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Abstract

Objective: High-Intensity Interval Training (HIIT) is known to be a time efficient method for improving cardiorespiratory fitness (CRF), however it is unknown what components would be most useful for an optimal HIIT protocol for use within the school setting. The purpose of this was to determine optimal design considerations from both outcome-oriented and pragmatic implementation perspectives.

Methods: A systematic review was conducted to determine optimal protocol elements as objectively as possible. Searches were conducted across four databases targeted at HIIT studies that incorporated measures CRF as part of their outcomes in school-aged youth. A series of two focus groups were used to assess pragmatic considerations for HIIT implementation by directly engaging with teachers and students of a local primary school.

Results: The systematic review revealed that running based protocols of at least eight weeks in duration using speed-based measures of intensity and work-to-rest ratios of less than one appeared to be optimal to elicit a greater CRF response when compared to protocols with other design features. The focus groups suggested that HIIT could be feasibly implemented in the school setting. Both teachers and students were willing to engage with HIIT. Children preferred novel activities with a strong aversion to running, and would be interested in some sort of monitoring or competition.

Conclusion: HIIT is a viable strategy for use within the school setting. Further research may benefit from further optimizing HIIT protocols for CRF outcomes and liaising with stakeholders to develop an intervention that is sustainable and meets the desires of all parties involved.

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Statement of Copyright

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1.0 Introduction

Physical activity (PA) is known to be an important proxy for many health outcomes including the reduction of risk of many chronic disease as well as improving functional across age groups (Strong et al., 2005; Hallal et al., 2006) with a clear dose-response between the intensity of PA and these benefits (Haskal et al., 2007). The UK has been facing a physical inactivity crisis for the past several decades. Data from the Health Survey England revealed that, excluding school-based activities, only 22% of children aged between 5 and 15 met the PA guidelines of being at least moderately active for at least 60 minutes every day (Scholes & Mindell, 2016). Even with the school system there is evidence to suggest that children are not getting the recommended amount of PA recommended by the UK's Association of Physical Education (Hollis et al., 2016). PA interventions in this age group have been arguably unsuccessful in terms meaningfully raising PA with any kind of consistency (Love, Adams, & van Sluijs, 2019; Mears & Jago, 2016; Metcalfe, 2012; Reilly & McDowell, 2003).

Cardiorespiratory fitness (CRF) is another proxy measure for many of the same health outcomes as PA (Ross et al., 2016). Many have argued that CRF should become a clinical outcome measure given its stronger association with these health outcomes than PA, and the availability of reliable, valid, cost-effective field-based measures (Ruiz et al., 2010; Zaquot et al., 2016). As with PA, increased levels of CRF are also shown to incur positive mental health benefits and may bolster elements of cognitive performance (Haapala, 2013; Pontiflex et al., 2011).

School-aged children and adolescents are good target populations for interventions designed to improve for CRF because the school provides an ideal setting for intervention dissemination and evaluation. Unlike school-based PA interventions which have had mixes results, the literature appears to mostly be in support of school-based CRF interventions, with studies reporting positive results of small to moderate effect sizes (Minatto et al., 2016; Pozuelo-Carrascosa, 2018).

Furthermore, there have been recent advances in the development of standards for what may be considered healthy CRF cut-offs, making it feasible to develop testable outcome measures (Kaminsky et al, 2017; Lobelo et al., 2009; Sandercock et al., 2012; Tomkinson et al., 2018).

High-Intensity Interval Training (HIIT) refers to physical activities of various modalities conducted with intervals of vigorous intensity interspersed with periods or relative or absolute rest repeated for one or more cycles or series (Weston, Wisloff, & Coumbes, 2013; Delgado-Floody et al., 2019). HIIT research has garnered attention in the past decade because it has been consistently shown to increase measures of CRF. HIIT has often been favorably compared to the more traditional moderate-intensity continuous training (MICT) in terms of both effectiveness (Ramos et al., 2015) and enjoyment (Thum et al., 2017). Furthermore, HIIT has often been touted as a time-efficient strategy for increasing CRF, addressing one of the key barriers to PA engagement (Boyle, Jones, and Walters, 2008; Tappe, Duda, and Ehrnwald, 1989).

Unfortunately, there is much that remains unknown regarding HIIT intervention design, particularly with respect to application within the school setting. Critics of HIIT argue that the rigor involved may be off-putting to potential participants and negatively impact sustainability (Biddle & Batterham, 2016). Despite the limited success of some HIIT protocols within the context of the school setting (Buchan et al., 2013, Weston et al., 2016), it is still unclear if there is any interest in these programs from the stakeholders' perspective. In other words, despite what is known about the positive effects on CRF, it is unknown whether the people most likely to benefit from HIIT – the school staff likely to be responsible for administering these programs and the students likely to engage in them - have any desire to partake.

Moreover, even if there were demand for HIIT-based school programs, there is still considerable debate as to what may be considered 'optimal' HIIT parameters for CRF outcomes. Buccheit and Larson (2015) identified nine modifiable components of HIIT protocols. While some work has been done to determine best-practice recommendations, including suggestions for modality, intensity, and intervention duration, there is still much work that is needed for the other components of protocol design such as work-to-rest ratio, optimal rest period parameters, number of series, and so on.

The purpose of this thesis was to provide the foundations for a future HIIT program for use in the school setting. After a literature on the subject presented in Chapter two, two studies were conducted: an evidenced-based series of optimal HIIT parameters based on a systematic review (Chapter 3) and focus groups conducted with students and teachers with the intent of providing a pragmatic view from the stakeholders perspective (Chapter 4), before detailing a list of recommendations (Chapter 5).

A systematic review of HIIT in children and adolescents was conducted in Chapter three to help determine optimal HIIT protocol parameters. Two series of online searches were conducted using several databases in an attempt to find HIIT studies in school-aged children and adolescents that assessed markers of CRF. These studies were pooled and meta-analyzed using subgroup analysis of their protocol features to determine which elements were 'optimal' in terms of incurring the greatest effect on measured CRF outcomes.

Focus groups were conducted in Chapter four as a means of engaging with stakeholders to assess what elements and considerations the students who may participate in HIIT may want in their program, and determine logistical considerations from teachers and other staff members who may be involved with the administration of these programs. It was felt that they were necessary as there is little point in designing an 'optimal' protocol if there was an unwillingness to adopt it from the stakeholder's perspective. The focus groups were transcribed, and key themes and higher order dimensions were codified.

The results of these two studies were then used to develop recommendations for the design and development of future HIIT research a development at the policy level, and for intervention design.

2.0 CHAPTER 2: LITERATURE REVIEW

The Chief Medical Office currently recommends that children and adolescents between the ages of five and eighteen engage in at least 60 minutes of moderate-to-vigorous physical activity (PA) per day (Gibson-Moore, 2019). Over the last decade, although participation in physical activity has slightly improved, the NHS has reported that only 18% of children and young people are meeting the Chief Medical Officer guidelines and 33% do less than an average of 30 minutes a day (Townsend et al., 2015, NHS digital., 2019). Weather, lack of time, both home and external environment, and safety have all been implicated as barriers to achieving PA efforts to significantly elevate physical activity through intervention remain questionable (Metclafe, 2012; Hesketh, Lakshman, & Van Sluijs, 2017).

Cardiorespiratory fitness (CRF) may be a more direct and important outcome proxy measure of overall health than PA (Ross et al., 2016; Warburton et al., 2016), and many have called for its use as a clinical outcome (Depres., 2016). High-Intensity Interval training is a form of physical activity that addresses some of the barriers discussed above due to its time-efficiency and ability to be conducted indoors without specialized equipment. Moreover, HIIT has been consistently found the elevate CRF levels across age groups. The purpose of this section is to review the current physical activity landscape in the UK, explain the value of CRF as a serviceable proxy outcome for public health, and discuss the potential role of HIIT as a public health intervention for use in the school setting.

2.1 PHYSICAL ACTIVITY

In this section physical activity as a health proxy is discussed and reviewed including the benefits of improving physical activity levels, the current physical activity guidelines around the world and in the UK, prevalence data from around the world and the UK, potential determinants of physical activity, and previous intervention strategies for improving PA.

2.1.1 Physical Activity Recommendations in the UK: Key Definitions, Benefits, and Structure

Physical activity (PA) refers to any bodily movement using skeletal muscles resulting in energy expenditure (Caspersen, Powell, & Christenson, 1985; Srirard & Pate, 2001), and has been highlighted by various researchers, governments such as the USA, UK, Australia, Canada, and non-governmental organizations, such as the World Health Organization as a key determinant for achieving and maintaining good health in children and adolescents (Cavill, Biddle, and Sallis, 2001, Strong et al., 2005., World Health Organization, 2010, Centers for Disease Control and Prevention, 2019; Australian Government Department of Health, 2019; Canadian Society for Exercise Physiology, 2019). PA, particularly moderate-to-vigorous intensity PA (MVPA) categorized by energy expenditure of at least four metabolic energy equivalents (METS), has been heavily researched over the past few decades, and, as such, many governments and public health organizations across the globe have deemed it necessary to generate recommendations for fulfilling minimal PA requirements (Janssen & LeBlanc, 2010; WHO, 2010; Oja et al., 2010; U.S. Department of Health and Human Services, 2019; NHS, 2019). In this section, the evidence-base for these recommendations will be discussed, highlighting the benefits of PA followed by the rationale behind their structure.

Partaking in the recommended amounts of MVPA has been associated with a plethora of health benefits. Previous research in children has been primarily focussed on the physical benefits of PA, particularly lauding their preventive effects on a variety of health conditions including noncommunicable diseases and conditions such as diabetes, cardiovascular disease, metabolic syndrome, obesity among many others (Eukland et al., 2012; Janessen & Leblanc, 2010; Kohl III & Cook, 2013; Poitras et al., 2016). There is also evidence to support the notion that PA may be beneficial for mental health and well-being, however this evidence is substantially weaker than that supporting the known physical health benefits (Biddle & Asare, 2011). There is sufficient evidence to support a causal association between PA and cognitive functioning, weak evidence to support a casual association between PA and depression, and no evidence suggesting that PA can improve self-esteem (Biddle et al., 2019).

Although the relationship between PA and self-esteem has been thought to be complex, the direct association between PA and academic performance and cognitive functioning has actually become a more recent area of focus in the field due to consistent supporting evidence, with some school-based interventions attempting to study the relationship between PA and academic performance, however, many questions still remain as to the best way to dose, and implement PA for maximum benefit (Donnelly et al., 2016; Marques et al., 2018; McPherson et al., 2018; Wright et al., 2016). A 2016 systematic review on the subject reported positive associations between PA and elements of cognitive functioning and academic performance, however noted that far more work was necessary to determine proper determine dosage, implementation, delivery, and ameliorate some of the methodological shortcomings of the literature within the field (Donnelly et al., 2016).

Undoubtedly, increasing PA offers many benefits, and it is no wonder that so many institutions have put forth PA guidelines as a public health tool, however it is important to understand how these guidelines are structured. First of all it is important to note that the recommendations in the UK (and other countries) are structured around PA – not exercise. A common misconception is that exercise and physical activity are one and the same, when in reality exercise may be distinguished from PA in that it is planned, structured, regimented, repetitive, and 'purposeful' in that it is typically done to improve a specific dimension of overall 'physical fitness,' which is in turn comprised of measurable health- or skill-related attributes (Caspersen, Powell, & Christenson, 1985). For example, PA may include taking a walk, going on a hike, or participating in a game of sport, whereas doing twelve reps of dumbbell curls for three sets with the specific intent of inducing muscle hypertrophy or improving strength may qualify as exercise. Exercise may be considered a form of PA, however not all PA is exercise.

Another important form of PA worth mentioning is that of 'sport,' which may be defined as organized leisure time physical activities with goal-oriented, competitive components that may be played in teams or individually (Crane & Temple, 2015; Eime et al., 2013). While there is considerable overlap between PA, sport, and exercise, there is some evidence to suggest that different age groups may have different preferences and motivations for the kinds of PA they chose to engage with (Allender, Cowbrun & Foster, 2006) which may be an important consideration for intervention design. Additionally, these terms tend to lend themselves to different types of research. In the context of public health, for example, researchers tend to gravitate towards PA, with many papers and systematic reviews studying the measurement of PA in specific populations (Cooper et al., 2015; Pate et al., 2002), the related health outcomes of achieving (Janssen & LeBlanc, 2010; Strong et al., 2005), or failing to achieve the recommended amount of PA (Poitras et al., 2016). More recently, there has also been a shift in the literature attempting to study associations between PA and cognitive outcomes, such as academic performance and cognitive functioning (Donnelly et al., 2016.; Marques et al., 2018). In contrast, research involving 'exercise' generally involves two major domains: the performance related consequences of exercise or training and the mechanisms underlying these adaptations. For instance, in a review of the effects of resistance training in children and adolescents, although health benefits comprised a small section of the outcomes of interest illustrating the grey area between PA and exercise, the majority of the paper was focussed one the effects that exercise had on dimensions of performance, such as muscular strength, endurance, power, balance, and co-ordination (Behm et al., 2008).

PA recommendations usually involve a ‘total duration’ component such as hours or minutes of total recommended PA per day or week, an ‘intensity’ component describing the difficulty of the PA that is expected, and a ‘modality’ component, providing recommendations for the types of PA that should be performed. For example, The World Health Organization (WHO) recommends that young people aged between 5-17 years partake in PA that includes games, sports, transportation, house hold chores, physical education, or planned exercise. The WHO advises that people in this age range should accumulate a minimum of 60 minutes of moderate-to-vigorous-intensity physical activity (MVPA) every day with an emphasis on aerobic activities. Additionally ‘vigorous intensity’ activities should be included at least three times per week (Global Recommendations on Physical Activity for Health WHO, 2010). The recommendations in the United Kingdom are similar, with the Chief Medical Officers currently recommending that children and young people aged 5-18 years engage in at least 60 minutes of moderate to vigorous physical activity (MVPA) per day as well as activities for muscle and bone development three times per week (Department of Health, 2011). Like the WHO recommendations, the UK guidelines also place particular emphasis on aerobic activities as these have been shown to have more health benefits than other types of exercise, such as lifting weights or flexibility work (Strong et al., 2005).

PA recommendations are broadly structured among three major components: the intensity of the recommended PA, the duration of recommended PA, and occasionally, the modality of recommended PA. While all three have been shown to be important factors for improving cardiometabolic health outcomes, intensity appears to matter most, as time spent in ‘vigorous’ activities has been consistently shown to induce greater protective effects against cardio metabolic risk outcomes (Aadland et al., 2018; Stone et al., 2009; Strong et al., 2005;Tarp., 2018). A dose-response relationship between PA and health outcomes has been observed across age ranges and sexes with the intensity of the PA consistently shown to be the most important factor for both health, and academic ‘fitness’ related outcomes (Ekelund et al., 2006; Ross et al., 2016; Van Dusen et al., 2011). Again, the UK guidelines for children recommend that children participate in moderate-to-vigorous intensity activities, in terms of intensity.

Unfortunately, the term ‘vigorous’ has been defined in multiple ways throughout the literature, highlighting an ongoing theme of lack of standardization. According to the NHS webpage, vigorous intensity activities are those that cause a person to increase their respiration rate, and must be done at a difficulty where casual conversation becomes impossible (NHS.uk, 2018). The site also explains that 75 minutes of weekly *vigorous* activity may confer the same health benefits as 150 minutes of *moderat*e intensity activity, another theme that will be discussed throughout this chapter (NHS.co.uk, 2018). While these criteria are likely acceptable for the layperson, more formal definitions have also been proposed and can be divided into absolute and relative measures of intensity (Royal et al., 2008). Metabolic Equivalent of Tasks (METS), which are defined as energy expended while sitting at rest, reported as an oxygen uptake of 3.5 millilitres per kilogram of body weight per minute, can be used as an absolute measure of intensity (Royal et al, 2008). Typically activities of greater than 6 METS are regarded as ‘vigorous,’ however some authors have used other cut-offs (Clark et al., 2009; Hallal et al., 2012; Owen et al. 2010; Puyau et al., 2002; de Rezende et al., 2014). For instance, Hallal et al (2012) used 8 METs as the cut-off point for vigorous activity in their review of global PA patterns.

Relative measures of intensity are those that can be expressed as a percentage of a person’s maximal heart rate, heart rate reserve, or aerobic capacity reserve (Royal et al., 2008). While again, there are no standardized cut-offs for these measures as of yet, various authors have suggested cut offs depending on the measure used. For instance, Strong et al.’s (2005) criteria of vigorous activities involve eliciting at least 80% of maximal heart rate (Strong et al., 2005). As early as 2001 there have been calls to record the components of PA such as detailed measures of frequency, duration (time), and intensity (absolute and relative), however the simple 'light, moderate, and high' classifications persist to this day (Kesaniemi et al., 2001).

Despite the lack of standardization with regard to intensity measures, the reason they are being discussed is because the effects of PA seem to be moderated more so by the intensity of the exercise than the duration or the modality. For example, Ruiz et al (2006) reported that only children who participated in vigorous PA - not moderate or low intensity PA - had significantly reduced body fat (Ruiz et al., 2006). Furthermore those who engaged in more (>40 min/day) vigorous PA had lower body fat than those who engaged in less (<18 min/day) vigorous PA (Ruiz et al., 2006). In this study, the intensity was more important than total duration of PA for body fat; however, both total duration and intensity were reported to influence CRF outcomes (Ruiz et al., 2006).

The findings of a more recent (2018) study directly examining the relationship between PA bout intensity and duration reported similar results. In this cross-sectional study the research team consulted the International Children's Accelerometry Database (ICAD) using the data from 38,306 observations across 29,734 individuals aged 4-18 years. This information was categorized into 16 combinations of intensity thresholds and bout durations. The researchers found that time spent at higher intensities, not bout duration, was the primary predictor for cardiometabolic risk factors (Tarp et al., 2018). Similar findings have been reported in numerous other studies. For instance, Stone et al (2009), which again used accelerometery recorded every two seconds in 47 boys aged 8-10 years. In this study, the frequency of all bouts of PA was most related to microvascular fitness, regardless of the duration of these bouts (short 4 second bouts vs long 5 minute bouts) so long as the intensity was at least 'light,' defined by the authors as 300-3581 counts/minute. However, when discussing waist circumference and fitness, they key modifiers were the frequency and duration of any bouts of ≥ moderate intensity (at least 4 METS or 3581 counts/min) supporting the notion that there may be minimal PA intensities necessary to elicit certain physiological changes (Stone et al., 2009). Another 2018 study also found that vigorous and moderate to vigorous physical activity were strongly associated with metabolic health while moderate or low intensity physical activity had only weak to moderate associations (Aadland et al., 2018). Finally, though direct experimental studies on exercise intensity are lagging behind cross-sectional observation, there is still support to further validate the importance of higher intensity PA.

Though intensity appears to be the most important factor for the preventive effects of PA in the case of children and adolescents, the duration of the bouts of PA also appears to matter, but not in the way one might expect. As stated above, most recommendations are structured around a minimum of 60 minutes of MVPA per day according the available evidence (Strong et al., 2005). While the total duration of PA has been shown to affect health outcomes, especially for lower intensity PA where greater duration is necessary for observable effects, another consideration is the duration of the individual bouts of PA in a given time frame. For instance, one might wonder if it is better for a child to accumulate their 60 minutes per day of PA all at once, or over smaller PA intervals scattered throughout the day.

The answer to this question is currently still under debate, however, there is evidence to suggest that younger age groups respond to shorter, more intense PA sessions than longer bouts of PA. In support of this is the idea that children and adolescents have been frequently reported to naturally engage in sporadic PA, suggesting that longer duration PA may not be as effective for them and may benefit from shorter, more intense bouts of PA for their daily/weekly accumulation. The sporadic nature of youth PA can be traced back to a widely cited study by Bailey et al (1995), where the researchers constructed a direct observation paradigm for 15 Californian children, aged 6-10 years. Direct observation was made every three seconds during four hour time blocks from 8am through 8pm. Percent of Peak VO_2, heart rate, and VO_2, were recorded among 42 coded activities. The researchers reported that the children accumulated an average of 22.3 minutes of high-intensity activities per day; however, these were burst-like in nature with the median duration of just 3-seconds (Bailey et al, 1995).

The burst-like nature of intense PA has since been further reflected in the literature as numerous authors have found shorter bursts of intense PA to be favourable over longer bout duration, which may be noteworthy for improving/expanding upon current PA recommendations or suggesting new guidelines future recommendations (Holman, Carson, and Janssen, 2011; Mark & Janssen, 2009; Stone et al., 2009). Janssen (2007) also acknowledged this issue when discussing the PA recommendations in Canada, advocating that PA guidelines should follow the PA sporadic patterns of the target populations that they are aimed at (Janssen, 2007). There appears, therefore, to be some disparity between PA recommendations and what children are actually likely to do in the real world setting. For a complete discussion of this issue, please refer to section 2.3.2.

The PA modality is the final factor worth mentioning with respect to PA guidelines, and serves as a segway into the discussion of cardiorespiratory fitness. As stated previously a key component of many PA recommendations is that they often include recommended modalities for PA. For example, on the UK physical activity guidelines Fact Sheet 3 for people aged 5-18 years, the website provides a brief explanation of several types of activities and some examples of each. Under moderate intensity exercise the fact sheet states that this type of PA should induce harder breathing and an increased heart rate, and includes bike riding and playground activities. Under vigorous activity, the site explains that children should breathe even harder and experience difficulty in maintaining a regular conversation using fast running and sports as examples. Finally, the guidelines also explain the significance of activities that strengthen bone and muscle tissue using resistance, including hopping and skipping and gymnastics and recommend these activities at least three times per week. Despite mentioning strength work, the UK guidelines, like many others, specifically emphasise the importance of activities geared towards improving aerobic fitness (Janssen & LeBlanc, 2010). It is interesting to note that many researchers have argued in favour of aerobic-based physical activity, a finding reflected in many of the health recommendations and guidelines mentioned above whereby greater emphasis is placed on this type of PA versus others such as resistance training of flexibility work. This is largely because aerobic activities have been repeatedly found to incur the greatest health benefits (Janessen & Leblanc, 2010; Kohl & Cook, 2013; Piercy et al., 2018; Strong et al., 2005).

Summary

- Physical activity (PA) consists of any skeletal muscle-induced movement that expends energy
- Increasing PA has been associated with many health benefits including preventing many NCDs, improving mental health, and possibly improving cognitive function
- Exercise and sport are subcategories of PA
- Aerobic PA has been found to have more health benefits than other forms of PA

2.1.2 Physical Inactivity in the UK: Prevalence Data

Although there is substantial evidence to back the importance of PA that has been heavily researched over the past several decades there are several issues that should be considered surrounding this topic. Prevalence data from numerous countries and within the United Kingdom itself paints the picture of a world that is increasingly failing to meet recommended PA guidelines (Townsend et al., 2012; NHS digital, 2019), however it is debateable to what degree this evidence should be trusted. Up until recently much of PA research has been based largely on subjective measures of PA (Pate et al., 20). In more recent cases where objective measures have been used, there are still disagreements within the scientific community as to appropriate cut-off points and methods of evaluation. In this section the methods for evaluating PA will be reviewed including their strengths and pitfalls. This will be followed by a presentation of prevalence figures in the UK.

Physical activity presents an interesting problem for researchers in that PA is behaviour instead of a clinical outcome, and this problem of measurement is one of the most frequently attacked issues by critics (Cain et al., 2013; Despres, 2016; Warburton & Bredin, 2016). Measuring PA can be divided into two major categories, subjective measures and objective measures. Subjective measures of PA include parent, or self-reporting methods such as self-report questionnaires, interviewer-administered questionnaires, proxy-report questionnaires, and diaries (Sallis & Saelens, 2001). While these subjective PA measures are cost-effective, easily administered, and may offer useful contextual information about PA, they often have low validity and may be influenced by the effects of bias and problems with human memory (Cain et al., 2013; Sallis & Saelens, 2001; Sirard & Pate, 2001). As mentioned by Sirard and Patel (2001) the sporadic nature of childhood PA can make it difficult for participants and parents to accurately recall, quantify, and categorize (Armstrong, 2013; Sirard & Pate, 2001).

Perhaps one of the most famous examples of subjective PA measures is the International Physical Activity Questionnaire (IPAQ), which is available in long and short form formats. In a systematic review of the short form (IPAQ-SF) conducted by Lee et al (2011), the authors reviewed 23 validation studies that measured IPAQ-SF scores against objective PA measures such as doubly labelled water, objective fitness measures, or wearable devices. The authors found that PA as measured by the IPAQ-SF was poorly correlated with objective measures, failing to meet the minimum literature standard of 0.5. In most cases the IPAQ-SF was found to overestimate PA by 36-173% making its use questionable (Lee et al., 2011). Others have also noted large discrepancies between self-reporting measures and objective measures, also highlighting the overestimation problem (Armstrong & Welsman, 2006).

Due to the limitations of subjective PA measures, like the IPAQ-SF, there has been a shift towards the use of objective measures of PA in many studies, possibly catalysed by the increasing accuracy and declining cost of many of these technologies (Chomistek et al., 2017). Objective measures of PA can be further divided into 'criterion standards,' including direct observation, doubly labelled water, and indirect calorimetry, and 'field-based' objective measures such as heart rate monitoring, pedometry, and accelerometry (Sirard & Pate, 2001). The main difference between these two groups is the balance between accuracy and practicality. For instance, doubly labelled water is considered the 'gold standard' for evaluating Total Energy Expenditure (TEE) under free-living conditions, and has been used to validate other objective PA measures in children and adults (Eukland et al., 2001; Murakami et al., 2016). Doubly labelled water is used by approximating the carbon dioxide production using isotope dilution (Sirard & Pate, 2001). Unfortunately, this method while extremely accurate suffers from several limitations that make it difficult to apply to larger scales. First of all, it requires at least three days and secondly, the isotopes needed are expensive. While the other criterion standards, such as direct observation are perhaps less monetarily costly, they are still difficult to implement at larger scales as they can incur a high experimenter burden depending on the observation system used (Sirard & Patel, 2001).

On the other hand, accelerometers, pedometers, and a heartrate monitors are cheaper and easier to use on larger scales, however the data generated by these measures is of lower quality than the criterion standards. Despite this drawback, these wearable technologies have several advantages making them attractive for PA research. Accelerometers are devices that, as the name implies, measure the acceleration of an object. As stated above, accelerometry technology has advanced rapidly within the past decade, substantially reducing cost (Trost, Mciver, and Pate, 2005). Currently, numerous companies are manufacturing accelerometers and according to Trost, Mciver, and Pate (2005) there is little difference in performance. Furthermore, smartphones also serve as another potential source of data as many models include built-in accelerometers or pedometers with reasonable levels of accuracy depending on the kind of activity measured (Bort-Roig et al., 2014; Case et al., 2015).

Though wearable technologies do have their advantages, they also come with their share of issues. One problem is the double edged-sword of 'big data.' Projects such as the International Children's Accelerometery Database (ICAD) offer great promise for evaluating PA over the long term and on large scales, however there are numerous hurdles facing data cleaning (Sherar et al., 2011). Cain et al (2013), for example, describe the influx of studies involving accelerometers from 2005-2010 highlighting the lack of standardization including differences between methods used for data collection, processing, and scoring. These authors suggested numerous research agenda points that are still ongoing including: coming to a consensus on MET values of MVPA, determining a standardizing epoch length, selecting appropriate cut-off points, standardizing 'non-wear' and 'valid day' definitions, brand comparisons, and periodic 5-year reviews of these issues. The final problem worth mentioning is that while the cost of these systems is decreasing, they do still require some funding and in cases where this may be limited so to may be the use of these technologies.

The future of wearable technologies, however, looks promising as these devices become cheaper to produce and more accurate. Another key advantage is the trend towards 'big data' analytics whereby the interconnectivity and online capabilities of these devices makes it possible to record and analyse vast amounts of data making novel analytic techniques possible, particularly as smart phones become more and more prevalent (Triano et al., 2014; Wannenburg & Malekian 2016). This coupled with machine learning algorithms potentially may allow future researchers to detect patterns that are currently not possible without the use of machine learning (Mannini & Sabatini, 2010). As more and more people use wearables accelerometers/pedometers it may be possible to create large scale databases that can then be used to generate objective PA health standards, however at the time of this review there is still much work to be done as there are discrepancies between lab-calibrated models and free-living situations (Farrahi et al., 2019).

With the advantages and limitations of PA measures in mind it becomes possible to discuss the current PA trends. First survey data at the global level will be presented followed by a more tapered look at patterns in the United Kingdom at the national and then regional level. This will then be contrasted with findings from studies using objective measures.

Physical inactivity can be considered a global pandemic (Kohl et al., 2012). According to surveillance data generated from the IPAQ and Global Physical Activity Questionnaire (GPAQ) spanning 122 countries, or roughly 60 percent of the 194 WHO member states, nearly 30% of adults (>18 years) and 80% of adolescents (13-15 years) are failing to meet the WHO guidelines of 60 minutes of MVPA per day (Hallal et al., 2012). Recalling from above the questionnaires often overestimate PA, this problem may be even worse than these figures may suggest. Unsurprisingly, PA declines with age globally; however there is heterogeneity depending on the region. For instance, southeast Asian adults aged 60 years or older are substantially more active than their counterparts from other regions of the world (Hallal et al., 2012). Men also appear to be more active than women at all levels of physical activity, particularly vigorous PA.

One trend that has emerged is that countries of higher economic development tend to suffer from greater physical inactivity, and this appears to remain true regardless of the age group observed (Hallel et al., 2012; Kohl et al., 2012; Ng & Popkin, 2012; Tremblay et al., 2016). Numerous factors have been implicated to explain this phenomenon. One explanation is that countries with higher economic development have the necessary infrastructure to allow for automobile use. This reduces the amount of people that participate in active transport (ex. riding a bike to bicycle to work). Another explanation is that the nature of work itself also changes. The sedentary office work seen in wealthier countries is thought to displace manual labour jobs that can be found in poorer countries (Hallel et al., 2012; Kohl et al., 2012; Ng & Popkin, 2012; Tremblay et al., 2016). Unfortunately, while this paradox may be explained by some of the ideas above, the relationship between socioeconomic status and PA is complex. Within wealthy countries, inhabitants of lower socioeconomic status often participate in less PA than their wealthier countrymen. Understanding the complexities that drive these trends is a key focus for future research, and perhaps pedometry and accelerometery databases can be used to help answer these questions as at the moment most of global figures are the result of questionnaire data. Another factor worth mentioning is the rise of Sedentary Behaviours due to electronic entertainment (ex. TV watching), some of which may displace time in PA (Hallal et al., 2012). Unfortunately there is less data available for less developed nations highlighting another gap in the research.

