activities. The total amount of high-intensity work was therefore 159 minutes (~15 minutes per week). In terms of exercise adherence, 75% of the participants attended $\geq 70\%$ of the scheduled exercise blast sessions. Further analysis of the fidelity of the intervention is discussed extensively in Study 4. The adjusted post-intervention effects for each outcome variable are shown in Table 16. Initially, the ANCOVA analysis revealed possibly beneficial or greater effects in the intervention group compared to the controls for eight variables (waist circumference, systolic blood pressure, 20 m multi-stage shuttle run test performance, daily MVPA, triglycerides, total cholesterol, HDL cholesterol and the lipid accumulation product). Prior to further interpretation, a design effect was applied to these using the ICC method described earlier (Wears, 2002). In the Active for Life Year 5 study (a school-based physical activity promotion cluster randomised control trial) an ICC of 0.05 was reported for waist circumference (Lawlor et al., 2011); therefore this value was also applied in the current trial. An ICC of 0.0205 was applied to daily MVPA, which was the same as that reported in a sub-study of the multi-centre cluster randomised Trial for Activity in Adolescent Girls (Murray et al., 2004). For systolic blood pressure, total cholesterol, HDL cholesterol and triglycerides ICC values of 0.0476327, 0.0000001, 0.0300762 and 0.0241539, respectively were applied. These values mirrored those reported by Parker et al. (2005) as part of the Cholesterol Education and Research trial. It was not possible to apply an ICC to 20 m multi-stage shuttle run test performance as there are currently no known values available for adolescents. For the lipid accumulation product, the ICC reported for triglycerides (0.0241539) by Parker et al. (2005) was applied. After

these adjustments, triglycerides were 27% lower (90% confidence interval [CI] -40 to -10%) in the intervention group compared to the controls, which was very likely to be beneficial. Waist circumference and the lipid accumulation product were 3.7 cm (90% CI, -5.8 to -1.7 cm) and 36% (90% CI, -53 to -13%) lower in the intervention group compared to the controls, respectively. Both of these changes were likely to be beneficial. Compared to the controls, daily MVPA was 14.2 minutes (90% CI, -2.6 to 30.9 min) greater in intervention participants which was likely to be beneficial. Possibly beneficial effects were observed in the intervention group compared to the controls for performance in the 20 m multi-stage shuttle run test (+4 shuttles; 90% CI, 0.2 to 6.9 shuttles) and total cholesterol (-3%; 90% CI, -6% to 1%). After ICC adjustment, the intervention effects on systolic blood pressure and HDL cholesterol became unclear. There were no clinically substantial intervention effects for any other outcomes at this time point. Post-intervention, six intervention and six control group participants met the IDF paediatric metabolic syndrome criteria and 40 participants (17 intervention) had a waist circumference higher than the 90th percentile reported for British 14 year olds.

Table 16. Mean post-intervention values adjusted for sex, baseline value and maturity offset from an ANCOVA analysis

Variable	CON	INT	Difference	90% Confidence interval	Likelihood (%) of intervention being beneficial/ trivial/ harmful	Clinical Inference
Weight (kg)	58.5	58.9	+0.4	-0.5 to 1.4	0.0/100.0/0.0	Most unlikely harmful
BMI	21.1	21.3	+0.2	-0.1 to 0.6	0.6/99.4/0.0	Most unlikely harmful
Body fat (%)	20.1	19.7	-0.3	-1.6 to 0.9	3.8/95.8/0.5	Very unlikely beneficial
SMM (kg)	25.3	25.7	+0.4	-0.09 to 0.8	2.8/97.2/0.0	Very unlikely beneficial
WC (cm)*	78.7	75.0	-3.7	-5.8 to -1.7	88.3/11.7/0.0	Likely beneficial
BP (sys) (mmHg)*	119.2	116.2	-3.0	-8.9 to 2.8	61.2/30.9/7.9	Unclear
BP (dia) (mmHg)	64.2	64.4	+0.2	-2.5 to 2.8	17.0/71.2/11.7	Unlikely harmful
20mSRT performance (No. of shuttles)	57	61	+4	0.2 to 6.9	35.8/64.2/0.0	Possibly beneficial
cIMT (mm)	0.417	0.410	-0.007	-0.039 to 0.026	43.4/36.9/19.8	Unclear
Daily MVPA (mins)*	55.0	69.2	+14.2	-2.6 to 30.9	79.9/17.0/ 3.1	Likely beneficial
TG (mmol/L)*	1.04	0.76	-27%	-40% to -10%	95.7/4.2/0.1	Very likely beneficial
TC(mmol/L)*	3.68	3.59	-3%	-6% to 1%	35.5/64.0/0.5	Possibly beneficial
HDL (mmol/L)*	1.13	1.21	+8%	-9% to 27%	51.1/40.8/8.0	Unclear
LDL (mmol/L)	1.65	1.57	-5%	-18% to 10%	22.2/74.8/3.1	Unclear
GLU (mmol/L)	5.26	5.30	+0.9%	-4% to 6%	27.0/61.8/11.2	Unclear
hsCRP (mg/L)	0.36	0.37	+3%	-14% to 24%	28.6/59.3 /12.1	Unclear
LAP*	16.4	10.5	-36%	-53% to -13%	78.6/21.3/0.0	Likely beneficial

* ICC adjusted

3-month follow-up effects

The adjusted 3-month follow-up effects for each outcome variable are shown in Table 17. Possibly beneficial or greater effects were observed in the intervention group compared to the controls for seven variables (waist circumference, systolic blood pressure, daily MVPA, triglycerides, total cholesterol, HDL cholesterol and the lipid accumulation product), therefore the aforementioned ICC values were applied prior to further analysis. After these adjustments, waist circumference was 2.8 cm (90% CI, -4.6 to -1.1 cm) lower in the intervention group compared to the controls, which was possibly beneficial. The lipid accumulation product was 27% lower (90% CI, -50 to 6%) in intervention participants compared to the controls, which was also possibly beneficial. After ICC adjustments were applied to systolic blood pressure, daily MVPA, triglycerides and HDL cholesterol the effects at this time point became unclear and the effect on total cholesterol became unlikely to be beneficial. Compared to the controls, performance in the 20 m multi-stage shuttle run test was lower in the intervention participants by 5 shuttles (90% CI, -8.6 to -1.5 shuttles) which was possibly harmful. There were no clinically substantial effects for any other outcome at 3-month follow-up. At this time point five intervention and six control participants met the IDF paediatric metabolic syndrome criteria and 37 participants (16 intervention) had a waist circumference higher than the 90th percentile reported for 14 year old British youths.

Table 17. Mean 3-month follow-up values adjusted for sex, baseline value and maturity offset from an ANCOVA analysis

Variable	CON	INT	Difference	90% confidence interval	Likelihood (%) of intervention being beneficial/ trivial/ harmful	Clinical Inference
Weight (kg)	60.8	61.2	+0.4	-1.0 to 1.8	0.7/99.2/0.0	Most unlikely harmful
BMI	21.6	21.7	+0.2	-0.4 to 0.7	4.7/94.7/0.5	Very unlikely harmful
Body fat (%)	20.5	20.5	<0.1	-1.8 to 1.9	7.5/86.2/6.3	Unlikely harmful
SMM (kg)	26.0	26.4	+0.4	-0.1 to 1.0	8.9/91.1/0.0	Unlikely beneficial
WC (cm)*	77.8	75.0	-2.8	-4.6 to -1.1	68.9/31.1/0.0	Possibly beneficial
BP (sys) (mmHg)*	115.6	116.6	+1.0	-3.9 to 5.9	36.5/48.4/15.1	Unclear
BP (dia) (mmHg)	65.0	65.3	+0.4	-2.5 to 3.3	22.1/66.1/11.7	Unlikely harmful
20mSRT performance (No. of shuttles)	56	51	-5	-8.6 to -1.5	0.0/35.9/64.1	Possibly harmful
Daily MVPA (mins)*	47.2	64.0	+16.8	-5.6 to 39	79.1/15.1/5.8	Unclear
TG (mmol/L)*	0.94	0.80	-15%	-33% to 9%	66.5/29.6/3.9	Unclear
TC (mmol/L)*	3.46	3.45	-0.4%	-1% to 4%	14.3/76.8/8.9	Unlikely beneficial
HDL (mmol/L)*	1.14	1.19	+4%	-10% to 21%	14.3/76.8/8.9	Unclear
LDL (mmol/L)	1.40	1.48	+6%	-13% to 29%	32.0/61.3/6.8	Unclear
GLU (mmol/L)	5.33	5.42	+2%	-2% to 6%	35.9/60.0/4.0	Unclear
LAP*	14.5	10.5	-27%	-50% to 6%	53.8/45.8/0.4	Possibly beneficial

*** ICC adjusted**

Discussion

Despite accumulating evidence on the benefits of low-volume HIT in adults, the effectiveness of this training concept in young people has yet to be fully elucidated. Furthermore, it remains unknown whether low-volume HIT models utilising exercise modes other than cycle ergometry or running can lead to favourable changes in health and fitness outcomes. The aim of this study therefore, was to examine the effects of a 10-week school-based low-volume HIT intervention on established and novel cardiometabolic risk markers and physical activity levels in 13 to 15 year old adolescents. Here, low-volume HIT consisted of repeats of 45-s 'all out' efforts of basketball, boxing, dance and football activities, each interspersed with 90-s rest. In terms of exercise session attendance, the intervention was well adhered to, with 75% of the participants attending $\geq 70\%$ of the sessions and only one intervention participant lost to drop out. The fidelity of the intervention, assessed via heart rate responses to the exercise blast activities and post-trial focus groups, will be examined in Study 4 of this thesis.

Following the 10-week exercise blasts programme, very likely beneficial or likely beneficial effects were observed in the intervention participants (compared to the controls) for triglyceride levels, waist circumference, lipid accumulation product and daily MVPA. Possibly beneficial effects were observed for 20 m multi-stage shuttle run test performance and total cholesterol. These observations extend the positive findings from previous youth-based low-volume HIT trials, where enhancements in fitness have also been displayed (Buchan et al., 2011a; de Araujo et al., 2012). Furthermore, this is the first study to the author's knowledge that demonstrates that a multi-activity low-volume HIT trial can substantially improve triglyceride levels, waist circumference measures, lipid accumulation product and daily MVPA in adolescents. The first two findings are of particular importance from a cardiometabolic risk factor clustering perspective; since high measures of these variables can indicate the presence of the metabolic syndrome (Zimmet et al., 2007). Accordingly, Project FFAB may represent a novel and viable way of improving adolescents' cardiometabolic health within the school setting.

Though it is documented that the aerobic exercise can improve triglyceride levels in children and adolescents (Kelley & Kelley, 2007), previous low-volume HIT studies have produced conflicting results on this outcome. In the work by Buchan et al. (2011a), triglycerides increased across the participants post-intervention; whereas in the study by de Araujo et al. (2012) a small effect (-9%; effect size 0.350) was observed in the low-volume HIT group.

