Vigorous intensity physical activity and the metabolic health of adolescents

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Human Potential Centre

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Abstract

Despite efforts to improve adolescent physical activity participation and adherence, as many as 80% of youth fail to achieve the recommended 60 minutes of moderate-to-vigorous intensity physical activity (MVPA) per day. Whilst physical activity guidelines are beginning to recognise the importance of vigorous intensity activity as an alternative to long-duration moderate intensity activity, there are no specific recommendations regarding specific session parameters such as the duration of each vigorous bout.

The primary focus of this PhD was to conduct a cohesive investigation into the metabolic effects of vigorous intensity physical activity, using both an epidemiological level study, and a detailed exercise intervention on a sub-sample of adolescents. This thesis is constructed in two parts to reflect the flow of investigation into vigorous intensity physical activity and adolescent metabolic health. Part 1 (Chapters 2-4) investigates the measurement techniques most appropriate to quantify physical activity in adolescents, and thereafter determines the contribution of activity intensity to adolescent health from a large cross-sectional study. Part 2 (Chapters 5-7) forms an investigation into high-intensity interval training (HIIT) as a strategy to deliver the health benefits of vigorous intensity physical activity in adolescents. The aim of Part 2 was to investigate the effect of HIIT on the metabolic health of low-active male adolescents, and explore the perceptual responses that may influence and determine long-term exercise adherence. Through Parts 1 and 2 of this thesis, a cohesive investigation into the metabolic effects of vigorous intensity physical activity was performed.

Outcomes from Part 1 showed that vigorous intensity physical activity was associated with key positive health outcomes in adolescents, supporting the concept of emphasising the importance of vigorous activity in youth physical activity guidelines. Data obtained by accurately measuring physical activity using accelerometry in 694 adolescents showed that vigorous physical activity was the only activity intensity associated with reduced body mass index (BMI) and waist circumference-to-height ratio (WCHt) in youth. Data also showed that an increase of 4.2% in daily duration of vigorous intensity activity was associated with a reduction in WCHt from the 75th centile to the 25th centile in adolescents. Hence, the clinical implication of these results

suggest that an increase in daily vigorous activity by an average of 1.1 minutes each day is associated with a 0.05 reduction in WCHt in the adolescent cohort.

Furthermore, in Part 2, the investigation into the dose-response relationship of HIIT with metabolic health showed that low-active adolescent males, performing a single HIIT set twice-weekly (consisting of 4 repeated bouts of 20 seconds of near-maximal exertion interspersed with 10 seconds of passive recovery), in addition to one resistance training session, gained meaningful improvements in fitness and body composition. Performing additional HIIT sets provided few additional health improvements to those of the lowest dose studied. In support for HIIT uptake and long-term adherence, participants also gained meaningful improvements in several sub-domains of physical self-perception and expressed high levels of enjoyment towards the exercise intervention. This research indicated an effect of incremental HIIT dose on the physical self-concept subdomains; thus, adolescents and practitioners can assume that performing even low doses of HIIT in addition to resistance training improves physical self-perception. This body of work provides strong support for the promotion of vigorous intensity physical activity in adolescents, specifically endorsing the utilisation of HIIT as a potent and practical alternative method to deliver health benefits of exercise in youth.

Through addressing the overarching research question, '**What are the effects of vigorous intensity physical activity on the metabolic heath of adolescents?**' this thesis, as a whole, contributes new knowledge to the science of adolescent physical activity and health. The wider implications of this research may help to improve the lifelong health and wellbeing of adolescents by suggesting novel physical activity strategies that incorporate the promotion of vigorous intensity physical activity. Through implementing this research in the adolescent cohort, policy makers and exercise practitioners may be able to reduce the burden of chronic lifestyle related diseases to public health.

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Attestation of authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any degree or diploma of a university or other institution of higher learning.

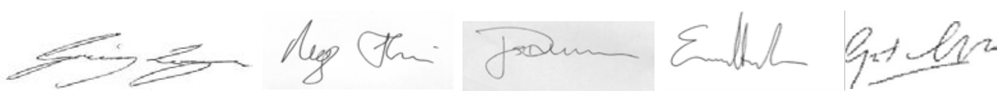
Chapters 3 to 7 of this thesis represent five separate papers that have either been published or have been submitted to peer-reviewed journals for consideration for publication. My contribution and the contributions of the various co-authors to each of these papers are outlined at the beginning of this thesis (see Co-authored works section). All co-authors have approved the inclusion of the joint work in this doctoral thesis.

Greig Logan

November 2015

Co-authored works

Chapter	Publication reference	Contribution
Chapter 3	Logan GRM, Duncan S, Harris N, Hinckson EA, Schofield G. (2016). Adolescent physical activity levels: Discrepancies with accelerometer data analysis. *Journal of Sports Science.* (published ahead of print)	GL 80% SD 5% NH 5% EH 5% GS 5%
Contribution	GL - Data collection, extraction and analysis. Manuscript writing SD - Guidance on data analysis and review of manuscript NH, EH & GS - Advice on interpretation of findings and review of manuscript	
Chapter 4	Logan GRM, Harris N, Duncan S, Hinckson EA, Schofield G. (2016). Exploring the relationship between adolescent physical activity levels and anthropometric parameters. *Sport Sciences for Health.* 12(1): 121-124	GL 80% NH 7.5% SD 7.5% EH 2.5% GS 2.5%
Contribution	GL - Data collection, extraction and analysis. Manuscript writing. NH - Advice on interpretation of results, structuring and review of manuscript SD - Advice on statistical modelling and review of manuscript EH & GS - Guidance on interpretation of findings and review of manuscript	
Chapter 5	Logan GRM, Harris N, Duncan S, Schofield G (2014) A review of adolescent high-intensity interval training. *Sports Medicine.* 44(8):1071–85.	GL 80% NH 10% SD 7.5% GS 2.5%
Contribution	GL - Search and review of literature, data extraction, analysis and manuscript writing NH - Guidance on data analysis, interpretation and review of manuscript SD & GS - Advice on interpretation of findings and review of manuscript	
Chapter 6	Logan GRM, Harris N, Duncan S, Schofield G. (2016). Low-active male adolescents: A dose-response to high-intensity interval training. *Medicine and Science in Sport and Exercise.* 48(3): 481-90.	GL 80% NH 10% SD 7.5% GS 2.5%
Contribution	GL - Data collection, extraction and analysis. Manuscript writing NH - Guidance on data analysis, interpretation and review of manuscript SD - Advice on statistical modelling and review of manuscript GS - Advice on interpretation of findings and review of manuscript	
Chapter 7	Logan, GRM, Harris N, Duncan S, Schofield G. (submitted). Modelling the effects of high-intensity interval training dose on physical self-perception in low-active male adolescents. *Journal of Sport Science and Medicine.*	GL 80% NH 10% SD 7.5% GS 2.5%
Contribution	GL - Data collection, extraction and analysis. Manuscript writing NH - Guidance on data analysis, interpretation and review of manuscript SD - Advice on statistical modelling and review of manuscript GS - Advice on interpretation of findings and review of manuscript	



Acknowledgements

I will never forget the day I left to embark upon my doctoral adventure. In the depths of a Scottish winter, the rain relentlessly fell from the granite sky; it was time to leave to a more welcoming climate. However, the fear of the unknown was visceral. Severing ties from the safety net of home, family, and friends, to fall headfirst into something and somewhere seemingly intangible was, without doubt, the most difficult challenge I have faced in this adventure. My first 'thank you' goes to my family who encouraged me to take this first step. Without your emotional and financial support I could never have stepped on the plane and stayed so far away. Skype has been a wonderful thing!

"Go confidently in the direction of your dreams. Live the life you've imagined."

The quotation by Thoreau gleamed from the leaving card my sister, Catriona, gave me. I'm not sure if it was the card or the first bottle of red wine on the flight, but I went ahead, somewhat confidently.

My next thank you should go to Julia McPhee who kindly met me at the arrivals of Auckland international airport. I think that without her I would be wandering around South Auckland looking for Mairangi Bay. Thanks Julia for looking after me!

Awaiting me in the car at the airport drop-off was my supervisor, Scott. Thanks you Scott, for getting me to New Zealand, enduring my endless barrage of questions, and mentoring me. I can only hope to reach your level of expertise in statistics, scientific graft, and calibre of writing.

Preparing for my initiation to the Human Potential Centre, I buttoned my shirt, tied the laces of my best shoes and prepared myself to make a good impression. My first encounter with the daunting leader of the HPC, Professor Schofield, was not what I had prepared for. "G'day" he shook my hand, "You must be ****ed from that bloody long flight." I wore jandles (flip-flops) to the HPC from that point forward. Thank you Grant for allowing me to dream big, broaden my horizons, challenge concepts, and ultimately complete the PhD that I really wanted to do.

Ethereal words of 'metabolic', 'HIIT', and 'insulin sensitivity' floated around the HPC during my first months, and it was only when Grant introduced me to Nigel that I was able to grasp hold of concepts that would form my PhD. On our first encounter I remember nodding fervently at shared interests, feeling consoled that I could follow his lead to produce a PhD in such an exciting area of research. The following meeting he punched me. During a boxing HIIT session I should add. I’m sure there have been many more times that you have wanted to hit me Nigel, possibly without the gloves, but without your enthusiasm, patience, attention to detail, and ever-present guidance, I truly couldn’t have achieved this PhD. I have been privileged to have you as my primary supervisor. I’ve enjoyed learning from you and learning with you, and I hope that our journey through science will continue in the future.