The situation in United Kingdom reflects many of the global trends discussed above, and indeed is shared by other developed nations. PA in these countries is low, however it appears to have at least plateaued and stabilised over the past decade (Armstrong, 2013). Physical activity still declines with age in the UK. Again, the greatest drop off occurs between the ages of 13 to 15 years. Also aligning with global trends is the propensity for males to participate in more PA than females. In adults 24% of males were classified as inactive compared with 27% of females. The proportion of boys who met

PA guidelines rose from 21% in 2012 to 23% in 2015. Meanwhile, the proportion of girls who met guidelines rose from 16% in 2012 to 20% in 2015 (Townsend et al., 2015). Data on childhood PA levels was not included in the most recent 2018 survey (NHS digital, 2018). These figures are also comparable with other developed countries in both Europe and North America (Armstrong and Welsman, 2006).

Geographically there appears to be a North/South divide in the UK. In England the highest proportion of men and women meeting the recommended guidelines was found in the South East (72% and 61% respectively). Perhaps unsurprisingly, the North West also had the lowest levels of activity (59% for men, 48% for women) and the highest levels of physical inactivity (26% for men and 31% for women). Apart from regional differences, socioeconomic status was found to have an even stronger association with differing levels of PA. Those with the highest income levels were substantially more likely to meet PA recommendations than those with the lowest income (76% vs 55% for men; 63% vs 47% for women). Those with lower incomes were also more likely to be classified as inactive (Scholes, 2016; Townsend et al., 2015).

Up until this point, much of the data presented thus far comes from survey data such as the IPAQ, GPAQ, and Health Survey England 2015/16 (Hallal et al., 2012; Scholes, 2016; Townsend et al., 2015). Other studies using objective measures have supported the findings presented in the report. Evidence from large scale youth studies using heart rate monitors, pedometers and accelerometers in the US, Australia, and Europe support the idea that PA has not declined from the 1980s to mid-2000s suggesting that although PA levels in these countries are worryingly low, at least the situation is not worsening in children and adolescents (Armstrong, 2013; Nyberg Ekelund and Marcus, 2009; Raustorp & Ekroth, 2010).

Although most trends are observable across countries such as the decline of PA with age and that males engage with more PA than females, there are actually substantial differences in between countries in terms of PA. Cooper et al (2015) demonstrate that Norwegian 9-10 year old females engage with less PA than their male counterparts, however this is relative. The Norwegian girls spent as much time in PA as American boys of the same age. This evidence suggests that there may be a complex network of determinants that mediate PA including individual, societal, and environmental factors. The accelerometery evidence presented from ICAD conflicts with some of the survey data from above suggesting that many developed nations are comparable with their PA. When observed objectively, differences become apparent, especially with older children (Cooper et al., 2015). Understanding the causes behind these differences is a target for future research.

At the time of this writing, accelerometery data for large scale studies was scarce, however several were underway. For example a feasibility study of 100,000 participants in the UK Biobank found that it was feasible to use accelerometery and laid down the foundation for future studies in adults (Doherty et al., 2017). In the ICAD study mentioned above, only 9% of boys and 2% of girls recorded at least 60 min of MVPA on all valid days that were measured in the UK (Cooper et al., 2015). In another study of 425 9-11 year olds from the South West of England a mixture of objective and subjective measures was used to assess correlates and potential specific PA and determine which correlates were associated with meeting PA guidelines. The authors reported that 52.7% of the children measured here were meeting the PA guidelines, which is well above the averages discussed above. Of this 52.7% 71.6% were male and 38.4% were female, heavily favouring male PA participation. The authors explain these discrepancies by stating that it is possible that they recorded particularly active days, and that the cut-off points used may have influenced this result, though the cut-offs used was rationalised based on previous research (Wilkie et al., 2018). In an older 2007 study of 11-year old children participating in the Avon Longitudinal Study of Parents and Children (ALSPAC), accelerometery was again used to assess PA in the South West of England. In this case only 2.6% of the children met international PA guidelines (Riddoch et al, 2007). More work using objective measures on large scales and in different geographical locations is needed to confirm or reject the findings of survey data.

Taking all of this into consideration it becomes clear that targeting the PA of young people should be considered a top priority for health interventions. First of all, children are less likely than adults to be meeting their recommended guidelines, meaning that this group is at the greater risk. As discussed above, in the UK roughly 1/3 of adults are failing to meet their guidelines, while only 1/5 of children are meeting theirs making them an obvious target (Townsend et al., 2015). This is particularly true of children 13-15 years of age as this is where the greatest decline in PA occurs. Therefore, preventing this drop by either focussing on this group directly or targeting children who are even younger to may be the logical target for future research.

Additionally, there is some evidence to suggest that PA patterns in childhood may track to adulthood (Telema, 2009; Telema et al., 2014). While this evidence is weak-to-moderate at best, Telema (2009) reported that it was significant in his review on the subject. Hallal et al (2006) discuss several potential pathways that may influence PA from adolescence to adulthood. Citing Twisk (2001), Hallal et al explain that part of the reason PA may be so important at a young age is that it may offer benefits that extend past purely physical health, including mental wellbeing and social development (Hallal et al., 2006; Twisk, 2001). This study mentions ‘consistent’ evidence that PA in adolescents is associated with adult PA levels (Hallal et al., 2006). In another 2014 study involving Telema in which six cohorts of Finnish youths were tracked from preschool to adulthood, the authors reported a moderate to high stability of PA along the life course, despite many other studies reporting otherwise (Telema et al., 2014). Also contrary to other studies was that activity tracked slightly better than inactivity (Telema et al., 2014). More objective research is needed to determine if PA tracking truly exists or not, and Telema also points out that determining the determinants of tracking would be an extremely useful area of research that currently has very little work (Telema et al., 2014). It has also been reported that the variety of PA that people participate may predict the level of tracking during their life, which will be an important point later in thie review (Dunmith et al., 2012). Others have argued that PA tracks very poorly and other outcome measures such as BMI remain more stable over the life course (Herman et al., 2009). The argument for tracking is not the strongest, but it is something for policy makers to consider.

Though tracking may be questionable, it is undeniable that prevention is more cost effective than treatment when it comes to public health, especially when discussing noncommunicable disease. The global cost of NCDs caused by physical inactivity has been estimated to cost $53.8 billion in 2013 (Ding et al., 2016). When direct and indirect costs of physical inactivity were combined this rose to $67.5 billion worldwide (Ding et al., 2013). Recall from Section 2.1.1 that PA and obesity appear to have a bidirectional association with one another. Interestingly, while PA tracking may be questionable throughout the life course, obesity actually appears to develop at an early age and remains difficult to treat incurring many long term costs to healthcare systems (Herman et al., 2009; Pandita et al., 2016). Physical Activity initiatives are seen as a major part of obesity prevention and treatment and may be a cost-effective way to deal with this problem at a young age and prevent it from developing further (Pandita et al., 2016).

Ensuring that young people engage with enough PA is an essential task for future policy makers. Though objective measures of PA are now being implemented on larger scales, there is evidence to suggest that young people are a high-risk group for failing to meet PA recommendations. In order to develop strategies and interventions that target PA in children it is first important to understand the determinants that motivate participation in PA and those that may act as barriers or obstacles. These will be discussed in the following section.

Summary

- Physical Inactivity is a global health problem
- Only 1/3 of adults and 1/5 of children are fulfilling PA recommendations
- PA is higher in males than in females
- PA generally declines with age, however the greatest drop-off occurs during the ages of 13-15 years
- The low number of children and adolescents fulfilling PA guidelines, the potential for PA behaviours to track throughout life, and the use of PA interventions to prevent the tracking of obesity throughout life all serve as key reasons that younger age groups should be targeted as priorities for health interventions

2.1.3 Determinants of Physical Activity

Clearly there is a problem in finding ways to engage youths in PA. In order to understand how to properly address the issue of lack of physical activity in British children and adolescents it is first necessary to identify the factors that influence PA participation. The determinants of PA can be divided into two broad categories: those that positively influence or motivate PA participation, and those that act as obstacles or barriers. The purpose of this section is to review the determinants of PA for children and adolescents.

Before discussing any of the factors that may mediate PA, it is first important to define several key terms that will be used throughout this section. Baumen et al (2012) distinguish between the terms 'correlates' and 'determinants.' According to these authors, a determinant has a causal relationship with PA, while correlates are simply factors that may be related to PA. In their review of correlates of PA the authors identify multiple individual-level correlates of PA such as age, sex, health status, self-efficacy, and previous PA as well as several determinants of PA based on ecological models that include physical and social factors. First the individual correlates will be discussed followed by environmental and social determinants.

First of all, recall from previous sections that PA is a type of behaviour, and as such is mediated by a complex array of factors that appear to change as people grow older (Baumen et al., 2012). Individual factors can be split into psychological components, such as beliefs, cognition, and personal motivation, and biological components comprised of genetic factors and evolutionary physiology. In young children (4-9) Buamen et al (2012) report that male sex is a consistent positive determinant of PA, however becomes a correlate as people age. This is consistently supported throughout the literature as it would appear that males are more likely to engage in PA than females throughout the life course . Sallis et al (2000), for example, reported that in a review of childhood correlates of PA, sex was the most commonly reported variable, and in 81% of cases, boys were found to be more active than girls (Sallis et al., 2000). Age is another correlate of PA, as increasing age is associated with decreasing levels of PA globally (see section 2.1.3). Understanding that age and sex may affect PA participation is an important consideration for public health interventions, as strategies may be needed to work around these correlates. For example, knowing that females typically engage with less PA means that perhaps that a specialised approach may be needed to understand the underlying causes behind this relationship and respond appropriately to maximise their participation in the future.

Individual psychological factors are also frequently reported as important correlates of PA in children and include personal motivation, self-esteem, and enjoyment, however arguably the most important correlate is that of ‘self-efficacy.’ Self-Efficacy is a psychological/behavioural science term coined by Albert Bandura in 1977 that refers to one’s own belief in their ability to achieve or fulfil a desired goal (Bandura, 1977). In the context of PA self-efficacy may be reflected in an individual’s confidence to perform well within a certain sport or complete a certain exercise. Self-efficacy is of high importance in this thesis because it has been shown to be a strong predictor for an individual's capacity to perform vigorous PA and that vigorous necessary to induce the greatest gains to health and fitness. Bauman et al (2012) and Van Der Host et al (2007) both cited self-efficacy as both a correlate and determinant of PA in children and adolescents. This has been supported by other findings. A 2018 multileveled analysis of UK data from the International Study of Childhood Obesity, Lifestyle and the Environment only self-efficacy remained significantly associated with meeting MVPA guidelines according to the Treuth cut-points, and was one of few correlates analysed that was consistently associated with vigorous PA (Wilkie et al., 2018). Self-perceived physical competence has also been associated with increased leisure-time PA, and this association is strengthened with age (Hamari et al., 2017). If these findings are generalizable, then building self-efficacy in young children is of critical importance to promote PA as they age.

Self-efficacy itself may be mediated by four main sources of development. 'Mastery experience' is the result of an individual accomplishing a task in the past and using the experience to build confidence for future endeavours. 'Vicarious experience,' as the name implies, comes from observing others accomplishing a task. 'Verbal persuasion' involves persuading someone that they are capable of performing a task, though Bandura (1997) believed this to be less powerful than the previously mentioned sources of self-efficacy development. 'Finally, psychological and effective states' may impact self-efficacy. Warner et al (2014) give the example of a person getting frustrated or angry before attempting a task, and having this mental state negatively affect the outcome (Warner et al., 2014). In a study of German, community-dwelling older adults, mastery experience, self-persuasion, and reduction of negative affect states were found to be important predictors of self-efficacy (Warner et al., 2014). Though similar studies could not be found in children and adolescents at the time of this writing, utilizing the four developmental factors of self-efficacy could prove useful for future intervention design.

The physical environment has also been shown to alter PA. Perhaps obviously, environments that are conducive to PA encourage participation, while those that are not act as barriers. For example, weather can affect PA participation where bad weather may (Eyre et al., 2015; Rhodes & Lim, 2018; Stankov, Olds and Cargo, 2012). While considerations like these may seem almost silly, they are noteworthy for intervention design as different geographical locations may have different issues with weather. Designing an indoor intervention that can be done regardless of weather conditions, for example, may help mitigate the effects of poor weather conditions. Environments with adequate PA equipment such as recreational public parks or opportunities for active transport (ex. Bike riding or walking to and from school) were also found to improve PA participation (Bauman et al., 2012). In some cases the environment can cause discomfort in other ways. The act of having to change into PE uniforms was highlighted as causing discomfort and acted as a barrier to PA (Allender, Cowburn, and Foster, 2006; Stankov, Olds and Cargo, 2012).

Finally, social or societal pressures may also influence PA, though these are complex. On the one hand, some societal pressures may positively influence PA in children. Allender, Cowburn, and Foster (2006) describe changes to PA motivations as people age. Younger children, for example, were found to prefer activities where they were not forced to compete. They were largely motivated by novel activities, experimentation, parental support, and safety. Teenagers and young women, however, were more socially minded, opting to engage in PA to form social circles, and manage their weight/body shape (Allender, Cowburn, and Foster, 2006). As life complicates with age due to significant others and increased school workloads, 'lack of time' emerged as a barrier for adolescents, however it should also be noted that physical education teachers also complained about the lack of time as resources are often allocated to study sessions instead of physical education, limiting their input (Boyle, Jones, and Walters, 2008; Tappe, Duda, and Ehrnwald, 1989).

There are many factors that influence how and why children and adolescents engage with physical activity, and no one determinant may be solely able to explain a regions PA patterns. For instance, a study between the ICAD countries examined the effects of weather on PA in various parts of the world and reported that children in places with unfavourable whether such as Northern Europe and Australia were actually more active than some of their counterparts in places with more favourable weather conditions (Harrison et al., 2017). Ideally, intervention design should be custom tailored to address some of these issues, taking advantage of determinants that bolster PA while reducing the effects of barriers.

Summary Points :

- PA has many complex determinants including lack of time, poor weather, equipment availability, parental PA patterns, and many more
- No single determinant appears to be a universal predictor of PA
- Interventions should involve stakeholders to better structure interventions around barriers to PA

2.1.4 Previous PA Interventions

Due to the importance of increasing PA and the improving understanding of what barriers may be affecting PA levels it is unsurprising that numerous interventions have been attempted to help remedy the problem. Unfortunately, it remains questionable as to whether or not these strategies have been working. In this section, previous PA intervention strategies will be discussed and reviewed.

First and foremost it must be understood that public health interventions exist in a variety of forms. A public health intervention refers to any activity (policy or otherwise) with the intent of improving human health by preventing disease, by curing or reducing the severity or duration of an existing disease, or by restoring function lost through disease or injury (Sith, Morrow, & Ross, 2015). Interventions can take a variety of forms that can be broadly categorized into: preventive interventions such as vaccinations and education/behavioural change interventions, therapeutic interventions such as treatment or active care for ongoing diseases, or other types of intervention, name legal or policy-based interventions (Sith, Morrow, & Ross, 2015).

Physical activity interventions tend be classified under the ‘preventive interventions’ category and often can be further subdivided. For example, some projects aim to influence the environment of their intended audience in an attempt to increase PA. Examples of these include public projects that facilitate active transport such as walking or improving cycling conditions. Other interventions include community-based interventions, education-based interventions, and multifaceted/multicomponent interventions that rely on one or more approached (i.e. PA education with a dietary component). The evidence supporting individual intervention strategies suggests questionable improvements, however several authors have suggested that multifaceted approaches may yield the best outcomes (Brown & Summerbell, 2008; Bourdeaudhuij, et al., 2011; Kreimler et al., 2011).

School-based designs have emerged as a common choice for intervention implantation as children and adolescents spend much of their day in this setting, allowing interventions to reach a wide range of students while limiting outside factors, such as family involvement (Kriemler et al., 2011). A systematic review on school-based programmes for improving physical activity in children and adolescents aged 6 to 18 years found that these interventions were ineffective for improving leisure time physical activity rates, systolic and diastolic blood pressure, body mass index, and pulse rate, however, positive effects were observed in duration of physical activity, television viewing, VO_{2max}, and blood cholesterol, highlighting the strengths of school-based interventions (Dobbins et al., 2013).

Although these interventions are all well-intentioned the fact is that recent research has revealed that they have been largely unsuccessful in their intended purpose. A 2012 meta-analysis of 30 PA interventions in children found that these programs increased PA by an average of only four minutes which is a woefully unimpressive number given the recommended sixty (Metcalf et al. 2012). Similar findings have been reported for adolescents (Borde et al., 2017). In cases where positive effects were reported these tended to be of small effect size and only for the short term, with no long term follow up, leading to questions as to their long term effectiveness and sustainability (Hyneman et al., 2016). Additionally, although numerous authors have cited the importance of increasing the overall duration of PA it may be more valuable to focus on the intensity of the PA instead (Strong et al., 2005; Hopkins et al., 2009; 2005Janssen and LeBlanc, 2010).

Given the questionable effectiveness of PA interventions it may be time to consider alternative approaches. The following section will discuss the potential roll of cardiorespiratory measures as a potentially more useful proxy measure of health than PA and as a possible target outcome for future interventions.

Summary

- PA interventions have taken numerous forms
- PA interventions have not been effective
- Future work is needed to determine if any positive effects that have been observed have any longer reaching consequences

2.2 CARDIORESPIRATORY FITNESS

The focus of health intervention research has been placed primarily on Physical Activity, as it has been arguably more extensively researched, and often serves as the basis for many health recommendations and guidelines around the world. On the other hand, CRF measures an attained state- not a behaviour - that may be standardized for ease of comparison between both individuals and populations. Furthermore, field-based measures of CRF do not require expensive equipment, though there are age and sex differences to consider.

The purpose of this section is therefore, to compare PA and CRF beginning with an analysis of their benefits and mechanisms of action, followed by a review of the prevalence of cardiorespiratory fitness globally and within the UK. Next, the maturation considerations that must be addressed surrounding CRF will be explained, including the effects of biological maturation and gender differences in children. Finally, the measurements of CRF will be reviewed. The central argument of this section is that despite the substantial evidence suggesting the value of PA as a key determinant of health and fitness, there is an argument to be made supporting the generation of CRF standardized guidelines to serve alongside the PA recommendations because:

1. CRF is a more powerful predictor of health than PA
2. Improving PA has been arguably unsuccessful thus far through current intervention approaches
3. PA involves a spectrum of behaviours making it difficult to measure whereas field –based CRF measures are both reliable and inexpensive

2.2.1 Cardiorespiratory Fitness and its Relationship to Physical Activity

Aerobic fitness, otherwise known interchangeably as Cardiorespiratory fitness (CRF), or cardiovascular fitness (CVF), refers an individual's ability to transport and deliver oxygen to skeletal muscles during sustained PA, and is comprised of both the circulatory (heart) and respiratory systems (lungs) (Armstrong, 2016; Ortega et al., 2008; Santos et al., 2013). Many of the health and fitness benefits associated with PA have also been found in relation to CRF (Ortega et al., 2008; Zaquot et al., 2016). As with PA, a dose-response relationship between CRF levels and increased benefit has been well-documented (Ross et al., 2016). In adults, the largest benefit of improving CRF occurs between the least fit, and next least fit groups of studied individuals (Ross et al., 2016). While this has only been shown in adults and less work has been done with children and adolescents, this remains a key point because increasing CRF at the low end may serve as a reasonable public health target. As stated previously, the majority of health benefits that come with PA are obtained only at higher levels of PA with respect to both intensity and overall duration, and this dose response is true for non-health related improvements, such as academic achievement (Van Dusen et al., 2011). Unlike PA, CRF also has additional practical application in the realm of sport, as higher CRF levels have been associated with improved performance, such as in football (Helgerud, 2001). Finally, a key distinction between CRF and PA is simply that CRF may be easier to measure as PA is just as much a measure of behaviour, whereas CRF can be directly measured both in the laboratory and through the use of numerous validated field tests (Armstrong, 2013; Barankowski, 1992).

CRF has been shown to be independently related to numerous positive health and fitness outcomes. In a 2008 study conducted by Kriemler et al., the authors used a cross-sectional analysis of 502 randomly selected rural Swiss school children. They reported that CRF and PA were independently inversely associated with measures of obesity, HOMA-IR, and the metabolic risk score. This effect remained observable independent of sociodemographic and nutritional parameters sleep duration, media use, BMI, and the neighbourhood environment. Again, the time spent engaged at differing levels of PA (light, moderate, vigorous) affected the degree of metabolic risk markers in the sample (Kriemler et al., 2008). Another cross-sectional study of 781 men and 890 women between the ages of 20-65 also reported similar findings. Participants who engaged in more PA had lower levels of triglycerides and atherogenic cholesterol levels regardless of their CRF. Meanwhile, for each level of increased CRF there was a gradual risk reduction of half or greater with respect to risk factor clustering independent of PA (Ekbolm-Bak et al., 2010).

Finally, as with PA, higher CRF levels have also been associated with improved cognitive performance, and there has been a recent shift in the literature to focus on the effects of CRF on cognitive fitness over the last decade or so. Higher levels of CRF are associated with improved academic performance (Donnelly & Lambourne, 2011; Hillman et al, 2009). Current research has indicated more significant relationships between high CRF levels and positive cognitive functioning and academic achievement than with PA and these outcomes

Unlike PA, however, there are no standardized recommendations for CRF levels in the UK, despite a call from many researchers to introduce standards or clinical diagnostic baselines (Blair, 2009; Depres, 2016; Ross et al., 2016). In fact, one of the current debates and one of the central themes of this chapter is whether CRF measures can be used as a substitute or alternative for PA measures, as there is some evidence to suggest that CRF is a more important determinant of both health and fitness (including mental/cognitive fitness) than PA (Blair, 2009; Blair, Cheng, and Holder, 2001; Ortega et al., 2008; Warburton & Bredin, 2016; Zaquot et al., 2016). Numerous authors within the past decade have even called for the use of CRF markers in regular health check-ups (Blair, 2009; Depres, 2016; Ross et al., 2016).

One application of CRF is the capacity of a person to perform prolonged periods of strenuous exercise, or what may be known colloquially as ‘endurance.’ CRF involves only the heart and circulatory systems, while cardiorespiratory fitness, or CRF, also includes the lungs, however, from a physiological perspective, respiratory adaptations, such as increases to lung capacity have only been documented following certain types of exercise, such as in elite swimmers, meaning that the two terms are for all intents and purposes interchangeable. Rather, most CRF changes are the result of morphological adaptations to central cardiovascular delivery systems (e.x. heart) in the form of maximal stroke volume (SV) or peripheral adaptations such as the increased capacity of mitochondria in cellular muscles for oxidative phosphorylation (e.x. cellular alterations), depending on the type of training (Armstrong , 2016).

Logically, one might assume that higher PA levels would be associated with higher levels of CRF, and this may be the case with acute bouts of PA, however the results are less clear over longer periods. For instance Kesaneimi et al (2001) explained that a single session (acute) of PA at an intensity of 50-100% of maximal oxygen uptake (Moderate to Maximal intensity) was able to lower 18-20mm Hg in systolic and 7-9mm Hg in diastolic blood pressure in adults. Furthermore these changes remained in effect for 12-16 hours following the exercise (Kesaneimi et al, 2001). In other words, physical activity of high enough intensity certainly elicits a cardiovascular response.

Unfortunately, the relationships between CRF and PA appear to break down over longer periods of time, though this may be largely due to a lack of PA of high enough intensity. CRF and total PA are at best weakly correlated, and more recent studies (post 2010) have shown that there may be no significant relationship at all. First the studies and papers supporting an association between PA and CRF will be disused followed by those that disagree. While there is some evidence to suggest a positive relationship between PA and aerobic fitness, these studies are older and the associations were weak (Andersen et al., 2011; Dencker & Andersen, 2008; Rowlands, Eston, & Ingledew, 1999;

Ruiz et al., 2006). Furthermore, the quality of measures used appears to influence whether or not the positive relationships are observable (Denker & Andersen, 2008). A review by Andersen et al (2011), for example, stated that correlational studies show a low-to-moderate positive relationship between PA and CRF indices in children (Anderson et al, 2011). Experimental studies were also discussed, and again vigorous PA was shown to improve CRF by roughly 10% (Anderson et al., 2011).

The key issue here is that PA is simply reported too inaccurately to take these studies at face value with inconsistencies in how it was categorised. As stated earlier, one of the key issues with PA is that it is difficult to compare different PA schemes as they often fail to report important protocol components such as duration, and time, and are frequently categorized by intensity as 'low, moderate, or high' (Kesaneimi et al., 2001). Another issue is that even if there is a weak correlation between PA and CRF, the direction of causality cannot be inferred as it may be that fatness or low CRF levels may somehow act as barriers to PA, not the other way around (Rowlands, Eston, & Ingledew, 1999).

More recently (post 2010) there has been some evidence to call into question whether or not there is any association between PA and CRF altogether, especially in younger age groups. For instance, Armstrong, Tomkinson, and Ekelund (2011) reported that although VO_{2max} (the gold standard CRF measure) is trainable in youths (ages 8-16 years); they found no meaningful relationship between habitual PA and maximal oxygen uptake (Armstrong, Tomkinson, and Ekelund, 2011). In a 2013 review on the subject of aerobic fitness and PA in children, Armstrong (2013) discussed the results of several studies that most reported nonsignificant or weak relationships between PA and VO_2 in free living populations of children and adolescents (Armstrong, 2013). Similar results were described in another study of 187 French children aged 6-12 years. In this case, fitness was tested using a battery of 7 field tests known as the European Physical Fitness (EUROFIT), which included the 20 meter shuttle run performance, a reliable field based proxy measure of maximal oxygen uptake, as well as additional body composition measures. Physical Activity was assessed using a uniaxial accelerometer over a week of consecutive data recording. The authors reported that the association between PA and fitness appeared poor at best, with only a trivial relationship between *vigorous* PA and body fatness observed (again, note the intensity). Light PA was also weakly positively correlated with body fatness (Blaes et al., 2011).

2.2.2 Cardiorespiratory fitness as a proxy measure of health

The benefits of increasing PA and CRF levels are unquestionable. From a public health standpoint, both have been implicated as key factors in the primary and secondary prevention of numerous non-communicable diseases including heart disease, stroke, type II diabetes, and certain types of cancers (Warburton et al., 2016; Warburton, Nicol and Bredin, 2006;). Moreover, additional benefits for both PA and CRF may be observed beyond the prevention and avoidance of illness. Numerous studies, healthcare professionals, and health/fitness organisations have recommended a minimum PA volume that expends 1000kcal per week, with additional benefits following greater energy expenditures (Warburton, Nicol, and Bredin, 2006). CRF is similar in that CRF levels of <5 METs are predictive of higher risks of mortality, while CRF levels of <5 METs are associated with a reduction in mortality with even greater benefits at higher MET levels (Ross et al., 2016). Though PA guidelines have been set in place by numerous organizations around the world, the primary purpose of this section is to assert that similar guidelines should be set in place to provide clear CRF goals measures because CRF may be simply be more important marker of health overall than PA, PA has thus far proven difficult to effectively increase, and finally CRF may be easier to measure from a public health standpoint.

To the first point, recent comparisons between the health effects of PA versus CRF made within the last decade support the notion that CRF is simply a stronger marker for health than PA, as higher levels of CRF have been consistently associated with greater risk reductions to all-mortality and chronic disease (Warburton, Shannon, and Bredin, 2016). Some have argued that CRF is a stronger predictor of cardiovascular disease (CVD) than PA (DeFina et al., 2015). Blair, Cheng and Holder (2009) reported that the dose-gradient response for multiple health outcomes is universally steeper for CRF than PA, at least in adults (Blair, Cheng, and Holder, 2009). According to DeFina et al (2015),"…CRF shows parallel benefits compared to PA in relation to CVD outcomes and in terms of risk prediction, CRF has been shown to improve the classification beyond traditional risk factors as well as cumulative lifetime risk of CVD mortality." Swift et al (2013) provide supporting evidence to this claim stating that, after controlling for CVD risk factors, CRF was shown to be a more clinically significant predictor of cardiovascular disease and mortality over PA, however acknowledge that this may limited by types of measures of PA used (Swift et al., 2013). In a 10 year study of 425 adults, changes to subjectively measured SBs, MVPA, and objectively measured CRF were assessed. Positive changes to CRF were found to benefit all individual cardiometabolic risk markers, while changes to SB or MVPA only affected some. Furthermore, CRF alterations have been found to mediate the associations of change in SB and MVPA in clustered metabolic risk, waist circumference, and, only for MVPA, HDL cholesterol (Knaeps et al., 2016).

Similar findings supporting the potency of the protective effects of CRF over PA have also been reported for younger populations including children and adolescents. Ortega et al (2008) reported that CRF enhancements were associated with a reduction in total and abdominal adiposity, a reduction in emerging CVD risk factors, and an increase in positive mental health outcomes including reducing the effects of depression, anxiety, mood status, self-esteem, and academic performance

(Ortega et al., 2008). As in adults, CRF in children also appeared to mediate the relationship between PA and other health outcomes. In a study of 201 Southern American children subjective and objective measures of PA and objective measures of physical fitness were taken. The PedsQL4.0, a 23-item self-report survey, was used to assess the children's health-related quality of life (HRQOL). The results of this study provided initial evidence that physical fitness serves as a mediator between PA and HRQOL, though there was not enough evidence to determine if fitness or PA were more important predictors of HRQOL scores (Gu, Chang, and Solomon, 2016). Anderssen et al (2007) tested CRF using a maximal graded cycle ergometer in 2845 randomly selected school aged children (9-15 years old) from Portugal, Denmark and Estonia. In this study CRF was again more strongly associated with clustering of CVD risk factors, independent of country, age, or sex (Anderssen et al., 2007). A large, cross-sectional, school-based study of children and adolescents in Sweden and Estonia also examined the relationship between PA, CRF and health outcomes. In this case PA was objectively measured using an activity monitor and CRF was assessed via a continuous maximal graded ergometer bicycle test. CRF was found to be more strongly related to cardiovascular risk factors than objectively measured PA in children and adolescents, though PA becomes more important as the children age (Hurtig-Wennlof et al., 2007).