In adult studies, a downward trend in triglycerides following low-volume HIT has been reported (Whyte et al., 2010) however this did not reach statistical or practical significance. Project FFAB is therefore the first low-volume HIT trial in either adults or young people to show a very likely beneficial reduction in triglycerides post-intervention (-27%, compared to the controls). Whilst the mechanisms behind this remain unclear, recent findings suggest that it may be due to reductions in the postprandial lipaemic response (Thackray et al., 2013). Indeed, a single session of low-volume HIT has been shown to attenuate postprandial lipaemia in healthy adult males (Freese et al., 2011; Gabriel et al., 2012), and more recently, in young adolescent boys (Thackray et al., 2013). In the latter, changes in fasting plasma triglyceride concentration were small to moderate (effect size 0.40), after a low-volume HIT running session based on the 10 × 60-s model devised by Little et al. (2011). Given that similarities between this protocol and that employed in the current study exist, it is reasonable to suggest that the observed decrease in triglycerides may be due to reductions in the postprandial lipaemic response. Whilst the effect became unclear at 3-month follow-up, the role of elevated triglycerides in the development of cardiovascular disease and the metabolic syndrome (Zimmet et al., 2007) vindicates the relevance of these findings. It is however possible that the decrease reflected a change in the participants' diet, as dietary intake was not recorded during the trial. Participants were however instructed not to change their eating habits throughout the study, so it is unlikely that such a substantial reduction in triglycerides could be attributed to this. Whilst a possibly beneficial intervention effect was reported for total cholesterol (-3%), the influence on HDL cholesterol and LDL cholesterol was unclear. As such, the impact of low-volume HIT on components of blood cholesterol remains relatively unknown.

Although no meaningful changes in body mass, BMI, percentage body fat and skeletal muscle mass were detected post-intervention, waist circumference was 3.7 cm lower in the intervention group compared to the controls. This effect was likely to be beneficial, and reflected an increase in the control participants' measures from baseline and a slight reduction in the intervention group. At 3-month follow-up waist circumference remained 2.8 cm lower in the intervention group, which was possibly beneficial. Further inspection of the results revealed that waist circumference was maintained in this group from post-intervention to 3-month follow-up. The smaller overall effect was therefore due to a slight improvement in the control participants' measures between post-intervention and 3-month follow-up. This therefore provides evidence of a maintenance effect in the intervention participants. Similar post-intervention observations have been reported in aerobic training

studies, such as that by Lee et al. (2005b). Here, statistically significant within-group differences were observed for waist circumference in lean and obese adult males with and without type 2 diabetes following a 13-week aerobic exercise programme. As in Project FFAB however, these changes were not accompanied by weight loss. Lee's findings confirmed earlier work from their laboratory, which, in the absence of weight loss, significant reductions in abdominal and visceral fat were found in obese men (Ross et al., 2000) and women (Ross et al., 2004) following aerobic training. More recently, Heydari et al. (2012) reported significant reductions (compared to the controls) in waist circumferences, abdominal and visceral fat levels of overweight young adult males following 12-weeks of high-intensity intermittent exercise, however these were also accompanied by a reduction in body weight. The present study therefore, is the first to demonstrate that low-volume HIT can, in the absence of weight loss, meaningfully reduce waist circumference in adolescents, which is still evident three months post-intervention. Given the apparent increase in waist circumferences of English adolescents over the last 35 years (Mindell et al., 2012), this finding is particularly encouraging.

Whilst the mechanisms that subtend reductions in waist circumference following low-volume HIT are unclear, several explanations have been offered. Firstly, there is evidence to suggest that, during exercise, lipid mobilisation from the abdominal region is greater than that in the femoral region (Arner et al., 1990). Although the body composition analysis device employed in the current study was unable to confirm or deny whether this occurred, it may partly explain why waist circumference decreased. It has also been reported that an acute session of HIT generates significant levels of catecholamines (Trapp et al., 2007). This could lead to elevations in post-exercise fat oxidation (Heydari et al., 2012), as catecholamines have been shown to drive lipolysis and are mainly responsible for fat release from visceral fat stores, in animal models at least (Issekutz, 1978). This however, has not been definitively examined in adolescents, and is therefore merely speculative at this time.

The likely beneficial reduction in the lipid accumulation product (-38%) in the intervention group reflects the changes in triglycerides and waist circumference that have already been discussed. As this index has been associated with metabolic syndrome prevalence in adults; it is possible that the marked reduction seen here may also represent a decrease in syndrome risk in the intervention participants. Since the diagnostic accuracy of the lipid accumulation product has not yet been assessed in young people however, this suggestion is largely speculative. Nonetheless, the usefulness of the index is evidenced when incidences of

metabolic syndrome are viewed alongside changes in individual syndrome components and the lipid accumulation product at the three data collection points. As the number of metabolic syndrome cases did not vary greatly across the study, it could have been deemed unsuccessful at reducing syndrome risk in young people. By including a continuous risk function variable and reporting changes in the individual syndrome components however, it was possible to provide information on which markers had changed, particularly in the areas that represent the greatest physiological danger. This is reflected in the lipid accumulation product scores, and provides further evidence against relying exclusively on a dichotomous diagnosis tool (Kahn, 2005).

The impact of low-volume HIT on youth physical activity levels has only been examined once previously (Boddy et al., 2010). Here, non-significant improvements in daily MVPA (2.97 minutes) were reported for the intervention group, with control data unavailable due to the majority of participants failing to meet the activity monitor wear time requirements. In Project FFAB, there was a likely beneficial effect for daily MVPA of 14.2 minutes in the intervention group compared to the controls. This reflected a decrease in the control participants' MVPA from baseline, and an increase in the intervention group. Whilst this effect became unclear at 3-month follow-up, it is nonetheless promising and warrants further investigation. It should however be highlighted that compliance to physical activity monitoring during the study was somewhat problematic. Very few of the physical activity logs were completed, which led to this data not being analysed. Additionally, across the three data collection points, the percentage of participants meeting the monitor wear time criteria decreased from 67% at baseline, to 35% and 26%, post-intervention and at 3-month follow-up respectively. These figures are however, not dissimilar to those reported in the Health Survey for England 2008 document (Craig et al., 2009). Here, 43% of boys and 47% of girls aged 4 to 15 years met the same monitor wear time criteria as that used in Project FFAB, with data only collected on one occasion. As such, whilst continued compliance was somewhat disappointing in the current study, this appears to be a common problem which has been highlighted by others (e.g. Trost et al., 2005). It is therefore suggested that readers are mindful of this limitation when interpreting the MVPA data presented here, and elsewhere in the literature. With regards to improving wear time compliance, it was noted that many of the participants did not like that their monitor could be seen by others, and that it interfered with their clothes choices at weekends. A similar complaint to the former was reported by Boddy et al. (2010), which questions the appropriateness of hip mounted monitors for use in adolescent populations. Whilst others have reported high hip monitor

compliance in US adolescents (86% of 282 participants wore monitors for ≥ 4 days) (Van Coevering et al., 2005), the authors acknowledged that this may have been aided by participants receiving two face-to-face reminder visits over the 7-day collection period. Furthermore, these participants received incentives in the form of cinema vouchers if they returned their monitor on time. Such strategies have been suggested by others to promote monitor compliance (Troost et al., 2005), however due to financial and time restraints, this would not have been possible in the current study.

Given that high levels of cardiorespiratory fitness in youth may offer disease protection (Brage et al., 2004; McMurray et al., 2010), the possibly beneficial effect of the intervention on performance in the 20 m multi-stage shuttle run test (+4 shuttles), an indirect measure of cardiorespiratory fitness, was encouraging. This occurred despite the exercise mode of the fitness test and the intervention sessions differing. It is important to highlight this due to reports that performance improvements are more likely in trials where there are strong similarities between the exercise testing and training sessions (Buchheit et al., 2012). This has been the case in the majority of the previous low-volume HIT studies, where both exercise test and the subsequent training have constituted either running or cycling activities. In the current study however, running was only included in some of the exercise blast sessions, and then often mixed with actions such as throwing and catching a ball and punching boxing focus pads. The findings therefore provide some support for the use of multi-activity low-volume HIT as a means of improving 20 m multi-stage shuttle run test performance in young people. It is necessary to highlight however, that at 3-month follow-up a possibly harmful effect (-5 shuttles) was observed for the intervention group, compared to the control. This suggests that taking part in the trial had a negative impact on the intervention participants' performance in the 20 m multi-stage shuttle run test three months later. Whilst this is potentially concerning, there are a number of factors that should be considered prior to interpretation of this finding. As Project FFAB is the first youth-based low-volume HIT trial to include follow-up measures, there is currently no data available to which the results can be compared. As such, it is unknown whether similar decreases in fitness may have occurred in other low-volume HIT studies once the intervention was removed. With regards to the actual fitness test, it often proved challenging to engage the participants in this, which appeared to become more pronounced in the later phases of data collection. This was not entirely unexpected, given earlier reports that adolescents often fail to participate in such tests, or deliberately produce poor performances (Naughton et al., 2006). The latter may have occurred during Project FFAB, particularly at intervention

school 2. Here, participants appeared to have disengaged with the study by the 3-month time point. Informal conversations between the researcher and the participants indicated that this may have been due to the participants' awareness that they were not going to receive any incentives for completing this section of the trial. Furthermore, the follow-up measures were completed at the start of a new school year. As such, the participants were in different PE classes from when they had completed the intervention, and it seemed that some resented being asked to leave their normal PE lesson to complete the multistage fitness test. This scenario did not occur at any of the other schools, where the participants remained grouped as they were during the earlier phases. Whilst purely speculative, the circumstances encountered at intervention school 2 may have led to feelings of resentful demoralisation (Cook & Campbell, 1979). This in turn, could then have influenced the participants' fitness test performance, which could partly account for the findings. Across the schools, there were also some discrepancies between how the PE teachers and the researchers administered the fitness test, which may have confused the participants. For example, some reported that when the test was undertaken under non-research conditions as part of normal PE, their teachers allowed them to miss three consecutive bleeps before dropping out. In the present study however, the researchers only permitted two. This may have led to feelings that the researchers were being unduly strict, which could have led to disengagement. Whilst these observations are only anecdotal, they highlight some of the problems that can be encountered when fitness testing takes places in 'real world' settings. Although it is documented that the multistage fitness test is reliable and valid for estimating VO_{2peak} in children and adolescents (Castro-Piñero et al., 2010), external, unforeseen issues experienced in the current study does question the appropriateness of the multistage test for some adolescents. To overcome this, future studies could look to include measures of fitness that have less 'stigma' attached to them (Cale & Harris, 2005). This may then allow the effect of low-volume HIT on cardiorespiratory fitness in adolescents to be fully elucidated.

Given the low values reported at baseline for hsCRP, observations of an unclear intervention effect were not surprising. A similar scenario was evident in the trial by Buchan et al. (2011a), where hsCRP did not significantly change in either the low-volume HIT or the moderate training group across the intervention period, despite average baseline values here being over three times that reported in the current study (~1.40 mg/L vs ~0.44 mg/L). Indeed, a third of data hsCRP collected in Project FFAB consisted of readings that were below the minimum range detected by the Cholestech LDX analyser (<0.3 mg/L). As such, these values were entered as 0.29 mg/L, which may be an overestimation of the true value.

When it is then considered that hsCRP values of <1.0 mg/L in adults are classified as low risk (Pearson et al., 2003), it appears that participants were at very low risk of inflammation from the study onset. This in itself may explain the unclear effect, as the hsCRP levels were already so low that further decreases may not have been possible, and slight increases did not represent physiological danger. Accordingly, whether low-volume HIT can positively influence inflammatory markers in adolescents presenting with low-risk values at baseline, remains unknown.