A great deal of gratitude goes out to the adolescents of New Zealand. The wonderful school students who participated in both the BEANZ and HIIT studies enriched my research with humour, inspiration, and hope. Without exception, all participants were kind, spirited and well mannered. Thank you all for giving me your time, making my research possible, and mostly for giving me faith in the future generations of your magnificent country.

Thank you to the HPC postgraduate students Tom Stewart, Erika Ikeda, Catherine Crofts, Kate Prendergast, Mo Chaudhury, Darren Coombes, Chloe Muir and Tom Gibbs, for your friendship and help along the way.

Most of all, this PhD is for Morven, who sacrificed everything to join me in New Zealand, supported me all through the journey, and put up with my PhD-induced mood fluctuation and irritations. Thank you for everything; I know how much you gave up so that I could follow this dream. I can’t wait for our next adventure, wherever life takes us…

Ethical approval

Ethical approval for Chapters 3 and 4 were granted by the Auckland University of Technology Ethics Committee (AUTEC). The AUTEC reference for these chapters was:

- 12/161. *Built environments and physical activity in New Zealand youth.* Approved on 31st July 2012 (**Appendix A**).

Ethical approval for Chapters 6 and 7 were granted by the Auckland University of Technology Ethics Committee (AUTEC). The AUTEC reference for these chapters was:

- 14/161. *The dose-response relationship of high-intensity interval training with the metabolic health of male adolescents.* Approved on 30th June 2014 (**Appendix B**).

List of abbreviations

Abbreviation	Definition
1RM	Maximal repetition
ANN	Artificial neural networks
ANOVA	Analysis of variance
AUTEC	Auckland University of Technology Ethics Committee
BEANZ	Built Environment and Physical Activity in New Zealand Adolescents
BMI	Body mass index
CRP	C-reactive protein
DBP	Diastolic blood pressure
DLW	Doubly labelled water
DXA	Dual-energy X-ray absorptiometry
EUROFIT	European physical fitness test battery
FMD	Flow-mediated dilation
GPS	Global positioning systems
HbA1c	Glycosylated haemoglobin
HDL	High-density lipoprotein cholesterol
HIIT	High-intensity interval training
HOMA	Homeostasis model assessment
HOMA-IR	Homeostasis model assessment - insulin resistance
HOMA%S	Homeostasis model assessment - percentage insulin sensitivity
HR	Heart rate
HR_{max}	Maximum heart rate
IL-6	Interleukin-6
IPAQ	International Physical Activity Questionnaire
IPAQ-S	International Physical Activity Questionnaire (short version)
LDL	Low-density lipoprotein cholesterol
METs	Metabolic equivalent of resting metabolic rate
MIIT	Moderate-intensity interval training
MSFT	Multi-stage fitness test
MVPA	Moderate-to-vigorous intensity physical activity
N.S.	Not statistically significant
NZREPs	New Zealand Registered Exercise Professionals
OGTT	Oral glucose tolerance test
PACES	Physical Activity Enjoyment Scale
PAI-1	Plasminogen activator inhibitor-1
PAQ-A	Physical Activity Questionnaire (adolescent version)
PSDQ-S	Physical Self-description Questionnaire (short version)
PE	Physical education

Abbreviation	Definition
RCF	Relative centrifugal force
RER	Respiratory exchange ratio
ROC	Receiver operating characteristic curves
RPE	Rate of perceived exertion
SBP	Systolic blood pressure
SPSS	Statistical Package for the Social Sciences
SSE	Steady-state aerobic exercise
TG/TAG	Triacylglyceride
VLDL	Very low-density lipoprotein cholesterol
VM	Vector magnitude
VO_{2max}/VO_{2peak}	Maximal/ peak oxygen consumption
WC	Waist circumference
WCHt	Waist circumference-to-height ratio
WHR	Waist-to-hip ratio

Chapter 1 - Introduction

1.1 Rationale

The formative life stage of adolescence is a key period for the development of healthy lifestyle behaviours, including physical activity, that continue into adulthood [1-3]. Maintenance of sufficient physical activity from adolescence into adulthood has been associated with a reduced risk of cardio-metabolic diseases; such as cardiovascular disease [4], type 2 diabetes [5], metabolic syndrome [6], and obesity [7]. However, on average the adolescent population exhibit a decline in physical activity levels of -7% each year from the end of childhood to early adulthood, resulting in an overall fall of around -65% [8]. Despite efforts to improve adolescent physical activity participation and adherence, as many as 80.3% of youth fail to achieve the recommended 60 minutes of moderate-to-vigorous intensity physical activity (MVPA) per day [9,10]. In view of this, alternative methods to increase youth exercise involvement must be explored.

For over a decade, research has focussed on MVPA as the activity range in which individuals should exercise to achieve health benefits. The health adaptations elicited from physical activity include: improved body composition and weight maintenance, insulin sensitivity, blood lipid profile and psychological well being; decreased body fat, and systemic inflammation. Public health guidelines recommend that youth should accumulate physical activity in exercise bouts of 10 minutes or more in the form of aerobic steady-state exercise (SSE) to achieve 60 minutes each day [10]. As a consequence of the attention research has paid to-, and the promotion of SSE, an one-sided population perception has developed, in that long-duration moderate intensity activity, and not vigorous intensity exercise, is the best strategy to improve and maintain health [11]. Undertaking activity of vigorous intensity undoubtedly elicits health adaptations which exceed the extent of moderate intensity activity [12]. Yet efforts to promote physical activity have concentrated on moderate intensity SSE, like walking and jogging, yet the nature of youth activity is spontaneous and intermittent bursts of high intensity activity [13]. Whilst physical activity guidelines are beginning to recognise the importance of vigorous intensity activity as an alternative to long-duration moderate intensity activity [14], there are no specific recommendations regarding the duration youth should perform high intensity activity.

Perceived ‘lack of time’ for exercise is the most commonly cited barrier to physical activity amongst inactive adolescents [15], and since moderate intensity SSE can be lengthy in nature, options for reducing the duration of exercise whilst delivering sufficient health benefits may lie in increasing the intensity of activity to vigorous levels without a need for concomitant increase in total volume [12,16,17]. Thus, the primary focus of this PhD was to investigate the relationship of vigorous intensity physical activity with the metabolic health of adolescents.

1.2 Research objectives

1.2.1 Overarching research question

This thesis was designed to address the following overarching research question:

What are the effects of vigorous intensity physical activity on the metabolic heath of adolescents?

The chapters of this PhD are constructed of studies designed to address specific research aims and objectives central to the overarching research question.

1.2.2 Aims

The overarching aim of this research was to conduct a cohesive investigation into the metabolic effects of vigorous intensity physical activity, using both an epidemiological level study, and a detailed exercise intervention on a sub-sample of adolescents. This thesis is constructed in two parts to reflect the flow of investigation into vigorous intensity physical activity and adolescent metabolic health.

Part 1: Firstly, the contribution of physical activity intensity to health was investigated on an epidemiological scale through utilisation of data collected from the Built Environment and Physical Activity in New Zealand Adolescents (BEANZ) study. The most accurate and feasible methods to measure activity intensity were explored, and subsequently employed to determine the relationships between activity intensities and adolescent health. Therefore, the aim of Part 1 was to investigate the measurement techniques to best quantify physical activity in adolescents, and to determine the contribution of activity intensity to adolescent health.

Part 2: The ensuing focus was then to explore a method to deliver vigorous intensity exercise in adolescents in the form of high-intensity interval training (HIIT), since vigorous intensity physical activity was identified as the intensity most important for adolescent health in Part 1. In doing so, metabolic health adaptations were investigated, as well as the psychological responses that may influence and determine exercise adherence. Therefore, the aim of Part 2 was to investigate the effect of HIIT on the metabolic health of low-active male adolescents, and explore the perceptual responses that may influence and determine exercise adherence.

Through investigating Parts 1 and 2 of this thesis, a cohesive investigation into the metabolic effects of vigorous intensity physical activity was performed, on both an epidemiological level and using detailed sub-sample of adolescents. The benefits of epidemiological research in the study of physical activity are that associations can be discovered, indicating potential avenues for intervention to improve population health; however, causality cannot be determined. To develop the findings from Part 1, utilisation of a sub-population of low-active adolescent males allowed for determination of the cause-and-effect related to vigorous intensity exercise with several detailed cardio-metabolic health risk factors and perceptual outcomes.

1.2.3 Specific objectives

The specific objectives of this research were to:

1. Review and critique the methods used to measure physical activity in adolescents, highlighting issues and technological advances (**Chapter 2**).

2. Investigate the effect of different epoch lengths (1, 5, 15, 30 and 60 s), axis selection, and cut points on derived levels of adolescent physical activity intensity using accelerometry (**Chapter 3**).

3. Investigate the contribution of objectively-measured light, moderate and vigorous physical activity to health indices in adolescents (**Chapter 4**).

4. Summarise the central characteristics of HIIT intervention trials involving adolescents, focussing on HIIT’s impact on metabolic health (**Chapter 5**).

5. Investigate the efficacy of incremental doses of HIIT on inactive adolescents’ health related outcomes after an 8-week school-based exercise intervention (**Chapter 6**).