The studies mentioned above repeatedly and consistently suggest that CRF is a more important health marker than PA across age groups, yet many health guidelines around the world, including those found in the UK, tend to be structured around increasing PA – not CRF (Janssen, 2007; Tremblay et al., 2011). All current PA guidelines recommend 150 minutes of PA activity of at least moderate intensity (Weed, 2016). For children and adolescents aged 5-17 in the UK, at least one hour per day is recommended. The rationale behind this is that increasing PA has been shown to incur a host of well-documented health benefits, including increasing CRF (Weed, 2016). In other words, CRF is often seen as an *outcome* of increasing PA, however, this is actually a misconception, as the relationship between PA and CRF may be more complex than previously thought. In short, only PA of appropriate intensity is thought to be associated with CRF

If CRF is indeed a more potent indicator of health, the next logical question is to understand why this may be the case. At the time of this writing, a finite conclusion cannot be made due to the measures used for assessing PA. A noticeable trend is that PA has often been assessed via self-report surveys which, as stated in Section 2.1.3, have their issues. Objective measures of PA are becoming more prominent in the literature, however until this becomes standard practice with internationally agreed-upon cut-offs, it becomes difficult to directly compare CRF and PA reliably. As stated by Gu, Chang and Solomon, "A possible explanation for the mediation role of fitness in this study is that the measures for PA were less precise and likely included more error than the assessments of physical fitness (Bauman et al., 2006). Blair and colleagues (2001) also supported the assertion that data from observational studies will likely demonstrate a higher association between physical fitness and health outcomes than for PA and health outcomes."

This leads to the second point: CRF may simply be more clinically relevant than PA because it may be easier to measure objectively, particularly for children and youth in schools. In terms of outcomes, physical activity, particularly aerobic activities, may be thought of as a 'middleman' to CRF, the clinically relevant outcome. As stated in Section 2.1, the relationship between CRF and PA is not entirely clear. Perhaps one explanation is that the term 'Physical activity' is too broad to be useful at the public policy level as it encompasses a wide range of behaviours ranging from simply walking, to concerted, purposeful exercises such as training for sport, or lifting weights. Increasing general PA may not necessarily improve individual markers of fitness if it is done inconsistently. If a population is engaged with increased flexibility PA, would we expect to see an increase in CRF? The logical answer is: probably not. We know from numerous studies that to achieve a desired fitness effect, the This example represents that crux of the problem in that PA recommendations, while founded in good research, lack clear outcome targets other than increasing the PA itself.

This is apparent even on governmental websites, recommendations, and various systematic reviews that assert that PA should be comprised of multiple types of activities. Although the emphasis is often placed on aerobic activities for the purposes of achieving/maintaining good health, flexibility work, balance work, and activities that enhance muscle and bone health are also recommended (NHS, 2018; Strong et al., 2005; Warburton, Nicle, and Bredin, 2006). While these various forms of PA are ideal for 'complete' health related physical fitness, there are no standards in place for

From a practical standpoint, this makes it extremely difficult to quantify how useful general PA can be on a person or population, as the end goals of the PA may be different. As a thought experiment, let us consider an obese population. From a public health perspective On the other hand, CRF is an outcome measure, and may serve to directly assess how various types of aerobic PA, such as moderate-intensity continuous training, or high-intensity interval training, affect the endurance of the participants.

CRF on the other hand, is consistently reported using validated measures, typically a maximal graded test of some kind, either on special lab equipment, or in the field, which brings us to our next point in favour of CRF: measurement. Recently, there have been numerous calls to shift focus to CRF measures due to the fact the CRF is an attained state rather than behaviour (Despres, 2016; Ross et al., 2016). This removes many of the complications facing measurement of PA, making CRF a potentially useful clinical tool. Though some have called into question the practicality of assessing

CRF, particularly in less-fit populations such as obese patients where maximal graded tests may prove too strenuous, one advantage to CRF is that there are alternatives. For instance, submaximal field tests such as the 6 Minute Walk Test can provide useful clinical information when resources are limited or the population in question cannot perform maximal graded tests (Ross et al., 2016). Additionally, validated estimates of CRF can be made using non-exercising equations which may serve to predict CRF in severely at-risk participants (Ross et al., 2016).

Blair, Cheng, and Holder (2001) have asserted that, from a public health perspective, it may be easier to encourage people to become more physically active than physically fit (Blair, Cheng, and Holder, 2001). Warburton, Nicol and Bredin (2006) have also argued that physical fitness assessment in large scale populations may be difficult, further arguing in favour of PA. Though these considerations may be true of adult populations who are more difficult to measure and preoccupied with the complications of adult life, it fails to consider the situation of young people, particularly school-aged children and adolescents. The school-setting provides a simple and highly accessible platform to both measure largescale physical fitness and encourage its development. The ALPHA (Assessing Levels of Physical Activity) health-related physical fitness battery involves a variety of physical fitness components, including the 20-minute multistage fitness test for the assessment of CRF. Multiple studies have shown that this battery (or its derivatives) is feasible to deliver within the school setting (Ruiz et al., 2010; Zaquot et al., 2016)

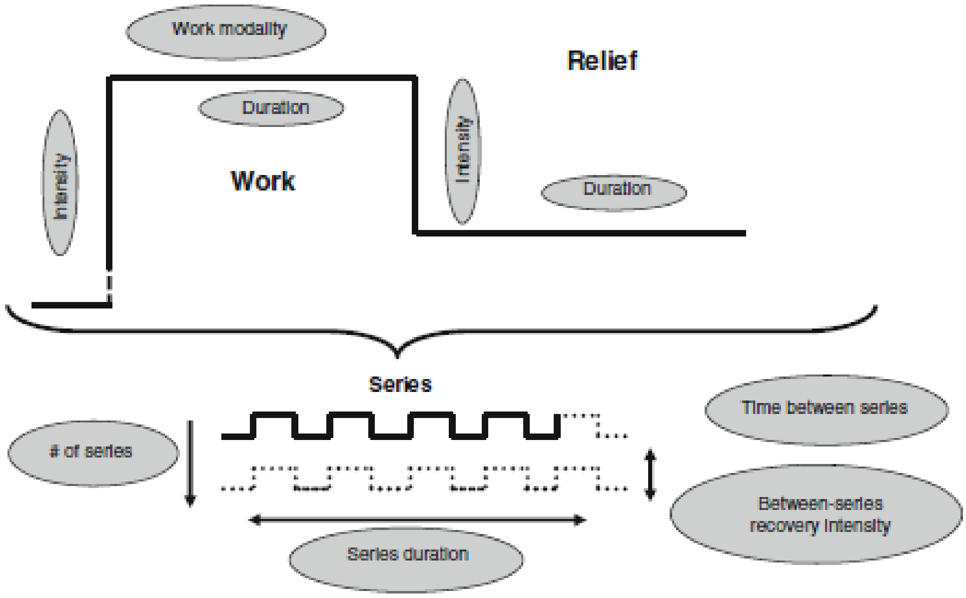
2.3. HIGH-INTENSITY INTERVAL TRAINING AS AN INTERVENTION STRATEGY TO INCREASE CARDIORESPIRATORY FITNESS

2.3.1 High intensity interval training: a brief overview

Studies investigating the effects of interval training first began to emerge in the 1970s (Weston, Wisloff, and Coombes; 2013). Early work examined the effects of various forms of interval training on different groups, including healthy adults, as well as patients in need of cardiac rehabilitation (Weston, Wisloff, and Coombes, 2013). One of the turning points in HIIT research came about after the publication of a 1981 study examining the effects of a 12-month intense training protocol on ischemic ST-segment depression on 10 patients between the ages of 44 and 63 with coronary artery disease (Ehsani et al., 1981; Weston, Wisloff, and Coombes, 2013). The researchers found that VO_{2max} increased from 25.5 ± 4.2 $mL \bullet k^{-1} \bullet min^{-1}$ (average ± standard deviation) to 35.3 ± 4.4 $mL \bullet k^{-1} \bullet min^{-1}$ (average± standard deviation) (Eshani et al., 1981). Though the training resulted in other positive effects, such as the elevation of double-product threshold for ischemic ST-segment depression, the substantial increase made to VO2max has prompted a wave of research in the field of HIIT, including the use of HIIT training in sport or athletic performance, and applications of HIIT for public health interventions in high-risk groups (Weston, Wisloff, and Coombes, 2013). Over the years, HIIT studies have evolved to include a wider range of groups, including a growing focus on the potential for this type of training for use in the school setting. The rate of publications concerning HIIT has risen dramatically in the last few decades. A Web of Knowledge search of “High Intensity Interval Training” yielded 8 novel relevant publications from 1987 to 1996, 58 from 1997 to 2006, and an astonishing 598 from 2007 to 2016, highlighting the explosion of interest in HIIT. The purpose of this section is to review the available literature surrounding HIIT, discuss the components of this type of training, discuss the benefits of HIIT, and finally, identify any gaps in the research that require further investigation.

To begin with, it is important to understand what constitutes a HIIT protocol. Though no standardized definitions for which elements constitute a HIIT exercise regime exist, there are hallmarks that remain consistent throughout the literature, and some authors have suggested definitions. HIIT typically involves periods of extreme intensity exercise, such as sprints, with rest intervals of little or no physical activity (Weston et al., 2014). Though there are some exceptions, most HIIT studies tend to use objective measures to prescribe the "high-intensity" and "low-intensity" phases for each workout to suit the fitness level of each individual participant by scaling a pre-tested measure to a predefined amount. These generally include tests such as a VO_{2max} test conducted prior to the intervention. For instance, in early work, such as the famed 1996 Tabata study on young, physically active Japanese males, 3-5 days of pretesting were used to determine the VO_{2max} and the power required to exhaust each subject prior to the intervention. The high-intensity exercise period of their actual HIIT cycles involved the athletes operating at approximately 170% of their previously tested VO_{2max} (Tabata et al., 1996). More recent studies also used a similar pre-test protocol in which the subjects VO_{2max} were measured prior to intervention (Little et al., 2010; Sperlich et al. 2010). Additionally, the objective measures used to determine intensity are often coupled with a more subjective element, such as the Borg Rating of Perceived Exertion Scale, that directly asks the participants how they feel about their level of activity during exercise (Sperlich et al., 2010). Other methods for monitoring/ensuring a high degree of intensity during HIIT protocols include measures of maximal heart rate (MHR), peak power output, and peak work rate (PWR) (Weston, Wisloff, and Coombes, 2013).

Figure 2.1 Buchheit Nine Elements of a HIIT Protocol



2.3.1.1 Outcome measures

HIIT interventions also tend to include certain key outcome measures, particularly change in VO_{2max} in the subjects following intervention, however, depending on the research question, other measures have also been used (Weston, Wisloff, and Coombes, 2013; Weston et al., 2014). For instance, studies investigating the underlying physiological mechanisms of HIIT may use muscle biopsies and other indicators of metabolic change (Little et al., 2010; Little et al., 2011). Researchers studying the use of HIIT in sport may include performance-based measures in their work. For instance, a study involving children aged 9-11 years old, found that the participants in the HIIT training group significantly reduced their times in a 2,000m race when compared to children in a more traditional MICT programme (Sperlich et al., 2010).

Despite the wide variation in outcomes recorded in HIIT studies, measures of cardiovascular fitness in the form of maximal oxygen uptake (VO_{2max}), peak oxygen uptake (VO_{2peak}), or scores on a 20m Multistage Fitness Test (20MSFT) remain the most widely used in HIIT studies. For instance in a systematic review conducted of adults suffering from lifestyle-induced cardiometabolic disease, 9 of 10 articles included for review incorporated changes to VO_{2max} as a principal outcome measure (Weston, Wisloff, and Coombes, 2013). This trend can be observed throughout the HIIT literature, perhaps due to the accepted validity of VO_{2max} as a reliable measure of cardiovascular fitness in the scientific community (Logan et al., 2014). Other estimations of cardiovascular fitness include maximal distance covered in a 7-minute run (Baquet et al., 2001).

There has been a recent trend in the use of Repeated Sprint Ability (RSA) as a key outcome measure in HIIT studies. Repeated Sprint Ability presents an interesting development in that it blurs the distinction between CRF measures and athletic performance measures. The relationship between RSA and VO_{2max}, for example, appears to have more to do with the type of RSA test used, as tests using longer sprint intervals may require a higher contribution from the cardiovascular system as opposed to anaerobic system (Turner and Stewart, 2013). For example, a moderate ($r = -0.35$) relationship between VO_{2max} was reported using 8 x 40m sprints with 30 seconds of recovery, but not 6 x 20m sprints (Azziz et al., 2000; Azziz et al., 2007). Other studies have also confirmed the controversial link between the two measures. A study of twenty-nine Brazilian soccer players, 7 sprints of 34.2m were conducted with 25 seconds of active rest time (da Silva, Guillermo, and Bishop, 2010). Correlations between velocity at the onset of blood-lactate accumulation (vOBLA) and the minimum velocity to reach VO_{2max} (vVO_{2max}) were found between Mean Time (MT) ($r = -0.49$, $p<0.01$ and $r = -0.38$, $p <0.05$, respectively) (da Silva, Guillermo, and Bishop, 2010). In another study of 41 professional soccer players, VO_{2max} was found to have a significant correlation with RSA, however it is interesting to note that the sprints used in this case were 6 x 40m sprints with active recovery (Jones et al., 2013).

It would appear that RSA is related to aerobic fitness, however, only when a certain threshold of sprint time or distance is reached. It would appear that the peripheral factors, such as vOBLA, which is associated with capillary density and the transport of H^+ ions, are more fitting (Turner and Stewart, 2013). Despite this, improving central factors, such as VO_{2max} may be useful when the RSA protocols involve sprints of at least 40m and at least 10 seconds per sprint (Turner and Stewart, 2013).

Although less RSA work has been done with respect to HIIT protocols, when compared to other measures (particularly VO_{2max}), the results appear to indicate that HIIT may be a useful strategy for improving RSA, or at least when compared with MICT. In a HIIT study involving 20 females and 5 x 6s sprints, the both the HIIT and MICT groups experienced significant improvements in VO_{2peak}, however HIIT was found to result in a significantly greater increase in total RSA work (Edge et al., 2005). Other studies have also found positive relationships between HIIT and RSA, and the literature in this field is growing, however more evidence is needed to determine the mechanisms behind these improvements (Turner and Stewart, 2013; Fernandez-Fernandez et al, 2015).

While common patterns have emerged in terms of measures used in HIIT studies, the protocols themselves may differ widely in exercise type, workload of the high intensity interval, work-to-rest ratios, intervention frequency, and total intervention durations.

2.3.1.2 Intensity of the Work Interval

Perhaps most obviously, HIIT protocols are characterised by 'high-intensity' intervals, however various authors have used different criterion and prescriptions of intensity in their work. Weston, Wilsoff, and Coumbes (2013), for example, suggested that HIIT protocols use prescribed intensities of 80-100% previously tested individual peak heart rate, while sprint interval training, a different form of HIIT, use a target intensity of 100% or greater of previously tested individual VO_{2max} (Weston, Wisloff, and Coumbes, 2013). Other authors have proposed alternative prescriptions of intensity.

Eddolls et al (2017) specified that studies needed to use prescribed intensities of ≥90% peak oxygen uptake, ≥100% maximal aerobic speed, and/or ≥90% of peak heart rate to be considered for their review (Eddolls et al., 2017). On the lower end of the spectrum, Garcia-Hermosa et al (2016) used cut off points of prescribed high intensity exercise conducted at 64–90% VO_{2max} and/or 77–95% maximum heart rate. Though these cut-offs are substantially lower than those used in other HIIT studies, they are not necessarily unwarranted as they match the recommendations made by Garber et al (2011) for what qualifies as 'vigorous intensity' physical activity (Garber et al., 2011).

HIIT studies with the intent of improving athletic performance on the field have used other prescriptions of intensity, such as selecting specific running speeds on set times for distances ranging from 800m-5000m. These preceptors are typically devoid of physiological markers (Buchhiet & Larson, 2013). The advantage to these approaches is that they can be custom tailored based on each athletes performance, and easily implemented due to the lack of equipment necessary compared with obtaining speed values associated with physiological markers such as maximal oxygen uptake, maximal aerobic speed, or lactate/ventilatory thresholds. The disadvantage is that it may be more difficult to assess how the protocol effects specific outcomes.

Finally, some older protocols have no measure of intensity, and simply ask their participants to engage with 'maximum effort.' Most contemporary HIIT studies tend to explicitly describe the intensity prescribed in their protocol, however it is important not to discredit the potential utility of self-selected recovery periods from a practical standpoint. At least in adults, self-selected recovery appeared to reduce the total amount of time spent at >90% maximum participant heart rate, however, this may have been compensated by more time spent at > 105% maximum aerobic speed. In other words, participants typically give themselves more time to rest which may facilitate increased performance during subsequent work sessions compared to other HIIT prescriptions at the cost of aerobic stimulus (Kellogg et al., 2019; McEwan et al., 2018). These findings are consistent throughout the HIIT literature in adult participants (Kellogg et al., 2019; McEwan et al., 2018), however the effects of self-selected recovery may be different in younger populations. In youth elite football players, self-selected recovery was found to have the opposite effect, with many of the participants engaging in shorter recovery intervals (Gibson et al., 2017). It remains to be seen whether or not this is consistent among younger participants or if this pattern owes to the elite, competitive nature of the participants in this study.

2.3.1.3 Exercise Modality

One of the advantages of HIIT is that it can be done using any number of exercises, so long as they are significantly difficult to induce a cardiorespiratory response. For instance, a recent review of HIIT in adolescents reported numerous exercise types used across 20 interventions. Of the studies included, the majority used sprint training (13/20) studies. Other training types included sprint cycling, treadmill work, roller ski skating, and one intervention that used a multi-exercise approach (Costigan et al., 2015). These findings are generally reflective of the literature as a whole. In a separate review of HIIT on adolescents, shuttle-runs were the most common modality of training (Logan et al., 2014).

The use of multiple exercise types reflects one of the key advantages of HIIT: adaptability. This is of particular relevance in the school setting where different forms of HIIT may be necessary to engage as many students as possible. Moreover, regardless of exercise type, HIIT consistently improves cardiovascular fitness. In almost all of the studies mentioned above, VO_{2max} or VO_{2peak} were increased significantly (Logan et al., 2014; Costigan et al., 2015). Unfortunately, these reviews also highlight a recurring lack of studies done in younger age groups. Though there are currently two systematic reviews concerning the effects of HIIT on adolescents, at the time of writing this review none could be found on children younger than 13 years of age.

Of course, that is not to say that there is no information in this realm. Studies conducted in younger children also support the notion that multiple modalities are useful. For example, a crossover HIIT intervention delivered twice per week over five weeks was reported to increase VO_{2peak} (+10.2%, effect size = 0.57) (Sperlich et al., 2010). Sprint training again makes up the bulk of the research in children. Future work may examine the effects of other modalities, and compare them to see which tend to be the most efficient at increasing cardiovascular fitness.

2.3.1.3 Workload of the high intensity interval

Despite the variability in exercise modalities, recent work has been more consistent in what is used with respect to the workload of the high intensity interval. Two classifications of interval training have been discussed. The first category of HIIT uses a target intensity of 80-100% of previously tested peak heart rate. The second category, known as Sprint Interval Training (SIT), uses VO_{2peak} as the key indicator of intensity, with target work intervals designed to meet or exceed 100% of VO_{2peak} (Weston, Wisloff, and Coombes, 2013). The differences between these categories require further study. These definitions of workload have been taken into account by numerous authors following the publication. For example, the Weston definition described numerous times above uses a similar set of parameters (Weston et al., 2014).

Many studies appear to use these definitions for their prescriptions of the high intensity interval, though not always. For instance, in adolescents, heart rate monitors were the most frequent tools used to assess the intensity of the work interval, used in 14/20 studies, though other measures, such maximal oxygen uptake and distance covered were also used (Costigan et al., 2015). Interestingly, heart rate appears to be used less in studies involving children, with studies simply assigning the interval based on pretested values, as in the case of the study mentioned above with competitive swimmers. The interval was set at 92% of the speed of their personal best times, though no data was reported on whether this speed was rigorous enough (Sperlich et al. 2010). Another study, which compared the effectiveness of HIIT and MICT in children 8-11 years, used a pre-test to determine maximal aerobic velocity (MAV), the velocity associated with maximal oxygen consumption. The work intervals throughout this intervention were set to increase starting at 100% MAV up to 190% of MAV (Baquet et al., 2010). In a study conducted in obese 8-12 year old children, the work interval was set to 100% maximum velocity sprints, while the MICT group was subjected to continuous bouts of treadmill running/walking set at 80% peak heart rate (Corte de Araujo et al., 2012). Cardiovascular fitness was again shown to improve in all of the aforementioned studies, indicating that the workload may be flexible. Future work must increase the methodological rigour at which these intensities are prescribed, and include objective measures as to whether or not they were maintained. This is particularly true of field-based studies where velocity may not be set.

One study in adolescents assessed the fidelity of a HIIT protocol in adolescents (mean age 14.0 ± 0.3 years) by using heart monitoring of the participants during the high-intensity intervals with ≥90% of maximum heart rate considered to be a satisfactory completion of the work interval (Taylor, Weston, and Batterham, 2015). The researchers reported that the overall fidelity of the intervention was moderate at best, however this may be attributable to the “intention to treat” scheme used in the study, as many of the sessions were missed (Taylor, Weston, and Batterham, 2015). Seeing as this is one of the first studies of its kind, future work may also look at different groups, such as children.

2.3.1.4 Type of Recovery Interval

HIIT protocols involve either passive recovery, in which the participant stops physical activity entirely for the prescribed duration, or active recovery in which they continue to engage in physical activity, usually at a greatly diminished intensity. In adults there have been a few studies which have directly investigated the effects of recovery types, however the literature is still in its infancy. It appears that there is no clear 'best' form of recovery, however, it would appear that passive recovery allows for significantly higher effort engagement during the work interval, at least in adults. (Germano Moises et al., 2019; Kriel et al., 2016). Different durations of passive recovery have been shown to have little effect on metabolic differences and lactate removal following a study of two different recovery models (two minutes vs six minutes), in adult men (Diego Germano et al., 2017), however this study only involved a sample size of eight participants, a common problem amongst the studies mentioned above.

There has been very little work regarding different types of recovery in school-aged youth. Previous reviews have been unable to comment on rest intervals due to paucity and methodological limitations for studies within this age range (Eddolls et al., 2017).

2.3.1.4 Work-to-rest ratios and numbers of HIIT cycles

Work-to-rest ratios (WRRs) and number of HIIT cycles vary tremendously across studies. In some cases, the WRRs are modified throughout the intervention as a means of increasing workload (Baquet et al. 2010). Additionally, the rest period in HIIT studies may be active, meaning light exercise is performed, or passive, meaning that the participant ceases to engage in PA for a time. For example, a study conducted in 54 obese and overweight Norwegian adolescents used a 4x4 protocol, where participants engaged in uphill treadmill running for 4 sets of 4-minute bouts set at 90-95% of maximal heart rate. The rest period for this intervention was three minutes of active recovery at 70% maximal heart frequency in between intervals (Tjønna et al., 2009). In contrast the participants of another study were instructed to engage in four 30-second bouts of "all out" sprints on a Wingate bicycle against a resistance equivalent to 7.5% of body mass. The rest periods included four minutes of unloaded recovery at 70 revolutions per minute. The participants repeated the circuit four times in earlier sessions, but this was increased gradually to seven repetitions for later sessions(Barker et al., 2014).

Despite the variability in these methods, again it can be observed that cardiovascular fitness is almost universally improved. Though more work needs to be done in young people to determine optimal interval ratios, there may be some insights available from research in adults. A meta-analysis of HIIT in adults under 45 years of age examined the effects of HIIT across 37 studies. As expected, an overall increase in VO_{2max} of 0.51 $L \cdot min^{-1}$ (95% CI: 0.43 to 0.60 $L \cdot min^{-1}$) was observed, however, the researchers also identified a subset of nine studies involving longer interval period that was shown to have a greater effect on VO_{2max} (~0.8–0.9 $L \cdot min^{-1}$) (Bacon et al., 2013).

At the time of this writing, only one study appeared to directly test the effects of different work-to-rest ratios in younger age populations, specifically adolescents. In this study of 47 Taekwondo athletes aged 15-18 years, 10 sessions of HIIT were preformed over four weeks. The participants were grouped into different work-to-rest ratios and one control group. In this study, significant changes were reported only in the group that used a 1:4 work-to-rest ratio (Seo et al., 2019). Other studies, however, have also found success with work-to-rest ratios that are even less (1:8, 1:10, 1:12) (Jones et al., 2019) or greater (2:1) (Moghadamm et al., 2019), although these studies have been conducted in older populations.
Future projects may utilize comparisons with multiple interval WWRs and number of cycles, perhaps making use of the longer interval durations described above.

2.3.1.5 Intervention frequency and total intervention duration

One of the most prevalent gaps in the research surrounding HIIT in children and adolescents is the lack of long-term follow up or long-term studies. Most interventions in young people tend to be five or six weeks in duration. Additionally, many of these interventions involve two or three sessions per week (Logan et al., 2014). Following the trends described above, the amount of total exercise performed during these studies is also quite variable. Total intervention exercise length as short as 60 seconds and as long as 3 hours and 20 minutes (Logan et al., 2014). Though measures of cardiovascular fitness appear to show improvement following even low amounts of HIIT, interval duration length as a significant modifier to other aspects HIIT outcomes, namely body fat percentage. Studies of eight weeks or longer appeared to alter body fat more than studies of shorter duration (Costigan et al., 2015). Again, more information is needed to confirm these results and determine if increased intervention length is necessary for improving body composition.

2.3.2 HIIT in context: the benefits of high intensity interval training

2.3.2.1 Cardiovascular fitness

As stated in previous sections, the most studied aspect of HIIT has been the effects on cardiovascular fitness (Weston, Wisloff, and Coombes, 2013; Weston et al., 2014; Logan et al., 2014, Costigan et al., 2015). This is relevant to the discussion of what interventions may be of most use in the school setting, as the research has shown that school-based interventions are suited for increasing measures of cardiovascular fitness (Dobbins et al., 2013). One of the most recurring themes in HIIT research is the heavy emphasis on comparisons between HIIT and MICT though these efforts appear to be mostly concerned with the preventive effects than on performance. For instance, one study compared the effects of HIIT versus MICT in 34 obese adolescent girls (mean age 15.9 +/- 0.3 years). The authors found that maximal oxygen uptake increased in both groups, while HIIT conveyed other additional advantages, such as decreasing waist circumference, triglycerides, and total cholesterol

(Racil et al., 2013). In a 12-week intervention study conducted in obese children the researchers randomly assigned 30 participants to one of two groups: a HIIT group following sets of 3 to 6 60-second sprints set at 100% of peak velocity, or an endurance training (ET) group preforming 30-60 minutes of continuous exercise set to 80% of peak heart rate (HR). The authors found that both training methods significantly improved VO_{2max} and indicators of metabolic health (Corte de Ajuro et al., 2012). No control group was used in this study, on the grounds that it was ethically unacceptable to deny the children, recruited from a medical hospital, treatment for their condition (Corte de Ajuro et al., 2012). Other studies using comparisons also face issues with control groups, and use various methods to account for this. For example in one study, the intervention groups (MICT and HIIT) were assigned to year 6 students while year 5 students acted as the control (Buchan et al., 2011).

Despite the inconsistencies with control groups, one thing remains clear: HIIT is at least as effective at increasing cardiovascular health and fitness as more traditional MICT (Logan et al., 2014; Costigan et al, 2015, Ramos et al., 2015). Moreover, these improvements are often made in substantially less total time. Large discrepancies in total time of HIIT groups versus their MICT group counterparts has been reported, though both have similar effects on measures of cardiovascular fitness (Logan et al., 2014). For example, in the study mentioned above comparing MICT and HIIT in obese children the MICT group underwent up to 360 minutes of total intervention exercise duration while the HIIT group underwent less than half, at up to 144 minutes (Corte de Ajuro et al., 2012). In another study, the difference was even greater with the HIIT intervention totalling a mere 42 minutes of total intervention exercise versus up to 7 hours for the MICT group (Buchan et al., 2011). One study was able to demonstrate positive results in as little as six HIIT sessions delivered over two weeks with a 5% increase in participant VO_{2max} (Barker et al, 2014). These results indicate that HIIT may be useful in the school setting if only for the effects on cardiovascular fitness, especially given the minimal time commitment. It may be possible to implement HIIT while changing very little else in the school curriculum, granting physical education teachers the freedom to incorporate HIIT at their leisure without disrupting other lessons or exercises, though school-based intervention studies are needed for confirmation.

2.3.2.2 Body composition and other health indicators

Numerous studies have also assessed other health benefits of HIIT interventions, including blood pressure, lipid profile, oxidative stress, insulin sensitivity, and body fat with HIIT observed to incur higher benefits to these biomarkers in adults (Ramos et al., 2015). In children, more research is needed. HIIT appears to significantly increase cardiovascular fitness rather rapidly (<8 weeks of intervention), though longer periods (≥ 8 weeks of intervention) are required to elicit changes to body composition (Costigan et al., 2015). Though the research shows that HIIT may be promising for improving these indicators, some holes still remain. Laboratory-bases studies are necessary to better understand the processes of energy substrate metabolism and the effects on underlying glycaemic and lipid regulation (Logan et al., 2014). In a review of HIIT studies conducted in 182 participants, HIIT was found to more consistently improve traditional CVD risk factors, and biomarkers associated with vascular function relative to MICT, in addition to cardiorespiratory fitness. Interestingly, the researchers noted that longer bouts of high intensity were associated with greater improvements in vascular function, however this remains to be confirmed for younger age groups (Ramos et al., 2015).