In both the trials by Buchan et al. (2011a) and de Araujo et al. (2012), significant within-group differences were reported for systolic blood pressure in the low-volume HIT participants post-intervention. Whilst between- rather than within-group differences were reported in the current study, a possibly beneficial effect was initially observed in the intervention group compared to the controls for systolic blood pressure (-3.0 mmHg). This effect however, became unclear after ICC adjustment. Nonetheless, as the design effect analysis was completed using an ICC value from a different study, the resulting inference may be somewhat conservative. With this, and the work of others in mind, it is possible that systolic blood pressure may indeed be influenced by low-volume HIT and warrants further study.

Limitations

Although this study is the first to demonstrate that a multi-activity low-volume HIT intervention can induce meaningful improvements in aspects of cardiometabolic health, fitness and physical activity levels in adolescents, it is not without limitations. The use of an observational rather than a randomised design may weaken the impact of the findings, due to the potential introduction of bias (Deeks et al., 2003; Shrier et al., 2007). Since the study participants were from four different schools, it is acknowledged that selection bias (where systematic differences in the treatment groups arise at baseline) may have occurred. Nonetheless, this was at least partly accounted for by including the participants' baseline value for each outcome in the statistical analysis. Further issues can arise however when potential confounders are not included in the analytical model, either because the researcher is unaware that they exist and has therefore not measured them, or has not measured them well (Shrier et al., 2007). Whilst this scenario can also transpire in non-observational trials, it is less problematic due to the expectation that potential confounders will be equally distributed in each group, thus removing any association between treatment exposure and the potential confounder (Shrier et al., 2007). This assumption cannot be made in Project

FFAB however, due to the non-randomised allocation of schools to the intervention or the control condition. As such, it is possible that despite the efforts to match the study schools on factors such as socioeconomic status and school specialism, unknown confounders may have impacted the study findings.

It could be suggested that the extrapolation of findings in the study is limited, due to the relatively small number of participants and school clusters. However, it is important to recognise that the study was exploratory in design, and led largely by one researcher. As such, the inclusion of more study schools at this stage would not have been feasible, and may have comprised the delivery of the intervention (Dumas et al., 2001). The enhancement of several health and fitness outcomes post-intervention however, provides justification for a similar definitive trial involving greater numbers of participants, across multiple school sites. The small number of girls in the intervention group was a potential concern, however this was unavoidable due to access issues at intervention school 2. Nonetheless, this is recognised as a shortcoming, as it remains unknown whether chronic responses to low-volume HIT differ by sex in adolescent participants. With regards to the study population, the heterogeneity in some of the outcome measures (namely performance in the 20 m multi-stage shuttle run test, daily MVPA and body weight) resulted in large SDs. This may therefore have decreased the likelihood of detecting trial effects, since the minimum clinically important difference is derived from the baseline SD (Hopkins et al., 2009). Nonetheless, the large SDs could also be interpreted as an indication that the trial successfully recruited a wide range of participants, in terms of health and fitness levels, instead of only, for example, particularly fit or unfit individuals. This also provides further support for the use of school-based interventions as a means of engaging with a diverse population of young people (Lobstein & Swinburn, 2007).

Conclusions

The results presented here build on work from earlier youth-based low-volume HIT trials, by demonstrating that a 10-week school-based low-volume HIT intervention based on basketball, boxing, dance and football, can lead to meaningful improvements in the triglyceride levels, waist circumference, lipid accumulation product and daily MVPA of 13 to 15 year old adolescents. In addition, possibly beneficial effects (compared to the controls) were observed for performance in the 20 m multi-stage shuttle run test and total cholesterol. Though the vast majority of these effects were not apparent at 3-month follow-up; the potential potency of the findings remains. Furthermore, the study goes beyond previous

work, by demonstrating that low-volume HIT can be applied in a ‘real world’ settings and utilising novel exercise modes. Whilst the limitations of the trial are acknowledged, Project FFAB may yet represent a novel and viable way of improving health and fitness outcomes in young people. Further work is needed to provide a definitive answer on this. In addition, it has recently been stressed that the results of an exercise study are of very little use without precise, thorough and in-depth information about the training itself (Mujika, 2013). As such, the final study presented in this thesis will examine the heart rate responses of the intervention participants during the 10-week trial.

Chapter 7: Evaluating the intervention fidelity of Project FFAB through mixed linear modelling and focus groups (Study 4)

Introduction

Despite many journals endorsing trial reporting guidelines such as the CONSORT (Consolidated Standards of Reporting Trials) statement (Schulz et al., 2010), the quality of

descriptions of health improvement interventions remains unacceptably poor (Hoffman et al., 2014). This can be problematic in exercise trials like Project FFAB, where establishing the exercise dose received by the participants is key (Resnick et al., 2011; Weston et al., 2014). This issue underlines the importance of intervention fidelity; the demonstration that an experimental manipulation has been implemented as intended, and in a comparable manner to all participants (Dumas et al., 2001). Fidelity is integral to the internal validity of intervention-based trials (Bellg et al., 2004; Horner, Rew & Torres, 2006) and it has recently been emphasised that the findings of an exercise intervention are of very little value without precise, thorough and in-depth information about the exercise itself (Mujika, 2013). Despite this, it appears that across health research, key features including intervention duration, dose, intensity, and monitoring are often missing or poorly described in trial manuscripts (Hoffman et al., 2014).

To date, intervention fidelity procedures have scarcely been reported in the literature (Bellg et al., 2004; Resnick et al., 2011). Perhaps unsurprisingly therefore, items 11 and 12 of the new Template for Intervention Description and Replication (TIDieR) checklist (Hoffman et al., 2014) relate directly to this issue. Here, it is suggested that “If the intervention adherence or fidelity was assessed, (authors should) describe how and by whom” (item 11), and “the extent to which the intervention was delivered as planned” (item 12). In exercise trials, authors frequently report adherence in the form of exercise session attendance, yet very often fail to indicate the extent to which participants complied with the prescribed exercise intensities (Miller et al., 2014). To ensure satisfactory intervention delivery, the gold standard is to evaluate or code sessions according to a priori criteria (Bellg et al., 2004). As exercise intensity is very often the essential component of an exercise trial, intensity monitoring throughout an intervention would provide an objective measure of the intervention validity (Horner et al., 2006). This could be afforded through heart rate monitoring which is regarded as one of the best ways to monitor exercise intensity (Impellizzeri et al., 2004). As the prescription of intensity via heart rate is commonplace, it is surprising that so few exercise studies use heart rate data to demonstrate intervention fidelity. Of the studies that have provided intervention heart rates (e.g. Weston et al., 2004; Boddy et al., 2010; Buchan et al., 2011a; Miller et al., 2014) only mean and standard deviation (SD) data are provided. However, repeated exercise sessions performed across an intervention period will give rise to between-participant and within-participant variability in the exercise intensity response. As the SD alone provides no information pertaining to this

variability, the reader is left unable to establish whether the content and process of the intervention was uniform for all participants throughout the trial (Dumas et al., 2001).

The use of mixed linear modelling would overcome this shortcoming, as the random effect component of the analysis provides an estimation of the between- and within-participant variability. This approach would therefore demonstrate the magnitude of consistency in the application of intervention exercise intensity for all participants across the intervention time period. The first aim of this study therefore, was to use mixed linear modelling to evaluate the fidelity of Project FFAB. Fidelity can also be assessed by exploring the participants' perceptions and understanding of the intervention (Moncher & Prinz, 1991; Bellg et al., 2004). As such, the second aim of this study was to explore the participants' experiences of the main trial, via semi-structured focus groups.

Methods

Design and Participants

Approval for this study was granted by Teesside University's School of Health & Social Care Research Governance and Ethics Committee in January 2011 (heart rate analysis; study number 008/11) and May 2011 (focus groups; amendment to study number 008/11). Full details of the 10-week low-volume HIT protocol can be found in Study 3. The heart rate data presented are from participants from both intervention schools (n=41). All those who completed the main trial were invited to take part in the post-intervention focus groups (n=40). Of these, 33 participants (14 from intervention school 1) returned parental consent and participant assent forms and went on to complete this section of the study. Reasons for non-participation included forgetting to return consent forms (n=6) and electing not to take part (n=1).

Heart rate analysis

At the start of each of the PE-based session participants put on a heart rate monitor (Polar RS400, Kempele, Finland), with data then collected at 5-s intervals throughout. Due to equipment shortages, this was only possible for 50% of the participants per session at intervention school 2. At intervention school one however, monitors were worn by all of the participants for the PE-based sessions. Time restrictions and an attempt to minimise participant inconvenience meant that heart rate data were not collected at the after school or lunchtime sessions. A cut-point of ~90% of maximal heart rate was used as the criterion for

satisfactory delivery of low-volume HIT, reflecting that used in previous HIT work (e.g. Boddy et al., 2010; Little et al., 2011). As was the case in Study 2, this cut-point was used to confirm the intensity of the exercise rather than prescribe it, and participants were not made aware of to what 90% of their maximum heart rate corresponded.

After each PE-based session, heart rate files were downloaded into the Polar ProTrainer software (Polar Electro, Kempele, Finland). Initially, all files were visually inspected and values outside the normal physiological range expected for the participants ($>220 \text{ beats}\cdot\text{min}^{-1}$ or $<40 \text{ beats}\cdot\text{min}^{-1}$) were corrected using the software's error correction function. Following this, any heart rate data still displaying uncharacteristic spikes or plateaux were omitted from the analysis due to a lack of validity. The mean and peak heart rates of each 45-s exercise blast from each individual file were then calculated. These values were expressed as a percentage of the individual's maximal heart rate. Participants' maximal heart rates were determined as the highest 5-s value recorded during the exercise blasts, or during the multistage fitness test. This method can enable a more accurate determination of maximal heart rate than a single maximal fitness test (Weston et al., 2004). The average (\pm SD) maximal heart rate for the entire intervention group was $204 \pm 7 \text{ beats}\cdot\text{min}^{-1}$. Of the 41 values that made up this dataset, 32 were attained by participants during the 20m MSFT (average $205 \pm 7 \text{ beats}\cdot\text{min}^{-1}$) and 9 during the exercise blast sessions ($201 \pm 6 \text{ beats}\cdot\text{min}^{-1}$). The mean and peak heart rate data for each 45-s exercise blast were then analysed via IBM SPSS Statistics Version 21, using a mixed linear model with random intercepts to estimate the variability of exercise intensity between- and within-participants. The latter was also adjusted for the random effects of session and exercise blasts nested within a session; as part of the within-participant variation can be attributed to all of the participants performing a particular session/blast at a higher or lower intensity. When analysing the mean heart rate averaged over the 45-s exercise blasts for intervention school 2 however, the random effects model failed to converge. A fixed effects model was therefore utilised, with session and exercise blasts within a session the fixed effects. As such, the random effects for session and exercise blast are not available for this outcome. Data are expressed as mean \pm SD, with uncertainty in the estimates expressed as 95% confidence intervals.

Focus groups

The focus groups were led by a trained Teesside University researcher who had not been present at the exercise sessions, but whom the participants were familiar with from the baseline data collection. This was enacted to maximise the likelihood of the participants

speaking freely about the intervention, without their responses being influenced by the presence of the lead researcher. Another researcher took notes during the discussions and provided a session summary. The focus groups took place during the participants' PE lessons in school classrooms, with the researchers sitting amongst the participants. The interview script was designed to encourage conversation on three broad topics; the exercise blast activities, the structure of the exercise sessions and the trial as a whole. As such, the sessions began with questions such as which activities the participants' liked and disliked, how long the blasts were performed for, and how they made the participants feel. In the second section participants were asked to compare their experiences of the PE based sessions to those held after school or at lunchtime. They then shared their reasons for attending and/or not attending the exercise sessions, and their opinions of the people that led them. During conversations on the trial in general, participants were asked if there was anything they would change about the study, and whom they thought the intervention might appeal. They were then asked to reflect on how they felt after taking part in the trial, and how they would feel if Project FFAB continued as part of their normal PE lessons. Finally, they were asked to anonymously record why they had volunteered for the study in the first place. All of the sessions were recorded using a digital recorder (Edirol R-09HR; Roland) and transcribed verbatim by the lead researcher. The raw transcription data were analysed using thematic content analysis (Burnard, 1991) in an identical manner to that described in Study 1. For further information on this method, please see the data analysis methods section of Study 1.