6. Explore the effects of eight weeks of an in-school, combined HIIT and resistance training intervention on the physical self-perception of low-active male adolescents (**Chapter 7**).

7. To summarise, discuss and conclude the findings of the research conducted, and present suggestions for future research directions (**Chapter 8**).

1.3 Thesis overview

1.3.1 Thesis organisation

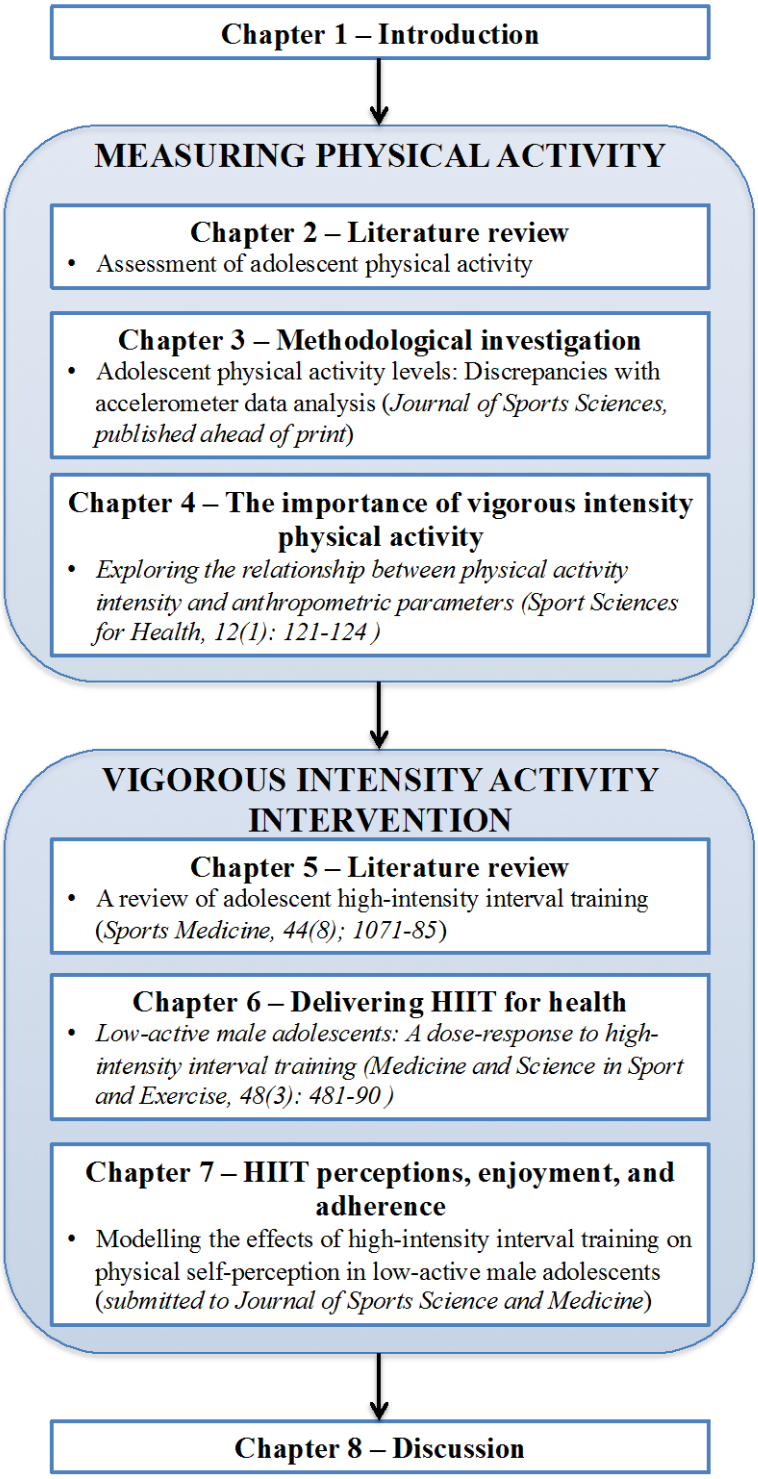


Figure 1: Thesis structure

This thesis is presented as a sequential progression of studies arranged in a series of chapters. Chapters 2-4 are concerned with the measurement of physical activity, and the contribution of activity intensities towards adolescent health. Chapters 5-7 are concerned with HIIT as a method to deliver vigorous intensity physical activity in adolescents (the intensity deemed most important for health improvements in Chapter 4).

Chapters 3-7 have been prepared as separate chapters for publication in peer-reviewed journals; therefore, some repetition of information occurs. Whilst these chapters are close in content to their published journal articles, some deviation from their published form occurs in this thesis, although all data and outcomes are identical. Prefaces for each chapter serve to link and outline the progression of studies as a cohesive whole. The purpose of Chapter 8 (final chapter) is to assemble the findings and study outcomes that emerged from this research and the overarching research question; discuss their contribution to the advance in knowledge in the field of physical activity and health; and consider the implications of this research for health promotion, inactivity and chronic non-communicable disease prevention.

References are standardised throughout this thesis to the Vancouver format, which may differ from referencing styles used in the respective journals where articles have been published, or are under review.

1.3.2 Thesis methodology

Chapters 3 and 4 of this thesis analyse data from the overarching BEANZ cross-sectional study, which investigates objectively measured physical activity, the built environment, and the health of New Zealand adolescents. An overview of the study methodology of the BEANZ research project is outlined in the report by Hinckson et al. [18]. In brief, six secondary schools in Auckland and two in Wellington, New Zealand, participated in the BEANZ study between February 2013 and September 2014. Adolescents (aged 12-18 years) were eligible to participate if they resided in either a high or low walkability neighbourhood, calculated from environmental variables surrounding their residential addresses using Geographic Information Systems (GIS). A total of 694 adolescents consented to participate in this research. After data reduction, 632 subjects were eligible for analysis.

Chapters 6 and 7 of this thesis involve the analysis of an exercise intervention study on a sub-sample of low-active male adolescents. For this study, a novel design was adopted (previously utilised by Stepto et al. [19] and Barnes et al. [20] in order to investigate the dose-response relationship of HIIT with cardio-metabolic risk factors, and also psychological outcomes that influence exercise adherence. This study involved three recruitment and three 8-week intervention phases from two secondary schools in Auckland, New Zealand, and was conducted between July 2014 and June 2015. Individuals were eligible to participate provided they were males aged 12-18 years, did not take PE, were not involved in extracurricular structured-sport and were identified as disengaged with physical activity by school teaching staff. Students were unable to participate if they had any diagnosed metabolic, hormonal, orthopaedic or cardiovascular condition. A flow diagram of participant recruitment and exercise compliance for this exercise intervention study can be seen in Figure 10.

1.3.3 Candidate contribution

This thesis fulfils the terms of an Auckland University of Technology Doctoral Degree through a significant, original contribution to knowledge regarding the physical activity of adolescents through critical appraisal of the existing literature and the completion of empirical studies.

The development of the research questions were solely undertaken by the candidate. In the first instance, these research questions were formed in response to disconnect between personal observations of the population of interest and evidence in the literature. Further development of the research followed two reviews of the literature, which identified significant knowledge gaps that continued to evolve in response to findings from collected data.

The candidate was involved in data collection and analysis for the BEANZ study, as part of a research team within the Human Potential Centre, which enabled travel to six schools in Auckland, and two schools in Wellington over a two-year period. The participation in data collection was an essential element in the formation of this PhD's research, and allowed the candidate to develop both research measurement techniques and interpersonal skills. This was important for connecting with the adolescent population, and developing ideas that would form the physical activity intervention element of this thesis. Analysis of data for this thesis was initiated, planned, and undertaken independently from the wider BEANZ study. Through the process of independent work, the ensuing chapters demonstrate well-developed skills of research, critical analysis, and application. Involvement in a large-scale study enabled the utilisation of a large sample size, and the use of accelerometers, allowing for a thesis of superior quality than could have been achieved under normal doctoral resources.

In addition to the BEANZ study data, the candidate was involved in planning, developing, and undertaking a research project performed using a sub-sample of adolescents for an exercise intervention study. This proved to be the most challenging, hands-on, and rewarding research conducted as part of this PhD. Working independently, the candidate performed an exercise intervention for three 8-week periods over the course of a year. Sourcing detailed cardio-metabolic health measures on a doctoral budget, communicating with school staff, recruiting adolescents known to be non-participants in structured sport, and organising logistics proved to be some of the many challenges that were confronted and successfully overcome. The data from the exercise intervention section of this PhD's research utilised a novel statistical approach and study design, and were analysed independently by the candidate. The resultant research has produced two robust, technical studies that form the main portion of this thesis.

Through the process of independent work, the ensuing chapters demonstrate developed application of research skills and critical analysis. In addition, on-going dissemination of research findings to the international academic community has been conducted in the form of peer-reviewed presentations and journal articles.

1.4 Research publications and conference presentations

The research studies from this doctoral thesis (Chapters 3-7) have resulted in conference presentations and are either in journal publications, or are articles that have been submitted for publication and are currently under peer review (Table 1).