2.3.2.3 Physical Performance

HIIT may also be used to improve physical fitness, however the results tend to be much more varied and inconsistent than the effects on cardiovascular fitness. Studies that analyse performance-related measures, such as sprint times or jump height tend to focus on pre-trained populations, leaving questions regarding the effects of HIIT on the general population. For example, in one study investigating the effects of HIIT on sprint times involved 14-year old football (soccer) players that had extensive training experience prior to the study. All participants belonged to a German Premier League club, (n=19) had at least three years of prior training, and regularly experienced a training workload of >4 units per week (Sperlich et al., 2011). In another study, elite junior cross-country skiers were subjected to HIIT and sprint performance was also assessed. Again, elite athletes were used (mean age 17.4 ± 0.5 years) (Sandbakk, Welde, and Holmberg, 2014). In both studies, sprint times were significantly improved following intervention (Sperlich et al., 2011; Sandbakk, Welde, and Holmberg, 2011). In contrast, other studies have found that HIIT programs were not associated with substantial gains to muscular performance, citing lack of training specificity in the HIIT protocols as a possible explanation (Costigan et al., 2015). Additionally, in young people there is a great lack of research regarding strength-related performance. Given what is known about the potential use of HIIT as time efficient replacements for MICT, it would be useful to know if these protocols may also be used for other types of exercises, possibly even with weights. Future work ought to target non-specialized populations and explore the effects of HIIT in other markers of physical performance.

2.3.2.4 Cognitive Performance

Many studies have explored the role of PA and CRF in cognition and many have described a positive relationship between physical activity and fitness and measures of cognition (Siblier et Etnier, 2003; Fedewa and Ahn, 2011). Aerobic fitness appears to incur the most benefit (Fedewa and Ahn, 2011). Though earlier HIIT studies tended to focus on the comparisons between HIIT and MICT in terms of the effects on various health indicators, there has been a growing trend in recent years (2014 onward) in the appearance of cognition-related HIIT studies due to the apparent success these interventions have with raising CRF, however due to the cutting-edge nature of this topic, very limited information is currently available.

As discussed previously, physical activity may improve both acute and chronic measures of cognition. Presently, 3 studies regarding HIIT and cognition could be found. Of these two involve adults (Alves et al., 2014; Drigny et al., 2014; and one involves adolescents (Costigan et al., 2016). These studies support the use of HIIT as a cognition intervention. The acute effects of HIIT were examined using the Victoria Version of the Stroop test, which measures a dimension of attention, and the Digit Span Test, associated with memory, in 22 middle-aged adults (Alves et al., 2014). The researchers found that the HIIT group preformed the Stroop "Colour Word Test" significantly more quickly than the control, though no significant findings were reported for other measures (Alves et al., 2014). The other two studies looked at the effects of HIIT over a longer period of time. In a pilot study of 6 obese patients (49 ± 8 years), the authors reported that four-months of HIIT significantly improved short-term and verbal memory, attention, and processing speed (Drigny et al., 2014). Similar findings were reported following an eight-week, 8-10 minute HIIT program in adolescents delivered in physical education or during lunch three times per week (Costigan et al., 2016).

This budding area of research has great potential for use in the school setting, as bolstering cognitive performance while simultaneously improving health may be a goal for many school administrators. Future work may benefit from more cognitive tests, as well as assessing practical measures of performance such as the effects on grades or standardized tests. Additionally, more work ought to consider the effects of HIIT on mental health, given that other forms of PA have been shown to improve mental well-being (Biddle and Asare, 2011).

2.3.3 Flaws with the research, knowledge gaps, and questions for the future

Despite the progress, many gaps remain in the literature. Firstly, methodological gaps appear to be widespread. The systematic reviews assessing HIIT in adolescents both cite methodological inconsistencies as barriers to analysis (Logan et al., 2014, Costigan et al., 2015). The treatment of control groups varies frequently between studies, while some opt to use none at all. This is understandable given the ethics involved when dealing with human participants, as it may be questionable to deny treatment to a group. A standardized approach may help future studies.

An important area of consideration for future research is to examine the physiological mechanisms of HIIT, particularly in children and adolescents, where no mechanistic HIIT studies could be found. Some of the literature in older populations offers hints as to the physiology behind HIIT; however applying these lessons to children must be done so with extreme caution due to differences in physiology. HIIT appears to aid both peripheral and central components of cardiorespiratory fitness. The peripheral components are those associated with the production and utilization of ATP (Laursen and Jenkins, 2002). On the cellular level, HIIT appears to increase mitochondrial biogenesis via increases in PGC-1α (Weston, Wisloff, and Coombes, 2013). The rate of calcium reuptake into the sarcoplasmic reticulum may also be raised by 50-73% (Weston, Wisloff, and Coombes, 2013). Finally, HIIT may aid skeletal muscles by enhancing their ability to buffer H^+ ions (Laursen and Jenkins, 2002; Weston, Wisloff, and Coombes 2013; Ramos et al., 2015) .

Because heart rate appears to remain unchanged following many HIIT interventions, it has been proposed that stroke volume is the primary cause for the improvements in central cardiovascular function (Laursen and Jenkins 2002). Numerous other physiological adaptations have also been reported following HIIT in adults such as changes to lipid profile, oxidative stress, insulin sensitivity blood pressure, and flow mediated volume, however it is unknown if these adaptations work the same way in children and adolescents (Weston, Wisloff, and Coombes, 2013; Ramos et al., 2015). Whether these changes are present in children, or work in a similar fashion remains to be seen and should be a target for future research.

Questions also remain regarding optimization of HIIT protocols. While some work has been done in adults to suggest the increased advantage of longer intervals, the same cannot be said for younger age groups (Ramos et al., 2015). This may be aided by a further study of the physiological mechanisms behind HIIT. Most studies also tend to use running/sprinting as the primary exercise, leaving room for future studies to evaluate alternate exercises with HIIT (Costigan et al., 2015). Methodological problems such as small sample sizes and failing to report measurements of the intensity of the work interval are also prevalent, particularly in younger children. Finally, there are no longitudinal HIIT studies, making it difficult to know the long-term effects of HIIT may be, or if these protocols are sustainable. Some evidence suggests that HIIT may be more enjoyable than MICT, however long term follow up may help answer whether or not HIIT is sustainable.

In short, HIIT has been consistently shown to improve measures of CRF, a potentially clinically significant health outcome. Given the failings of previous intervention strategies, it may be useful to design a HIIT intervention for the school-setting where it would be easy to implement.

3.0 Chapter 3: The Effects of Differing Parameters of HIIT Protocol Design on Cardiorespiratory Outcomes: A Systematic Review

3.1 Introduction

HIIT has been touted as a time-efficient means of increasing CRF (Gibala et al., 2012; Gibala et al., 2018; Ito, 2019). Unfortunately, despite the promise of HIIT there is much that remains unknown regarding 'optimal' implementation. At the time of this writing, no clear definition of HIIT has been proposed in the literature, although certain features have been defined. Buchheit and Larsen (2013) identified nine modifiable core elements of HIIT protocol design: the intensity, modality, and duration of the work interval, the intensity and duration of the rest interval, the number of total series repetitions, the duration of these series, the time between series, and the recovery intensity in between series (Buchheit & Laurson, 2013).

One of the main weaknesses in HIIT research has been a lack of standardization among studies, with many investigations utilizing different protocols varying greatly in many of the nine dimensions discussed above. In the Literature Review (See Chapter 2), some of the progress made with regard to optimization was discussed, including studies that were directly aimed at examining the differences in HIIT outcomes with respect to one of these dimensions. The purpose of this section is to specifically examine previous HIIT systematic reviews, particularly with respect to children and adolescents to discuss their strengths and weaknesses and explain the rationale for this review.

One of the main objectives common to many past HIIT systematic reviews was to establish 'best practice' in terms of optimizing outcomes following HIIT interventions. Perhaps unsurprisingly, CRF-related outcomes have been frequently explored across reviews, however, they have not been the only subject of inquiry. A 2015 review by Costigan et al suggested that HIIT interventions of ≥ 8 weeks of duration were necessary to incur changes to body composition. Similar findings were reported by Eddolls et al (2017) in their review, suggesting a total intervention of >7 weeks for maximum effect on multiple health indices. In both of these reviews multiple outcomes of HIIT interventions, including the effects on body composition were considered. It remains unknown what the minimal total intervention duration is necessary to incur purely positive changes to CRF. In obese adolescents, a 12-week minimum was proposed (Garcia-Hermosa et al., 2016). Eddolls et al. (2017) also identified that running-based HIIT interventions (modality) at an intensity of 90% maximum heart rate or 100–130% maximal aerobic velocity (intensity), preformed two to three times a week (sessions per week) to improve health markers, however, these have been unconfirmed by other work. These recommendations, while helpful, only address a few of the nine HIIT dimensions described by Buchheit and Laursen (2013). The goal of this project was to expand on these gaps in the literature by providing additional information on how some of the dimensions of HIIT can be optimised to improve CRF in school-aged youth. Given the goals of generalizability and transferability, it may be useful to determine the optimal requirements and program considerations for a HIIT protocol needed to incur a positive and significant CRF response, particularly with regard into what can be easily implemented and scaled in the context of public health. Here the term 'optimal' is used to refer to protocols which elicit the greatest effect sizes with respect to CRF outcomes. These will be outlined in greater detail below:

3.1.1 Participant Age

Previous reviews have investigated the effects of HIIT in adolescents (Costigan et al., 2015 Garcia-Hermosa et al., 2016, Eddolls et al., 2017), however there has been significantly less work done in prepubertal children with only the Eddolls (2017) paper looking into this younger demographic. HIIT has been found to be effective for both children and adolescents however questions remain as to whether or not there are different considerations for different ages. Although numerous HIIT reviews have been conducted on school-aged youths, none thus far have examined differences in CRF outcomes as a result of HIIT across these ranges. In other words it is currently unknown if younger children or older adolescents respond better to HIIT.

Research Aim:

Determine if HIIT has differing effects on CRF depending on the age range of participants.

5.1.2 Work-to-Rest Ratio

The work-to-rest ratio may defined as the time spent in the high-intensity interval divided by time spent during the recovery interval. As with passive versus active recovery, the literature comparing and testing different work-to-rest ratios is lacking, particularly with respect to younger age groups. Success has been produced with work-to-rest ratios above and below one, however, there has been very little work with respect to optimal work-to-rest ratio for younger populations.

Research Aim:

To determine if there is an optimal work-to-rest ratio for improving CRF outcomes in children and adolescents.

3.1.3 Intervention Duration

Costigan et al. (2015) suggested that HIIT interventions lasting at least eight weeks in duration were most effective for various health outcomes. Similar results were reported by Eddolls et al. (2017) who suggested that interventions of seven weeks were capable of producing appreciable CRF-related results. Other work has shown that HIIT can incur significant changes to CRF in as little as two weeks, however it remains to be seen if this can be applied to children and adolescents (Campbell & Phillips, 2020).

Research Aim

Determine what the optimal HIIT intervention duration is needed to incur a positive change to CRF in children and adolescents.

3.1.4 Intensity of the Work Interval

Perhaps surprisingly, one of the most frequently varied aspects of HIIT protocols is that they tend to rely on different prescriptions of intensity for their work intervals, leading questions as to what may be considered 'high-intensity' training. On the lower end of the spectrum Garcia-Hermosa et al (2016) used 64–90% VO_{2max} and/or 77–95% peak heart rate to define their searches for what was considered HIIT training, while others have used substantially more rigorous prescriptions for HIIT, such as supramaximal VO_{2max} (Weston Wisloff, and Coubmes, 2013). At the time of this writing, no 'minimal' prescription of HIIT intensity has been seen in the literature. It is also unknown which type of intensity prescription, such as VO_{2max}, peak heart rate, or maximal aerobic speed, is optimal.

Research Aim:

Determine which type of HIIT intensity prescription is optimal for incurring CRF benefits.

3.1.5 Recovery Type

Passive recovery refers to rest intervals in which the participants do not partake in any kind of additional activity, resting completely for the allotted time. Active recovery refers to additional activities, however these are typically prescribed at an intensity much lower than the high intensity interval. At the time of this writing it is unknown if active or passive recovery is more effective for younger age groups, and, if active recovery is superior, it is unknown which intensities are best suited for youths. Given the myriad of different prescriptions of active recovery intensity, for the purposes of this review it was only of concern to separate between active versus passive recovery.

Research Aim:

Determine if passive or active recovery is more effective for CRF outcomes in school-aged youth.

3.1.6 Laboratory Measures versus Field-Based of CRF Outcomes

Laboratory based measures of CRF typically involve maximal oxygen uptake, the gold standard of assessment, usually expressed in absolute (L/min) or relative terms (L*kg/min) (Armstrong, Tomkinson,& Ekelund, 2011). Maximal oxygen uptake is considered to be the current best assessment of CRF in terms of accuracy and validity, however numerous field-based measures of CRF have also been implemented. Field-based measures of CRF, such as the 20-meter Multistage Fitness Test (20-MSFT) have been shown to be accurate and reliable proxy measures of CRF, and may serve as the basis for population-level assessment of CRF (Ross et al., 2016). Recent work has begun to explore cut-offs for what may be considered healthy or unhealthy levels of CRF based on performance on these tests (Ruiz et al., 2011).

Research Aim:

Determine if there is a difference in CRF effect size based on the type of CRF measures used (laboratory vs field-based).

3.1.7 Modality

The modality of the HIIT protocol has also been the subject of debate, with many protocols built around different modalities. In adolescent studies, running has been shown to incur the greatest CRF response, however, it should be noted that this may simply due to the fact that is the most common modality amongst studies (Costigan et al., 2015, Eddolls et al., 2017). Other modalities, such as cycling, or mixed-methods approaches have also been shown to be effective, however, the literature surrounding these approaches is sparse, particularly in younger age groups (Astorino et al., 2018).

Research Aim:

Determine the optimal HIIT modality for improving CRF outcomes in school aged youth.

3.2 Methods

3.2.1 Search Strategy

This study involved an amended search strategy that developed over the course of the project. The first search strategy was designed with the PRISMA guidelines in mind. Four electronic online databases were searched: Science Direct, PubMed, Web of Knowledge, and the Cochrane Library. These databases were chosen because they were free to use, supported Boolean search terms, and were compatible with the lead researcher's data-management tools including Mendely and End Note.

The lead researcher attended the York Systematic Review Course in June of 2016, which resulted in several amendments to the initial search strategy, which were registered on PROSPERO. The amended search strategy can be found here:
http://www.crd.york.ac.uk/PROSPEROFILES/33247_PROTOCOL_20160015.pdf.
The second search was conducted on the 24 June, 2016, with a date restriction of records up to January 31, 2016; however, this was later amended to August 1, 2018 during a second search due to the ongoing nature of the project.

The search terms were based on both Prisma 2015 statements' PICO (population, interventions, comparators, and outcomes) recommendations (Moher et al., 2015) and the terms used by Costigan et al (2015) for their review. A two-field search strategy was used each database. The first field (intervention) was intended to search for studies involved with HIIT interventions and include the terms "High Intensity Interval Training" OR "High Intensity Intermittent Exercise" OR "High Intensity Interval Exercise" OR "Sprint Interval Training" OR "Intermittent Training." The second field (population) was intended to sort studies based on the target age range of 5-17 years and include the terms "Children" OR "Adolescents" OR "Teenage" OR "School-Aged" OR Prepubertal OR "Prepubescent." Because the purpose of this project was primarily to investigate HIIT and not compare it to other physical activity modalities no search terms were used to limit the comparator. In preliminary searches terms pertaining to cardiorespiratory fitness were trailed, however they were found to greatly reduce the number of retrieved records, so they were ultimately excluded from the final search strategy. Only studies written in English were included. Additional studies were found through a combination of reference-checking included studies and google scholar.

The search strategy involved three phases. The first included an identification phase where records were retrieved from database searches and duplicates removed. The second phase involved a title and abstract screening of relevant papers. The third and final phase involved a full text screening. The protocol has been registered in the International Prospective Register for Systematic Reviews [PROSPERO], registration number CRD42016033247.

3.2.2 Inclusion Criteria:

Studies were included in the review if they were: (1) Published before August 1, 2018, (2) Published in English, (3) Of RCT, crossover, or quasi-experimental design, (4) Conducted in humans, (5) Involved participants between 5-17 years in age, (6), Included a NON EXERCISING control group, (7) Included a HIIT arm with adequate description of protocol including at least 3 of the following: work/rest ratio, fidelity, intensity of work interval, intensity of rest interval, total intervention duration (number of weeks and/or total number of HIIT sessions), modality, total duration length, number of sessions per week, and total number of repeated cycles, (8) Included a measure of CRF as a primary outcome (maximal oxygen uptake or 20 meter multistage fitness test (9) At least 2 weeks in duration or involved at least 6 sessions of HIIT.

3.2.2.1 Participants

This review included school-aged children and adolescents between the ages of 5 and 17.

This study aimed to investigate the effects of HIIT on school-aged children between the ages of 5-17 years. Participants were included if their mean pre-intervention age was between 5 and 17 years. No limits were placed on the health status of the participants or their level of physical activity prior to the HIIT intervention.

3.2.2.2 Intervention

The study needed to include an adequate description of the HIIT protocol that was used including at least three of the following: work/rest ratio, fidelity (how intensity was recorded/maintained), intensity of work interval, intensity of rest interval, total intervention duration (number of weeks and/or total number of HIIT sessions), modality, total duration length, number of sessions per week, and total number of repeated cycles. If adequate description was lacking, the study was excluded. This also included sprint interval training (SIT), which at the time of the initial searches was considered to elicit similar physiological responses to HIIT and can be considered a direct variant (Wiston, Wisloff, and Coombes, 2013).

The initial protocol had no limits placed on the intensity of the work interval, as there was a lack of standardised definitions for HIIT at the time it was published, however, this was later amended to include a minimal requirement of 77% peak heart rate was set based on a review by Garcia-Hermoso et al (2016). Although other cut-off points have been mentioned, this was selected as it was the lowest one that could be found in the literature, and the focus of this study was on establishing minimums for HIIT. Because formal definitions have not been established for other methods for prescribing intensity such a maximal aerobic velocity, maximal oxygen uptake, and peak power, no limits were placed on these.

3.2.2.3 Control

HIIT has often been compared with moderate intensity continuous training in the literature, and most research has supported that HIIT is at least as effective in so far as improvements to cardiorespiratory fitness are concerned (Costigan et al. 2015). In this study the only comparator groups selected were against non-exercising controls asked to continue their normal physical activity habits.

3.2.2.4 Outcome

The primary laboratory-based outcomes were changes to maximal or peak oxygen uptake, expressed in absolute (L*min^-1), relative (mL*kg^-1*min^-1), or adjusted for lean body mass, as maximal oxygen uptake is often considered the 'gold standard' for measuring cardiovascular fitness (Armstrong, Tomkinson, & Eukland, 2011) . Additionally, as part of the purpose of this project was to inform future HIIT protocols for use in the school-setting, changes to performance on the 20-meter multistage fitness test, a field based measure was also used as a primary outcome. Although other field based measures are associated with HIIT, such as the yo-yo intermittent recovery test and 30-15 intermittent fitness test the literature supports the notion that they tend to measure anaerobic activity capabilities instead maximal oxygen uptake (Thomas, Dawson, & Goodman, 2006; Buchheit & Rabbani, 2014). Repeated sprint ability was also initially considered as another field-based measure and listed in the original protocol, however it was ultimately excluded as its association with maximal oxygen uptake is questionable and depends on the exact format of the test.

3.2.3 Data Extraction

Retrieved records were downloaded via End Note and Mendeley, as multiple computers were used during the data extraction process and End Note was only installed on one of them. The initial list was then exported to an excel file. After the removal of duplicates the records underwent two phases of independently screening conducted by two reviewers. The first phase involved only titles and abstracts. The second phase involved a full text screening. In both cases pre-written screening sheets were used to guide the selection process and for record-keeping. If information was missing from a potential study the lead researcher attempted to contact the primary author via email. If there was no response the study was excluded from the final review. The following information was extracted by reviewers: study information (e.g. author, year, country, date), baseline descriptive characteristics, HIIT characteristics (frequency, mode, duration, work-to-rest ratio, number of cycles), pre-and post-intervention CRF.

3.2.4 Quality Assessment

Quality assessment was conducted using a 12-item, pre-written quality assessment sheet adapted from the PEDRO scale used in previous HIIT-related reviews (Costigan et al., 2015; Weston, Wisloff, & Coumbes, 2013). The quality assessment criteria are specified in table X. Each paper was independently assessed by two reviewers, and any disagreements were resolved by a third reviewer. If a conclusion could not be reached a third reviewer was consulted for a final verdict. Each studywas classified by the number of criteria met: poor (0-3), fair (4-5), and high (6+), using a similar grading scale as Costigan et al (2015).

A funnel plot was also generated using Comprehensive Meta-Analysis (CMA) Software Version 3.0 (Biostat, USA) to detect outliers.

Heterogeneity between studies was assessed by examining the I^2, which is thought to be a better representation of heterogeneity than the Q statistic (Huedo-Medina et al., 2006). As with previous works, the I^2 cut-offs of 25%, 50%, and 75% were used as benchmarks to indicate small, moderate, and high levels of heterogeneity (Borenstein et al., 2016).

3.2.5 Data Synthesis and Meta-Analysis

Meta-analyses was conducted using the Comprehensive Meta-Analysis (CMA) Software Version 3.0 (Biostat, USA). Changes made to relative maximal oxygen uptake (mL*kg^-1*min^-1) were plotted in the software. In cases where mean and Standard deviation change from baseline for each study arm (control and HIIT) were provided, these values were used in the plot. In cases where these values were not provided, the lead researcher imputed them using methods recommended in the Cochrane Handbook using the following formulas (Higgins & Green, 2006):

Correction Coefficient calculation:

$Corr_{Experimental\ Group} = (SD^2_{E,baseline} + SD^2_{E,final} - SD^2_{E,change}) / (2 \times SD^2_{E,baseline} \times SD^2_{E,final})$

$Corr_{Control\ Group} = (SD^2_{C,baseline} + SD^2_{C,final} - SD^2_{Cchange}) / (2 \times SD^2_{C,baseline} \times SD^2_{C,final})$

Calculation of Standard Deviation change from baseline:

$SD_{Experimental\ Group,change} = ((SD^2_{E,baseline} + SD^2_{E,final} – (2 \times Corr_E \times SD^2_{E,baseline} X SD^2_{E,final}))^{1/2}$

$SD_{Control\ Group\ change} = ((SD^2_{C,baseline} + SD^2_{C,final} – (2 \times Corr_C \times SD^2_{C,baseline} X SD^2_{C,final}))^{1/}$

Changes made to relative maximal oxygen uptake (mL*kg^-1*min^-1) were plotted in the software. In cases where mean and Standard deviation change from baseline for each study arm (control and HIIT) were provided, these values were used in the plot. In cases where these values were not provided, the lead researcher imputed them using methods recommended in the Cochrane Handbook using the following formulas (Higgins & Green, 2006).

The imputed r calculated was compared to the imputed r used in another HIIT systematic review (Keating et al, 2017). As with the Keating paper the researchers experimented with different values of r ranging from 0.5 to 0.9. The final number of participants analysed for each group (control and HIIT) as well as the difference in means (pre-post) and imputed SDs (see above) was entered into CMA and used to calculate hedges' G. Hedge's G was used instead of Cohen's d because of the small sample size (<50 participants) reported in most studies.

3.2.6 Subgroup Analysis

Subgroup analysis was also conducted on CMA and involved the following subgroups:

3.2.6.1 Age

Two subgroups were created to determine if there were any differences on the effects of HIIT and age: those under 12 versus those 12 and over, as those ages corresponded with children in primary versus secondary school. If mean age was not reported or a range of participants of different ages were used (ex. participants were between 12-17 years), then they were excluded from analysis. If mean age was not reported, but the participants clearly belonged to a group (ex. all participants were between 10-11 years) then they were included.

3.2.6.2 Intervention Duration

Studies were grouped by the total duration of their intervention into those that were 8 weeks or fewer, and those equal to or greater than 8 weeks, as per the recommendations of previous reviews.

3.2.6.3 Work-to-rest ratio

The work-to-rest ratio is simply the duration of the 'high-intensity' interval divided by the duration of the rest interval. Work-to-rest ratios were separated into less than or equal to one and those greater than one. Cases where work-to-rest ratios were variable throughout the intervention or not reported were not included in this subgroup analysis.

3.2.6.4 Intensity of the work interval

The intensity of the work interval was separated by the method in which the intensity of the HIIT interval was prescribed including: speed-based prescription (maximal aerobic speed, distance to travel between cones in field-based HIIT), percentage of maximal heart rate, peak power, and in cases where participants were asked to preform 'all out' activity, effort based intensity.

3.2.6.5 Passive versus active recovery

Studies were also grouped into those that assigned passive, non-exercising recovery periods versus those that used some form of active recovery, where the participants engaged in some form of physical activity albeit at a lower intensity than the high-intensity interval.

3.2.6.6 Laboratory versus field-based measures of relative maximal oxygen uptake

The studies were grouped into those that used direct laboratory measures of relative oxygen uptake versus those that used approximations based on the results of field testing.

3.2.6.7 HIIT modality

For this analysis, interventions were separated into those that used running as their primary physical activity modality versus those that used other methods (ex. cycling, or mixed modalities).

3.2.6.8 Study quality

Following quality assessment, the studies were separated based on their scores into poor, fair, and high quality.

3.2.7 Sensitivity analysis

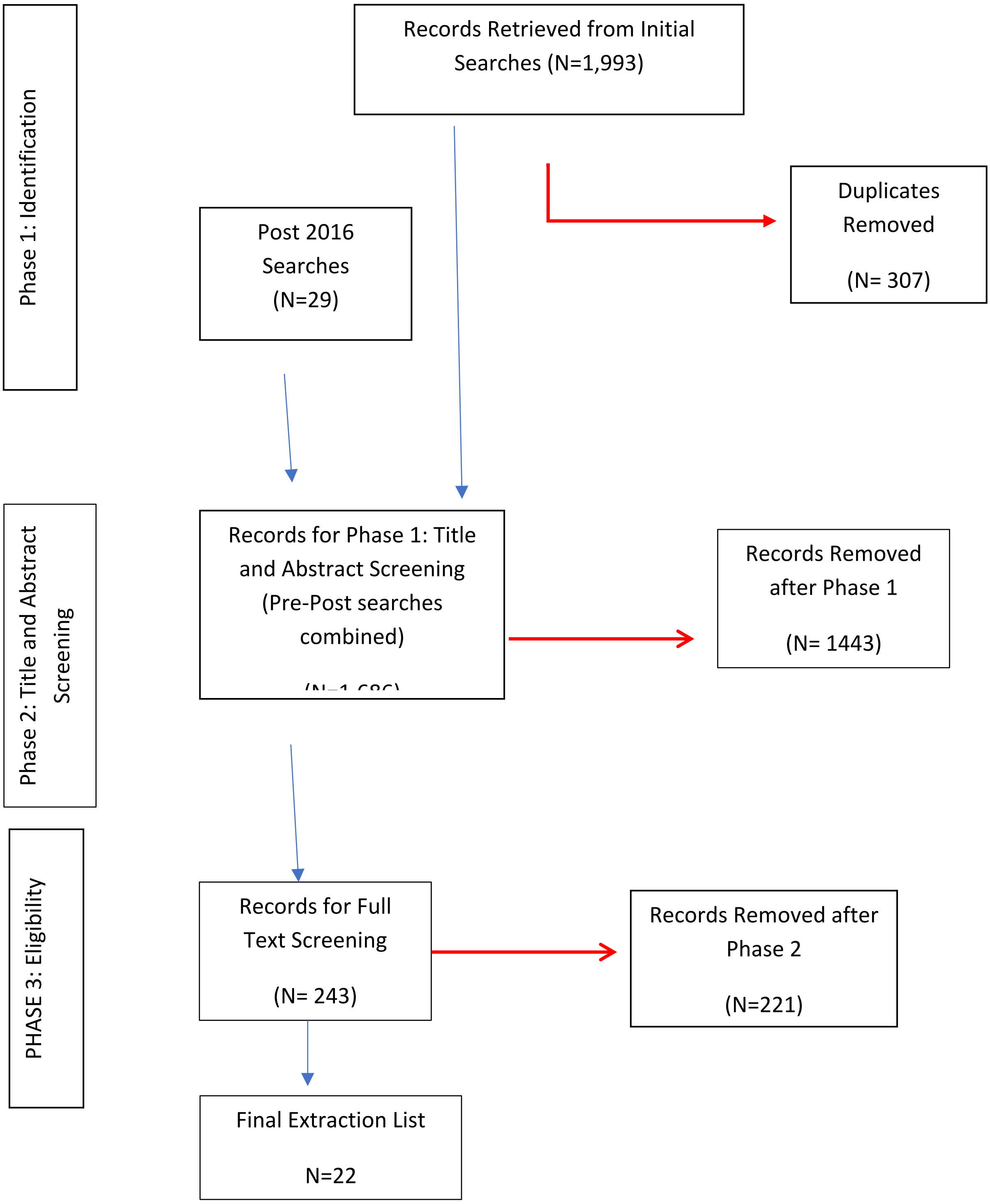
A funnel plot was generated in CMA to identify any outliers. Individual studies were selectively removed for each analysis (overall and subgroup) to determine if they had any effects on the effect size. In cases where individual studies affected I^2 greatly, both effects sizes (studies included and excluded from analysis) were reported.

5.3 Results

5.3.1 Records retrieved

The initial and updated searches yield a total of 1993 records. From those 1,686 titles and abstracts were screened and 1,443 records removed due to being ineligible, leaving a total of 243 studies that were eligible for full-text screening. Of these 22 met all the inclusion criteria. For a full schematic of the search strategy, please refer to Figure 5.1.

Figure 5.1: Systematic Review Search Flow Chart


Phase 1: Identification
Records Retrieved from Initial Searches (N=1,993)
Post 2016 Searches (N=29)
Duplicates Removed
(N= 307)
Phase 2: Title and Abstract Screening
Records for Phase 1: Title and Abstract Screening (Pre-Post searches combined)
Records Removed after Phase 1
(N= 1443)
PHASE 3: Eligibility
Records for Full Text Screening
(N= 243)
Records Removed after Phase 2
(N=221)
Final Extraction List
N=22

3.3.2 Study Characteristics

A summary of the studies included in this review can be found in Table 5.1 A total of 22 studies were ultimately included for review. Ten of the 22 included studies involved prepubertal children, while the rest involved pubertal participants. Various forms of CRF measures were used, including field and lab-based measures of cardiorespiratory fitness, and in some cases, both. Maximal oxygen uptake expressed in its relative form (mL*kg^-1*min^-1) was the most commonly used measure of CRF, and served as the primary outcome in the meta-analysis with 15 papers using this metric. Other measures included absolute maximal oxygen uptake (L*min^-1) or field based measures, such as results from the 20MSFT (6), yo-yo intermittent running test (1) and 6 minute walk (1). Furthermore, it should be noted that the results of the 20MSFT were not reported consistently across studies, which also reported in a previous review (Logan, 2014).