Results

Heart rate analysis

One participant at intervention school 1 dropped out of the study after week 6; however their heart rate data up to this point was included in the analysis. As such, 146 of a possible 166 individual heart rate files (88%) from this school were analysed. At intervention school 2, two participants sustained injuries unrelated to the study after weeks 5 and 7. Here, 133 of a possible 231 heart rate files (58%) were analysed. Missing files were due to participant absence or invalid data. As stated previously, data was not collected at the after school/ lunchtime sessions. Accordingly, the data presented herein refer to the PE-based sessions.

At intervention school 1, the mean heart rate averaged for the 45-s exercise blasts across the low-volume HIT sessions was 85.6% of individual maximal heart rate, with a between-participant SD of 3.1 percentage points (95% confidence interval 2.2 to 4.5 percentage

points). This indicates that the mean heart rate averaged across the 45-s blasts varied between participants from 82.0% to 88.7% of individual maximal heart rate (Figure 7). The within-subject SD was 4.4 percentage points (4.3 to 4.6 percentage points), which was adjusted for the random effects of session (1.2 percentage points; 95% confidence interval -0.9 to 1.9 percentage points), and repetitions nested within a session (1.6 percentage points; 1.3 to 2.0 percentage points). As such, the participants' mean heart rate averaged over 45-s varied from 81.2% to 90.0% of maximal within different low-volume HIT sessions and/or exercise blasts across the intervention (Figure 7).

The mean peak heart rate for the 45-s exercise blasts across the intervention at school 1 was 91.4% of individual maximal heart rate, with a between-participant SD of 2.6 percentage points (95% CI, 1.8 to 3.8 percentage points). This indicates that the mean peak heart rate varied between participants from 88.0% to 94.0% of individual maximal heart rate (Figure 8). The within-subject SD was 3.6 percentage points (95% CI, percentage points), which was adjusted for the random effects of session (1.1 percentage points; 95% CI, -0.7 to 1.7 percentage points), and repetitions nested within a session (1.3 percentage points; 95% CI, 1.0 to 1.6 percentage points). As such, the participants' mean peak heart rate varied from 87.8% to 95.0% of maximal within different HIT sessions and/or repetitions across the intervention (Figure 8).

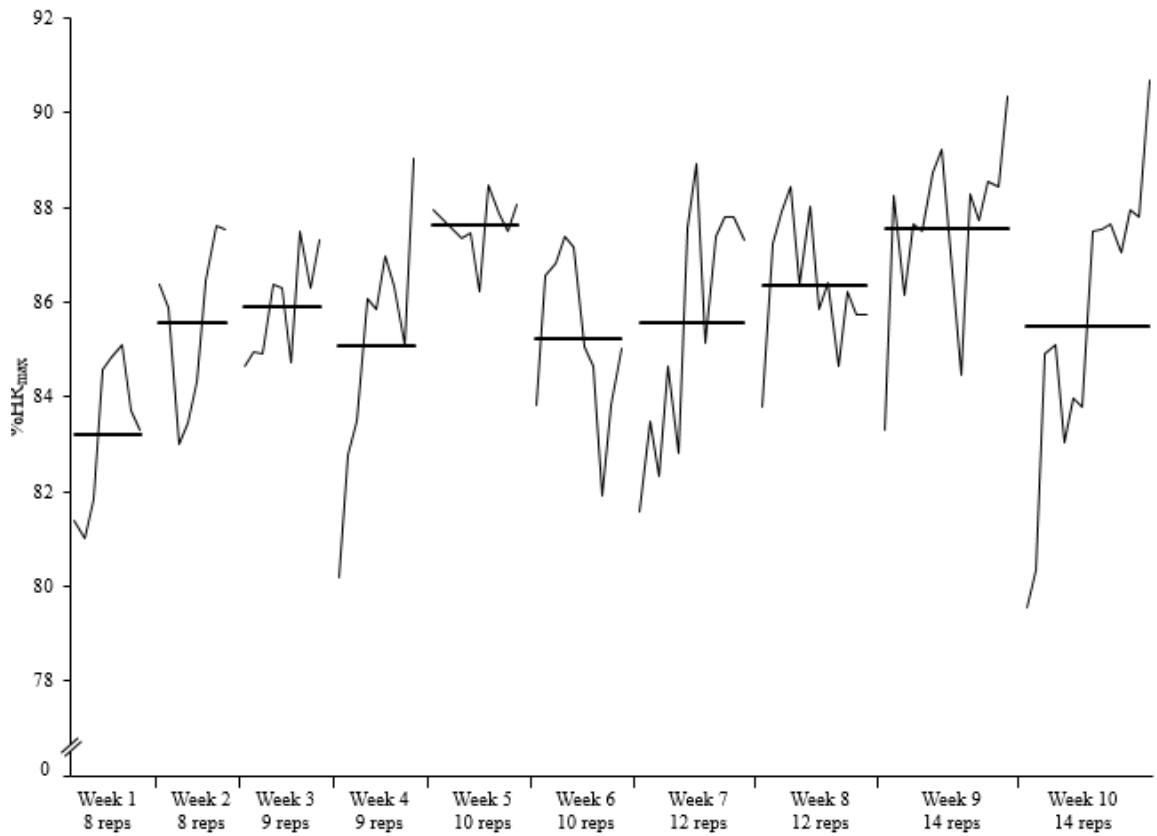


Figure 7. Mean heart rate responses averaged over each 45-s exercise blast (Intervention school 1)

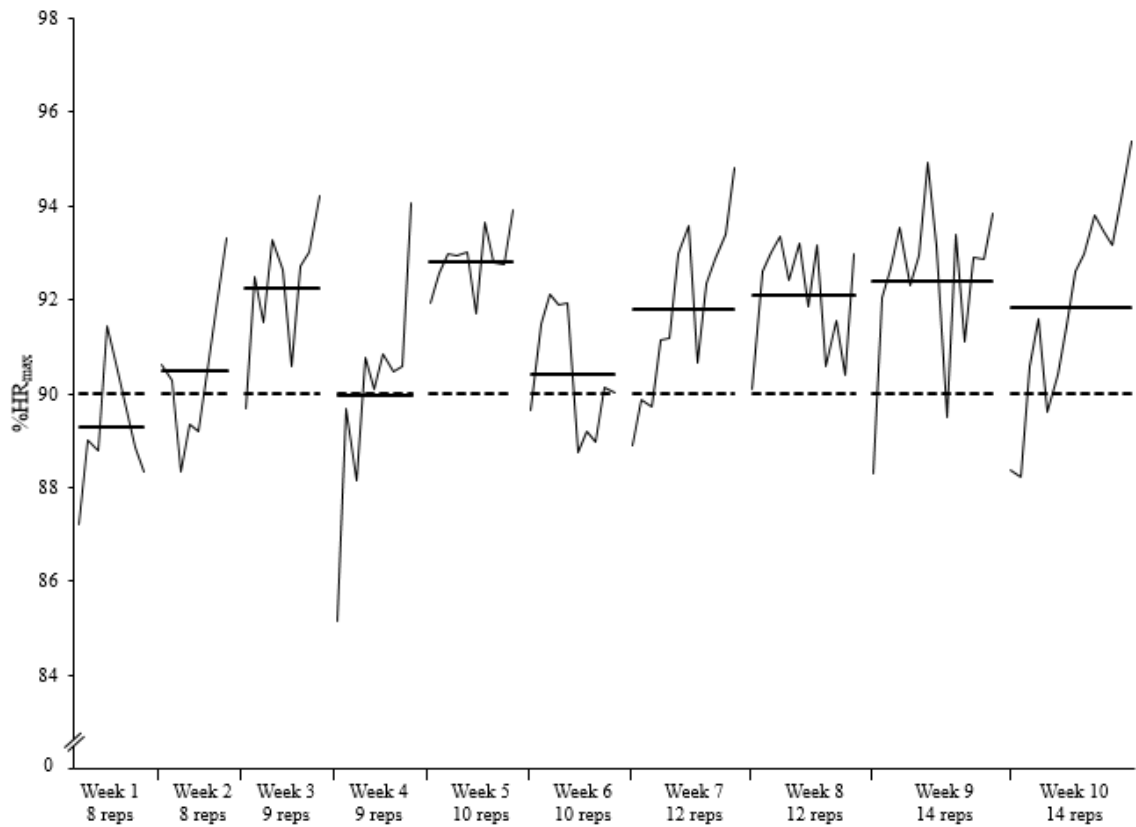


Figure 8. Mean peak heart rate response for each 45-s exercise blast (Intervention school 1)

At intervention school 2, the mean heart rate averaged for the 45-s HIT repetitions across the intervention was 84.1% of individual maximal heart rate, with a between-participant SD of 3.6 percentage points (95% CI, 2.6 to 4.9 percentage points). This indicates that the mean heart rate averaged across the 45-s exercise blasts varied between participants from 80.5% to 87.7% of individual maximal heart rate (Figure 9). The within-subject SD was 5.4 percentage points (95% CI, 5.2 to 5.7 percentage points). As such, the participants' mean heart rate averaged over 45-s varied from 78.7% to 89.5% of maximal within different HIT sessions and/or repetitions across the intervention (Figure 9).

The mean peak heart rate for the 45-s exercise blasts across the intervention at school 2 was 90.0% of individual maximal heart rate, with a between-participant SD of 3.6 percentage points (95% CI, 2.7 to 5.0 percentage points). This indicates that the mean peak heart rate varied between participants from 86.4% to 93.6% of individual maximal heart rate (Figure 10). The within-subject SD was 4.5 percentage points (95% CI, 4.3 to 4.7 percentage points), which was adjusted for the random effects of session (1.9 percentage points; 95% CI, -0.9 to 1.8 percentage points), and exercise blasts nested within a session (0.5 percentage points; 95% CI, -1.3 to 1.5 percentage points). As such, the participants' mean peak heart rate varied from 85.5% to 94.5% of maximal within different HIT sessions and/or repetitions across the intervention (Figure 10).