Table 1: Research publications and conference presentations originating from Chapters 3-7 of this PhD thesis

Chapter	Conference publication or presentation
Chapter 3	Logan GRM, Duncan S, Harris N, Hinckson EA, Schofield G. (2016). Adolescent physical activity levels: Discrepancies with accelerometer data analysis. *Journal of Sports Sciences.* Published ahead of print. *(Impact factor: 2.246).*
Chapter 4	Logan GRM, Harris N, Duncan S, Hinckson EA, Schofield G. (2016). Exploring the relationship between adolescent physical activity levels and anthropometric parameters. *Sport Sciences for Health.* 12(1): 121-124 *(Impact factor: 0.201)*
Chapter 5	Logan GRM, Harris N, Duncan S, Schofield G (2014) A review of adolescent high-intensity interval training. *Sports Medicine.* 44(8):1071–85. *(Impact factor: 5.308)*
Chapter 6	Logan GRM, Harris N, Duncan S, Schofield G. (2016). Low-active male adolescents: A dose-response to high-intensity interval training. *Medicine and Science in Sport and Exercise.* 48(3):481-90. *(Impact factor: 3.983).*
	Logan GRM, Harris N, Duncan S, Schofield G. (2015). Low-active male adolescents: A dose-response to high-intensity interval training. Presented at the 2015 New Zealand Sports Medicine Conference, Christchurch, New Zealand (presented by N Harris).
Chapter 7	Logan, GRM, Harris N, Duncan S, Schofield G. (Under review). Modelling the effects of high-intensity interval training dose on physical self-perception in low-active male adolescents. *Journal of Sport Sciences and Medicine. (Impact factor: 2.185).*

Chapter 2 - Assessment of adolescent physical activity

2.1 Preface

Physical activity levels decline throughout adolescence, exposing individuals to an increased risk of chronic cardio-metabolic diseases in later life. Emerging research is beginning to understand the contribution of higher intensities of physical activity to the health of adolescents; however, identifying the most appropriate method of physical activity measurement is essential to accurately associate physical activity intensity, frequency, and duration with meaningful health outcomes. As such, the purpose of this review was to highlight and discuss measurement issues and technological advances pertinent to the assessment of adolescent physical activity.

2.2 Abstract

Background: Selecting the most appropriate methods to measure the free-living physical activity of adolescents is crucial to understand its contribution to, and develop strategies for, health improvement. Challenges in physical activity measurement are heightened in adolescence due to the psychological, physiological, and biomechanical changes that occur during development.

Methods: This short review summarises the issues surrounding current methods used to measure physical activity in adolescents.

Results: Popular subjective assessment methods include self-report questionnaires, and frequently used objective methods use movement-sensing devices such as accelerometers. Measurement limitations include: overestimation of subjectively measured activity providing optimistic population physical activity levels; unstandardized objective data processing methods which lead to incomparability of data between studies; and uncertainty in the estimation of energy expenditure due to individual variability. Combining assessment techniques is a potential route to improve reliability of measurements; however practicality, cost and resource availability often dictate the use of measurement methods.

Conclusions: Awareness of the limitations of each method's activity quantification is essential for the interpretation of physical activity data, and researchers are encouraged to consider the reliability and accuracy when using each instrument in the adolescent population.

2.3 Introduction

Determining the true habitual physical activity of youth is essential for understanding its contribution to physiological and psychological health, and for developing strategies towards their improvement [21,22]. Precise, yet practical physical activity quantification is required to accurately determine frequency, distribution and trends in adolescent physical activity [23]; observe the effects of interventions and policies to improve physical activity [24]; ascertain dose-response relationships with specific health outcomes [25]; and to identify biological, psychosocial, and environmental factors which influence adolescent physical activity [26,27]. Through accurately understanding adolescent physical activity, researchers and practitioners may become better informed to intervene in order to improve lifelong activity levels and health [1].

Whilst the nature of adult physical activity is generally planned, structured and ranging in intensity, youth activity is characterised by spontaneous, intermittent bursts of activity with 96% of activity bouts less than 10 seconds [28,29]. This has implications for all aspects of measurement, processing, and interpretation of physical activity data in adolescents, making it a potentially more difficult paradigm to accurately quantify than adult activity [27]. In spite of the technological advances recently made with physical activity assessment, adolescent physical activity assessment remains challenging; measurement limitations are often amplified in adolescence due to biomechanical, physiological, and cognitive changes that occur during puberty, growth, and development.

The dimensions of physical activity measurement consist of: **1)** intensity, often expressed as the metabolic equivalent of resting metabolic rate (METs; light = 1.8-2.9, moderate = 3.0-5.9, vigorous $\geq$6.0); **2)** frequency (number of sessions, bouts or days); and **3)** duration (units of time). Additionally, the mode by which the activity is performed (for example, walking, cycling, or running) and the context or locations in which the activity is undertaken (e.g. leisure, physical education, or transport) are important elements of physical activity. Practicality, resource availability, and cost are the main factors that dictate the form of activity measurement(s); however, identifying the most appropriate tool to capture the dimension of physical activity that the research question poses is of key importance.

Physical activity assessment methods can be categorised into either subjective or objective measures. Subjective activity measures factor in the element of human perception, whereas objective measures aim to provide non-biased physical activity data. These techniques are optimised to measure specific aspects of activity, such as energy expenditure, activity recall, or step count, and can be combined to provide a more complete picture of individuals' activity if necessary. In this review, measurement issues and technological advances pertinent to the assessment of adolescent physical activity will be discussed.

2.4 Subjective measurement

Subjective measures include questionnaires, diaries, interviews, and log books and are typically used with large population samples due to the ease of data collection and the low-cost of materials. Assessment using subjective techniques often rely on participant memory recall, and individuals' perception of time-based activities and with their characteristic activity intensities, which inherently introduce a margin of error; however, benefits of using them include the ability to contextualise activity and categorise exercise modality.

2.4.1 Self-report questionnaires

Studies will often use the standardised questionnaires like the International Physical Activity Questionnaire (IPAQ), which was developed in 1998 to measure population levels of physical activity across countries. Craig *et al.* [30] assessed the validity and reliability of the IPAQ between 12 developed and developing countries and concluded that it exhibited measurement properties that were at least as good as other subjective measures of physical activity. They also recommended that the IPAQ-S (short version) should be used for population level measurement and that the long version of the questionnaire be used in specific sample groups. The IPAQ has been applied globally, with modifications being made for country-specific physical activity behaviour measurement. The PAQ-A has been adapted from the IPAQ to quantify adolescent-specific physical activity behaviours. Such age group distinctions are important to improve the accuracy of quantifying physical activity behaviour through self-reported methods; however, Hagströmer et al. [31] recently assessed the validity of the IPAQ-A in European adolescents and found that the questionnaire was valid for assessing adolescents aged 15-17 years of age, but not those of 14 years or younger. Explanations for such findings may lie in the ability for youth under 14 years of age to accurately recall activity behaviours, or it is likely that such questionnaires ask youth to recall activities lasting several minutes, which is not sensitive to the spontaneous, intermittent nature of physical activity in younger adolescents [25,29].

A major limitation of self-report questionnaires is that they give a biased indication of physical activity levels, actually measuring individuals' perceptions of physical activity, and not physical activity itself. Introducing human emotion, whether through fear of being judged, guilt of inactivity, or simply forgetting daily activity, physical activity duration and intensity is consistently overestimated, thus large health surveys often give optimistic statistics of population-level physical activity. Prince *et al.* [32] systematically reviewed 187 studies comparing self-report and direct measurements of physical activity. They discovered that 60% of all studies showed higher self-reported physical activity estimates when compared to objective measures, and greater differences between measures were seen for vigorous than for light or moderate levels of physical activity. When comparing the objective measure of accelerometry with self-reported physical activity, a 44% higher mean percentage difference was seen in male study groups, whereas females self reported higher levels of physical activity by 138%. Thus, these data highlight the difficulties in accurately assessing population level physical activity through questionnaires alone; however, although questionnaires do not reflect true levels of physical activity, an indication of population physical activity is achieved through their use. Using questionnaires and self-report diaries in addition to objective measures can reveal the modality of physical activity, which may be unseen by objective measures alone. They can provide useful information that can be used to verify objective physical activity data, and are also helpful tools in research in indicating when individuals have removed measuring devices, like accelerometers, and when they are simply sedentary or inactive.

2.4.2 Direct observation

Direct observation is also used to subjectively quantify physical activity. This is an uncommon method for adolescent physical activity measurement due to the obtrusive nature of researchers either filming individuals' behaviour, or watching their movement, and so, is more frequently used in child physical activity quantification. The subjective nature of measurement is placed on the researcher to identify times participants have spent in activity intensities, and unreliability issues may arise through differences in measurement between researchers [33]. Also, the effect of researcher presence may modify youth activity behaviour and therefore show an unrepresentative level of individuals' physical activity. For the researcher, observational methods are labour and time intensive, and so are best used to validate other measurement methods such as accelerometers and pedometers [23].

2.5 Objective measurement

Objective methods used to determine physical activity involve the measurement of biomechanical or physiological parameters, often used to estimate an individual's energy expenditure as a proxy to physical activity levels.