Table 3.1 Study Summary Table

Study [year] Country	Study Characteristics			General Intervention Characteristics			General Intervention Characteristics		HIIT Characteristics		
	Setting	**Study Design**	**Randomized (Y/N)?**	**Age Mean in Years (SD) of *analysed* participants**	**N(Males/Females)**	**Fitness/Activity Level**	**Intervention Duration (number of weeks)**	**Frequency (Sessions per week)**	**Modality**	**Dosage HIIT Interval**	**Dosage Recovery Interval**
Baquet[2002] **France**	School	Quasi Experimental Intervention (additional HIIT PE Sessions)	No	HIIT: 9.5 (0.9) Control:9.9 (0.4)	33 (13/20) 20 (10/10)	School children	7 weeks	2	Running (with some jumping)	10-20 seconds at 100-130% maximal aerobic speed	10-20 seconds PASSIVE recovery
Baquet[2010] **France**	School	Quasi Experimental Intervention (additional HIIT PE Sessions)	Yes	HIIT: 10 (9.5) Control: 9.8 (1.2) MICT: 9.3 (0.9)	22 (11/11) 19 (9/10) 22 (12/10)	School children	7 weeks	3	Running	5-30 seconds 100-190% maximal aerobic velocity	5-30 seconds PASSIVE recovery

Briel[2010] **Switzerland**	National Training Centre	Quasi Experimental Intervention	No	HIIT: 17.4 (1.1) Control:16.6 (1.1)	13 (9/4) 8 (6/2)	Elite junior alpine skiers, 3+ years training, competed at FIS	11 days (3 day block training)	5 sessions, every 3 days with 1 rest day in between	Cycling (12/15) Obstacle Course (3/15)	4 minutes at 90-95% HR max.	3 minutes ACTIVE recovery
Buchan[2011] **Scotland**	School	Quasi Experimental Intervention	Yes	HIIT: 16.7 (0.1) Control:16.3 (0.5) MICT: 16.2 (0.1)	17 (15/2) 24 (20/4) 16 (12/4)	Adolescent school students	7 weeks	3	Running	30 seconds maximal effort sprints	30 seconds passive recovery (reduced to 20 during final week)
Buchan[2013] **Scotland**	School	Quasi Experimental Intervention	Yes	HIIT: 16.8 (0.5) Control:16.6 (0.6)	42 (30/12) 47(34/13)	Adolescent school students	7 weeks	3	Running	30 seconds maximal effort sprints	30 seconds passive recovery (reduced to 20 during final week)
CHUENSIRI[2018] **Thailand**	School	Quasi Experimental Intervention	Yes	HIIT: 11(0.3) Control: 10.6(0.3) SupraHIIT: 11.1(0.2)	HIIT: 11 Control: 11 SupraHIIT: 15	Healthy preadolescent boys	12 weeks	3	Cycling for both HIIT	HIIT: 2 minutes at 90% peak power output Supra HIIT:	HIIT 1 minute passive recovery Supra HIIT:

										20 seconds at 170% peak power output	10 seconds passive recovery
Costigan[2015] **Australia**	School	Quasi Experimental Intervention	Yes	HIIT AEP: 15.7 (0.7) Control: 15.6 (0.6) HIIT RAP: 15.5 (0.6)	21 (16/5) 22 22 (15/7)	School Students	8 weeks	3	HIIT AEP: gross motor cardiorespiratory exercises ex(shuttle runs, jumping jacks) HIIT RAP: combination of cardiorespiratory and bodyweight resistance training (pushups)	30 seconds of work	30 seconds passive rest
Counil[2003] **France**	Inpatient pulmonary rehabilitation clinics	Quasi Experimental Intervention	Yes	HIIT: 14 (0.6) Control: 13.9 (0.8)	HIIT: 7 (7/0) Control: 7 (7/0)	Boys with mild-to-moderate asthma	6 weeks	3	Cycling	1 minute sprints against maximal aerobic power	4 minutes
Delgado-FLoody[2018] **Chille**	School	Quasi Experimental Intervention	No	8.39 (1.15)	$HIIT_{ow}$: 59(27/32) $HIIT_{ob}$: 92(43/49)	School participants between 6-11 years, participation in HIIT group	28 weeks	2	Mixed circuit (running, jumping throwing)	4–6 min repetitions of exercises; circuit training with 30-60 seconds	Other exercise: 1-2 minutes

					Control$_{ow}$: 17(8/9) Control$_{ob}$: 29(11/18)	required that the participants were overweight or obese				exercise. 80-95% maximum heart rate determined via Tanaka formula	Circuit:30-60 seconds passive recovery
DIAS[2017] **Australia and Norway**	Multicentre: university labs and hospital outpatient settings.	Randomised Controlled Trial	Yes	7-16 year olds		Children and adolescents with obesity	12 weeks	3	Mixed (walk, run on treadmill or cycling on a stationary bike)	85-95% HR Max for 4 minutes	50-70% Hrmax for 3 minutes active recovery
Gamelin[2009] **France**	Laboratory	Quasi Experimental Intervention	Yes	HIIT: 9.8 (0.7) Control: 9.3 (1.2)	22 (12/10) 16 (7/9)	Children with no history of CVD of hypertension or pubertal onset	7 weeks	3	Running	5 -30 second runs of 100-190% of MAV	15-30 seconds passive recovery
Klijn[2004] **Netherlands**	Laboratory (Medical Centre)	Quasi Experimental Intervention	Yes	HIIT: 13.6 (1.3) Control: 14.2 (1.3)	11 9	Cystic fibrosis patients	12 weeks	2	Mixed	30 seconds work near maximal intensity 5 exercises/set	Active recovery. Aerobic activities of low intensity 5min rest in between sets

Lambrick[2015] **United Kingdom**	School	Quasi Experimental Intervention	Yes	HIIT: 9.3 (0.9) Control: 9.3 (0.8)	28 (18/10) 27(14/13)	Normal weight and obese children	6 weeks	2	Mixed	6 minutes high intensity exercise (various games) + 4 minute circuit at the end	2 minutes
Lau[2014] **Hong Kong**	School	Quasi Experimental Intervention	Unclear (no)	HIIT: 11 (0.6) Control: 10.6 (0.6) LIIT: 9.9 (0.9)	15 12 21 (total: 36M, 12F)	Overweight children	6 weeks	3	Running	15 seconds at individualized distance for each child to achieve 120% MAS	15 seconds
Martin[2015] **Scotland**	School	Quasi Experimental Intervention	Yes	HIIT: 16.9 (0.4) Control: 16.8 (0.5)	20 (13/7) 23 (18/5)	Healthy adolescence	7 weeks	3	Running	30 seconds sprints 20 m apart	30 seconds passive recovery

Mathisen[2013] **Norway**	Indoor and Outdoor Practice facility	Quasi Experimental Intervention	No	HIIT: 10.6 (0.7) Control: 10.8 (0.7)	10 (10/0) 6 (6/0)	Soccer players	5 weeks	2	Mixed	10 seconds – 4minutes , HR > 80% HRmax	-
Mcmanus[2005] **Hong Kong**		Quasi Experimental	Yes	Age in Months HIIT: 124.2(2.8) Control: 125 (5.6) MICT: 1126.1 (4.6)	 10(10/0) 15 (15/0) 10(10/0)	Prepubescent Chinese boys, obese	8 weeks	3	Cycle ergometer	30 second interval sprints set at peak power elicited at peak VO2	2.45 minutes active rest, unloaded
Mucci[202] **France**	School	Quasi Experimental Intervention	Yes	HIIT: 9.8(0.6) Control: 10.3(0.7)	9 (4/5) 9 (6/3)	Prepubescent children	8 weeks	2	Running	10 or 20 seconds at 110-130% MAV	10-20 second (equal to active) passive recovery, 3 minutes passive standing recovery in

											between sets
Racil[2013] **Tunisia**	Outdoor Track	Quasi Experimental Intervention	Yes	HIIT: 15.6 (0.7) Control: 15.9 (1.2) MIIT: 16.3 (0.52)	11 (0/11) 12 (0/12) 11 (0/11)	Obese adolescent females (BMI >97th percentile by French standards)	12 weeks	3	Running	30 seconds 100-110% MAS (or the speed associated with VO2peak).	30 seconds active recovery at 50% MAS. 4 minutes passive recovery in between sets
Racil[2016] **Tunisia**	Outdoor Track	Quasi Experimental Intervention	Yes	14.2 (1.2)	HIIT: 17 (0/17) Control: 14(0/14) MIIT: 16(0/16)	Obese adolescent females > 97th percentile	12 weeks	3	Running	15 seconds 100% MAS	15 seconds active recovery at 50%MAS. 3 minutes passive recovery in between sets. 3 sets
Racil PLyo[2016] **Tunisia**	School	Quasi Experimental Intervention	Yes	HIIT: 16.6 (0.9) Control: 16.9 (1)	23 (0/23) 19 (0/19)	Young obese females tr	12 weeks	3	HIIT: Running HIIT + Plyo: Running with additional plyometric work	HIIT: 30 seconds running at 100% vVO2peak. Intensity increased by 5% vVO2peak every 4 weeks.	30 seconds active recovery at 50% vVO2peak. Each block separated by 4 min passive recovery.

				HIIT + Plyo: 16.5 (1.2)	26 (0/26)					HIIT+ plyo: Same as above except with additional 2 blocks	
Rosenkranz[2012] **USA**	Laboratory	Quasi Experimental Intervention	Yes	HIIT: 8.6 (0.6)	8	Healthy prepubescent children (7-12 years)	8 weeks	2	Running	10 x 10 seconds increased to 5 x 20 seconds at 100-130% MAS	10-20 seconds passive recovery
				Control: 9.6 (1.4)	8 (2/14)						
Taylor[2016] **United Kingdom**	School	Quasi Experimental Intervention	No	HIIT: 14.1(0.3)	41 (33/8)	Adolescents from North-Eastern schools	10 weeks	3	mixed	45 seconds maximal effort exercise (>90% peak maximal HR)	90 seconds passive
				Control: 14.1 (0.3)	60(30/30)						

3.3.3 Risk of bias

Table 5.2 illustrates how the studies were rated in terms of their quality. Studies were separated based on their scores into brackets of poor, fair, and high quality. If neither reviewer was able to find the item in the study, or if the item was unclear, then it was marked as a 0. A score of 0.5 indicates a disagreement between reviewers, and a score of 1 indicates that both reviewers were able to identify the item. Seven studies (32%) were rated as 'high quality,' twelve (54%) as 'fair quality' and three (14%) as 'poor quality.'

Table 3.2 Quality Assessment Scores

Author and Year	Item												Total Score	Quality Bracket
	1	2	3	4	5	6	7	8	9	10	11	12		
Baquet 2002	0	0	0	1	0	0	1	1	1	1	0	0	5	fair
Baquet 2010	0.5	0.5	0	1	0	0	0.5	0.5	1	1	0	0	5	fair
Breil 2010	1	1	0	1	0	0	1	0	1	1	0	0	6	fair
Buchan 2011	1	1	0.5	1	0	0	1	0	1	1	0	0	6.5	high
Buchan 2013	1	1	0	1	0	0	1	0	1	1	0	1	7	high
Chuensiri 2017	1	1	0	0	0	0	1	0	1	1	0	0	5	fair
Costigan 2015	1	1	0	1	1	0	1	0	1	1	0	1	8	high
Counil 2003	1	1	0	1	0	0	1	0	1	1	0	0	6	high
Delgado 2018	1	0	0	1	0	0	0.5	0	0	0.5	0	0	3	low
Dias 2017	1	1	1	0.5	0	0	0	1	1	1	0	1	7.5	high
Gamelin 2009	0.5	1	0	1	0	0	0	0	1	1	0	0	4.5	fair
Klijn 2004	1	1	1	1	1	0	1	0	1	0	0	0	7	high
Lambrick 2015	0	1	0	1	0	0	1	0	1	0	0	0	4	fair
Lau 2014	0	0	0	0	0	0	0.5	0	1	1	0	0	2.5	poor
Martin 2015	0	1	0	1	0	0	1	0	1	0	0	1	5	fair
Mathisen 201	0	0	0	0	0	0	0	0	1	0.5	0	0	1.5	poor
Mucci 2013	0	1	0	1	0	0	0.5	0	0	0	0	0	2.5	poor
Racil 2013	1	1	0	1	0	0	1	0.5	1	1	0	0	6.5	high
Racil 2016a	1	1	0	0	0	0	1	0	1	1	0	0	5	fair
Racil 2016b	1	1	0	1	0	0	1	0	1	0	0	0	5	fair
Rosenkranz 20	1	0.5	0	1	0	0	1	0	1	0	0	0	4.5	fair
Taylor 2015	1	0	1	0	0	0	1	0	1	1	0	1	6	high
Totals	14/22	15/22.	3/22.	16/22	2/22.	0/22.	15/22.	2/22.	20/22.	14/22.	0/22.	5/22.		

3.3.4 Meta-Analysis: The effects of HIIT on relative maximal oxygen uptake

It would appear that HIIT consistently and significantly elevates cardiorespiratory fitness as measured by relative VO2max/peak. The effect size for Hedges's G was found to be 1.496 for the fixed effects model (SE 0.10, I^2 = 81.32) and 1.811 for the random effects model (SE = 0.25).

Model	Study name	Hedges's g	Standard error	Upper limit	Lower limit
	Baquet 2002	1.169	0.301	1.760	0.579
	Baquet 2010	1.294	0.339	1.958	0.630
	Briel 2005	0.522	0.439	1.382	-0.339
	Chuensiri 2017	7.426	1.192	9.763	5.089
	Dias 2017	1.301	0.314	1.918	0.685
	Gamelin 2009	1.710	0.377	2.448	0.971
	Klijn 2004	0.869	0.452	1.754	-0.017
	Lambrick 2015	0.667	0.273	1.203	0.131
	Martin 2015	1.465	0.364	2.178	0.751
	Mathisen 2015	1.482	0.554	2.568	0.396
	McManus 2013 I	1.422	0.443	2.290	0.553
	Mucci 2013	1.775	0.538	2.829	0.721
	Rosenkranz 2012	1.826	0.572	2.948	0.704
	Racil 2013	2.371	0.533	3.416	1.326
	Racil 2016b HIIT	2.913	0.440	3.775	2.051
Random		1.600	0.217	2.026	1.175

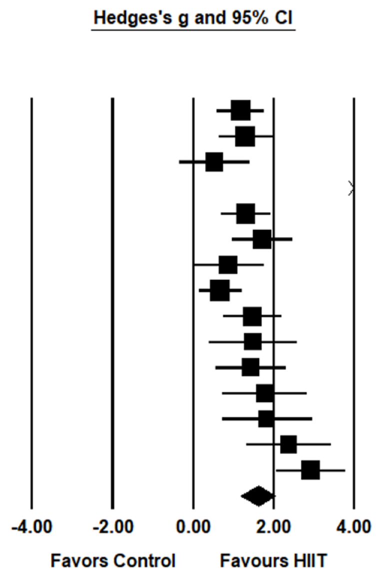
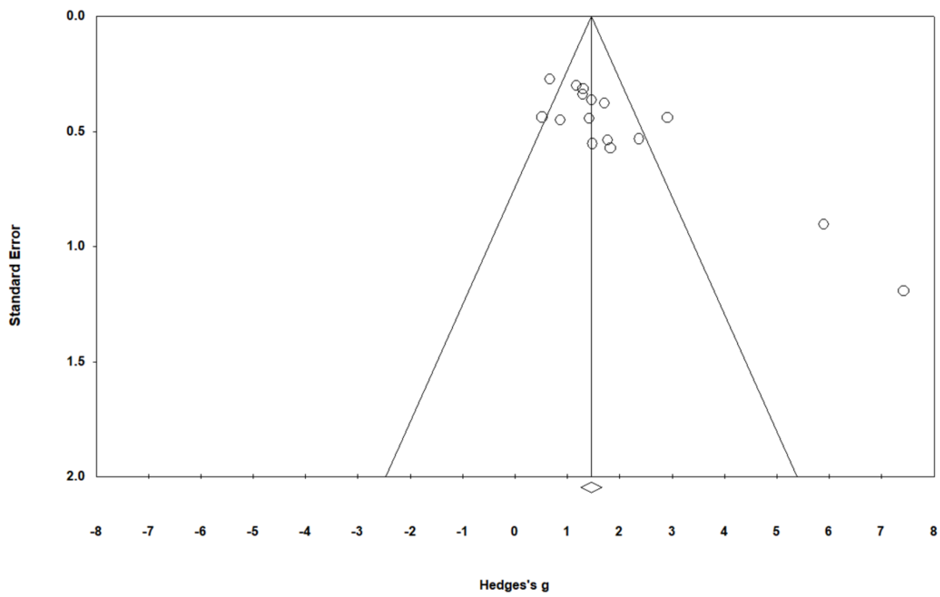


Figure 3.2 Random Effects Model for Relative VO2max

It should be noted that after conducting the sensitivity analysis via funnel plot, two studies, Chuensiri 2018, and Racil 2016b were found to be clear outliers due to their inordinate effect sizes (Hedge's G).



When they were removed from analysis the effect size was still significant and positive with 1.257 (SE = 0.11, I^2=28.04) for the fixed effect and 1.29 (SE=0.13) for the random effects model. It should be noted that the difference in I^2 changes the results from 'strongly' heterogeneous to 'moderately' heterogeneous.

3.3.5 Subgroup Analysis

Due to the pronounced effects of the outliers discussed above, analysis was conducted both with the inclusion and removal of the outlier studies. Please refer to Table 5.3 below.

3.3.5.1 Participant Age

When sub- grouped by age the effect for studies with participants under mean age 12 had a fixed effects size of 1.4 (SE = 0.136, I^2 = 86.53) and random effect of 2.096 (SE = 0.4). For participants with mean ages equal to order greater than 12 years, the fixed effect size of 1.6 (SE = 0.185, I^2 = 74.942). When the outliers were removed the fixed effects values changed to 1.224 for participants with a mean age under 12 years (SE=0.15, I^2 = 32.43) and 1.369 for those greater than 12 (SE = 0.21, I^2 = 56.02).

3.3.5.2 Intervention Duration

Interventions of 8 weeks or fewer were found to have a fixed effect size of 1.22 (SE = 1.21, I^2=21.45) and a random effect size of 1.246 (SE = 0.14). Interventions greater than 8 weeks in duration had a fixed effect size of 1.22 (SE = 2.078, I^2=90.94) and a random effect size of 3.16 (SE = 0.72). When the outliers were removed interventions of fewer than 8 weeks were found to have a fixed effect size of 1.23 (SE = 1.3, I^2=30.52) and a random effect size of 1.27 (SE = 0.157). Interventions greater than 8 weeks of duration had a fixed effect size of 1.43 (SE = 0.24, I^2=58.41) and a random effect size of 1.50 (SE = 0.39).

3.3.5.3 Work-to-rest ratio

Studies that used work-to-rest ratios of one or less were found to have a fixed effect size of 1.76 (SE = 0.18, I^2 = 54.99) and a random effect size of 1.79 (SE = 0.26). Studies that used work-to-rest ratios greater than one were found to have a fixed effect size of 1.02 (SE = 0.18, I^2 = 90.81) and a random effect size of 1.88 (SE = 0.69). When the outliers were removed interventions used work-to-rest ratios of one or less were found to have a fixed effect size of 1.55 (SE = 0.19, I^2 = 3.70) and a random effect size of 1.55 (SE = 0.20). Interventions with work to rest ratios of greater than one were found to have a fixed effect size of 0.86 (SE = 1.9, I^2=34.73) and a random effect size of 0.86 (SE = 0.24).

3.3.5.4 Intensity of the work interval

Speed-based prescriptions of HIIT were found to have a fixed effect size of 1.67 (SE = 0.15, I^2 = 56.48) and a random effect size of 1.80 (SE = 0.24). Those that used peak power for prescription were found to have a fixed effect size of 2.15 (SE = 0.42, I^2 = 95.51) and a random effect size of 4.32 (SE =3.00). Those that used a percentage of heart rate for prescription were found to have a fixed effect size of 1.04 (SE = 0.26, I^2 = 52.09) and a random effect size of 0.97 (SE =0.39). Those that instructed participants to engage in self-regulated 'all out effort' for prescription were found to have a fixed effect size of 0.94 (SE = 0.20, I^2 = 35.44) and a random effect size of 0.97 (SE =0.25). When the outliers were removed speed-based prescriptions of HIIT were found to have a fixed effect size of 1.53 (SE = 0.17, I^2 = 2.074) and a random effect size of 1.53 (SE = 0.17). As Chuensiri (2018) was one of two studies that use peak power, these could not be analysed once it was removed. Those that used a percentage of heart rate for prescription were found to have a fixed effect size of 1.04 (SE = 0.26, I^2 = 52.09) and a random effect size of 0.97 (SE =0.39). Those that instructed participants to engage in self-regulated 'all out effort' for prescription were found to have a fixed effect size of 0.94 (SE = 0.20, I^2 = 35.44) and a random effect size of 0.97 (SE =0.25).

3.3.5.5 Active vs Passive Recovery

Interventions which used active recovery were found to have a fixed effect size of 1.494 (SE = 0.172, I^2=75.42) and a random effect size of 1.55 (SE = 0.35). Interventions that used passive recovery had a fixed effect size of 1.43 (SE = 0.13, I^2=86.64) and a random effect size of 2.13 (SE = 0.39). When the outliers were removed interventions which used active recovery were found to have a fixed effect size of 1.24(SE = 0.19, I^2=50.40) and a random effect size of 1.26 (SE = 0.27). Interventions that used passive recovery had a fixed effect size of 1.25(SE = 0.17, I^2=28.88) and a random effect size of 1.30 (SE = 0.17).

5.3.5.6 Laboratory versus field-based measures of relative maximal oxygen uptake

Interventions which used field-based measures of HIIT were found to have a fixed effect size of 1.75 (SE = 0.18, I^2=68.47) and a random effect size of 1.90 (SE = 0.34). Interventions that used laboratory-based measures had a fixed effect size of 1.23 (SE = 0.13, I^2=78.44) and a random effect size of 1.48 (SE = 0.29). When the outliers were removed interventions which used field-based measures of HIIT were found to have a fixed effect size of 1.51 (SE = 0.20, I^2=28.67) and a random effect size of 1.56 (SE = 0.25). Interventions that used laboratory-based measures had a fixed effect size of 1.14 (SE = 0.13, I^2=29.25) and a random effect size of 1.16 (SE = 0.16).

5.3.5.7 HIIT modality

Interventions which used running as their primary modality in the high-intensity intervals (n=8) were found to have a fixed effect size of 1.663 (SE = 0.14, I^2=50.49) and a random effect size of 1.74 (SE = 0.21). Interventions that used other modalities (n=6) were found to have a fixed effect size of 1.09 (SE =0.16, I^2=85.14) and a random effect size of 1.499 (SE = 0.44). When the outliers were removed interventions which used running as their primary modality in the high-intensity intervals (n=7) were found to have a fixed effect size of 1.52 (SE = 0.15, I^2=0) and a random effect size of 1.52 (SE = 0.15). Interventions that used other modalities (n=5) were found to have a fixed effect size of 0.98(SE = 1.5, I^2=6.05) and a random effect size of .99 (SE = 1.6).

Table 5.3 Comparisons Between Metanalysis by Subgroup Following the Removal of Outliers

Grouping	Fixed Effect Size: All Studies		Fixed Effect Size: Outliers Removed	
	Hedge's G (Standard Error)	I^2	Hedge's G (Standard Error)	I^2
Participant Age				
Under 12	1.4 (0.14)	86.53	1.224 (0.15)	32.43
12 and Over	1.6 (0.19)	74.942	1.369 (0.21)	56.02
Intervention Duration				
8 Weeks or Fewer	1.22 (1.21)	21.45	1.23 (1.3)	30.52
Greater than 8 Weeks	1.22 (2.08)	90.94	1.43 (0.24)	58.41
Work-to-Rest Ratio				
1≤	1.76 (0.18)	54.99	1.55 (0.19)	3.70
>1	1.02 (0.18)	90.81	0.86 (1.90)	34.73
Work Interval Intensity				
Speed-Based	1.67 (0.15)	56.48	1.53 (0.17)	2.07
Heart rate	1.04 (0.26)	52.09	0.04 (0.26)	52.09
Self-regulated	0.94 (0.20)	35.44	0.94 (0.20)	35.44
Recovery Type				
Active	1.49 (0.17)	75.42	1.24(0.19)	50.40
Passive	1.43 (0.13)	86.64	1.25(0.17)	28.88
Laboratory vs Field-Based Measures of CRF				
Field	1.75 (0.18)	68.47	1.51 (0.20)	28.67

Laboratory	1.23 (0.13)	78.44	1.14 (0.13)	29.25
HIIT Modality				
Running	1.66 (0.14)	50.49	1.52 (0.15)	0
Other modalities	1.09 (0.16)	85.14	0.98 (1.5)	6.05

3.4 Discussion

The purpose of this project was to conduct a systematic review with the aim of determining optimal HIIT protocol parameters with the intent of maximizing CRF response. Previous work has established that HIIT can consistently raise CRF levels significantly, and this remained true in the present study. In terms of 'optimal' HIIT, other reviews have established that longer duration interventions of at least eight weeks are necessary to incur positive changes to CRF and other measures of health, including body composition (Costigan et al., 2015, Eddolls et al., 2017). Additionally, running has been highlighted as the most efficient modality for HIIT, with a prescribed work intensity of ≥90% peak heart rate, or 100-130% maximal aerobic speed (Eddolls et al, 2017).

3.4.1 Participant Age

HIIT appeared to induce a greater CRF response in participants below the age of 12 when compared to those who were 12 or older. The statistical significance of this difference is unknown; however, these findings may be supported by the propensity of this younger age group to engage with sporadic physical activity, similar to the patterns found in HIIT (Aadland et al., 2018; Verswijveren et al., 2018). Furthermore, although VO_2 is known to increase dramatically in both boys and girls due to maturation, physical activity levels during this age tend to decrease dramatically during adolescent years (Tomkinson et al, 2011; Townsend et al., 2015). In other words, the natural activity patterns of children combined with their relatively increased PA may explain why they benefited more from the HIIT.

Another explanation is that children may also have a physiological advantage in that they have superior recovery post high-intensity activity than older age ranges (Engel et al., 2018Ratel, Duche & Williams, 2006; Zanconato, Cooper, & Armon, 1996). Ratel, Duche, and Williams (2006) suggest that children may be better suited to high-intensity exercise due to their ability to resist fatigue due to numerous reasons. Their lower muscle mass means that they generate less power during their work intervals, and are less likely to engage type-II muscle fibres than adults. Children may also have a tendency to draw from oxidative as opposed to glycolytic pathways during exercise. Other factors explaining their superior recovery may include: faster phosphocreatine resynthesis, greater oxidative capacity, better acid-base regulation, faster readjustment of initial (Ratel, Duche, & Williams, 2006). This greater recovery following bouts of high-intensity exercise could explain why they may benefit more from it, and future work may investigate if more or less cycles of HIIT are better suited for different age ranges. For example, if children are better at recovery they may benefit from more cycles of HIIT than more mature adolescents or adults who may benefit from only a few cycles of HIIT.

3.4.2 Intervention Duration

Previous reviews have suggested HIIT intervention durations of at least 7 (Eddolls et al., 2017) or 8 (Costigan et al., 2015) weeks. The results of this review were similar, with a noticeable dose-response relationship between intervention duration and effect size. Initially, 2-weeks was intended to be the cut-point for minimal intervention duration, however, studies of this short duration were sparse, particularly for younger age groups. These findings are interesting because they are actually substantially less committal than previous recommendations for increasing CRF. In a review of cardiorespiratory training for children and adolescents aged 8-18, Armstrong, Barret, and Welsman (2013) recommended a minimum volume of 3 to 4 sessions per week, of 40 to 60 minutes duration, at an intensity of 85 to 90% of maximum heart rate, over a period of at least 12 weeks. Furthermore, it should be noted that several HIIT studies have reported positive changes to CRF in as little as two weeks, however, the majority of these have been conducted in adults. It still remains in question what is the minimal HIIT volume necessary to induce positive CRF in children and adolescents.

3.4.3 Work-to-Rest Ratio

Studies that used a work-to-rest ratio of ≤1 (RSE =1.55, SE = 0.20) had a greater effect size than those that used work-to-rest ratios >1 (RSE 0.86, SE = 0.24). This is consistent with some of the research in adults that found work to rest ratios of ≤1 were also effective (Seo et al., 2019, Jones et al., 2019). It is possible that greater rest periods allow participants to better engage with the work intervals at higher intensity. By allowing more recovery time, participants may be able to exert more effort on the later high-intensity intervals, and it is currently understood that maintaining the high-intensity may be the most important overall factor in a HIIT program (Karlsen et al., 2017). On the other hand, larger work-to-rest ratios may allow participants to complete their HIIT more quickly, thereby saving time. Again, more research is needed to determine whether work-to-rest ratios of ≤1 consistently improve CRF more efficiently than those with work-to-rest ratios of greater than one.

3.4.4 Intensity of the Work Interval

Eddolls et al (2017) suggested selecting HIIT intensity set to ≥90% peak heart rate, or 100-130% maximal aerobic speed in children and adolescents. In the present study, all prescription intensities were found to significantly increase CRF, however speed-based prescriptions (ie, maximal aerobic speed) were found to incur the greatest effect (RES =1.53 (SE = 0.17) when compared with those based on percentage of peak heart rate (RES=0.97, SE =0.39) and those that simply asked participants to give their 'all out effort' (RES = 0.97, SE =0.25), suggesting that choosing maximal aerobic speed may be optimal if possible.