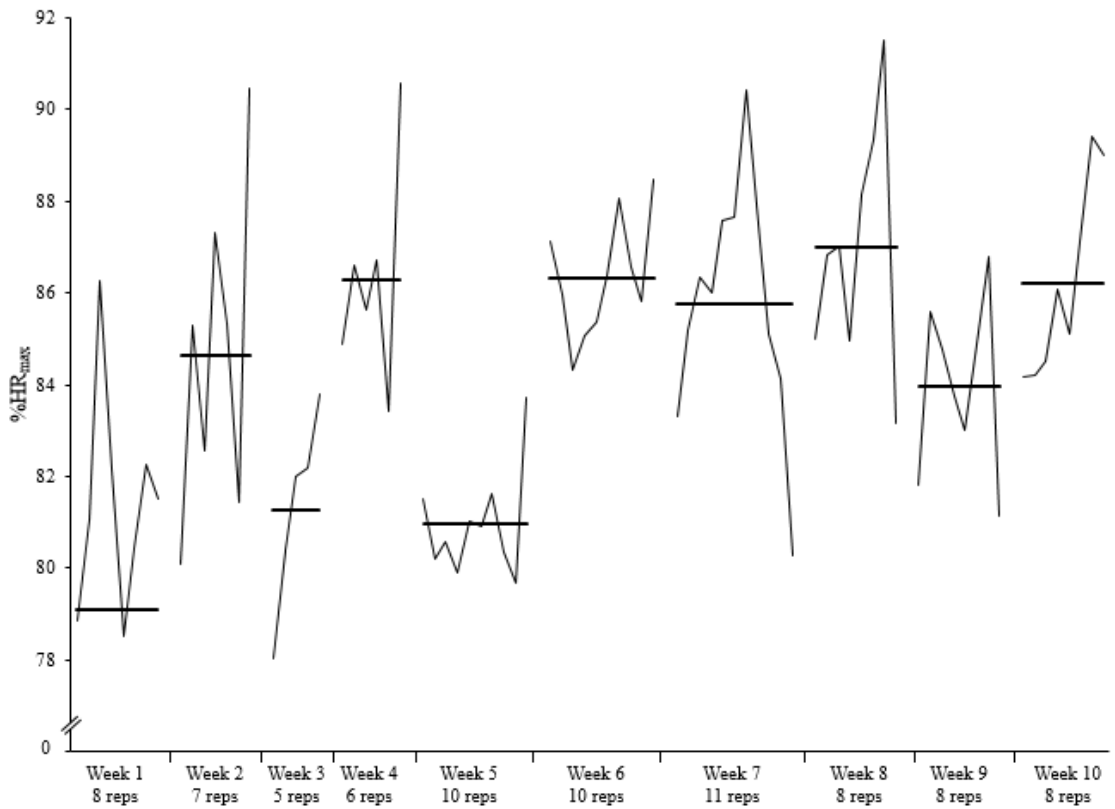


Figure 9. Mean heart rate response averaged over each 45-s exercise blast (Intervention school 2)

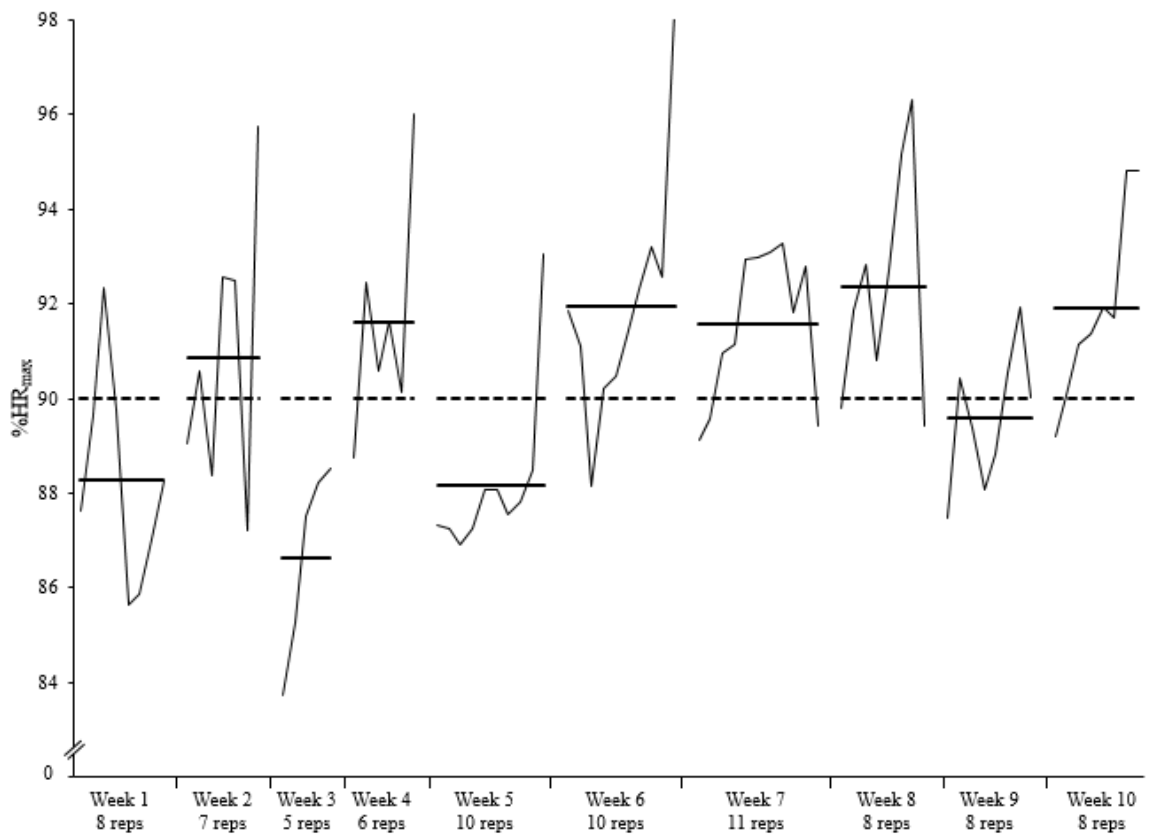


Figure 10. Mean peak heart rate response for each 45-s exercise blast (Intervention school 2)

Focus groups

Two focus groups were conducted at intervention school 1, and a further three were held at intervention school 2. As such, the qualitative data consisted of five transcripts that resulted in 81 pages of raw transcription data. The main topics of discussion are summarised below, with illustrative quotes provided where appropriate. Due to the intervention delivery differing slightly across the two schools (e.g. double versus single sessions, different exercise blast activities), the findings from each school are presented separately.

Intervention school 1

Exercise blast activities

Participants described exercise blasts consisting of boxing, basketball, cheerleading, dance, football and running. Generally, the blasts were spoken about positively, with participants citing different activities as their favourite and least favourite. No single activity emerged as the most popular or unpopular, though a few males and females reported that they did not like the dance and the boxing, respectively. Participants then elaborated on why they enjoyed certain activities, which often related to trying something new and mastering a skill, as illustrated in the quotes below.

“I just liked it. It was different from what you normally do in football, in a PE lesson... We did that toe touching thing that I’ve actually never done before and I actually started to get better at it.”

(Male; Focus group 1)

“I liked it all, but I’ve gotta say dancing cause I really like dancing. I’m doing BTEC next year. Then cheerleading cause I’d always wanted to do it and it was something I never got round to doing until I did it here. And then the boxercise cause it was really fun. I was like, really lazy, but once we started challenging the others I got really competitive. And then last the running cause I’m not really a running person.”

(Female; Focus group 2)

The participants then recalled how long they had performed each exercise blast for, and how the blasts made them feel. The majority were aware that each activity had lasted for 45-s and that the number of drills increased from eight in week 1, to 14 in week 10. All of the participants stated that the 45-s blasts made them feel tired, with some reporting that they felt less fatigued as the trial progressed. Despite the feelings of tiredness, many of the

participants said they enjoyed the blasts and felt good about themselves once they had completed them. Participants also described how the feedback from the heart rate monitor watches helped them gauge the intensity of their performance, as explained below.

“My heart rate would be like, through the roof. It’d be up near 200 and in the 200s, which shows that it’s high.”

(Male; Focus group 1)

“After a few weeks I’d, worked out what I could do. I realised that (at) about 180 to 190, I was trying but I could try harder...Once I got to 200, that was like, I was trying really hard.”

(Male; Focus group 2)

Exercise blast sessions

Here, the participants discussed both the PE and after school sessions and reported that the latter were generally the same as the former in terms of exercise intensity. They did note however that, as heart rate monitors were not worn during the after school sessions, it was harder to tell how hard they were working. Reasons for missing the after school sessions were disclosed, which included guitar lessons, play rehearsals and family commitments. This led to discussions on the optimal time to hold the third session; with lunch time, during other school lessons and weekends suggested. When discussing the people that led the exercise blasts, the participants spoke enthusiastically about the lead researcher and the dance teacher who had delivered the Zumba™ dance sessions, however were less positive about the second dance teacher, as illustrated below.

“The one who did Zumba, she was proper encouraging everybody. She was like come on, get up, get up, come on!”

(Female; Focus group 1)

(About the lead researcher) *“She was good, like constantly encouraging you to keep going... She’d join in if she needed to.”*

(Male; Focus group 1)

(About the second dance teacher) *“Wasn’t very good to be honest... She was showing you how to do things but she wasn’t very good at them herself...She should be pushing you.”*

(Male; Focus group 2).

Project FFAB

When discussing ways in which the trial could be improved, the participants suggested increasing the rest period in between blasts as they needed more time to get their breath back. They also thought that the study would appeal to people their age, and anyone who wanted to try and improve their fitness. Generally, the participants thought that the programme would not be suitable for younger children, as health and fitness does not interest this population and the exercises might be too hard. When questioned on how they would feel if Project FFAB was continued as part of their normal PE lessons, the participants' opinions varied, as shown below.

"It'd be cool, I'd do it. Cause like, in PE, it's like you're just doing your physical activity and you're done....You don't know whether you're improving or not, and you don't know whether you need to improve."

(Male; Focus group 2)

"I think, it's different (from normal PE), so we should be doing our school stuff in there (normal PE) but then have it (Project FFAB) like a club, so then you can do your harder bits, like once a week or something, instead of doing it quite hard in PE".

(Female; Focus group 1)

When asked to explain how they felt after taking part in Project FFAB a few participants reported feeling no different, whereas several others said that they felt fitter, healthier, could run faster and for longer, and had lost weight. Some also disclosed that it would be strange going back to normal PE lessons, as this often involved standing around and not doing much. Lastly, when asked why they had volunteered for the study in the first place, half of the participants wrote that they thought it would be fun and/or was something different to do. A further five participants explained that they wanted to see how healthy they were, improve their fitness and/or lose weight. The reasons given by the remaining two participants were that they liked sport, and wanted to help with the study.

Intervention school 2

Exercise blast activities

Here, participants described boxing, football, running and basketball exercise blasts. Across the groups, the participants' favourite activity differed. Some preferred boxing as they felt

it enabled them to work harder and they enjoyed punching the focus pads. Others preferred football because it was something they were used to and they were allowed to kick the ball hard. The exercise blasts which involved purely running (e.g. running around a square or diagonal course) received mixed responses. Some participants thought these drills were fun and easy to do, whereas others found them confusing and the most tiring of the blast activities. Despite the fact that basketball-based exercise blasts were completed in a number of sessions, these were seldom mentioned. The discussions then moved on to the length of the exercise blasts and how they made the participants feel. Generally, the participants recalled completing four exercise blasts at the study onset, which increased to eight by week 10. Whilst they knew that each blast was 45-s long; some thought that the rest periods lasted for 45-s or less, when it was actually 90-s. This was particularly apparent when the running activities were discussed, as illustrated below.

“We had to do the square run in 45 seconds and then breath, and then the square run again... The rests always seemed shorter than the running...I think she (the lead researcher) was trying to fool us...to make us work harder.”

(Male; Focus group 3)

Similar to the first intervention school, the participants all agreed that the exercise blasts made them feel tired and out of breath. They also thought that the blasts got easier as the weeks went on, as they knew what to expect. Many also reported feeling happy, proud or on a high after the sessions because they had got something out of them. With regards to feedback, the participants perceived that high heart rates were a good indicator that they were working hard. They also felt that encouragement from the lead researcher and their classmates motivated them to try their best, as described here.