2.5.1 Doubly labelled water

The gold-standard technique for measuring energy expenditure is doubly labelled water, (DLW) an assay that is often performed to validate other measurements of physical activity, such as questionnaires [34]. Doubly labelled water uses an isotope of water, which is ingested by the participant and exits the body as a metabolite of daily energy expenditure; the metabolised product is measured in urine, faeces and exhaled carbon dioxide to determine an individual's total energy expenditure. A drawback when considering physical activity assessment and associations with health is that it does not give an indication of the intensity of activity at a given time, only a total of energy expenditure over the time DLW is in the body. Also, a more concerning limitation is that the use of such a technique is impractical for physical activity assessment in large populations due to the great expense and labour intensity of measurement.

2.5.2 Pedometers

A common technique used in the objective quantification of physical activity is pedometery. The small, inexpensive electronic device is worn on the hip and measures step-counts, or footfalls, through motion detection. The most widely used pedometers in large-scale surveillance studies are Yamax (Yamax, Tokyo, Japan) pedometers, however the New Lifestyles NL-2000 pedometer (New Lifestyles, Inc, Lees Summit, MO, USA) is also a popular choice because it has a 7-day memory capacity. Advanced devices are able to estimate energy expenditure through averaging the calories expended through steps per minute. Pedometers have been used successfully in physical activity intervention studies, as the devices give individuals feedback on the number of steps they have achieved [35,36]. Although Tudor-Locke et al. [37] have provided evidence for a sedentary lifestyle index for adults as <5000 steps per day, and have identified a threshold of 10,000 step per day for individuals to aim for in order to achieve the health benefits of physical activity, researchers have failed to identify an equivalent value for adolescents.

Since the devices only measure steps, a major drawback is that they cannot distinguish between physical activity intensities, or exercise modality, thus the outcome is a value of total ambulatory steps. Also, those who have unusual gaits or lower-limb disabilities may not register step counts as accurately as healthy and able-bodied individuals, which may impact data reliability. A concern for the use of pedometers in adolescence is that due to fast physical growth during puberty, changes in gait and stride length can affect the estimation of distance covered using pedometers, and as a result influence the sensitivity of pedometery in this age group [27]. Another limitation is that pedometers can only sense movement in the lower-body, and do not take into account upper-body activity such as resistance training. Whilst pedometers have their place as a method to increase free-living individuals' physical activity, they are less commonly used as a way of quantifying youth physical activity in research.

2.5.3 Accelerometers

Accelerometry is the most commonly used objective measure of physical activity assessment in youth, and has had the greatest rise in popularity relative to other objective measurement [27]. Accelerometry has provided new insight and detail into the intensity and daily patterns of adolescent physical activity that pedometers have failed to show. Unlike many pedometers, accelerometers are of 'black box' design, preventing individuals from gaining feedback about their daily physical activity, which limits physical activity behaviour modification and provides a more representative measure of activity. Accelerometers are small motion sensor devices worn on the hip or arm, which measure the intensity of accelerations through piezoelectric movement sensors on up to three separate axes (uni-axial, bi-axial and tri-axial); these accelerations are used as proxies to the energy expenditure of body movement at a given time, and thus frequency, duration, and intensity of physical activity intensities can be calculated.

The most commonly used device in research has been the MTI ActiGraph (MTI, Florida), which also has the greatest body of high-quality evidence supporting its use [38]. The ActiGraph models have evolved since their release in the 1980s; the first released model was the AM7164, which was then replaced in the mid 2000s by the GT1M. With further advances in accelerometer technology, recent models include the GT3X+ which is smaller and lighter than previous models; additionally it is water resistant and able to store large amounts of data, making it the physical activity research accelerometer monitor of choice for many modern studies [39]. Other brands or models, such as the tri-axial Tritrac, Actical and the RT3, have also been shown to be effective. Rowlands *et al.* [40] investigated the validity and reliability between the Tritrac and RT3 aforementioned tri-axial devices. Participants were put through a standardised protocol of treadmill walking and running, hopscotch, kicking a ball, and sitting quietly. Output from the newer RT3 device was consistently higher than that of the Tritrac, highlighting that physical activity data from studies using different accelerometer brands cannot be validly compared. Since the majority of physical activity research uses ActiGraph models, literature is becoming more comparable; however, many differences between study physical activity outcomes also lie in the processing of raw accelerometry data [41]. The process of physical activity measurement using accelerometers is illustrated in Figure 2.

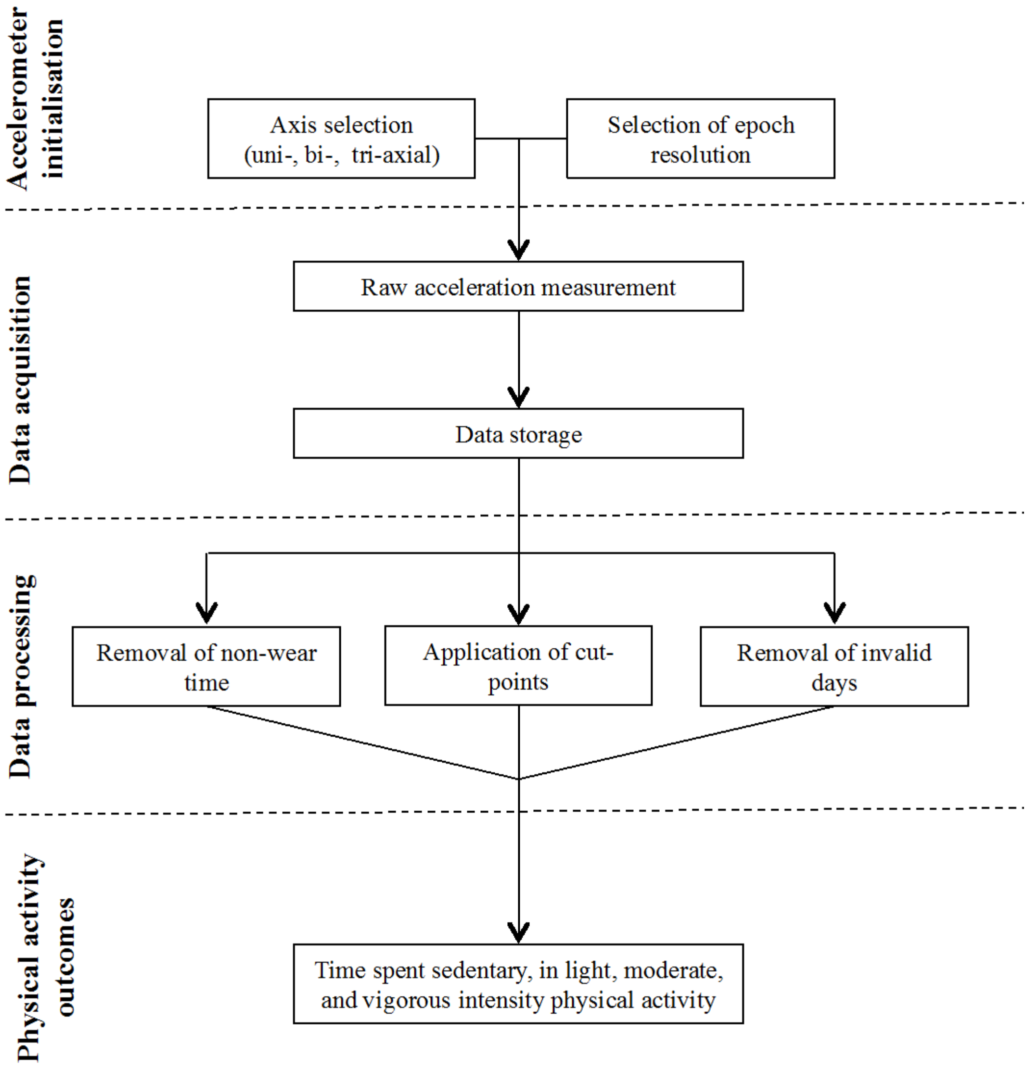


Figure 2: The main stages of accelerometer data collection. Accelerometer initialisation and data processing stages can influence physical activity outcomes.

Accelerations are measured at different sampling intervals, or epochs, traditionally 60 seconds long; however, modern devices are able to store epochs up to 1 second in length. Using shorter, high-sensitivity epochs are valuable for registering and accurately measuring brief bouts of activity and accurately classifying their intensity, whereas using longer epoch lengths will average accelerations within the epoch, potentially diluting the intensity of movement during the sampling time. For example, Edwardson and Gorley [42] observed the differences in child and adolescent physical activity levels across epoch lengths ranging from 5 to 60 seconds, reintegrated from the same data set, and concluded that data from studies using 5-, 15-, 30-, and 60-second epochs can not be compared due to the significant effect of epoch length on sedentary time, light, and vigorous physical activity levels. This is a concern when associating physical activity data with health outcomes in youth, as false associations may be seen if the epoch length does not reflect the true activity of the individual, therefore it is advised that researchers use the shortest epoch length possible.

Once data have been collected, raw data are processed. First, data are cleaned through the identification and removal of non-wear time. Removing data considered to be confounding because the subject has removed the device can introduce bias. That is, if the acceleration counts are zero for long periods, the researcher must decide whether this is because they are sedentary and therefore not producing accelerations, or have simply taken the accelerometer off. Traditionally, studies have excluded data as non-wear time if there are uninterrupted strings of zeros for greater than 10 minutes; however, recent studies [43] have used up to 180 minutes of zero counts per minute as a cut off for non-wear time [44,45].