Given these results an investigation directly comparing different intensities in young people may be warranted. The effectiveness of 'all-out' prescription intensities may also have public health implications if these effects on CRF can be reliably reproduced. Current work has delved into potential of 'self-selected' HIIT in which participants are free to determine their own intensity, selecting increments of 10% of previously determined peak power output. Higher power output was reported in the self-selection group (Kellogg et al., 2019). If children and adolescents can continually 'try their best' then perhaps this may provide a means to circumvent a lot of unnecessary planning in (for example), schools with limited time and resources for more rigorous methods of intensity prescription. Unfortunately, due to the variability in protocol design, analysis for determining the minimal required MAS or peak heart rate for improving CRF could not be determined in this study. Future work may benefit from a direct investigation into different HIIT prescriptions of intensity to determine which is best-suited for improving CRF.

3.4.5 Recovery Type

There appeared to be no real difference between protocols that used active recovery during their rest intervals and those that used passive recovery (RSE = 1.26, SE = 0.27 vs RSE = 1.30, SE = 0.17). This is consistent with the literature in adults (Germano Moises et al., 2019; Kriel et al., 2016). A limitation in this analysis is that there was no statistical comparison between the passive recovery and active recovery studies, as we were unsure of how to conduct this. Future work may benefit from a direct comparison of active vs recovery HIIT designs in both children and adolescents.

3.4.6 Laboratory Measures versus Field-Based of CRF Outcomes

Research Aim:
Determine if there was a difference in CRF effect size based on the type of CRF measures used (laboratory vs field-based.)

Studies that used field-based measures, may have overestimated their effectiveness compared with those that used laboratory-based assessment of maximal oxygen uptake (RSE =1.56, SE = 0.25 vs RSE =1.16, SE = 0.16). This is perhaps, unsurprising but it does highlight a potential consideration for future intervention design. It may be ideal, for instance, to use a combination of lab and field-based measures. The latter could be used from a week-to-week assessment while lab-based measures could be used over longer time periods to elucidate the 'true' effect of a long-term HIIT intervention.

It should be noted that there were inconsistencies in both the reporting of lab-based and field-based measures of HIIT with many studies electing to use different means of reporting. Some, for instance reported only absolute changes to maximal oxygen uptake, others used relative maximal oxygen uptake, and others used lean-bodyweight adjusted maximal oxygen uptake. Converting between these was beyond the scope of this review, so only relative maximal oxygen uptake was used as the lab-based measure. Future work may care to investigate differences in HIIT between these lab-based measures. There was even more variability in the manners of reporting field-based measures. These were not meta-analysed because it was unknown if it was possible to convert the scores.

The variability in reporting highlights a problem in the field: the lack of standardization. Perhaps different measures can be used for different outcomes, but the HIIT research community must come to a consensus on when to use what, and how to report these findings consistently.

5.4.7 Modality

Running has been shown to consistently be the best modality for improving CRF with HIIT in children and adolescents, (Costigan et al., 2015, Eddolls et al., 2017) and that remained true in this analysis In terms of modality, running was the most prolific modality used (RES = 1.52 SE = 0.15), and incurred the greatest effect on CRF versus interventions of other modalities (RES =0.99, SE = 1.6). That being said, interventions that used other modalities were 'successful' in that they did significantly elevate CRF levels. This is an important note from a public policy perspective because in the case of Taylor et al. (2016), the authors were able to customise their intervention using focus groups to determine which activities the children deemed most engaging. In other words, if the intensity of the work interval is sufficiently rigorous it may be enough to incur positive CRF changes regardless of modality. A limitation in this study is that other studies that did not involve running as the primary HIIT modality were in the minority, so future work may benefit from direct comparisons between HIIT modalities.

3.5 Conclusion

Apart from confirming previous findings that running-based HIIT interventions of longer durations (>8 weeks) incurred the greatest benefit to CRF, the meta-analysis conducted here also revealed new insights into HIIT protocol design, some of which were surprising. While the choice of passive versus active recovery appeared to have no effect, protocols following work-to-rest ratios of ≤1 appeared to be more effective than those using work-to rest ratios >1. Other factors also appeared to have an influence on effect size, including the age of participants and the type of CRF measure used (laboratory versus field-based).

Although these findings are novel in terms their implications for future protocol design, they should be interpreted with caution due to a number of limitations. First of all, in this study there was no statistical comparison between the effect sizes in each protocol, so it cannot be said if the differences between them are statistically significant. Secondly, many of the included studies had similar methodological pitfalls described by other HIIT-related systematic reviews, including variability in reporting. This was especially true of field-based studies that often reported the results of the 20MSFT differently, making meta-analysis of the direct results of these impossible. It should also be noted that two studies severely influenced the overall results of the meta-analysis, and excluding them greatly decreased heterogeneity as well as effect size.

Another limitation was the tools used in the project, specifically, the quality assessment tool. The PEDRO scale was selected because, at the time the project was started, it was the tool used by other systematic reviews in the field (Weston, Wisloff, and Coumbes, 2013). Other tools such as the Downs and Black scale existed, however these were not chosen due to their depth and length which were thought to have been too time consuming for the purposes of the review (Aubut et al., 2013). The PEDRO scale is mostly designed for use with clinical trials. As such, it may be innately misaligned for use with exercise/physical activity-based interventions where blinding may be impossible. Future work may consider using quality assessment tools that fit more favourably with the type of studies being investigated. To this end, it may be necessary to develop quality assessment tools for different types of interventions.

Finally, the variety of reporting methods used in the studies limited the types of analysis that could be conducted. This study primarily used relative VO_{2max} as the primary method for evaluating CRF, however other methods exist. Relative maximal oxygen uptake was used in this case purely because it was the most frequently reported. Particularly in cases where field-based measures were used there were multiple ways in which these measures were reported making it difficult to compare and meta-analyse their results. Future works may find more sophisticated ways to analyse and scale different measures of CRF, or perhaps as more HIIT studies are conducted, there will be a greater number of studies to draw upon to evaluate the results of HIIT on these other measures of CRF.

Due to these limitations, it is recommended that future HIIT related studies directly investigate some of these findings using different HIIT protocols as separate groups. Additionally, reporting outcome measures should also be standardized to allow for ease of comparison between studies.

In short, despite the limitation noted, HIIT appears to be effective in increasing CRF, however, protocols of >8 weeks in duration, using speed-based measures of HIIT, with running as the primary physical activity modality, and work-to-rest ratios of ≤1 may offer the most benefit for children, but there aren not enough studies to confirm any of these findings for certain. A recent 2019 review investigating HIIT in 6-18 year old obese adolescents also found HIIT programs to be effective at improving CRF, however, also reported great heterogeneity in their findings (Thivel et al., 2019). HIIT research in younger populations could certainly benefit from more studies comparing different types of HIIT to specifically investigate how manipulating the nine different dimensions of HIIT design can effect the ultimate CRF outcomes.

In terms of real-world recommendations, perhaps the most important conclusion from this study, is that HIIT is useful for improving CRF in children/adolescents despite the many different ways it can be administered. Perhaps it is less important to focus on what exactly are the best or most efficient dimensions to improve CRF, but rather to realise that assuming there is sufficient intensity, any activity can be used as part of a HIIT protocol to this end. This has clear implications for school-based interventions as it suggests that HIIT is highly modifiable and customizable, making it a potential candidate for use within the school-setting. While it is certainly important to continue research in HIIT optimization, the goal should be to provide people with as many ways to improve health as possible. Future work, therefore, may focus on finding ways to engage the target intensity necessary to illicit the CRF response seen in HIIT in a sustainable manner.

4.0 CHAPTER 4 USING FOCUS GROUPS TO INFORM THE DESIGN OF A NOVEL HIGH-INTENSITY INTERVAL TRAINING PROTOCOL FOR USE IN THE SCHOOL SETTING

4. 1 Introduction

The purpose of this study was to use focus groups to assess the feasibility of a novel High-Intensity Interval Training (HIIT) protocol for use within the school setting amongst year 7 students and their teachers. HIIT may serve as a useful way to improve cardiorespiratory fitness, an important indicator of overall health, making it a potentially useful candidate for school-based interventions.

HIIT may prove to be a useful alternative to more conventional physical activity interventions because:

1.) HIIT has consistently been shown to effectively elevate cardiorespiratory fitness levels (Costigan et al., 2015, Eddolls et al,. 2017; Garcia-Hermoso et al., 2016;).
2.) HIIT is 'time-efficient,' requiring less time to achieve health-related benefits than comparable bouts of moderate intensity continuous activity, directly addressing the 'lack of time' barrier to PA cited by both school staff and students (Costigan et al., 2015; Garcia-Hermoso et al., 2016; Gibala, 2018; Gillen & Gibala, 2018).

These features make HIIT a possible school-based intervention strategy. Previous work has made it difficult to identify the 'core components' of a HIIT protocol that make it effective. The goal of this project was to engage with the stakeholders, in this case the children who will preform the HIIT and teachers and staff members who will deliver it, in an attempt to determine what activities and concerns may be addressed to inform the 'core components' of a future HIIT school-based protocol, and identify what could be done to facilitate engagement.

4.1.1 Previous Intervention Strategies, Barriers, and Solutions

The effects of increasing PA have been universally recognised resulting in the widespread adoption of PA guidelines in many countries. Numerous efforts to increase PA levels in children and adolescents involving various intervention strategies have been trialled, but have, arguably, been unsuccessful. They fail to significantly raise PA when it is measured objectively (Metcalf, Henley, and Wilkin, 2012), suffer from heterogeneity and methodological discrepancies such as a reliance on subjective measures for large scale studies (Dobbins et al., 2013; Kreimler et al., 2011), and perhaps most importantly, many fail to improve other key health-related indicators such as BMI and cardiorespiratory health indices (Dobbins et al., 2013; Kriemler et al., 2011; Guerra et al., 2013; Harris et al., 2009). The US Department of Health and Human Services (2018) reported that some interventions may have potential benefits, however these were mostly limited to individual-level interventions requiring one-to-one focus allowing highly specified and custom tailored focus, which the report acknowledges may be too time consuming and costly in the long-run (US Department of Health and Human Services, 2018).

The final issue with previous intervention studies is that many of them look specifically at raising PA as the primary objective, with other key health measures treated as secondary outcomes. While PA research is undeniably important, it would appear that the underlying goal of actually affecting health has been lost. In some cases, the interventions fail to generate significant changes to other important health indices, such as maximal oxygen uptake, and Body Mass Index (Dobbins et al., 2013; Kriemler et al., 2011; Guerra et al., 2013; Harris 2009). Naylor et al. (2015) specifically noted that interventions should strive to link their implementation with health outcomes.

Whatever the reasoning, it would appear that many PA interventions are not effective for improving PA and health in children and adolescents (Biddle & Batterham, 2015). Rather than trying to generate a PA intervention that work, it may be time to look for alternative strategies. Note, that this is not an attack on PA research, as the positive effects are irrefutable. Rather, the point is to broaden our horizons to other measures of health instead of just purely focusing on PA outcomes.

Cardiorespiratory fitness (CRF) levels have been argued by many to be a more powerful indicator of overall health than PA. In adults, more than half of the reduction of all-cause mortality occurs between the least fit, and next least fit groups (Ross, 2016). Similar findings have been reported in a study of 510 European adolescents across nine countries where the cardiorespiratory fitness recommendations offered by the American Heart Association (AHA) were found to be associated with favourable cardiorespiratory health profiles (Ruiz, et al., 2014).

CRF may be easier to measure than PA on large scale due to the development of various proxy measures such as the 20-meter multistage fitness test. This is particularly relevant normative data for population-level cardiorespiratory fitness is beginning to emerge which may make assigning population level targets a possibility (De Miguel-Etayo et al., 2014; Milaim & Murat, 2018; Ramírez-Vélez et al., 2017; Ramos-Sepúlveda et al., 2016; Sandercock, 2012). Numerous validated maximal graded fitness tests for determining cardiorespiratory fitness in children and adolescents have been trailed in the past decade. Ruiz et al (2014) used the ALPHA (Assessing, Levels of Physical Activity) battery of measures including, body mass index, handgrip strength, skinfold thickness, and the 20-meter shuttle run test to assess cardiorespiratory fitness in children and adolescents (Ruiz et al., 2014). Though not as precise as lab-based measures, these studies show that clinical cardiorespiratory fitness can be measured at larger scales, particularly in the case of children in school-based settings.

Looking at different outcome measures, such as cardiorespiratory fitness may help address some of the problem, but another key flaw with previous interventions is that they often do not directly consult the target population in question, leading to oversights in the stakeholders' wants and needs. Put simply, an intervention that has been proven to be highly effective will still fail if no one wants to do it, or if they do not have the means to do it. In addition to not inquiring stakeholders directly, many interventions appear to disregard known barriers to PA. Admittedly, it is difficult to address all of the known barriers to PA as they are diverse, complex and the relationship between them is still not fully understood. They include personal factors, institutional limitations, community/culture, local public policy, and the physical environment (Buaman et al., 2012; Dobbins et al., 2013). Even so, the outcomes of many studies appear to disregard what is known about these barriers.

One example of an ignored known barrier is 'lack of time,' which has been cited as a problem for both educators and students of various ages. For example, of 22 unique categories that may influence intervention effectiveness, 'time' was the most frequently reported, even above 'availability of equipment/resources.' (Naylor et al., 2015). Within the school setting, lack of time has been cited as a barrier to PA as physical educators struggle to deliver the lessons they have planned (Boyle, Jones, and Walters, 2007). In a qualitative study regarding PA barriers in UK adolescents, the researchers utilized semi-structured interviews amongst Heads of PE (HOPE), and Heads of School (HS) and identified several key themes. The interviewed HOPEs strongly expressed frustration with the amount of time they had to allocate to PE lessons. This clashed with the opinions of the Heads of Study, who believed that the allocated PE time was sufficient (Boyle, Jones, and Walters, 2007). The competition between PA and academics for time has also been cited by other authors, despite the fact that both acute and long-term enhancements to PA and cardiorespiratory fitness may benefit academic performance (Kohl & Cook, 2013). Students themselves have also been found to cite time as a key barrier to PA, especially as they age and their lives become busier (Brunton, 2003; O'dea, 2003; Smith et al., 2018; Tappe, Duda, and Ehrnwald, 1989; Tergson and King, 2002).

Many interventions appear to ignore barriers and instead opt for their own theory-based approaches (Heath et al., 2012). The PA guidelines themselves recommend at least 60 minutes of PA outside of the school; despite the fact that adolescents express frustration with the lack of time they have in their days. In a review by Kriemler et al. (2011) the authors found interventions that were able to effectively improve indices of fitness were at least 45 minutes in duration and required delivery through a PE specialist taking up valuable time and resources. This may seem unsurprising, however it does raise questions as to how feasible it would be to deliver an intervention to as many schools and school systems as possible. It appears as though the evidenced-based recommendations are at odds with real-world conditions adding to the already questionable transferability described by several authors (Dobbins et al., 2013; Kriemler et al., 2011; van Sluijs et al., 2007).

One solution may be to custom tailor interventions to individual populations in question. As discussed by Heath et al. (2012), "…Because disparities exist in amount of physical activity in subgroups of the populations, public health professionals need to tailor policy and environmental efforts and programmes to promote increased physical activity opportunities everywhere, with specific attention to initiatives that address the needs of disadvantaged subgroups (Heath et al., 2012 pg. 278)." This theme of tailoring interventions to their particular settings has been highlighted by more recent work. Co-production, for instance, has been used for the development of healthcare services (Batalden et al., 2016). Buckley et al (2018) recently employed this method to devise an exercise referral scheme using needs-analysis, open questions, multidisciplinary debate and reflective practice. Perhaps more relevant to this work, Gillison et al. (2012) conducted a co-production intervention intended to promote dietary and PA change for people with high cardiorespiratory risk. In this case multiple stages were used. In the first stage the criteria for scientific quality and local appropriateness were selected based on patient interviews, a literature search to extract evidence-based criteria for behavioural interventions, and stakeholder consultation (Gillison et al., 2012). In all of these cases the common element is the engagement of the target population and the relevant stakeholders, granting them ownership and incentive to be involved with their own solutions.

4.1.2 High-Intensity Interval Training as an Intervention to Raise Cardiorespiratory Fitness

HIIT typically involves cycling intense bouts of work with rest periods of passive or active recovery, often requiring less-time than other forms of exercise (Gibala et al., 2018; Gibala et al., 2012). HIIT may serve as a valuable school-based intervention for two reasons. First of all, it has been consistently shown to improve markers of cardiorespiratory fitness, which is arguably a stronger predictor of overall health than PA (Anderssen et al., 2007; DeFina et al., 2015; Ortega et al., 2008; Warburton, Shannon, and Bredin, 2016). Unlike other interventions that assess changes to PA as a primary outcome, a HIIT intervention that raises cardiorespiratory fitness levels would have a clear effect on a health-related measure. Secondly, HIIT requires less time than traditional forms of PA, which is important due to how commonly this is cited as a barrier to PA (Naylor et al., 2015). HIIT is often touted as as 'time efficient' (Gibala et al., 2012). Many HIIT protocols fall well below the current PA recommendations in terms of total time commitment (Costigan et al., 2015; Eddols et al., 2017; García-Hermoso et al., 2016), with multiple reviews on the subject citing the time-efficiency as a key strength. Eddols et al (2017) suggest that as little as two to three sessions of HIIT with intensities of 90% maximal heart rate or 100-130% maximal aerobic velocity for seven weeks are needed for improvements to health markers in children or adolescents. This is substantially less than the current UK recommendations of 60 minutes per day.

The efficiency of HIIT is perhaps its greatest strength, however, it also leaves questions as to how it fits in the context of PA recommendations as a whole. Most HIIT studies focus on cardiorespiratory fitness, with very little attention paid into its effects on overall PA, raising some questions as how HIIT may fit into the current PA guidelines. For example, perhaps HIIT can be worked in as part of the 60 minutes per day, or maybe it can be used as a complete 'time-efficient' alternative whereby the same effects of 20 minutes of HIIT may observed with other PA activities that require 60 minutes to achieve. The main argument here is that if this is the case, that is to say, if HIIT can accomplish similar positive health benefits with less time than the recommended guidelines, then it may serve as an attractive alternative for some people who prefer this style of activity. The goal of this study is to explore if HIIT may be feasible in the school setting, and identify what can be done to a potential HIIT protocol to make it as attractive, enjoyable, and easy to implement for a school as possible.

Unfortunately, optimising HIIT remains a difficult task partly because there is still much that remains unknown, particularly with children. Selecting an 'efficient' HIIT protocol aimed at increasing cardiorespiratory fitness can prove problematic due to both the range of protocols that have been used and the lack of justification for their use. In many cases, protocols are seemingly chosen without a rationale. This is troubling because there are documented differences in physiology as people age, so it is questionable to adapt a protocol used in adults for younger groups without a rationale, yet this happened in previous HIIT research (Armstrong, 2013; Armstrong & McNarry, 2016). For instance, a paper by Barker et al (2014) reported on the effects of a two-week HIIT protocol on several outcome measures in 10 adolescent boys (Barker et al., 2014). The authors referenced a 2005 paper by Burgomaster and colleagues as the source for their training regimen; however, the authors did not elaborate as to why this protocol in particular was selected for use in their adolescent study. This is especially odd considering the age of the participants in the Burgomaster paper were substantially older (mean age 22 +/1 years) than those in the Barker study (Burgomaster et al., 2014). A similar discrepancy between the age of the subjects used in the HIIT protocol source material and the participants tested may be found in a 2003 study on the effects of HIIT on asthmatic children. In this case the protocol was adapted from Gimenez, Severa, and Salinas (1982), who examined the effects of a cycle ergometer in trained and untrained adults, again making the link unclear as to why this protocol was used as an intervention for asthmatic children and adolescents (Counil et al., 2003; Giminez, Servera, & Salinas 1982).

It is possible to explain the variability and lack of justification in older (pre 2015) HIIT studies with a simple explanation that there was even less information available at the time of their writing, so perhaps the authors above relied on dose-response evidence from their cited adult studies or other sources. Furthermore, some studies acknowledged this problem directly. For instance, a commonly cited piece by Tjonna et al (2009) finish their introduction section by stating, "Despite the recent advances in understanding the biology underlying improved cardiovascular health with exercise training, several questions remain unresolved. For instance, the optimal programme, e.g. when to initiate, whom to prescribe exercise to and which exercise-intensity is required, and the actual design of the treatment programme remain to be determined. (Tjonna et al., 2009 pg. 318)."

More recent work, such as a systematic review preformed by Eddolls et al. (2017) has identified some of the elements that appear to be 'best practice' with respect to HIIT. These authors suggest that This running-based sessions, at an intensity of 90% maximum heart rate or 100–130% maximal aerobic velocity, two to three times a week and with a minimum intervention duration of seven weeks. These recommendations, while helpful, only address a few of the nine HIIT dimensions described by Buchheit and Laursen (2013). Given the lack of knowledge around protocol at this point in time, one of the goals of this project is to investigate what components should be incorporated into HIIT from the user end and how they might influence the nine HIIT dimensions.

Given how consistently HIIT seems to work despite the variability in protocol design, the main focus of this study is to investigate how HIIT can best be applied to the school-setting. To answer this question, there are many issues that must be addressed. For example, HIIT faces logistical concerns surrounding the equipment that may be used both for the modality of training (ex. using treadmills), and for monitoring fidelity (ex. ensuring that the participants are engaged at sufficient intensity during the 'work' periods). While many studies use field-based measures conducted on athletic tracks to both prescribe and administer their HIIT sessions (Baquest et al., 2002; Baquet et al., 2010; Gamelin et al., 2002Racil et al., 2013; Racil et al., 2016), some studies involve treadmills (de Araujo et al., 2012; Ingul et al., 2010) or specialised cycle ergometers (Barker et al., 2014; McManus et al., 2005). Selecting the appropriate equipment for schools is a key concern, and may affect the outcomes of a study. For example, after a seven-week HIIT program in Scottish adolescents, the participants expressed that they found the onscreen heart rate readings used to asses fidelity to be a good motivational tool, so exploring if this kind of equipment may be useful to schools is warranted (Buchan et al., 2013).

Additionally, although there is some evidence to suggest that HIIT is at least as enjoyable as MICT, little has been done to investigate how to make it more enjoyable for participants and those who may have to deliver the HIIT protocol (ex. physical education teachers). Previous authors have postulated that HIIT mimics the spontaneous and burst-like nature of normal childhood physical activity (Baquet et al., 2010), and what little data has been collected has indicated that HIIT may be regarded as equally enjoyable (and therefore at least as sustainable) as MICT, though this cannot be said conclusively. For example Klijn et al (2004) reported that the children enjoyed their training, motivating them to attend 98% of sessions, however this high degree of attendance is not universal among HIIT studies, and in fact, some report high-dropouts of less than 70% attendance due to a numerous complications including injury, illness, and failure to attend the critical number of sessions (Brøgger, Mathisen, & Pettersen, 2013; Gutin et al., 2002; Klijn et al., 2004). Exploring whether or not the children enjoy HIIT-type exercises and identifying what can be done to improve their experience may be useful for future protocol designs to increase adherence. One of the major goals of this project was, therefore, to ask teachers and students what kinds of elements they would like to see included or excluded from a potential HIIT protocol to make it fun for the kids and easy for the teachers to deliver.

At the time of this writing the lack of consideration of intervention design and implementation feasibility for HIIT in children is a key criticism of the extant literature. Though much research has been conducted in recent years, there are still ample questions regarding the 'best possible' protocols designs in terms of effectiveness. There is little sense in designing an intervention that operates optimally from a literature-based perspective if it fails to meet the real-world demands of those that will ultimately engage with it.

Various authors have recognized the disparity between research and real-world scenarios, and frameworks have been suggested to address the issue. Some hold the view that randomized controlled trials (RTCs) are actually not appropriate for real-world scenarios because they lack the essential component of ‘context level adaptation. (Hawe, 2004). Hawe (2004) argues for ‘functional’ evaluations of an interventions progress instead of ‘compositional’ explaining that interventions should not be standardized to work everywhere as this is not feasible. Rather, intervention frameworks should concern themselves with the essential, fixed components of an intervention and then custom tailor these as needed for different environments (Hawe, 2004). With respect to HIIT, these ‘essential functions’ or ‘core elements’ may include the nine components of HIIT protocol design: the intensity, modality, and duration of the work interval, the intensity and duration of the rest interval, the number of total series repetitions, the duration of these series, the time between series, and the recovery intensity in between series (Buchheit & Laurson, 2013). Additional considerations may include the total duration of each individual HIIT session, the number of sessions per week, and the total intervention duration. A systematic review was conducted to identify the most effective core elements in HIIT for the improvement of cardiovascular fitness for children and adolescents based on the available literature (see Chapter 3).

While the core components are essential for any protocol design, the main goals of this project are to help align the findings of the systematic review with the goals and wants of schools in the North East of the United Kingdom using a co-production framework employed by other recent health and fitness projects (Routen, 2017; 2018). For a more detailed discussion of co-production, please refer to the Chapter 2. The aims of this study are to use elements of co-production as a theoretical framework to underpin the use of focus groups in generating client-side information from the target schools to better understand what can be done to improve adherence to a novel HIIT protocol in this setting. The primary aims of this study were to explore the thoughts and feelings of both the students who would likely participate in HIIT and the teachers or staff members likely to administer the protocol.

Specifically this study aimed to identify:

1.) What are the considerations` of both members of staff and children regarding the feasibility and practicality of incorporating a high intensity interval training intervention into the school setting?

2.) What kind of activities would be conducive to both enjoyment and long-term adherence of HIIT-based exercise, and could realistically be employed within the school environment.

4.2 Methodology:

4.2.1 Rationale for Focus Groups

Focus groups are a type of qualitative research method involving interviewing a small group of participants with the intent of extracting information as to how they feel about an event, or idea (Frietas et al., 1998). This technique has seen considerable use with its origins stemming from sociology and further adoption in marketing, product design, and more recently, domains of public health, including physical activity communication (Frietas et al., 1998; Segar et al 2017; Smithson, 2000).

As stated previously, many HIIT studies failed to consider real-world implementation, however there have been some examples of school-based HIIT where the target audience was involved in some capacity. In these cases focus groups were the primary mode of communication with the students and teachers. Focus groups were chosen as the principle form of data collection for this study as they have had limited implementation in other recent HIIT studies involved with the school setting (Buchan et al., 2013; Taylor et al., 2012, Weston et al., 2016) and yet have been shown to effectively inform the design of PA interventions (Young et al., 2006). In the study by Buchan et al (2013) focus groups were conducted post intervention to determine how the teachers and students responded to the training (Buchan et al., 2013). This study highlighted the importance of researcher-participant interaction as a key factor in the interventions success (Buchan et al., 2013). In a more recent series of studies by Weston et al (2012, 2016), the researchers used a similar approach to the one in this study, where they used focus groups to inform their intervention design. The researchers reported that the participants expressed a desire for a constant rotary of different exercise modalities (Taylor et al., 2012; Weston et al., 2016). It should be noted that both of these studies were directed toward adolescents, making this, to our knowledge, the first HIIT focus groups conducted in preadolescent participants. In this case, focus groups were chosen because it was important for us to a establish a face-to-face relationship with the stakeholders as part of the co-production process (Boyle and Harris, 2009). Additionally, they were less invasive into a school day than alternative methods such as interviews, which may have taken longer. Focus groups also foster conversation and elicits responses that may otherwise not be considered during surveys.

4.2.2 Focus Group Protocol

4.2.2.1 Sampling and Eligibility Criteria

Ethical approval was obtained from the School of Applied Social Sciences Ethics Committee, Durham University. Ultimately, the practical issue of access and availability led to the selection of a specific secondary school in the north east of England. The school Principal as well as the Head of physical education both expressed interest in the study and a further desire to participate once the protocol was finished. The school was also in close proximity to the lead researcher.

The only eligibility criteria placed by the researcher were that the children were within the target age range of age 10-11 years (year 7), and that any participating staff members were involved to some degree in the provision of physical education at the school. At the request of the school, the teachers selected the children for participation. The teachers chose the children based on their perceptions of the children's observed physical activity levels during physical education, and known participation of sports and PA outside of school, permitting a range of physical activity engagement. The goal was to recruit a diverse assortment of children in terms of their PA participation habits as observed by their teachers. It should be noted that the physical activity of the children was at no point measured objectively or subjectively, and was based solely on the teachers' perceptions of the children's PA levels. Participants were identified through their PE teachers who had worked with the children and were able to observe them on a regular basis. They were well acquainted with those who did and did not participate in after school sport or organized extracurricular PA.

Efforts were made to recruit teachers or staff members involved with physical education or health nutrition. Participating teachers all showed interest in the development of the HIIT protocol.

4.2.2.2 Consent

The school Principal was initially contacted via email and sent an information sheet and school consent form which was returned electronically. Participant consent forms and information sheets were given to the children, their parents/legal guardians, and any participating members of staff. These forms were administered by teachers of potential participants during class time. Participants had one week to read the forms with their parents. Signatures of both the children and their parents/guardians were required for participation in the study. The signed sheets were collected by the teachers and then returned the lead researcher. All teachers interested in participating in the study were involved with, or had an interest in physical activity and health. They were given their own set of information sheets and consent forms. These were also signed and returned to the lead researcher before any focus groups took place.

The teachers and children were both involved in the focus groups at the same time. This was done so that the voices of both groups of stakeholders could be heard simultaneously. They were not separated as it was felt that it would be beneficial for the teachers and students to hear each other's perspectives, particularly in cases where they may not agree. Each focus group consisted of at least four children, one teacher, and the lead researcher.

Samples of the information and consent forms administered to the parents, children, and teachers may be found in the Appendix (please see Figures A2 and A3).

4.2.2.3 Focus Group Design

Focus groups are thought to operate best when they contain between four and twelve participants, though can be modified to suit the context of the study with trade-offs between group size and the level of detail of individual responses (Bender & Ewbank, 1994). For the purposes of this project, the groups were arranged to contain between 4-10 participants, depending on what the school could schedule. In previous HIIT focus group studies, the numbers of participants was similar, with as little as four participants in a group (Buchan et al., 2013). The groups were expected to last between 30 minutes and one hour, again in line with previous research (Buchan et al., 2013). All focus groups were to take place on school grounds during school hours in rooms pre-booked rooms. Attempts were made to hold at least two focus groups, with more if possible. Two focus groups were ultimately held and completed.