“I think other people like giving you a positive reaction to what you’ve been doing... Yeah, like if you didn’t work hard enough, they’d help you push yourself to your max and help you.”

(Male; Focus group 3)

“She kept saying go on, go on, like encouraging us. She was running with people as well.”

(Male; Focus group 1)

Exercise blast sessions

When the participants compared the lunch time and PE-based sessions, they reported that the former were generally shorter and that less people turned up. Some felt that the PE sessions were boring towards the end of the trial, whereas others thought they were structured well, as illustrated below.

“They were good, but everyone was talking. So, she had it all planned out, she had it all written but she couldn’t do anything because we were all talking during the later sessions. At the beginning we didn’t, most of us were talking towards the end because we got bored.”

(Male; Focus group 1)

“They were set up good because we were never like, not doing anything. We were doing a rest and then doing something, we were never bored of it.”

(Male; Focus group 3)

Participants reported that the main reason for missing the lunch sessions was that did not want to lose time during their lunch hour, as they thought this should be spent socialising. They were however, undecided on when an extra session could be held instead and noted that staying after school required parental consent. Several of those who did attend the lunch time sessions disclosed that their motivation was the incentive of a free t-shirt and/or the chance to win a pair of trainers. Largely, the participants spoke positively about the researcher who had led the sessions; reporting that she was fun and supported them during the activities.

Project FFAB

When asked about the project’s appeal to others, the participants felt it might not be suitable for those who were overweight, lazy or did not like PE. Instead, they thought it would appeal to individuals who wanted to get fit and healthy and/or try something new. The majority of participants felt the project could be improved by including a wider variety of activities, with several suggesting that music could be played during the sessions. The participants’ responses varied when asked how they would feel if Project FFAB was incorporated into their normal PE lessons. Several thought this was a good idea, and could be rotated with normal PE on a week to week basis. Others felt it would depend on what the exercise blast sessions replaced, whilst some said they would not do it if they were not offered incentives. A number of participants reported feeling fitter, faster and stronger after taking part in the

study. Others also reported feeling more confident and motivated to be active, and that the study had helped them change aspects of themselves. The last point is illustrated in the quote below.

“Before you start you feel like, oh well, this isn’t going to help me at all. But when you come to the end of it, you’re like whoa, it’s changed me a bit.”

(Male; Focus group 2)

Some participants said they were glad to be going back to normal PE as it was less tiring and they missed playing normal sports. This viewpoint was not shared throughout the groups though, with several viewing the fact that they did more physical exercise in the project than during normal PE as a good thing. Some were sad that the project was over, as they felt they had got a lot out of it. When asked to disclose why they had volunteered for the study, 10 participants stated that they wanted to learn about different ways to be healthy and/or improve their fitness. Two participants took part to try and win the trainers and get a free t-shirt. A further four participants thought it sounded like fun, with the final four saying that they volunteered because everyone else in their class did.

Discussion

The need for better reporting of health improvement interventions has recently been highlighted in the new TIDieR checklist (Hoffman et al., 2014). Previous low-volume HIT trials that have included heart rate data to evidence exercise compliance have only reported group mean and overall SD values, which do not allow between- and within-participant differences to be explored. This questions the fidelity of these interventions, as there is no data to confirm that they were delivered as intended to all of the participants, throughout the intervention time period (Dumas et al., 2001). The primary aim of this study therefore, was to use mixed linear modelling to evaluate the fidelity of Project FFAB. This was achieved through the analysis of heart rate data collected during the 10-week exercise blasts programme. The second study aim was to explore the intervention participants’ experiences of the exercise blast sessions through semi-structured focus groups.

The application of mixed linear modelling to heart rate data collected during the PE-based sessions provided evidence that fidelity was largely upheld at both schools, as a high-intensity stimulus (~90% of maximal heart rate) was delivered to all of the study participants (demonstrated by the between-participant SD), consistently throughout the intervention

period (indicated by the within-participant SD). At intervention school 1, the variation in both heart rate measures across the different sessions and repetitions nested within sessions were small (1.2 percentage points and 1.6 percentage points, respectively [mean heart rate averaged over 45-s] and 1.1 percentage points and 1.3 percentage points, respectively [mean peak heart rate]). This indicates that the intensity that the participants performed at remained relatively consistent throughout each individual session and repetition. This level of data was unavailable for the mean heart rate averaged over the 45-s exercise blasts at intervention school 2, as the random effects model failed to converge. For mean peak heart rate however, the variation across the different sessions and repetitions nested within sessions was also small (1.9 percentage points and 0.5 percentage points, respectively). With the exception of mean peak heart rate responses to repetitions nested within a session at intervention school 2, it appears that overall heart rate responses were slightly less variable at intervention school 1, as evidenced by the smaller SDs and narrow confidence intervals. It should be noted however that the analysis of heart rate responses from intervention school 2 may have been confounded by missing data as it was only possible to analyse 58% of the heart rate files. This was largely caused by complications with the heart rate monitors during the exercise blasts sessions; if a participant's monitor was not working there was often little opportunity to rectify this without disrupting the entire session. This was due to the large number of participants taking part in the exercise sessions at intervention school 2 (n=24), and the fact that head researcher led these sessions alone. To avoid similar instances of missing data in the future therefore, a second researcher should attend the exercise sessions to ensure that any equipment malfunctions can be corrected in a timely fashion. Withstanding this issue however, there is strong evidence to suggest that fidelity was upheld at both intervention schools during the PE-based sessions.

Fidelity may have been enhanced by the fact that the entire intervention was developed and delivered by one researcher at only two intervention sites, which minimises the risk of "drift" from the original protocol (Bellg et al., 2004). Nevertheless, some variability in the heart rate responses was still apparent. For example, at both schools the mean and peak heart rates during week 1 of the intervention were lower than the rest of the trial period. This may have been due to the participants being unaccustomed to performing such intense exercise. Accordingly, it is recommended that future exercise trials include a familiarisation session prior to the start of the intervention. This will provide participants with a 'taster' of the activity they will perform during the trial. Other variability in the data, such as that displayed for week 3 and 5 at intervention school 2, may be due to natural biological and/or behavioural

and motivational variations, which requires further investigation. It is also important to acknowledge that, in an attempt to minimise participant inconvenience, heart rate data was not collected at the after school or lunch time sessions. Whilst this is a potential limitation of the study, during the focus groups the participants reported that, in terms of exercise intensity, the PE-based and after school/ lunch time sessions did not vary. Although it is not possible to quantify this, it is important to recognise that the third exercise session took place in the participants' own time. Had they therefore been required to wear monitors, the length of the session would have increased. This may have negatively impacted on adherence, as during the focus groups the participants spoke positively about that the brevity of the after school and lunch time sessions. Whilst this quantification issue may have been resolved by collecting participants' rating of perceived exertion via the Children's OMNI-walk/run scale (Utter et al., 2002) post-session, recommendations suggest that these ratings should be secured 30 minutes after interval type exercise (Foster et al., 2001). This would therefore necessitate that the participant either waited for 30 minutes after the session (thus negating the time efficiency), or completed the scale in their own time and returned it at a later date. Given the number of participants that forgot to complete their physical activity logs in Study 3, the latter scenario would have been unlikely to have been successful.

The focus group sessions also provided valuable information on the participants' experiences of the 10-week intervention and insights into how such a programme could progress in the future. From these it was evident that participants enjoyed performing different exercise blasts, which was highlighted by no single activity emerging as a clear favourite. Often, the female participants spoke enthusiastically about the dance activities, which mirror the favourable reports of the dance-based low-volume HIT trial by Boddy et al. (2010). As such, this mode of exercise may be a way of engaging adolescent females with low-volume HIT. The findings also justify the use of a multi-activity approach in the main trial. This is particularly encouraging, as such a model may better resemble normal PE lessons, in terms of the number of activities on offer. This therefore highlights the scope and potential for similar school-based low-volume HIT trials in the future. Comparison of the focus group data collected at each school however, highlighted variations in the participants' motivation for taking part in the main 10-week study. At intervention school 1, the majority of participants volunteered because they thought the study sounded fun, or that they wanted to improve their health and fitness. Although similar themes emerged at intervention school 2, several participants said they only participated to get a free t-shirt, with others stating that would not take part in future exercise trials if incentives were not offered. Some would

suggest that these differences may be due to socio-economic status, since those from a high socio-economic status (e.g. participants at intervention school 1) are thought to be more enthusiastic and aware of the benefits of leading healthy lifestyle (Hanson & Chen, 2007). Whilst this is acknowledged, it is also possible that the participants' responses reflect their individual experience of the trial. Due to the smaller group sizes at intervention school 1, the participants had more autonomy over their choice of activities and often were permitted to play music during the sessions. At intervention school 2 however, the group consisted of 24 adolescent males, who were sometimes prone to chatting and misbehaving. Such issues have been acknowledged by others, who have warned that unruly and over demanding participants can disrupt group sessions, leading to a lack of participation by others (Morgan, 1997; Orwin, 2000). On occasion, this was certainly the case during the exercise blast sessions, which was also noted by the participants during the focus groups. Here, they complained that they had become bored of the repetitive nature of the sessions, but acknowledged that this likely occurred because other participants were misbehaving. Indeed, participants at this school did not receive the autonomy that participants at intervention school 1 received, however this was enacted to ensure that the fidelity of the intervention was not compromised, despite the conditions. Largely, however the participants' reasons for volunteering were positive, with the above issue merely highlighting some of the challenges of juggling engagement with the maintenance of fidelity in 'real life' conditions.

Throughout the focus groups, participants reported that whilst the exercise blasts were very tiring; they often associated them with positive feelings such as accomplishment or the mastering of a new skill. Largely, the perceived enjoyment of low-volume HIT in adolescents is unclear, though some qualitative data is beginning to emerge (Buchan et al., 2013). To establish whether low-volume HIT has the potential for long-term exercise adherence however, it is crucial that future trials attempt to address this unknown (Logan et al., 2014). In the current study, the importance of receiving positive feedback from the researcher, fellow classmates, and the heart rate monitor watches was often discussed. With regards to maintaining intervention fidelity, it is possible that the immediate feedback from the heart rate monitor watches may have enhanced compliance, due to the participants' acute awareness of their performance. Indeed, although the participants were not told what 90% of their maximum heart rate corresponded to, it is clear that they knew that a high heart rate response likely equalled an intense training stimulus.

Whilst participants' heart rates were used to confirm the high-intensity nature of the intervention, it is acknowledged that the usefulness of heart rate monitoring for controlling and adjusting the intensity of low-volume HIT sessions has been questioned (Buchheit & Laursen, 2013). This is largely due to the heart rate lag at exercise onset, as discussed in Study 2. Despite this, the results presented here evidence that participants' heart rates peaked at ~90% of individual maximum within a 45-s repetition. The intensity estimates may therefore be conservative, and, as such, further reinforces participant compliance with the low-volume HIT intervention. The validity of the findings is also strengthened by the fact that mean heart rate responses were averaged across the 45-s repetitions, therefore did not include any of the recovery period. This then avoided an overestimation of physiological load, which can occur when heart rate continues to rise after exercise cessation (Seiler & Hetlelid, 2005).