Another important factor to consider when using accelerometry in physical activity research is the data inclusion criteria of the accelerometer. In general, previous studies have used a period of 6 to 12 hours per day to define a valid day of accelerometer wear-time, however, a recent literature review by Cain et al. [46] observed that there was a lack of agreement between researchers on protocols used to collect, process and score data for children and adolescents. Also, no consensus has been reached on the number of days of accelerometer monitoring required to reflect an accurate representation of adolescent physical activity; Trost et al. [47] recommend 4 or 5 days as an adequate number of days, whereas Reilly et al. [48] state that a wider 3-7 days are desired.

The application of cut-points to raw acceleration data is perhaps the most influential step to gaining meaningful physical activity outcomes. Age-specific cut-points have been developed due to differences in activity patterns between age groups. Children generally have sporadic, short periods of high intensity physical activity [29], whereas adults tend to participate in more structured light-to-moderate activity. Adolescent behaviour, however, is thought to lie somewhere in-between these groups. There is no standardised cut-point classification for the adolescent cohort, and enormous variation exists in resultant physical activity outcomes when different cut-points are applied [49]; this complication is often referred to as the ‘cut-point conundrum’ [48].

Cut-point calibration studies aim to identify accurate intensity cut-points by relating raw accelerometry data to energy expenditure during specific tasks. Many calibration studies have used treadmill protocols to develop cut-points; however, this exercise modality does not represent the habitual behaviour of free-living individuals, therefore investigating accelerations during a range of activities at different intensities is more appropriate in defining cut-points. Trost et al. [50] independently compared the output of five adolescent specific ActiGraph cut-points, and concluded that Evenson et al. [51] cut-points were the most reflective of their subjects' activity protocol. Such research comparing cut-point calibration studies is important for informing researchers as to which cut-points to use, perhaps moving towards a standardised classification. As technology advances and new accelerometer models are released, cut-point research must evolve alongside in order to accurately assess physical activity.

Whilst accelerometers provide a good overall picture of physical activity, they have limitations. Unless the device is worn on the arm, physical activity measurement is limited to lower-limb body movement and cannot account for the energy expenditure of upper-body movement. For example, devices cannot measure the relative intensities of resistance-based activity, therefore data collected during a period of weight training or cycling are not representative of the energy expenditure used the time when accelerations are measured. The complications in data processing and data reduction can introduce subjectivity from the researcher and therefore an element of bias [43]. Research must acknowledge the challenges associated with accelerometer data processing and work towards a standard protocol [52].

2.5.4 Heart rate monitoring

Assessing individuals' heart rate is a relatively inexpensive and useful method to measure adolescent physical activity intensity, both in controlled and free-living environments method. Heart rate assessment is most commonly used during exercise interventions to accurately measure exercise intensity, or ensure individuals exercise at a set intensity during a range of aerobic activities. It can be used as proxy to physical activity under free-living conditions; however, physical activity is quantified by relating heart rate to energy expenditure and the relationship between the two is weak during light intensity activity, thus reducing measurement reliability. Since the relationship of heart rate and energy expenditure can differ between individuals, calibration can be conducted using expired gas collection during exercise under laboratory conditions to improve accuracy of physical activity measurement. It is possible to calculate an individual's activity intensity using thresholds applied to an estimation of maximum heart rate (typically calculated as 220 minus years of age), which provides a practical option to monitor activity intensity and estimated energy expenditure under real-world conditions. This approach however, is an estimation that does not account for individual variation in heart rate response. Research has identified a so-called ‘flex-point’ [53] in the relationship between heart rate and energy expenditure, below which assessment of activity intensity is problematic. This flex-point occurs during light intensity activity, where a degree of uncertainty in heart rate response is exposed due to the influence of stress, anxiety, or environmental temperature fluctuations; achieving activity intensities higher than at the flex-point are not as influenced by such variables and therefore monitoring is more reliable and a linear relationship between energy expenditure and heart rate occurs. Therefore, it is recommended that heart rate monitoring should only be used to record moderate and vigorous activity intensities [27].

2.5.5 Global Positioning Systems

Recently, Global Positioning Systems (GPS) units have been employed to assess physical activity by tracking individuals’ movement in their living environment [54,55]. Previously, GPS has been used in the sporting domain to offer accurate information about an athlete’s speed and positioning to improve performance; however, only recently has the technology been used to quantify physical activity in free-living conditions. Modern GPS units are small, light, non-invasive, and calculate velocity of movements through relaying positional coordinates with satellites [54]. The ability to relate individuals’ movement to their surroundings is of key interest to those studying the effects of location and physical activity, as contextualisation of activity can provide insight into how youth interact with their environment.

Using modern geospatial modelling, physical activity energy expenditure can be estimated and computer mapping can distinguish movement modality (e.g. walking from motorised transport) [55]; however, the most promising avenue for application of GPS is to integrate data with accelerometer measurement. This provides a better insight into both intensity of activity (accelerometry) paired with contextualised data (from GPS) [56]. Another possibility to gain more accurate information of activity intensity is to combine GPS with heart rate monitoring. A New Zealand study showed that GPS could discriminate the velocity of children’s movement during play, whilst heart rate data were used to quantify the energy expenditure associated with movement [57].

The use of GPS technology in research is in its infancy; however, it has already been used to successfully measure physical activity. The handling of GPS data is relatively hands-on, and coupling GPS data with other measurement devices adds a layer of complexity that may only appeal to specialist researchers. As yet, there is no standardised method for data collection in specific age groups; as with accelerometry, a consensus must be agreed for the minimum requirements for data recording, in addition to a standardised approach to manage and interpret data. Unfortunately GPS technology is largely limited to outdoor use and cannot be used indoors due to signal loss. Also, restricted recording rate limit the ability to accurately capture sporadic adolescent movement. These barriers have perhaps reduced researcher utilisation of the GPS technology; however, GPS has the potential to become a popular method to measure physical activity in adolescents.

Table 2: Summary characteristics of assessment methods for physical activity in adolescents

	Subjective measurement			Objective measurement				
	Self-report questionnaire	Diary/Log book	Direct observation	Doubly labelled water	Heart rate monitoring	Pedometery	Accelerometry	GPS
Data output	Perceived physical activity duration (mins per day)	Duration, modality, and context of physical activity	Physical activity duration (mins per day)	Energy expenditure (kJ)	Beats per minute (BPM)	Step count (steps per day)	Acceleration counts, converted into duration spent in different activity intensities (mean mins per day)	Geo-locational data
Device/material cost	Low	Low	High	Very high	Moderate	Moderate	High	High
Practical considerations	Easy to distribute and useful for large population studies and surveys. Can be conducted online	Useful for indicating activity modality and can provide useful information for verifying objective measurement wear time	Highly labour intensive measurement, which can be difficult to gain ethical approval. Useful for validation of other activity measurement methods	Highly labour intensive measurement. Not practical for large study samples. Useful for validation of other activity measurement methods	Useful for assessing exercise intensity in intervention studies. Not advised for measuring intensity less than MVPA	Easy to distribute devices and interpret data. Useful to measure walking	Ability to capture frequency, duration and intensity of activity and can be used in large population studies	Provides valuable data on human movement and interaction with their environment. Useful when paired with devices measuring intensity of activity
Limitations	Captures perceptions of activity, often overestimating true activity levels	Outcomes can be qualitative data, and best used in addition with other measurements	Time-consuming quantification of activity that is dependent on researcher perceptions of intensity	Unable to quantify intensity, frequency, or duration of activity	Unable to accurately measure activity of light intensity. Influenced by emotion, ambient temperature, and fitness	Unable record intensity or modality of exercise	No standardised method of data interpretation. Unable to capture intensity of resistance exercise	No standardised method of data interpretation. Unable to measure intensity of small movements. Complex interpretation of data

GPS, global positioning system; MVPA, moderate-to-vigorous physical activity

2.6 Summary

The available methods to quantify physical activity in free-living adolescents is summarised in Table 2. The assessment of physical activity in youth provides several challenges for investigators. To date, there is no single method that can accurately capture frequency, duration, intensity, location, and modality of physical activity; however, a combination of methods may be applied.

The most commonly used methods for physical activity assessment in adolescent epidemiological studies are subjective self-report questionnaires and objective movement sensing devices. Accelerometers are currently the most complete single method for activity assessment, providing detailed information on frequency, duration, and intensity of adolescent activity; however, the unstandardized processing of raw objective accelerometer data are a concern, as there are several steps during researcher data processing which may influence youth physical activity levels, namely: choice of epoch length, axis selection, cut-point selection, removal of non-wear time, and inclusion of valid days. It is important for researchers to work towards a consistent method for raw accelerometer data interpretation; however, with the arrival of new devices, model updates, and advances in technology, standardisation of measurement may prove challenging.

The variety in levels of physical activity generated using different physical activity methods may generate unreliable associations with health outcomes in adolescents and limit comparisons between studies. Awareness of the limitations of each method's activity quantification is essential for the interpretation of physical activity data, and researchers are encouraged to consider the reliability and accuracy when using each instrument in the adolescent population. Ultimately, selection of the most appropriate method to assess physical activity largely depends on the intended research outcomes, and resource availability.