As stated previously, the main purpose of this study was to explore the thoughts and feelings of both the students who would likely participate in HIIT and the teachers or staff members likely to administer the protocol. The groups began with a brief icebreaker asking about their favourite sport and/or colour, followed by a discussion of the current PA guidelines in the UK and whether or not the children felt that they or their peers were meeting these recommendations. This was intended to get the children thinking about physical activity and what kinds of activities they or their friends enjoyed doing and why or why not. This was followed by questions probing into their enjoyment of physical activity/sport and what elements they felt made these things more enjoyable. Next the group was asked what kinds of elements should be avoided during PE.

The final part of the focus groups involved the lead researcher demonstrating a brief sample version of a HIIT protocol consisting of a brief demonstration by the lead researcher that consisted of a single 'cycle' of the types of HIIT activities lasting no more than four minutes. The majority of each focus group was devoted purely to the discussion of HIIT with very little time spent on this demonstration or the ensuing questions,. This sample protocol did not use information from the systematic review mentioned above, as it was unavailable at the time, however the design was influenced by various factors. First of all, in initial meetings with the school staff, they expressed the desire for the protocol to require as little equipment and space as possible, so the sample involved simple exercises that could be done with no additional equipment and within a very small area. Another request was that the HIIT be doable indoors to offset the often poor weather conditions in winter. Additionally, based on the idea of lack of time being a key barrier to PA in PE (see above), the lead researcher wanted to ensure that the total duration of the HIIT would be under 20 minutes per session, leaving enough time for other PE activities during their hour-long PE sessions. At this point the full HIIT would have taken roughly 20 minutes, however only a brief demonstration of these activities were shown.

To satisfy the conditions mentioned above, the lead researcher created a draft HIIT protocol for purely demonstrative purposes that could be shown as a sample to the teachers and students. This protocol involved four exercises: burpees, press-ups, mountain-climbers and Heismans. Each exercise was performed with 40 second interval of work followed by a 20 second period of passive recovery before the next exercise was completed. Once all four exercises were completed, there was a minute of passive rest in between series. This cycle was intended to be repeated four times for a total of 20 minutes. During the demonstration, a single cycle was used totally four minutes. As many previous HIIT studies involving younger age groups utilise sprints as their exercise modality, which are space consuming, or instead use specialised equipment such as treadmills and cycle ergometers, different exercises were searched for in the literature. Surprisingly, very little information could be found regarding the 'intensity' of specific exercises as measured as indicators of cardiovascular output (e.x. percentage of VO_{2max} or percentage of Maximum Heart Rate), particularly with respect to young children, highlighting a gap in the research. Due to this dearth of information adult literature was consulted and a framework from a Tabata protocol in adults was used as the model (Emberts et al., 2013). Exercises included burpees, press-ups, and jumping activities that could be performed within a confined space, and previously shown to illicit high heart rates and percentages of VO_{2max} (Emberts et al., 2013). The 2:1 work ratio was also adopted from the Emberts et al (2013) study.

No participants were required to or asked to participate in the sample HIIT – it was merely a demonstration of what a short time duration, low equipment, and low space HIIT design may look like. The group was then asked how they felt about a protocol like the one demonstrated and what could be improved or changed to make it more fun for the children and easier for a teacher to facilitate.

4.2.2.4 Records and Confidentiality

Data was recorded via two recording devices: a Dictaphone and an iphone 5c (model number, origin of manufacture needed) as a back-up. Two devices were used in case there were any technical issues or problems with one of them during recording. The audio files were transcribed by the researcher for analysis. Any names were changed to protect the participant's identities. Recordings and transcripts were not shared outside of the research team. Identification numbers or pseudonyms were assigned to participants and used in place of names on any subsequent written and/or published material. All written records were stored in locked filing cabinets, accessible only by the lead researcher and supervisors, with any records containing names (eg. consent forms) stored separately to those using ID numbers or pseudonyms. All electronic data, including the sound files from the recording devices was stored on password-protected computers, accessed only by the lead researcher and supervisors. The sound files were deleted from the recording device as soon as they are uploaded onto the protected university network.

All information and data collected during the research will be stored in line with the Data Protection Act and destroyed 7 years following completion of the study to follow with the Data Compliance Act regulations.

4.2.2.5 Coding and Analysis

The transcribed data from the focus groups was coded and sorted into key emergent themes and higher order dimensions by the lead researcher and checked by another member of the research team. Coding included three separate categories of data. The first involved the raw quotes taken from the focus group participants transcribed during each session. These were then grouped based on content into first order themes, such 'physical activity preferences' which were then further grouped into major 'higher order' dimensions for consideration in a final HIIT intervention. The key themes and higher order dimensions that emerged from the analysis were recorded and coded.

4.3 Results

4.3.1 Focus group characteristics

Two focus groups were conducted on the premises of the selected school. Both focus groups were held at 13:00 on Fridays and involved children in Year 7 of schooling. The first group consisted of eight individuals: three male children, three female children, one male physical education (PE) instructor, and one female nutrition instructor. The second group was smaller, with two male children, two female children, and a female nutrition instructor, the same female instructor present during the first focus groups, as the school wanted a staff member present and she was the only one available at the time. The first focus group was 28 minutes in duration, while the second lasted considerably longer at approximately 50 minutes, however this was also influenced by the participants' in this group's desire to actively engage with the demonstration and try the HIIT, accounting for approximately 10 minutes of additional time. Though no measures (objective or otherwise) were taken of physical activity in for any participants in this study, the teachers made efforts to select a range of individuals based on their perceptions of the children's activity during school and known activity outside of school.

4.3.2 Themes and Higher Order Dimensions

Each focus group was recorded and transcribed on the same day that the group was run. Themes and higher order dimensions were coded by the lead researcher and reviewed by another member of the research team. Three higher order dimensions were identified: *gender considerations*, *motivational concerns*, and *progress tracking*. A table of the analysis may be found (please see Appendix Table A1). Participants labelled with “C’s” were student (child) participants, while those labelled with a “T” were teachers. The “H” label denoted participants from the first focus group group while the “L” label was used for participants in the second focus group.

4.3.2.1 Gender Considerations

One of the higher order themes that became apparent during these focus groups was the issue of gender, however it was more complex than it may initially appear. Gender considerations can be split into two elements: perceived competencies as a barrier for female participants and the issue of whether or not to separate genders. There were only slight differences in physical activity preferences, with the males of both focus groups heavily preferring football, while females were strongly opposed to football. In contrast, only the females mentioned netball as a preferred activity. Apart from these two activities, both genders enjoyed a wide variety of sports and activities, in including ice-skating, wheelchair basketball, dancing, netball, and hockey. There was a strong vocal dislike of football, explicitly stated by both girls in Focus Group 2, however it is unknown how the other girls felt about it. Further quotes from Focus Group 2 indicate that part of the reason the girls seemed so opposed to it may have had to do with their perceived lack of skill in the game, which was noteworthy considering that they did not seem to mind other team-based sports, like wheelchair basketball, basketball, or regular basketball.

The male teacher in Focus Group 1 raised the second theme: the separation of girls and boys during PE. The results here were mixed as the following exchange transpired:

> TH1: What about, erm…what about the whole "getting sweaty" thing. Cuz that can sometimes be for a girl "Oh, I don't want to get sweaty."

CH2: Well, that's gonna happen if you do sport…

TH1: It is-yeah. But do you think it'd be a barrier? Do you think we can get peo[ple] - do you think we're gonna get people who if we say ,"Right, you're gonna do this at real high intensity, you're gonna get out of breath, you're gonna start to sweat," and people will go, "euugghh, at the start of school I don't…eughh"

CH1: I don't know.

CH3: I think some of them might think that everyone will think that they're disgusting… (she thought that perhaps other girls might think that other people would think of them as disgusting if they sweated)

CH1: I think it all depends who you ask."

Two of the girls in the group appeared to dismiss the notion that sweat would factor into the enjoyment of sport at all. CH3 noted that other girls may feel disgusting by sweating, however did not express any concerns with it personally. Another female participant also conceded that whether or not an individual cared about sweatiness would largely depend on who was asked. It should be noted that this issue largely appeared to be pushed by the teachers, a possible limitation of the study. None of the female child participants involved in this study seemed opposed to sweating, though they did acknowledge that some of their female peers did not like participating in sports altogether, and some may consider sweatiness to be an issue. The male children did not seem to care about the issue at all and simply let their female peers discuss the matter when it was raised.

Further support for possibly separating girls and boys came from the female participants in the second focus group, as they vocalized some of the concerns they had when playing with boys, however these did not involve embarrassment. Rather, Child CL2 stated that she did not like playing with boys due to how seriously they took the games compared to her. Child CL4 echoed similar concerns, complaining that she was often relegated to the position of goalie. This may be a problem with other children who may be pushed into certain positions due to their classmates perceptions of their athletic ability, making a game not fun when it otherwise might be. This was echoed by CL2 who also expressed disdain for the way male children dismissed the girls and forced them to either goalie positions or did not let them play at all. The girls also mentioned that they feared getting hurt when playing with people who lacked skill, such as hockey players hitting them in the shins.

4.3.2.2 Motivational Concerns

Two major themes emerged in terms of barriers to HIIT, or any PA. The children did not like activities that they perceived boring or difficult. Although the girls in the second group expressed distaste for football, children of both genders and in both groups seemed to vocalise a particular dislike of running as it was perceived as monotonous. This was reinforced by some of the concerns that the male PE teacher had, as he worried that HIIT may be too difficult for some of the lower-activity students that he taught. For example, when the participants of the second Focus Group were asked about what kinds of activities they would like to avoid seeing in a physical activity programme both girls expressed a heavy distaste for any PE involving running.

> CL2: I don't like our one- hour PE because we have to run for 12 minutes straight. It's boring.
>
> CL4: I don't like the Tuesday PE. We have to run.

Part of the reason running was so scorned was the monotony. The children disliked repetitious activities that they felt were boring and hard. Although the difficulty of the activity appeared to be off-putting in some cases (such as running), the relationship between difficulty and willingness to engage seemed to be complex, as the children enjoyed certain difficult activities including obstacle courses and even the sample HIIT. In the second group, the girls again expressed frustration with some of their gymnastics activities in that they did not learn anything complex or interesting – only how to land safely when jumping. The children understood why they were learning what they were learning but did not find it enjoyable or exciting:

> CL4: …Like I remember Mr. <teacher's name> yesterday, cuz they were doing gymnastics in like the 2-hour PE session, but like all they learnt was 'how to jump off a bench.'
>
> CL2: …It's just basic stuff, like jumping off the bench like that big (*she showed how high the bench was)* and it's just jumping off it. Like it's not rocket science.
>
> Researcher: So, like landing without hurting yourself.
>
> TL1: So you see the reason for it, but it's boring?
>
> CL2, CB4: Yeah

The difficulty of the activity of the exercise seemed off-putting in the case of running, perhaps because of its longer duration, however, difficulty in and of itself did not seem to be a barrier to enjoyment. Many of the children, for instance, expressed great joy in doing obstacle courses and other 'challenging' activities. Unfortunately, the relationship between difficulty and enjoyment was not thoroughly explored in these groups so it may be the subject of further investigation in future works.

The final note worth mentioning here is that the children, at least in the second group, were adverse to 'difficult' activities, however this had less so to do with the intensity, and more to do with their perceptions of their own or their classmates' skills. The girls did not enjoy football, for instance, because they felt that they were often relegated to boring positions such as goalie, and that they did not like competing with boys who would take the games too seriously. The girls in most groups appeared to enjoy a range of team sports, from hockey to tag rugby, so the sports themselves did not appear to be the issue. Rather, the conditions in which the children play may be causing these perceptions of difficulty.

4.3.2.3 Progress Tracking

The children in both focus groups appeared to favour the use of a tracking sheet or method to monitor their progress. Competition was identified as a major theme, and as key motivator for PA for both the girls and boys. Some children expressed their desire to enhance their performance and win, while others liked the idea of a record as personal progress for internal competition. For example, two of the male children in the first focus groups explained that they enjoyed the competitive element in sport, while the third male child preferred to compete with himself, 'like a ghost.' Two of the girls in the group also liked the idea of progress tracking. Though external competition was only expressed as a positive motivational factor for some of the children, others did not enjoy competing with their peers. Because of this, a progress sheet where the children could 'compete' with themselves may be the best way to approach the issue in future working, allowing for some level of gamification without adding the stress or pressure of peer versus peer competition.

Despite the positive response to progress tracking, children in both groups expressed concern that their peers would somehow cheat in various ways, including lying on any tracking sheets. This concern was prevalent in both groups across both genders. For instance, a male in the first group was concerned that his peers would simply not try hard enough during the HIIT. The females appeared concerned with deviant tactics in recording the HIIT. For example, CL2 felt as though some people may lie on a self-reporting sheet:

> CL2: So like say bronze is 5 more burpees. So then… at home they wait until a week and haven't done it, obviously, so they just tick those five. So that when they come into PE and they're like "Ah, Mrs. I've done these five" and give them a bronze award.

Progress tracking presents on opportunity for the children to develop self-motivational skills and may help influence self-efficacy via ‘experience mastery’ as described by Bandura (1997). By gradually increasing the difficulty of the HIIT, the children may gain confidence in their own abilities.

4.3.2.4 Diverse Range of Requested Activities

The main goal of conducting these focus groups was to find out what kinds of activities the children and staff may enjoy seeing in a novel HIIT-based protocol. The answers to this question were diverse and surprising. Multiple types of activities including dancing, hockey, tennis, rugby, football, wheelchair basketball, cricket, handball, ice-skating, netball, and others were put forward as positive activities. Wheelchair basketball was highly praised as an activity by almost all of the children. Perhaps the novelty of this activity or the use of the special equipment contributed to this as other studies have also found novel activities. The requested activities of the children were slightly at odds with the teachers, who had, prior to the focus groups, requested that the HIIT sessions be done indoors, with low equipment, space, and time requirements, however perhaps a compromise can be reached.

The diverse range of activities already used in HIIT protocols suggests that the modality does not matter as much as the intensity of the exercise itself. With this in mind, it may be possible to adapt any of the activities mentioned by the children into HIIT-type activity so long as the intensity is sufficient. What is of concern is how feasible it would be to monitor and deliver such an intervention for the school. Additional research will be needed to test whether adapting some of these exercises into HIIT is possible, and if they can be done at a high enough intensity.

4.4. Discussion

The aims of this study were to explore the feasibility of implanting a novel high-intensity interval training program in the school setting of Year 7 children. The data collected here has provided useful feedback as to the kinds of issues that should be considered when designing an intervention, including not only preferences and logistical concerns, but also some insights into some of the more subtle challenges, such as designing the intervention for different genders or children with different levels of prior PA engagement. Four major higher order dimensions that emerged from this research were those of gender considerations and differences, motivational concerns, issue of progress tracking, and a diverse range of preferred activities for preadolescent children.

The role of gender in motivation and fitness perceptions emerged as a potential barrier to activity for female students, and though there actually is a substantial body of evidence surrounding this topic, it was not an issue that the lead researcher had even though about before the focus groups. There are decades of work looking into the construction of female identity and both societal and cultural pressures to conform to a certain idea of beauty or femininity, and indeed many of the findings presented here raise many of the same questions. In a study of Australian female experiences with PE, the participants reported that they often felt as though their male peers held most of the control in PE (Garret, 2004). This finding was also reported in this study. While some of the female participants in this study played competitive sports such as hockey, two of the girls were vocal in their opposition to team-based sports, particularly if they were required to play with boys who they saw as overly competitive and unwilling to let them participate. Some of the participants in the Australian study were happy and willing to engage in team sports, while others shared many of the same feelings as the female participants in focus group 2, in that they felt either like they lacked the skill to play well, or that their male peers would relegate them to inferior positions (Garrett, 2004). One quote from the Garret study stuck out in particular as one of the women involved stated:

> "Just games, they weren't much fun if you couldn't already do them. We never did much else. (Nadine)"
>
> "The people who played sport are the ones who wanted to and I sat there—I never really wanted to play sport. I felt really uncoordinated. (Annya) (Garret, 2004 pg. 229)."

These quotes match the feelings of the girls in the second focus group also explaining the frustration they faced from perceived lack of skill:

> CL2: "Like, it depends on what group of boys you do it in front of. Cuz, like, there's some boys who're like, "Oh obviously you can't do that." Like with football, if you're doing it against boys then they'll obviously go off on everything."

That being said, just as in the Garrett study, there were also girls who enjoyed competition and team sport, though it should be noted that these girls came from the were involved with PA outside of the school. These attitudes may be strongly influenced by the girls' experiences outside of school, where they have the added advantage of extracurricular activity in which they have the opportunity to practice their skills and build confidence.

The positive attitudes of the girls in the first group may be influenced by their involvement in extracurricular sport. Positive perceptions of competence are associated with higher levels of enjoyment in physical activity, so it may be important to factor this into the design of future interventions and physical education as a whole (Carroll and Loumidis, 2001; Cairney *et al.,* 2012). During these focus groups, the male children did not mention any issues with skill gaps, or complaints about playing with their peers, however, given the small sampling it may be a worthwhile topic for further investigation in future research to identify if there are any unseen subgroups of males who may also benefit from some kind of separation to avoid embarrassment regarding their abilities.

Competition emerged as a potential factor to drive participation in PE, with external competition being a more prevalent motivator for the boys who engaged in extracurricular sport, however it is currently unknown if this will apply to multiple settings. Only the children in the first focus group appeared to express the desire to add a competitive element. Of this group, four (two boys and two girls) engaged in additional activity outside of the class, and in some cases did so at a competitive level with multiple hours of additional training per week. This is again supported by the literature, which explains that the phenomena may be driven by societal or cultural norms regarding the perceptions and expectations of 'masculinity' (Archer and Mcdonal, 1990; Berg and Lahelma, 2010).

The children also expressed a desire to monitor their own progress somehow; however, there were further questions as to what kind of monitoring would be best for use in the school setting. The school already has a reward system in place for children who 'exceed expectations,' academically or otherwise, however, given the potentially conflicting conversation of external vs personal competition discussed above, it remains unclear whether these progress sheets should be public or individualized and confidential as to avoid embarrassing any of the participants. The children also appeared to be highly adverse to the idea of their peers lying or cheating on their progress sheets. In previous regarding HIIT, the researchers conducted focus groups following a HIIT intervention in adolescents and found that the children were highly motivated by seeing their heartrates on a live-feed system, so perhaps using an objective measure may be an option for future interventions if it is feasible to acquire the necessary equipment (Buchan et al., 2013). Exploring tracking/reward options further is another area that requires further investigation.

When it came to the activities themselves, children of both genders were actually surprisingly diverse in their preferences, conflicting with the results of previous studies that have identified common gender associations between sports. In a study of 43 school girls between 9 and 14 years, netball and gymnastics were associated with femininity while cricket, rugby and football were regarded as distinctly masculine (Archer and McDonald, 1990). In these focus groups, only the females preferred netball, and only the males mentioned enjoying football, however, children from both groups and both gender enjoyed an array of activities including obstacle courses, rugby, basketball, and dance. It remains to be seen if other children in this area are as open to activity as the children in this study. If not, it may be worth looking into using 'gender neutral' sports such as tennis, if any games are to be used in future interventions (Archer and McDonald, 1990).

The diverse range of activities made any specific preferences difficult to identify in such a small group, however, what can be said is that most of the children agreed that they did not like 'boring' exercise, such as the 12 minutes of mandatory running that they would sometimes have to do in their PE lessons. Repetitive activities were consistently cited as boring or unenjoyable, particularly with respect to running. This is noteworthy for two reasons. First of all, running is the most frequently tested HIIT modality used within the literature, and secondly, the school explicitly asked that the final protocol be something that could be done in a tight, confined space. Although running should not be ruled out as an exercise modality for HIIT given its effectiveness at improving measures of cardiovascular fitness, working around running, or incorporating other modalities in addition to running may be of use in future protocols.

It should be noted that the lead researcher demonstrated some of the exercises in both groups, including a full set of an un-finalized protocol involving four exercises involving no additional equipment at a work to rest ratio of two to one with 40 seconds work interspersed with 20 seconds of rest. At the time of designing the focus group, there were no definitive norms or standards when it came to the design of HIIT, so again, the protocol was used as it met the schools specifications. In the first group the children all approved in unison, and TH1 appeared to really enjoy the notion of a low-maintenance (in terms of time and space) exercise program, and commented further on this after the focus groups were completed. Even more impressively, the second group of children actually *asked* to take part, and together the lead researcher and group of four children did a set of the un-finalized HIIIT together. Despite only completing one round of four activities, all four children were sweaty and out of breath, but when asked if they would like to continue they all said 'yes.' It should be noted that the HIIT was stopped for the sake of timing, as the children still had school and the focus group was nearing the end of the allowed hour. It is uncertain if the children could maintain the level of intensity of the HIIT session, but they certainly seemed willing to try and accept the challenge. Obviously, this is a very small sample, but this type of reaction bodes well for HIIT as both the children and teachers appeared to be happy with it and eager to test it.

Lastly, it should be noted that the children seemed to prefer 'novel' activities such as wheel chair basketball and obstacle courses – activities that were typically outside of their normal everyday scheduling. While it may be difficult from a logistical standpoint to incorporate equipment-dependent activities into all schools, perhaps the main lesson is that children do not enjoy monotony and may benefit from a diverse range of activities in a future HIIT protocol. So long as the intensity is sufficient, almost any physical activity can be modified into a HIIT version.

4.5 Conclusions, Limitations and Future Work

The purpose of this research was to use focus groups to explore the thoughts and feelings of both the students who would likely participate in HIIT and the teachers or staff members likely to administer the protocol.

Specifically this study aimed to:

1.) Identify the practical/logistical considerations regarding the delivery of a high intensity interval training intervention into the school setting.

2.) Identify what kinds of activities would be conducive to both enjoyment and long-term adherence of HIIT-based exercise, and could realistically be employed within the school environment.

We found that:

1.) Both the teachers and students seemed eager and willing to implement a short (time duration), HIIT protocol using limited space and equipment and thought that the idea was feasible from a logistical standpoint.

2.) Children apparently enjoyed novelty more than anything. Although some ideas were generated as to what should be avoided in the final protocol, such as running, it was difficult to elucidate what the children and teachers did want to see in the final protocol in terms of activities, and the common trend in activities they did seem to enjoy was that these activities were rarer in their everyday scheduling. The diverse range of preferred activities suggests that different children might be engaged by different styles of HIIT, which is something that should be considered for school-based implementation. This can be seen as a benefit as the implication is that HIIT can be custom tailored to suit any child based on the activity that they choose, assuming a high enough intensity is reached.

3.) We also discovered that the children and teachers may want to see a tracking system of some kind implemented in the HIIT protocol as a way to track progress and develop self-efficacy, however, more data is needed in this regard as there are concerns over what kind of tracking system would be best to mitigate the effects of cheating.

4.) The main barriers that were raised were those of motivational concerns, particularly with respect to less active participants, and gender considerations. Determining if these issues are widespread, or localised to this school may also be useful.

In general, this study showed that HIIT may have a place in the school setting. As discussed in the introduction of this chapter, it is important to identify the 'core components' of a successful HIIT design and then further refine these for each setting. This study was limited by numerous factors. First of all, the sample size was very small and only from one school. Future focus groups involving more students in more schools could help determine if some of the issues raised in these groups are localised or widespread, as this information is important for protocol design. Furthermore, though the response to the sample HIIT protocol featured here was unanimously positive, questions still remain regarding which activities are best suited for the school setting from both the evidence-based end (regarding intensity) and real-world practicality. Future focus groups across more school/students may help identify what activities are the most favourable among specific demographics of children, such as certain grades or children of certain activity levels. This may help with adherence in the long run. If novelty is what children ultimately prefer, then perhaps future protocols might incorporate a wide range of modalities to keep the HIIT interesting to the children.

Finally, with respect to co-production, one item that is missing from these focus groups was to ask what outcomes the students and teachers wanted from the HIIT protocol Though we touched on tracking measures as a means of increasing adherence rates, true coproduction also involves the school administration achieving their goals. In the context of this PhD the overarching goal is to increase measures of CVD, however, the schools may have their own fitness assessments and evaluations to consider. Perhaps more importantly, is to ask what the children want. The children seemed well aware of the lack of activity surrounding them. Moreover, they were aware of what they were being taught and the benefits of physical activity, however, this does not mean that they enjoy it. It is crucial to understand what outcomes the children want. Perhaps they just want HIIT as another activity to enjoy, or perhaps they would like something to make them fitter for competition. Perhaps older children see the value in HIIT as a workout to improve their self-image. These questions remain unanswered and it may be valuable to run further focus groups to determine what outcomes the children and teachers would like to measure or achieve.

Future focus groups could be the subject of further investigations to address some of the issues raised in the focus groups presented here, including a greater number of schools to increase the generalizability of these findings with regard to the 'essential components' of a robust HIIT protocol.

Limitations

There were two major limitations in this study. The first was the involvement of the teachers in the focus groups, as this may have increased student reticence. As stated earlier, the opinions of staff members was sought as they would likely be the ones delivering a HIIT-type protocol in the future. They would likely be familiar, at least to some degree, with what works and does not work with their students. That being said, the presence of the teachers in the groups may have influenced the thinking of the children, and may have interfered with what they would have said that the teachers been absent. This was perhaps most noticeable in the discussion about separating males from females as it is uncertain if the issue would have been raised at all had the PE teacher not brought it up. Future work may seek to separate the teachers from the students.

The second major limitation is that PA was not assessed in any of the participants, making it impossible to determine if there were any patterns between activity level and preferred activities. Although the teachers made an effort to bring in a diverse range of students with varying levels of PA engagement based on their own observations, the fact is that PA was not measured and it may be true that selection bias occurred. It was not the goal of this study to assess PA, however, future works may benefit by collecting PA data on the children prior to their involvement in focus groups, as this may add a layer of analysis to the study that may prove useful for detecting patterns to target certain demographics.

While the underlying goal was to collect opinions on preferable activities and activities to avoid, the findings presented here cannot be generalised due to third major limitation of this study: the small sample size. The focus groups involved a very limited range of children from a single school, a problem which could be addressed by conducting similar focus groups among a greater breadth of both schools and age ranges to improve generalizability. The next step in research is to identify how we can take a given activity and increase the intensity such that it may qualify as HIIT to reap the cardiovascular benefits of this kind of physical activity.

Chapter 5: Recommendations for HIIT-Based Policy, Interventions, and Future Research

The purpose of this chapter is to discuss the conclusions of this thesis within the context of the literature as a whole and provide recommendations for HIIT at the policy, intervention, and research levels.

5.1 Public Policy

5.1.1 Recommendation 1: HIIT best-practice guidelines should be added to the UK PA recommendations for children and adolescents as a PA option to promote CRF.

HIIT has already been added to the UK's Chief Medical Office PA guidelines for adults, following an update in 2019 acknowledging the clear clinical benefits (Gov.uk, 2019). Additionally, the total recommended MVPA has changed from a daily recommendation to a cumulative recommendation, promoting the idea that people can customize their physical activities to suit their needs. These new recommendations also mention the limitations of HIIT, citing the unknowns in terms of optimal implementation, but demonstrate a more outcomes-based approach to PA as opposed to simply trying to meet the daily requirements.

Given that HIIT has been accepted as an option for adults, why has it not been added to recommendations for younger age ranges? As with adults, HIIT has been consistently shown to elevate CRF levels amongst both children and adolescent populations (Eddolls et al., 2017). The results of the systematic review in Chapter three furthered this argument by demonstrating that, while manipulations of the 9 components of HIIT protocol may produce slightly different results, leading questions as to what may be considered 'optimal,' perhaps the greatest lesson from the study was that HIIT repeatedly raised CRF regardless of these changes in protocol. Additionally, these changes in CRF are often reported as more effective than other forms of PA including traditional cardiovascular activities If the purpose of PA recommendations is to encourage public PA engagement for the health-related effects and HIIT is known to raise CRF, an important proxy measure of health, then it follows that it should be added to the PA recommendation list of useful activities.

This is not to say that HIIT should replace all forms of PA – not in the least. Critics of HIIT typically highlight the rigorous nature of this type of PA as barrier to sustainability, which very well may be true. That being said, the point is not that HIIT, or any type of PA is for everyone, but rather that everyone should be informed about HIIT, and all methods of improving their health to increase their pool of options.

The results of the focus groups and many ongoing reviews also appear to suggest that the difficulty of HIIT may not be as large a threat to sustainability as one might think. The relative success of HIIT studies in children and adolescents has already demonstrated the efficacy of these types of interventions across multiple types of participants and settings, some of which included obese and overweight participants, and schools (Costigan et al., 2015; De Araujo et al., 2012; Buchan et al., 2013, Martin-Smith et al., 2020; Weston et al., 2016;). HIIT studies in younger populations still lack any kind of longitudinal follow up of more than 12 weeks, with the exception of Tjonna et al. (2009), highlighting an ongoing gap in the literature, however, given the lack of conclusive evidence of PA tracking throughout the life course (Telama et al. 2005), this may be irrelevant. Again, the recommendations are not about forcing people to engage with PA, but rather about giving them the options they need to explore PA choices that work for them.

The focus groups presented in Chapter four of this thesis demonstrated that both children and teachers were willing to engage with HIIT. Despite the concerns of user engagement echoed by one of the participating PE teachers with critics of HIIT, the general response appeared to be very positive. One of the key findings from these groups was that children seemed to prefer a variety of activities. This paired well with the findings from the systematic review in Chapter three, which demonstrated that HIIT protocols could be successful despite their variability. This presents an opportunity for people to select whatever activities they prefer, provided the intensity is high enough (Karlsen et al., 2017).

5.1.2 Recommendation 2: Policy makers must devise effective strategies for disseminating best-practice HIIT guidelines.

Given the relative novelty of HIIT, it is important the public stay informed as to what constitutes HIIT, and how they can safely and effectively engage in this type of PA. One of the themes throughout this thesis has been the lack of standardization across HIIT protocols, and the lack of consistent definitions. While these are issues for researchers to address (see Section 6.3), a key challenge facing policy makers is to find ways to properly disseminate whatever information about HIIT is known.