Across health interventions, fidelity measures should be employed to ensure that trials are optimally tested and not accepted or rejected on the basis of inadequate or incomplete information (Resnick et al., 2011). Here, a framework for evaluating fidelity in the context of a low-volume HIT trial for adolescents has been provided; and important insights into the participants' trial experiences gained. The mixed linear model however, could be used across disciplines for any outcome with a continuous variable (e.g. the number of steps accumulated as part of a walking intervention) where the researcher wishes to demonstrate between- and within-participants variability, rather than purely relying on the group mean and SD. This will enable a richer understanding of whether intervention fidelity has been upheld, and instil greater confidence that the study outcomes were indeed due to the intervention, rather than the unintentional omission or addition of unknown factors (Cook & Campbell, 1979). Indeed, the heterogeneity of childhood obesity prevention interventions has been highlighted (Kamath et al., 2008), therefore the model presented here could be used to evaluate the extent to which treatment strategies vary in this context. Furthermore, it has been emphasised that fidelity may be threatened during complex interventions, where, for example, multiple sessions per intervention are offered (Horner et al., 2006) and the location of the intervention varies (Soldano & Markell, 1997). As such scenarios are now commonplace across health intervention studies; frameworks which aid the assessment of fidelity are timely.

Conclusions

This study has provided the first example of how exercise intervention fidelity can be objectively evaluated using mixed linear modelling. This was examined in the context of Project FFAB and demonstrated that intervention fidelity, in terms of exercise intensity, was largely upheld. It is proposed that the application of this model extends beyond exercise science, and as such, could serve as a framework for demonstrating intervention fidelity across health research disciplines. The post-intervention focus groups also provided rich insights into the participants' experiences of the novel low-volume HIT trial, which can be used to shape future work in this area. Here, it was evident that the participants' engaged with the exercise blast sessions, and were capable of performing, and to some extent enjoying, intense exercise based on boxing, basketball, dance and football. This is particularly encouraging and facilitates the development of multi-centre school-based low-volume HIT studies in the near future.

Chapter 8: Discussion and conclusions

General summary

The work presented in this thesis documents the development, implementation and evaluation of Project FFAB (Fun Fast Activity Blasts); a novel school-based low-volume HIT intervention. The first objective of this programme was to develop a practical low-volume HIT protocol that could take place in secondary schools, and was engaging and

accepted by the participants. The second objective was to determine whether the intervention was an effective model for improving the cardiometabolic health profile, cardiorespiratory fitness and physical activity levels of Year 9 school students (aged ~14 years) from the Tees Valley region of North East England. This programme of work utilised a sequential mixed methods design (Creswell et al., 2003) and was guided by the MRC framework for developing and evaluating complex interventions (Craig et al., 2008). As such, data were collected over four studies, of which the main findings are summarised below. In addition, a meta-analytical review of the effects of low-volume HIT on fitness in adults was conducted as part of international research collaboration with colleagues from the School of Social Sciences and Law, Teesside University, and AUT University, New Zealand. This was published in *Sports Medicine* in July 2014, and can be found in the last section of Chapter 2 of this thesis.

Summary of individual study findings

Study 1

The purpose of this study was to explore the attitudes, beliefs and opinions of secondary school pupils aged 13 to 15 years towards high-intensity physical activity and aspects of a proposed school-based low-volume HIT intervention. This was examined via semi-structured focus groups; with the data generated used to inform the design of a novel school-based low-volume HIT model. Participants were 43 (25 female) Year 9 and 10 students (aged 14.1 ± 0.7 years; mean \pm SD) from one secondary school in Redcar and Cleveland. Early in the focus group discussions it became evident that many of the participants associated vigorous/high-intensity activity with feelings of discomfort and sweating. This was potentially problematic, as at this stage the programme of work had been named the VIEWS (Vigorous Intensity Exercise Within Schools) study. To therefore place a greater emphasis on the enjoyment element of the activity, rather than the exercise intensity, the programme was renamed Project FFAB (Fun Fast Activity Blasts). The strongest theme to emerge from the focus groups was that the participants wanted to have an element of choice in the activities they performed. This observation is supported by previous work which has highlighted a shift towards independent decision making during adolescence (Gibbons & Naylor, 2007; Enright & O'Sullivan, 2010). Accordingly, it was proposed that during the main trial, participants would be provided with a menu of activities from which to choose. Based on the most popular suggestions from the focus groups, this menu would include boxing, dance and football activities. Whilst there was no clear consensus on where the intervention should be held, PE-based sessions were frequently mentioned. Furthermore,

the majority of participants thought the sessions should take place within the school premises, as this was somewhere that was familiar and would not induce transportation problems. In accordance with earlier low-volume HIT models (e.g. Burgomaster et al., 2005; Buchan et al., 2011a), it was projected that main trial participants would complete three low-volume HIT sessions per week. To allow for this, it was decided that two of these would take place during school PE lessons, and the third performed either after school or at lunchtimes. During further discussions, it was reinforced that the person leading the intervention should be fun and willing to get involved with the activities. Participants often also expressed that they would prefer someone other than their PE teacher to take the exercise sessions. To enable this, the head researcher would lead the intervention, and recruit an experienced dance teacher for the dance-based activities if necessary.

Detailed information on how focus group data can be used to tailor the development of exercise intervention is currently lacking in the literature. Indeed, whilst previous studies have utilised qualitative data to tailor physical activity promotion programmes for adolescents, (e.g. Moe et al., 2006), how this data is used in the intervention development process is seldom reported (Young et al., 2006). Accordingly, this study was the first to document how adolescent insights on a proposed school-based exercise programme were used to shape the design of a novel low-volume HIT model suitable for their teenage counterparts. On reflection, a focus group with the PE teachers may have been useful to establish whether the proposed intervention was feasible and accepted by them also. Future studies should therefore look to involve not only the potential study participants in the research design process, but also key figures from the intervention setting.

Study 2

The findings from Study 1 indicate that adolescents may prefer multi-activity exercise interventions, rather than those based exclusively on one type of activity. To date however, the former has not been used as the basis of a low-volume HIT programme. Accordingly, the first aim of Study 2 was to assess the heart rate and perceived exertion responses of female Year 9 students to three prototype prescriptions of low-volume HIT, based on boxing, dance and football activities. The second was to gain insight on whether the main intervention activities could be successfully applied under 'real life' school conditions. Participants (24 females; aged 13.6 ± 0.5 years) completed four exercise blast sessions over a 4-week period at one secondary school in Stockton-on-Tees. Here, it was demonstrated for the first time that novel 45-s second exercise blasts, based on boxing, dance and football

can elicit heart rate responses indicative of high-intensity work (~90% of age-predicted maximum heart rate) in adolescent females. Indeed, the mean peak heart rate values (expressed as a percentage of age-predicted maximum heart rate) found for boxing, dance and football-based exercise blasts were $95 \pm 8\%$, $96 \pm 5\%$ and $91 \pm 4\%$, respectively. Similar values were seen in the dance-based low-volume HIT trial by Boddy et al. (2010), who reported mean peak heart rate of 94.2%, 93.7% and 96.8% of maximum, across weeks 1 to 3 of their programme respectively. The current study was also the first to quantify the intensity of interval-type activities on a bout-by-bout basis in young people. This enabled the demonstration that a high-intensity training stimulus was maintained across all of the exercise blasts throughout the trial.

It therefore appears that activities other than treadmill running models (e.g. de Araujo et al. 2012) and the repeated Wingate test (e.g. Burgomaster et al., 2005) are capable of inducing a high-intensity training stimulus. From this, it could then be argued that low-volume HIT protocols incorporating novel activities may also elicit changes in health and fitness outcomes, comparable to that found in more 'traditional' low-volume HIT models. It should however be highlighted that the results presented here were from a relatively small sample, across only four exercise blast sessions. The generalisability of the findings was therefore questionable and it remained unknown whether such high heart rate responses could be maintained across an intervention lasting a number of weeks, or whether similar values would be observed in, for example, adolescent males. This was further compounded by the fact that the responses were expressed in age-predicted, rather than individual, maximal heart rates. This could have led to an under or overestimation of the exercise intensity, as the inter-individual variability for age-predicted maximum is high ($\pm 12 \text{ beats}\cdot\text{min}^{-1}$; [Arena, 2013]). Nonetheless, mean peak heart rates were consistently $\geq 9 \text{ beats}\cdot\text{min}^{-1}$ higher than the 90% of age-predicted of maximum value of $179 \text{ beats}\cdot\text{min}^{-1}$ across weeks 1 to 3 of the trial. It is therefore likely that despite the caveat of using the age-predicted value for classification, the exercise blasts were still high-intensity.

The exercise blast sessions were well received by the participants (indicated through positive comments on the feedback forms), and could thus form the basis of a novel school-based low-volume HIT intervention. Trialling the exercise blast sessions within a busy PE lesson also highlighted several practical issues that were imperative to address ahead of the main trial. The most significant of these was the need to extend the recovery time in between exercise blasts to 90-s, and to only have one type of activity running per session. In addition,

whilst the small-sided football games were popular, the range of skill level among the participants was too great to ensure that a high-intensity response would consistently be achieved by all of the participants. These were therefore dropped as blast activities for the main trial, but retained for warm-up and cool-down purposes. Whilst the perceived exertion responses to the activities were lower than expected, the underlying reasons for this are unknown which warrants further investigation.

Study 3

Despite accumulating evidence on the benefits of low-volume HIT, it unknown whether models utilising exercise modes other than cycle ergometry or running can lead to favourable changes in health and fitness outcomes in adolescents. The aim of Study 3 therefore, was to determine the effect of a 10-week school-based low-volume HIT intervention on established and novel cardiometabolic risk markers, cardiorespiratory fitness and physical activity levels in 13 to 15 year old adolescents. Here, low-volume HIT consisted of repeats of 45-s 'all out' efforts of basketball, boxing, dance and football activities, each interspersed with 90-s rest. Participants were 101 Year 9 school students (38 females; aged 14.1 ± 0.3 years) from four secondary schools in the Tees Valley region. Two schools were assigned to the intervention condition and two to the control. In terms of exercise session attendance, the 10-week intervention was well adhered to, with 75% of the participants attending $\geq 70\%$ of the sessions and only one intervention participant lost to drop out.