Chapter 3 - Adolescent physical activity levels: Discrepancies with accelerometer data analysis

3.1 Preface

Having identified accelerometry as the most appropriate method to objectively quantify physical activity intensity in free-living adolescents, Chapter 3 is an investigation into aspects of accelerometer data processing, which can influence the interpretation of accelerometer data. The three variables that are investigated are:

1. Epoch length
2. Axis selection (uni-axial, or tri-axial)
3. Cut point selection

Whilst these variables have been previously investigated independently, no study has simultaneously explored their effects on adolescent physical activity levels across the full spectrum of activity intensities. This was an important first-step in exploring the relationship of physical activity with adolescent health, since technological advances in accelerometry have now made it possible to measure and interpret physical activity intensity with potentially more precision. The findings from this study contribute to a better understanding of accelerometer-derived measurement of physical activity in adolescents. The manuscript resulting from this chapter is published in the peer-reviewed Journal of Sports Sciences.

3.2 Abstract

Purpose: This study investigated the effects of epoch length and cut point selection on adolescent physical activity intensity quantification using vertical axis and vector magnitude (VM) measurement with the ActiGraph GT3X+ accelerometer.

Methods: Four hundred and nine adolescents (211 males; 198 females) aged 12-16 years of age wore accelerometers during waking hours. The GT3X+ acceleration counts were reintegrated into 1, 5, 15, 30 and 60-second epoch lengths for both vertical axis and VM counts. One cut point was applied to vertical axis counts and three different cut points were applied to VM counts for each epoch length.

Results: Significant differences ($p < 0.01$) in mean total counts per day were observed between vertical axis and VM counts, and between epoch lengths for VM only. Differences in physical activity levels were observed between vertical and VM cut points, and between epoch lengths across all activity intensities.

Conclusions: Our findings illustrate the magnitude of differences in physical activity outcomes that occur between axis measurement, cut points and epoch length. The magnitude of difference across epoch length must be considered in the interpretation of accelerometer data and seen as a confounding variable when comparing physical activity levels between studies.

3.3 Introduction

Adolescence is recognised as a key stage in the development of healthy lifestyle behaviours, including physical activity. Understanding adolescents' physical activity behaviours and their relationship with health outcomes is essential for efficiently implementing interventions to improve physical activity levels to produce health benefits which reduce the risk of developing non-communicable diseases [27,58]. The accelerometer has become the most popular tool for the objective quantification of physical activity [41,59]. The small and lightweight devices are most commonly attached to the hip to quantify accelerations of whole body movement in free-living subjects. The raw acceleration data are then cleaned and filtered to be used as a proxy to the energy expenditure associated with the intensities of physical activity undertaken. The meaningful output is the quantification of the duration, frequency and intensity of individuals' activity [60]. Whilst the raw accelerations give accurate, objective measurements of movement at a given time, the interpretation of these data towards classifying times spent in light, moderate and vigorous intensities of physical activity is not standardised. The researcher must therefore decide which data analysis criteria to use by applying 'cut points' to raw data, which introduces a degree of bias [49]. This fundamental component to the analysis of accelerometry data can limit the ability to compare results between studies [42], which is essential to epidemiological physical activity research.

Calibration of cut points relies on equations derived form energy expenditure measured by indirect calorimetry. To define cut points, set activities or tasks are given (sitting, jumping, running, etc.) to provide a range of energy expenditure responses [50]. These activities are most commonly performed under controlled laboratory settings. Age-specific metabolic equivalents (METs) of the activities are calculated and matched with raw accelerometer data to define the acceleration 'count' ranges which constitute sedentary behaviour (<1.5 METs), light activity (≥1.5 METs and <3 METs), moderate activity (≥3 METs and <6 METS), vigorous (≥6 METs) and moderate-to-vigorous physical activity (MVPA, ≥3 METs).

The brand of accelerometer with the greatest body of high-quality evidence supporting its use is the ActiGraph (ActiGraph™, Pensacola, FL) [38]. With advances in technology, ActiGraph models have evolved from early devices such as the 7164 model (1993) which has limited data storage and records accelerations on the vertical axis only, to the most recent GT3X+ (2010) which has greater capacity for data storage and can measure accelerations on three axes. Accelerometers sample accelerations at specified frequencies, or epochs. A new feature of the GT3X+ allows for the recording of raw acceleration data for retrospective processing into user-selected epoch lengths using ActiGraph proprietary software. Additionally, the counts measured by each of the three axes can be examined individually or together (vector magnitude) after raw data have been downloaded from the GT3X+. This is in contrast with earlier ActiGraph models, which required setting of epoch length, and axis measurement at the time of unit initialisation, i.e. prior to data collection [52]. For this reason and because of limited data storage, research conducted in adolescents has traditionally used longer epoch lengths of up to 60 seconds [59,61]; in contrast with present methods, which are able to quantify intensity of movement in shorter 1-15 second epochs on up to three axes, as a result of advanced accelerometer technology.

Youth activity is often described as spontaneous, intermittent and of high intensity [29,62], with the majority of bouts lasting between 3 and 22 seconds [63]. Studies are beginning to reveal the importance of accumulation of short bouts of vigorous-intensity physical activity on the health of youth [12,64]. During data analysis, epoch length is set and acceleration 'counts' are averaged over this time period. The epoch is then classified as 'sedentary', 'light', 'moderate' or 'vigorous' using intensity cut points applied to acceleration counts. Selecting longer epoch lengths can effectively dilute the intensity of accelerations and misclassify physical activity as lower-intensity movement.

Recent research has shown that measurement of movement over three axes is more sensitive for youth than adult and older adult populations [65]. Therefore, to accurately assess youth activity, tri-axial accelerometry must be investigated. The differences in epoch length on physical activity levels in adolescents is limited to one study [42] and no study has yet compared uni-axial cut points with new tri-axial cut points on the physical activity levels of adolescents. The present study utilises Evenson et al. cut points [51] currently recommended for use in adolescent accelerometer studies to best represent the vertical axis measurement of physical activity [50], and thus is used as a reference against the more recently developed vector magnitude cut point derived physical activity quantification.

The purpose of this study is to investigate the effect of different epoch lengths (1, 5, 15, 30 and 60 seconds) on derived levels of physical activity intensity using Evenson *et* *al.*'s uni-axial cut points [51] (applied to accelerations on the vertical axis) and three tri-axial cut points (applied to vector magnitude (VM) accelerations) [65-67].

3.4 Methods

3.4.1 Participants

Research was conducted in four secondary schools in Auckland, New Zealand between February and October 2013 as part of the Built Environment and Physical Activity in New Zealand Adolescents (BEANZ) study. Adolescents (aged 12-18 years) were eligible to participate if they resided in either a high or low walkability neighbourhood, calculated from environmental variables surrounding their residential addresses using Geographic Information Systems (GIS). Full methodology of the BEANZ study has been published elsewhere [18].

A total of 423 adolescents (mean age: 15.2 ± 1.7 years) consented to participate in this research. After data reduction, 14 youths were excluded and a total of 409 subjects' (211 males; 198 females) accelerometer data were eligible for analysis. Written informed assent was obtained from each participant and informed parental consent was gained for those under 16 years of age. Ethical approval was gained from Auckland University of Technology Ethics Committee.

3.4.2 Procedure

All participants were asked to wear an ActiGraph GT3X+ accelerometer for 8 d during waking hours. Each accelerometer was initialised with a start and end time. Each accelerometer was set to collect raw tri-axial acceleration signals at 30 Hz. Accelerometers were attached to an elasticated belt and positioned on the waist at the right hip. After 8 days, accelerometers were collected and uploaded for data processing and reduction using MeterPlus^{TM}, Version 4.3 (Santech Inc., San Diego, CA). A valid day was classified as ≥8 hours of monitoring per day [41,48,68]. Participants with less than 4 days of complete monitoring were excluded from the analysis [48]. Non-wear time was defined as ≥60 minutes of consecutive zeros [48]. Both the epoch length (1, 5, 15, 30 and 60 seconds) and output for either the vertical axis or VM were selected during data processing. To determine the time spent sedentary (<1.5 METs), in light (≥1.5 METs and <3 METs), moderate (≥3 METs and <6 METS), vigorous (≥6 METs) and moderate-to-vigorous physical activity (MVPA, ≥3 METs), four different age-specific cut-points, derived from the energy expenditure prediction equations, were applied to count ranges; Evenson et al. [51] was applied to the y-axis count ranges only and Santos-Lozano et al. [65], Romanzini et al. [66] and Hänggi et al. [67] were applied to VM count ranges. Count ranges for each cut-point were calculated to correspond to the outcome of 1, 5, 15, 30 and 60-second epochs. The count ranges used in this investigation are presented in Table 3. Evenson et al. cut points were chosen to best represent y-axis cut points for adolescents [50]. For the purpose of comparison between vigorous activity levels between using different cut points, the 'very vigorous' activity cut point (>9 METs) defined by Santos-Lozano et al. was not applied to data and was included in the vigorous activity output in this study.