One of the problems discussed in the literature review (Chapter 2) was the lack of engagement with current PA guidelines. While HIIT may be a useful component to include within these new guidelines, it does very little if people do not know how to use it. Despite the research that has gone into the current UK Chief Medical Offices PA guidelines, past research has shown that historically the majority of people are still unaware of them. Data collected from national and online-administered surveys revealed that despite the involvement of various dissemination campaigns, only 18% of adults could accurately recall the national recommended guidelines. (Knox et al., 2013). Lessons from previous PA campaigns can be used to inform future HIIT dissemination strategies, to avoid this lack of engagement. The ACTIVE for LIFE campaign that ran from the 1990s to early 2000s may have been called a moderate success in terms of its overall coverage, but was considered largely unsuccessful (Hillsdon et al., 2001; Milton & Bauman, 2015). The more recent Change4Life campaign, launched in 2009 was initially intended to last three years with a £75 million from the Department of Health included social media elements. This campaign was moderately successful at its start, but also dropped in effectiveness before funding was withdrawn due to diminishing performance by July 2010 (Milton & Bauman, 2015).

It is beyond the scope of this section to assess and analyze the success and failures of previous dissemination strategies, but rather to caution against adding HIIT to the guidelines without a clear and well-developed plan.

5.1.3 Recommendation 3: The UK should develop measurable, CRF-related outcome goals for any of its PA programs

Key to any public health strategy is arguably generating effective means of assessment to determine if said strategy is effective (Kahn et al., 2002). As stated in the literature review, PA itself is a proxy measure of health. Although PA is irrefutably associated with health outcomes, an ongoing theme of this thesis has been that CRF may serve as more useful proxy measure of health for two reasons. The first is that CRF has been repeatedly shown to be a stronger predictor of health than PA (Davidson et al., 2018; Lee et al., 2011; Ross et al., 2016). The second is that assessing CRF may be more practical than assessing PA, especially within the context of public health (De Fina et al., 2015). In children PA is highly variable even within a four-day period, whereas CRF typically remains stable (Ekelund, 2007).

One advantage to CRF testing is that field-based measures such as the 20-MSFT are reliable, accurate, and cheap, however, many of these tests require physical evaluation (De Fina et al., 2015). While this may be a significant problem in adult evaluation, schools present an excellent opportunity for mass evaluation in children and adolescents. There is also enough evidence to help develop standardized value for healthy CRF standards making it possible to develop targets for use within the UK schooling system (Ruiz et al., 2010; Zaquot et al., 2016).

Again, the point of this is not to take away from the importance of PA, which has been independently been associated with many positive health benefits, but rather to suggest that CRF-related outcome measures may provide an easily implementable solution for the evaluation of both PA and HIIT-based policies and programs. Future work may be further needed to develop CRF cut-off points across different age ranges and evaluate which measures are best suited for wide-spread use.

5.2 HIIT Intervention Design

Both the focus groups and the systematic review provided useful information which could applied to intervention design for future HIIT protocols for use with children and adolescents within the school setting.

5.2.1. Duration

Recommendation 4: HIIT programs should be designed to run for at least eight weeks

The work presented in the systematic review in Chapter 5 was consistent with previous HIIT research suggesting that eight weeks is the minimal requirement for producing appreciable results in CRF as well as other health-related parameters such as body mass and composition, (Costigan et al., 2015; Eddolls et al., 2017). Although HIIT has been shown to incur positive benefits to CRF in as little as two weeks in adults (Child, Leggate, & Gleeson, 2013), it is currently unknown if this can be consistently applied to younger age groups due to a lack of literature on the subject. Future HIIT research may benefit from assessing the minimal requirements for both duration and frequency needed to elicit positive CRF outcomes.

5.2.2. Modality

Recommendation 5: The modality of HIIT should be selected by the participants to increase adherence and long-term sustainability. Intensity is more important for achieving favorable results.

The results from the systematic review indicated that running may be the 'optimal' modality in terms of generating the greatest effect size when compared with other modalities. Again, this is consistent with other findings (Costigan et al., 2015l Eddolls et al., 2017). The results from the focus groups presented in Chapter four, however, suggest that perhaps ‘optimal’ does not always imply ‘effective.’ The children in these groups expressed a great distaste and resentment of running in their PE classes. Perhaps more interestingly, they also appeared to particularly enjoy novel activities within their PE programs, such as wheelchair basketball.

The results from the systematic review also showed that, although running may induce the greatest CRF response, other modalities such as cycling and mixed-methods approaches also achieved significant albeit smaller CRF responses, a finding consistent with other systematic reviews (Thivel et al., 2018; Amigo et al., 2018). With this in mind, and the idea that children may prefer a variety of activities, it follows that from a public health perspective HIIT protocols should empower participants by giving them as many modality choices as possible, provided they are preformed at sufficient intensity. At the time of this writing, only one study is known to have directly asked stakeholders for their inputs in protocol design. Weston et al. (2016) used focus groups to inquire what kind of modalities students may want to see in their HIIT protocol to success. Future work may expand on ways to commune with stakeholders in order to customize HIIT protocols to suit individual school needs.

5.2.3. Work Interval

Recommendation 6: Future HIIT researchers should be directed at determining practical means of prescribing intensity. Specifically, HIIT researchers should assess the effectiveness of self-mediated ‘maximal effort’ prescriptions of intensity.

Perhaps one of the most frustrating aspects of HIIT research is the overall lack of consistency between studies. At the time of this writing, no 'minimal' prescription of HIIT intensity has been seen in the literature. It is also unknown which type of intensity prescription, such as VO_{2max}, peak heart rate, or maximal aerobic speed, is optimal. Numerous methods have been used to prescribe intensity, ranging from MAS, to heart rate. Pervious recommendations for intensity have included: 64–90% VO_{2max} and/or 77–95% peak heart rate (Garber et al., 2011; Garcia-Hermosa et al., 2016), or 90% heart rate maximum/100–130% maximal aerobic velocity (Eddolls et al., 2017). The results of the systematic review presented in this thesis also supported the notion that speed-based prescriptions of intensity were optimal in terms of effect size, however, again, 'optimal' does not necessarily equate to real-world success.

One of the interesting measures of intensity that was largely missing from HIIT research as whole was the classification of intensity based on absolute measures (METs), likely due to the impracticality of measuring METs on the field. Heart rate, VO_{2max} and other measures of intensity associated with HIIT are all considered relative measures of intensity. METs are frequently used in the context of PA research, particularly when classifying the intensity of PA (Powell et al., 2011). It may be useful to select HIIT modalities known to be of vigorous intensity, however measuring intensity based on METs may be less useful than relative measures of intensity due to heterogeneity within populations (Mendes et al., 2018; Shephard, 2001).

From a public health perspective assessing or prescribing HIIT using any of these prescriptions seems to be impractical to say the least. It may be instead better to evaluate how good children and adolescents can be at self-mediating their own intensity. Self-mediated studies that used ‘maximal effort’ as their prescription of HIIT may not have been as effective as more rigorous measures of intensity, but they were still able to incur significant changes to CRF.

5.2.4. Rest Interval

Recommendation 7: More research needs to be conducted to determine ideal rest interval parameters.

At the time of this writing there is no clear answer as to what type of rest is ‘optimal.’ The results of the systematic review presented here demonstrated very little difference in effect size between HIIT protocols that used active versus passive recovery types. The few studies that have assessed differences in active versus passive recovery types have typically been conducted with adult participants, so it is difficult to make any recommendations for younger populations. In these cases, active recovery may be slightly favored not just with respect to CRF outcomes but also for other biomarkers such as plasma glucose, glucoregulatory hormones (Abdurrahman et al., 2018) as well as body fatness and BMI (Avazpor, Kalkhoran, & Amini, 2016). Furthermore, at least in young adults, active recovery was reported to not attenuate training adaptation (Wiewelhove et al, 2018), however, again, studies such as this are lacking for younger populations.

5.2.5. Work-to-Rest Ratio

Recommendation 8: More research is needed to determine optimal work-to-rest ratios, work interval duration, and rest interval duration for younger populations.

The data from systematic review presented here suggests that at least for school-aged participants, work-to-rest ratios of one or less may be ideal. This was a novel finding, as data regarding work-to-rest ratios is generally lacking from the HIIT literature in younger populations with only one study directly assessing the impact of work-to-rest ratios (Seo et al., 2019). Although previous systematic reviews have also been conducted, these have largely not mentioned work-to-rest ratios due to heterogeneity within HIIT protocol design. Part of the problem is that HIIT can be modified in many ways even within protocol designs to ensure that is getting sufficiently more difficult as participants advance. For example, some simply elevate the intensity periodically, while others modify work or rest interval durations, thereby changing the work-to-rest ratios even within a single study (Baquet et al., 2002; Gamelin et al., 2010). As with any kind of training, progressing the level of difficulty is necessary to incur ongoing adaptations, however, future HIIT research may benefit from specifically assessing work-to-rest ratios or differences in both work interval and rest interval duration.

6.3 Future Directions for HIIT Research

HIIT has repeatedly demonstrated an ability to improve CRF and other health outcome measures, yet there is still much that remains unknown. One of the most vital challenges facing HIIT research is the lack of standardization amongst definitions with great variability across HIIT protocols. While this may be considered an advantage in terms of its applicability to a wide range of scenarios and settings, it creates problems for researchers attempting to generate minimal or optimal HIIT protocol parameters.

Apart from optimizing HIIT protocols, the research is currently set in the same trend as general PA research in that many newer studies are beginning to focus not on health outcomes, but rather on the effects of HIIT on cognitive outcomes (Costigan et al., 2016). HIIT has often been compared to MICT in the past, with many studies stating that HIIT is at least as effective at improving CRF as MICT, if not more so, but these comparisons have continued into investigations of cognition with similar results. In older adults, HIIT was found to improve several measures of cognition more so than other types of training including MICT and resistance training (Coetsee & Terblanche, 2017).

In children and adolescents much of this cognitive HIIT research has been conducted with respect to academic settings, and is still in its youth. Leahy et al., (2020) reported that following maximal intensity exercise students improved performance on certain cognitive tasks such as the Digit Spin, which measures attention span, short-term memory, and verbal working memory, however performance on the RAVLT test which evaluates verbal learning ability and immediate memory recall suffered for one hour before returning to baseline. Costigan et al., (2016) investigated the effects of two types of HIIT protocols, one involving strictly gross aerobic activities, the other involving aerobic activities and bodyweight resistance training in adolescents and reported that the small positive effects on executive functioning in the aerobic HIIT group, and moderate effects on executive function in the resistance HIIT group. Both groups were also found to incur small benefits to mental wellbeing. Still, this research is in its infancy and it remains to be seen if HIIT optimization for CRF benefits is necessarily the same as HIIT for cognitive outcomes.

Finally, HIIT is still largely devoid of any studies greater than 12 weeks, leaving questions as to how sustainable it can be. Within the context of public health, this is less of an issue as the whole point of the PA guidelines should be to provide people options that work, not necessarily prescribe mandatory PA. That being said, it still may be useful to know long term adherence/sustainability patterns for HIIT within the context of school programs for dissemination programs. It is important to not only find best practices for HIIT, but also find what works from a practical perspective in terms of delivery. As Socrates said, “Education is the kindling of a flame, not the filling of a vessel.” When applied to HIIT it becomes clear that almost anything ‘works’ given enough intensity, so it may be beneficial to stress the enjoyment of HIIT and demonstrate how to fulfill these protocols safely. As stated throughout this thesis one of the main benefits of HIIT is the lack of time necessary needed to achieve significant results, and this may become an appealing aspect, particularly as students age and are faced with less time for PA.

Glossary of Terms

AHA - American Heart Association

BMI- Body Mass Index

HIIT- High Intensity Interval Training

MET-Metabolic Energy Equivalent

MICT- Moderate Intensity Continuous Training

MVPA-Moderate to Vigorous Physical Activity

NCD-Non-communicable disease

PA – Physical Activity

PiA-Physical Inactivity

SB- Sedentary Behaviour

WHO – World Health Organization

Appendix

Group Number	**Abbreviation**	**Gender**
	CH1	Female
	CH2	Female
	CH3	Female
	CH4	Male

Focus Group 1	CH5	Male
	CH6	Male
	TH1	Male
	TH2	Female
Focus Group 2	CL1	Male
	CL2	Female
	CL3	Male
	CL4	Female
	TL1	Female

Figure A.1 Focus Group Coding Abbreviations

Table A1: Focus Group Coding

Raw Data	First Order Themes	Higher Order Dimension
Preferences Males • CH4: I do Rugby, football, and table tennis. • CH4: Football. • CH5: I do table tennis, football, and tennis. • CH6: My…uh favourite one's football, rugby and hockey. • CB1: Me favourite sport is football…eh… Child B3 (male): *interrupts CB1* I'm CB2. My favourite thing to do is street dancing and my favourite colour is green. • CL1: I like some PE. CL1: Like football and exercise. • Researcher: But you guys (referring to CL1 and CL3) presumably like football, right? CL3: I love it. • CL3: Everything about PE I love. • CL3: I just go to the gym. Researcher: Gym? Do you lift weights? CL3: Yeah. • *When asked if they preferred just exercise, or exercise plus some kind of game* CH5: Like that, yes (in reference to a mixed kind of HIIT games + exercise) CH4: At high intensity, yeah, I'd like a shot at something.	Physical Activity Preferences	Diverse Range of Recommended Activities

- CL1: I like playing with other people.

Females

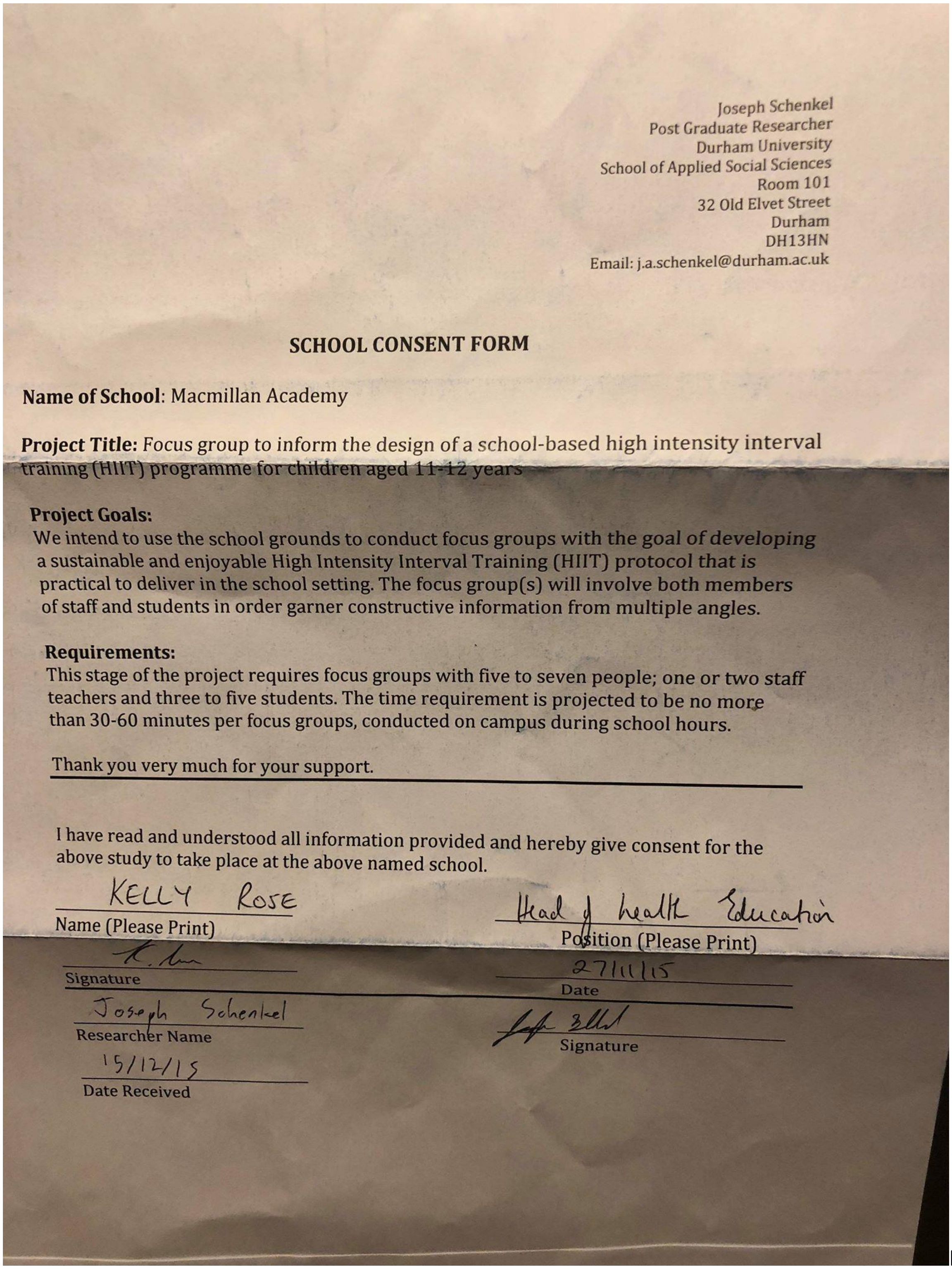
- CH1: Uh, outside of school I do dancing…but my favourite sport's tag rugby
- CH1: Netball
- CH2: In school I do netball and hockey.
  CH2: Wheelchair basketball.
  CH2: Netball
- CH3: Um, I do hockey and I play inside and outside of school.
- CH3: And also cricket
- CL2: In primary, for SATS we did wheelchair basketball.
  CL4: That's SOOO fun.
- TH2: Alone for me. Yoga or running, just….alone.
- CL4: Oh yeah. I forgot to say that I hate playing football.
- CL2: I like trampolines.
- CL4: I LIKE PLAYING DOEDGEBALL! Dodgeball's fun.
- CL4: Bulldog. Yeah, Bulldog.
- CL4: And cricket!
- CL2: And I love playin' that, when you put a bit behind your back and you have to…
  CL3: Oh! When you have to grab it and pull it out.
  CL2: Yeah
  Researcher: Tag rugby.
- CL2: Yeah! Basketball!
- CL2: I like…like stuff you don't really think is exercise, but it is cuz it's like fun so you don't think its exercise.
  CL4: I agree with that.
- CL2: I like the big hoola-hoop one when you get like a big hoola-hoop and just spin it around until it like, skipping rope
- CL2: Yeah I love doing obstacle courses.

Dislikes		
Male • CH5: Uh, sprinting on the spot would be quite hard. • *when asked about which exercises they definitely did not want to see* CL1: Running. Female • CH3: My friend doesn't like any sports. • CL2: It depends what we're doing in our two hour PE, if I'm honest. Like I don't like football. Don't like…yeah just football? • CL2: I don't like our one- hour PE because we have to run for 12 minutes straight. It's boring. • CL4: I don't like the Tuesday PE. We have to run. • CH2: I don't like-I don't play anything outside of school. • CL4: Oh yeah. I forgot to say that I hate playing football • Researcher: Yeah, of course you would! Nice! Yeah, it's a fun game. And do you guys (referring to TB1, CB2, and CL4) not like it because of the running involved, or because you're…it's difficult? • CL4: It depends what team I'm on, because, like sometimes the team play is a bit, like- • CL2: Hard. • CL4: Not, like, rough, but like, "Oh I can play football," but like you're really bad at it, so like go goalie. • CL2: I like playing hockey, but then I don't because it depends who's playing. Like if someone who doesn't know how to play hockey, like, I just don't want to play, cuz most of the time they'll just whack you in the shin with the hockey stick or the ball. • CL2: I like games, like with loads of people. But, if, sometimes it turns out bad, because some people are, like, sore losers. So then they go in like a mood, if they like, like if our team won and stuff like that. But it's nice.CH3: My friend doesn't like any sports. • TH2: I don't like tennis cuz I can't hit anything. I try and do things like yoga and running. • CL4: Not, like, rough, but like, "Oh I can play football," but like you're really bad at it, so like go goalie. Researcher: Oh, so you don't wanna' get stuck in the goalie position, right? CL4: Yeah. • CL2: Oh noooo…I hate burpees • CL4: That is fun! I don't like the mountain climbers but I like everything else.	Physical Activity Dislikes	

Male • CH4: Standards. Cuz, like, I don't like losing and I want to win. • CH5: How, you can, like, challenge yourself. Set targets. • CH5: Yeah I'm competitive • CH6: Have fun • TH1: Stress release for me. Female • CH1: Get to meet new people. • CH1: Yeah, I do it for fun. • CH3: Competitive. I enjoy it. • TH2: Same here. Just gettin' out to have a run. Clear you head. Stress release, definitely.	Motivation for PA	Gender Differences and Considerations
• TH1: UHHh (exhales). For me, in terms of-we…the biggest problems we have in terms of PE, especially with this sort of stuff is, is uh, people who have been…people who have never experienced that level of intensity and don't understand that being out of breath is not a bad thing. We've got a lot of students in year seven who have never been under that sort of strenuous level of activity and they're sort of afraid of it. TH1: They get physically scared. So you'll get students come to you goin, "Sir, I can't breath." And they don't know it's OK to be out of breath. Or, "My legs are hurting," cuz that's just lactic acid, they, you're legs aren't…they're not injuring themselves-you get lots of people claiming injury. People in this room won't cuz we've, we've, we've ended up with six sporty individuals that don't mind, but that's the biggest barrier in PE for us. And that's…that's not against students at this school, that's a societal thing in general, in terms of my perspective as a PE teacher. I've been here for seven years now. First couple of year seven student that came in were REMARKABLY different in terms of their attitudes towards exercise compared to some of the students here now…Not you all, by the way. You're all a fantastic, but as a whole it's quite a scary…uh, change. • CL4: It depends what team I'm on, because, like sometimes the team play is a bit, like. CL2: Hard. CB4: Not, like, rough, but like, "Oh I can play football," but like you're really bad at it, so like go goalie Researcher: Oh, so you don't wanna' get stuck in the goalie position, right? CB4: Yeah.	Separating Boys and Girls	

Researcher: I know that feeling. That was me when I was your guys' age. Not fun. CB2: I'm same as her, but I like playing with girls.		
• TH2: I don't like tennis cuz I can't hit anything. I try and do things like yoga and running. • *When asked if there were any crticisms for HIIT* CH4: Like, not working hard enough for the whole amount of time (referencing his peers). Researcher: So do you think that those other people are just gonna kinda slack of during training? CH4: Yeah. • CL4: It depends what team I'm on, because, like sometimes the team play is a bit, like- CL2: Hard. CL4: Not, like, rough, but like, "Oh I can play football," but like you're really bad at it, so like go goalie. • CL2: I like playing hockey, but then I don't because it depends who's playing. Like if someone who doesn't know how to play hockey, like, I just don't want to play, cuz most of the time they'll just whack you in the shin with the hockey stick or the ball. • •	Perceived Competence Difficulty	Motivational Concerns
• TH1: UHHh (exhales). For me, in terms of-we…the biggest problems we have in terms of PE, especially with this sort of stuff is, is uh, people who have been…people who have never experienced that level of intensity and don't understand that being out of breath is not a bad thing. We've got a lot of students in year seven who have never been under that sort of strenuous level of activity and they're sort of afraid of it. TH1: They get physically scared. So you'll get students come to you goin, "Sir, I can't breath." And they don't know it's OK to be out of breath. Or, "My legs are hurting," cuz that's just lactic acid, they, you're legs aren't…they're not injuring themselves-you get lots of people claiming injury. People in this room won't cuz we've, we've, we've ended up with six sporty individuals that don't mind, but that's the biggest barrier in PE for us. And that's…that's not against students at this school, that's a societal thing in general, in terms of my perspective as a PE teacher. I've been here for seven years now. First couple of year seven student that came in were REMARKABLY different in terms of their attitudes towards exercise compared	Engagement / interest	

to some of the students here now…Not you all, by the way. You're all a fantastic, but as a whole it's quite a scary…uh,change.		
• CH4: Competitive, cuz I wanna like sign for like a better… like, be a professional footballer. • CH5: Yeah I'm competitive. • CH6: You do wanna try to, like, beat yourself. Like a ghost. • TH1: …Workout, at the same time. So we have the team element but I want to beat you. • CH2: Yeah have, like a record. • CH3: Competitive. I enjoy it. • CL4: Do you know what? It's like running's the same as tag, but running around a circle sucks, but like running after other people is fun.	External vs Self Competition	Progress Tracking
• CH4: Like, not working hard enough for the whole amount of time. Researcher: So do you think that those other people are just gonna kinda slack of during training? CH4: Yeah. • Researcher: But would you-my question is would you like that kind of thing. Like something that can help track your progress. *Unanimous 'YEAH'* CL3: I'd love it. CL4: But then that's the thing. Some people can literally cheat and stuff. • CL2: So like say bronze is 5 more burpees. So then like quickly like, not quickly like, but at home they wait until a week and haven't done it, obviously, so they just tick those five. So that way they come into PE and they're like "Ah, Mrs. I've done these five" and give them a bronze award.	Cheating Deviant tactics?	



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SCHOOL CONSENT FORM

Name of School: Macmillan Academy

Project Title: Focus group to inform the design of a school-based high intensity interval training (HIIT) programme for children aged 11-12 years

Project Goals:
We intend to use the school grounds to conduct focus groups with the goal of developing a sustainable and enjoyable High Intensity Interval Training (HIIT) protocol that is practical to deliver in the school setting. The focus group(s) will involve both members of staff and students in order garner constructive information from multiple angles.

Requirements:
This stage of the project requires focus groups with five to seven people; one or two staff teachers and three to five students. The time requirement is projected to be no more than 30-60 minutes per focus groups, conducted on campus during school hours.

Thank you very much for your support.

I have read and understood all information provided and hereby give consent for the above study to take place at the above named school.

KELLY ROSE
Name (Please Print)

Head of Health Education
Position (Please Print)

Signature

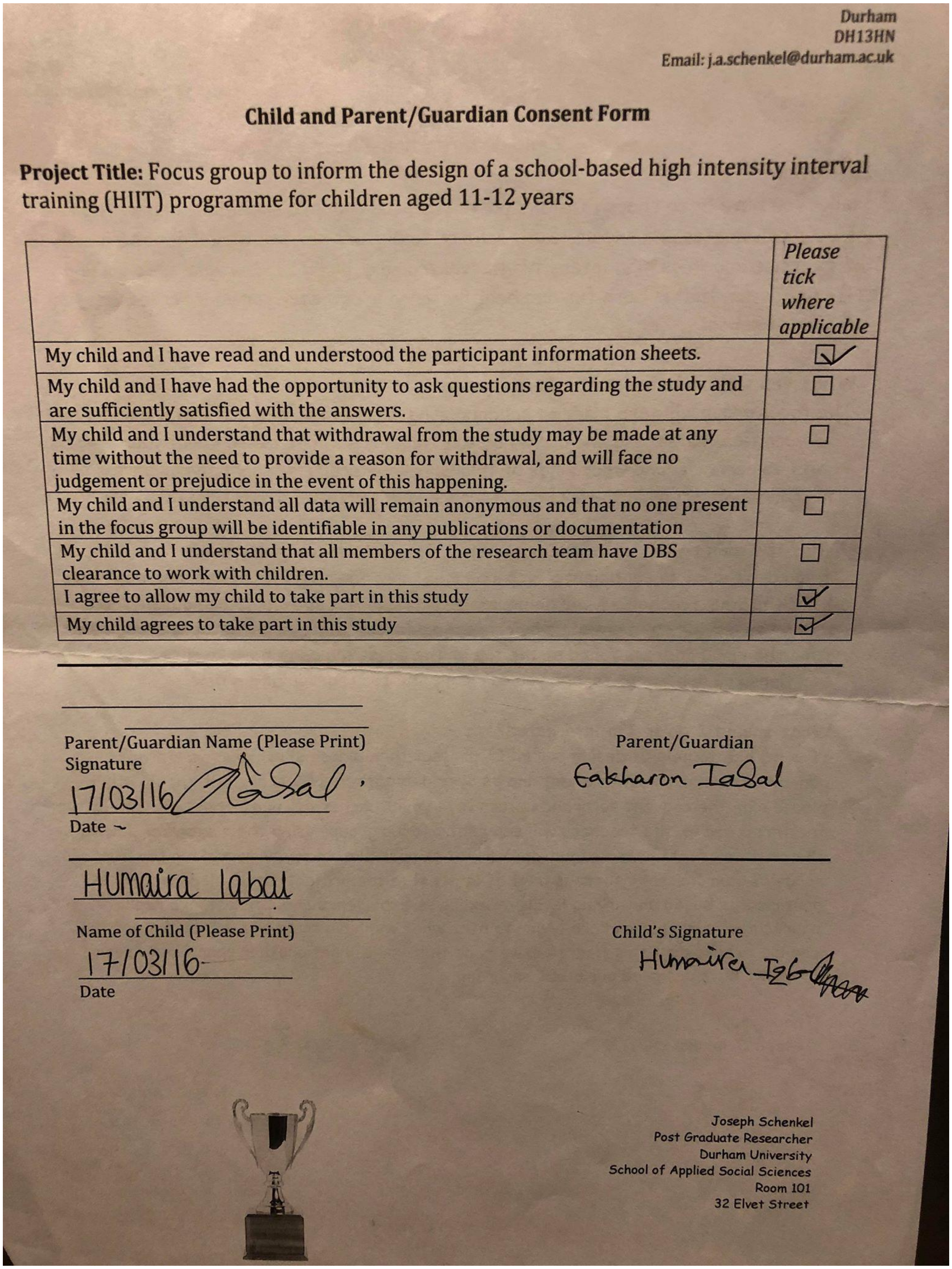
27/11/15
Date

Joseph Schenkel
Researcher Name

Signature

15/12/15
Date Received

Figure
A2 School Consent Form



Durham
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Email: j.a.schenkel@durham.ac.uk

Child and Parent/Guardian Consent Form

Project Title: Focus group to inform the design of a school-based high intensity interval training (HIIT) programme for children aged 11-12 years

	Please tick where applicable
My child and I have read and understood the participant information sheets.	☑
My child and I have had the opportunity to ask questions regarding the study and are sufficiently satisfied with the answers.	☐
My child and I understand that withdrawal from the study may be made at any time without the need to provide a reason for withdrawal, and will face no judgement or prejudice in the event of this happening.	☐
My child and I understand all data will remain anonymous and that no one present in the focus group will be identifiable in any publications or documentation	☐
My child and I understand that all members of the research team have DBS clearance to work with children.	☐
I agree to allow my child to take part in this study	☑
My child agrees to take part in this study	☑

Parent/Guardian Name (Please Print) Fakharon Iqbal

Parent/Guardian Signature

17/03/16

Date

Humaira Iqbal

Name of Child (Please Print)

Child's Signature

17/03/16

Date

Joseph Schenkel
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Figure A3 Child and Parent Consent Form

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