Post-intervention, very likely beneficial or likely beneficial effects were observed in the intervention group (compared to the controls) for triglyceride levels (-27%), waist circumference (-3.7cm), lipid accumulation product (-36%) and daily MVPA (+14.2 min). Whilst the purpose of this study was not to compare the effects of low-volume HIT to other forms of physical activity *per se*, it should be noted that some of changes observed here are similar, or greater, to that seen in other youth-based exercise programmes. In obese youths, there is strong evidence that aerobic training can decrease waist circumference, though the effect of aerobic training on other cardiometabolic risk markers is less consistent (Alberga et al., 2013). Following two aerobic training (performed at $\sim 70\%$ of maximal heart rate) studies (Ferguson et al., 1999 & Meyer et al., 2006b), triglyceride levels in obese youths (aged 7 to 11 [Ferguson et al., 1999] and 11 to 16 years [Meyer et al., 2006b]) decreased by $\sim 24\%$ post-intervention. Earlier, Hardin et al., (1997) reported significant changes (-29.7%) in the triglyceride levels of US Hispanic youths (aged 0 to 12 years) after a 6-week aerobic exercise intervention performed at 75 to 80% of maximal heart rate. Here, participants

exhibited high levels of cholesterol at baseline. In Project FFAB however, participants were not selected on the basis of risk factor presence and/or weight status. Indeed, only 22% of the sample was classified as overweight or obese and only 8% displayed three or more risk markers of the paediatric metabolic syndrome. This is encouraging, as it suggests that the intervention can benefit a broad range of individuals, rather than just those considered “high risk” due to abdominal obesity and/or other cardiometabolic risk markers. Furthermore, in the aerobic training studies described participants completed 60-minute exercise sessions. This is nearly double the longest single session completed during Project FFAB (33 minutes; week 10), which is inclusive of the 5-minute warm up, eight exercise blasts and rest periods (18 minutes), and the 5-minute cool down. This demonstrates the potential efficiency of such training, as benefits similar to that described previously have been seen using an exercise model that requires half the time. As the primary aim of Project FFAB was not to promote physical activity *per se*, it would be inappropriate to compare the improvements reported here with studies that based their intervention model around this outcome entirely. Possibly beneficial effects were observed for performance in the 20 m multi-stage shuttle run test (an indirect measure of cardiorespiratory fitness [+4 shuttles]) and total cholesterol (-3%). There were no clinically important intervention effects for any other outcome at this time point. A potential exception to this was systolic blood pressure, where a possibly beneficial effect became unclear after ICC adjustment for the design effect. Earlier youth-based trials have reported significant reductions in systolic blood pressure in low-volume HIT participants, albeit at the within-group level (e.g. Buchan et al., 2011a; de Araujo et al., 2012). The ICC adjustment to systolic blood pressure in the current study therefore, may have led to an over-conservative estimate of the effect, and as such, justifies further study. Aside from this, the observations presented here extend the positive findings from previous youth and adult-based low-volume HIT trials, where enhancements in fitness (Buchan et al., 2011a; de Araujo et al., 2012; Weston et al., 2014), waist circumference (Whyte et al., 2010) and small effects for triglycerides (de Araujo et al., 2012) have been reported. To the author’s knowledge, the study is also the first to demonstrate that a multi-activity low-volume HIT trial can meaningfully improve triglyceride levels, waist circumference measures, lipid accumulation product and daily MVPA in adolescents. It should however be highlighted that with the exception of waist circumference, the positive effects displayed post-intervention had diminished by 3-month follow-up. As this is the only known low-volume HIT study to include follow-up measures after the intervention has been removed, there is no data to compare these findings with at this stage.

The observed improvements in triglycerides, waist circumference and lipid accumulation product may be attributed to reductions in the postprandial lipaemic response (Thackray et al., 2013) and elevations in post-exercise fat oxidation brought about by increased levels of catecholamines (Trapp et al., 2007; Heydari et al., 2012). Whilst the role of these potential mechanisms remains unclear, it raises the interesting question of whether reductions in waist circumference following low-volume HIT reflect decreases in triglyceride levels, or vice versa. In the study by Heydari et al. (2012), decreases in waist circumference were observed after 6-weeks of high-intensity intermittent exercise, but did not reduce further after this. From this, it could be suggested that reductions in waist circumference precede triglyceride changes, however this is largely speculative. With regards to daily MVPA, further research with increased adherence to monitor wear time is needed before it can definitively be confirmed or refuted that forms of low-volume HIT can positively impact this outcome. Nonetheless, given the worldwide public health agenda to improve youth physical activity levels (Department of Health, 2011), the finding presented in the current study regarding this is promising. The effect of the intervention on performance in 20 m multi-stage shuttle run test may have been confounded by the participants' lack of engagement with the test itself. As this appears to have been less of an issue in other youth-based low-volume HIT trials, lessons can be learnt from these. Given the growing body of research on the relationship between muscular fitness and cardiometabolic risk in youth (e.g. Artero et al., 2011; Smith et al., 2014), a larger definitive trial could include measures of this type of fitness which were not feasible in the current programme; and a cardiorespiratory fitness measure that does not have the stigma of the multistage fitness test attached (Cale & Harris, 2005).

There were several limitations to this study that may limit the wider impact and application of the findings. These related to unavoidable compromises in the study design, such as non-randomised group allocation and clustering effects, which may have introduced bias. Additionally, due to the head researcher leading both the data collection and the exercise intervention, it was not possible complete blind assessments. Whilst these shortcomings are acknowledged, it is unlikely that resentful demoralisation may have confounded the results in the control group. This can occur when participants perceive themselves to be in the less desirable of the study groups, and can lead to them disengaging from the trial and its outcomes (Cook & Campbell, 1979). In Project FFAB however, control group participants were not aware that an exercise intervention was taking place at other schools, and all participants received a thank you pack after completion of the post-intervention measures, regardless of their group allocation. It could also be argued that despite the documented

limitations, the study has uniquely demonstrated that low-volume HIT can be applied in ‘real world’ settings utilising novel exercise modes. Further trials with greater sample sizes and study sites are now needed to fully establish whether Project FFAB represents a novel and viable way of improving health and fitness outcomes in young people.

Study 4

Across health improvement trials, interventions are often poorly described and crucial information pertaining to the treatment quantification and fidelity is lacking (Hoffman et al., 2014). This can be problematic in trials like Project FFAB, where establishing the exercise dose received by the participants is key (Resnick et al., 2011; Weston et al., 2014). The first aim of Study 4 therefore, was to use mixed linear modelling to evaluate the fidelity of Project FFAB. Here, the random effect component of the analysis provides an estimation of the between- and within-participant variability. This allows the magnitude of consistency in the application of intervention exercise intensity for all participants across the intervention time period to be examined. The second study aim was to explore the intervention participants’ experiences of the 10-week exercise blasts programme, via semi-structured focus groups.

At intervention school 1, the mean heart averaged for the 45-s exercise blasts across the low-volume HIT sessions was 85.6% of individual maximal heart rate, with a between- and within-participant SD of 3.1 and 4.4 percentage points, respectively. The latter was adjusted for the random effects of session (1.2 percentage points), and repetitions nested within a session (1.6 percentage points). The mean peak heart rate for the 45-s exercise blasts across the intervention at school 1 was 91.4% of individual maximal heart rate, with a between- and within-participant SD of 2.6 and 3.6 percentage points, respectively. Again, the latter was adjusted for the random effects of session (1.1 percentage points), and exercise blasts nested within a session (1.3 percentage points). At intervention school 2, the mean heart rate averaged for the 45-s exercise blasts across the intervention was 84.1% of individual maximal heart rate, with a between- and within-participant SD of 3.6 and 5.4 percentage points, respectively. The mean peak heart rate for the 45-s exercise blasts across the intervention at school 2 was 90.0% of individual maximal heart rate, with a between- and within-participant SD of 3.6 and 4.5 percentage points, respectively. Here, the latter was adjusted for the random effects of session (1.9 percentage points), and exercise blasts nested within a session (0.5 percentage points). From this data, it is evident that fidelity was largely upheld at both schools, as a high-intensity stimulus (~90% of maximal heart rate) was delivered to all of the study participants (demonstrated by the between-participant SD),

consistently throughout the intervention period (indicated by the within-participant SD). Some variations in the data were apparent however, particularly during week 1 of the intervention. This may have been due to the participants being unaccustomed to performing such intense exercise, so it is recommended that future low-volume HIT trials incorporate a familiarisation session into their study protocols to provide participants with a ‘taster’ of the exercise they will be asked to perform. It is also important to highlight that the heart rate data was collected during the PE-based sessions only, and as such the fidelity of the afterschool and lunchtime sessions remains relatively unknown.

During the post-intervention focus groups, participants reported that they enjoyed performing a variety of activities during the exercise blast sessions. This validates the decision to design a multi-activity low-volume HIT model in the first instance. It was however highlighted that unruly behaviour from some of the participants at intervention school 2 led to more repetitive exercise sessions towards the end of the study period. This was enacted to ensure that the fidelity of the sessions was not compromised, however may have led to participants disengaging. Generally however, participants from both schools reported that they enjoyed taking part in the study, and was something they would recommend friends and family who wanted to get fit and/ or try something new. The role of enjoyment may prove key to participants’ long term adherence to low-volume HIT, and has yet to be explored adequately (Logan et al., 2014). As such, it is recommended that this is examined further in both adult and youth-based low-volume HIT studies. It was also highlighted that the use of the mixed linear model devised here extends beyond exercise science, and could be utilised for any outcome with a continuous variable where the researcher wishes to demonstrate between- and within-participant variability. Accordingly, it is proposed that the analysis could serve as a framework for evidencing intervention fidelity across health research disciplines.

Overall conclusions and implications for future research

The work presented in this thesis demonstrates that a practical school-based low-volume HIT model based on basketball, boxing, dance and football, can serve as an effective strategy to meaningfully improve triglyceride levels, waist circumference, lipid accumulation product and daily MVPA in adolescents. A possibly beneficial intervention effect was also observed for cardiorespiratory fitness. Furthermore, it has been demonstrated that a low-volume HIT intervention can be carried out under ‘real world’ conditions, whilst maintaining high fidelity and providing an engaging and enjoyable experience for the participants.

Although the novel findings of the main trial have inevitably led to more unanswered questions on the mechanisms subtending these changes, this was not the focus of the programme of work. Rather, the purpose was to extend the positive findings from earlier high-intensity training studies, by applying a practical low-volume HIT model, based on participant chosen activities in an everyday school setting. Whilst it is acknowledged that this approach may have exposed elements of the trial, and indeed the researchers, to challenges they would unlikely have experienced in the laboratory, this widens the application and ‘real world’ relevance of the findings.

Questions remain however, over the role of low-volume HIT as an effective and appealing alternative to traditional endurance-based activity for achieving health and fitness outcomes in youth (Buchan et al., 2013). The current programme of work can shed little light on these questions as it was not the focus of the research, nor was it feasible to include a ‘moderate intensity training’ comparator group in the main trial. Nonetheless, whilst research on the minimum amount of low-volume HIT required to accrue health benefits continues (Tjønnå et al., 2013), it also appears that the application of HIT outside of the laboratory is gaining momentum. Indeed, findings from a HIT trial held in a community park in New Zealand have recently been published (Lunt et al., 2014). Furthermore, the potential of school PE lessons as a setting for HIT is beginning to be recognised by others (Bendiksen et al., 2014). It is therefore hoped that the findings presented in this thesis will stimulate further work in the area of field-based low-volume HIT, and the use of this training concept in paediatric populations. This, of course, leads to questions over the scalability of Project FFAB, as extending the programme beyond an exploratory trial led by one researcher, could require far greater financial and time resources. As such, the sustainability of Project FFAB will remain unknown until a definitive trial can be implemented. It should also be stressed that models such as Project FFAB are not intended to replace or displace the learning that can occur in “traditional” PE. Rather, in the long term, these programmes could complement and/or work alongside predetermined lesson structures and goals. The aims of the National Curriculum for Physical Education in England state that all pupils (1) Develop competence to excel in a broad range of physical activities; (2) Are physical activity for sustained periods of time; (3) Engage in competitive sports and activities and (4) Lead healthy, active lives (Department for Education, 2013). Clearly, it would not be advocated that a multi-activity low-volume HIT programme could meet all of these goals alone. Nonetheless, the role of PE in public health remains widely debated, due to the diverse nature of the lesson focus and delivery across the world (Chen, Kim & Gao, 2014). Indeed, it has been questioned whether

significant health benefits can be derived from PE at all (Pate, O'Neil & McIver, 2011). With this, and the positive outcomes of Project FFAB in mind, it is possible that low-volume HIT sessions could be incorporated into normal, teacher led PE lessons. This would, of course, require the full support and engagement of the PE staff. The time-efficient and multi-activity nature of Project FFAB does lend itself to the PE lesson structure however, and could be embedded into pre-existing lessons via drills on the selected activity. Whilst the merits of low-volume HIT in adolescents would need to be firmly established before such an idea could be explored further, this could prove an exciting avenue for field-based low-volume HIT research in the future.

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