Table 3: Cut point ranges for one-second epochs

Cut points	Sedentary behaviour (counts)	Light physical activity (counts)	Moderate physical activity (counts)	Vigorous physical activity (counts)
Evenson et al. [51]	≤2	>2 to ≤38	>38 to ≤67	>67
Romanzini et al. [66]	≤12	>12 to ≤50	>50 to ≤74	>74
Hanggi et al. [67]	≤3	>3 to ≤56	>56	-
Santos-Lozano et al. [65]	-	>2 to ≤35	>35 to ≤109	>109

3.4.3 Statistics

Analysis was conducted using the Statistical Package for the Social Sciences (SPSS) version 20.0 (IBM Corporation, Armonk, NY). Descriptive statistics were used to examine mean and standard deviation for sedentary time, and time spent in light, moderate, vigorous and moderate-to-vigorous physical activity for all epoch lengths. Data were examined for distribution; since assumptions were fulfilled for normal distribution, all further analysis was performed for normally distributed data. A general linear model with repeated-measures examined the differences in time spent in the different intensity levels for all cut-points and epoch lengths. A one-way repeated-measures ANOVA was also used to investigate the effect of uni-axial vs. tri-axial 'mean total counts per day' within and between axes measurements for 1, 5, 15, 30 and 60-second epoch lengths. Bonferonni corrections were used to adjust 95% confidence intervals (CI). Statistical significance was set at $p < 0.05$.

3.5 Results

A total of 423 adolescents' GT3X+ accelerometer data were analysed. Of these subjects, 13 (3.1%) were excluded due to insufficient valid days of data. The remaining 410 subjects' data were further analysed. The total mean counts per day were compared between vertical axis and VM acceleration output for 1, 5, 15, 30, and 60-second epoch lengths (Figure 3). On the vertical axis, no significant differences were observed with the total mean counts per day between epoch lengths, whereas for the VM total counts per day, significant differences were observed between all epoch lengths ($p < 0.01$). Furthermore, there were significant differences in total mean counts per day between the vertical axis and VM for all epoch lengths. There were 51.5%, 49.4%, 48.3%, 47.7% and 47.2% differences for total mean counts per day between VM and the vertical axis output for 1, 5, 15, 30, and 60 second epoch lengths respectively.

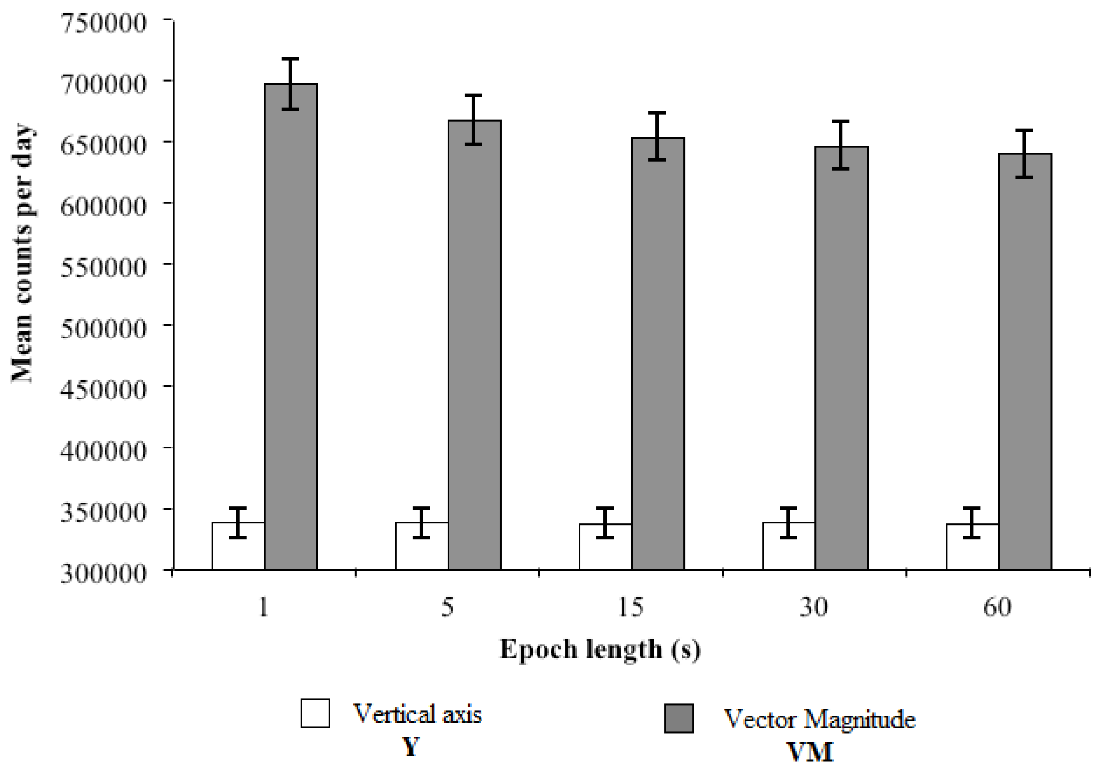


Figure 3: The mean total acceleration counts per day observed for the vertical axis and the vector magnitude using 1, 5, 15, 30 and 60 second epoch lengths (with 95% CI).

3.5.1 Sedentary behaviour

Significant differences ($p < 0.01$) in time spent sedentary (Figure 4) were observed between each activity output for all epoch lengths with the exception of 5 second epoch Evenson et al. with 1 second and 5 second epoch Romanzini et al. cut points ($p > 0.05$). Santos-Lozano sedentary behaviour cut points were not established in their study [65]. A decrease in sedentary time occurred as epoch length increased for all cut points. A 159 minute (23.6%), 56 minute (9.0%) and 180 minute (30.4%) decrease was observed between the 1 second and 60 second epoch for Evenson et al., Romanzini et al. and Hänggi et al. cut points respectively.

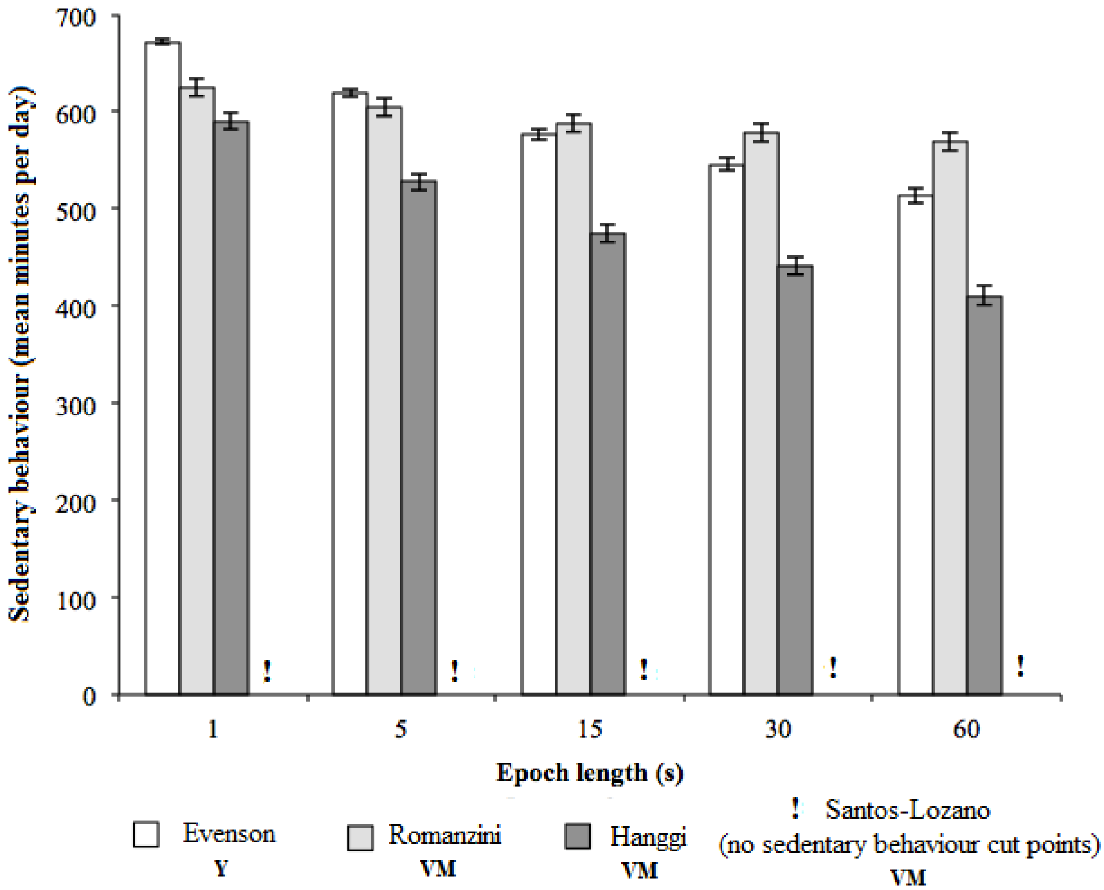


Figure 4: Mean minutes spent in sedentary time per day interpreted using one vertical axis cut point (Y) and three vector magnitude (VM) cut points at five different epoch settings (95% CI).

3.5.2 Light intensity physical activity

Mean minutes of light intensity physical activity per day (Figure 5) between cut points and epoch lengths were statistically significantly different ($p < 0.01$) with the exception of: 5 second epoch Evenson et al. with 1 second epoch Santos-Lozano et al. ($p < 0.05$); 30 second epoch Evenson et al. with 5 second epoch Santos-Lozano et al. ($p > 0.05$). Santos-Lozano light intensity physical activity cut points could not be established due to the absence of established sedentary behaviour cut points in their study [65]. An increase in time spent in light activity occurred as epoch length increased for all cut points. A 170 minute (69.8%), 89 minute (49.6%) and 211 minute (60.7%) increase was observed between the 1 second and 60 second epochs for Evenson et al., Romanzini et al. and Hänggi et al. cut points respectively.

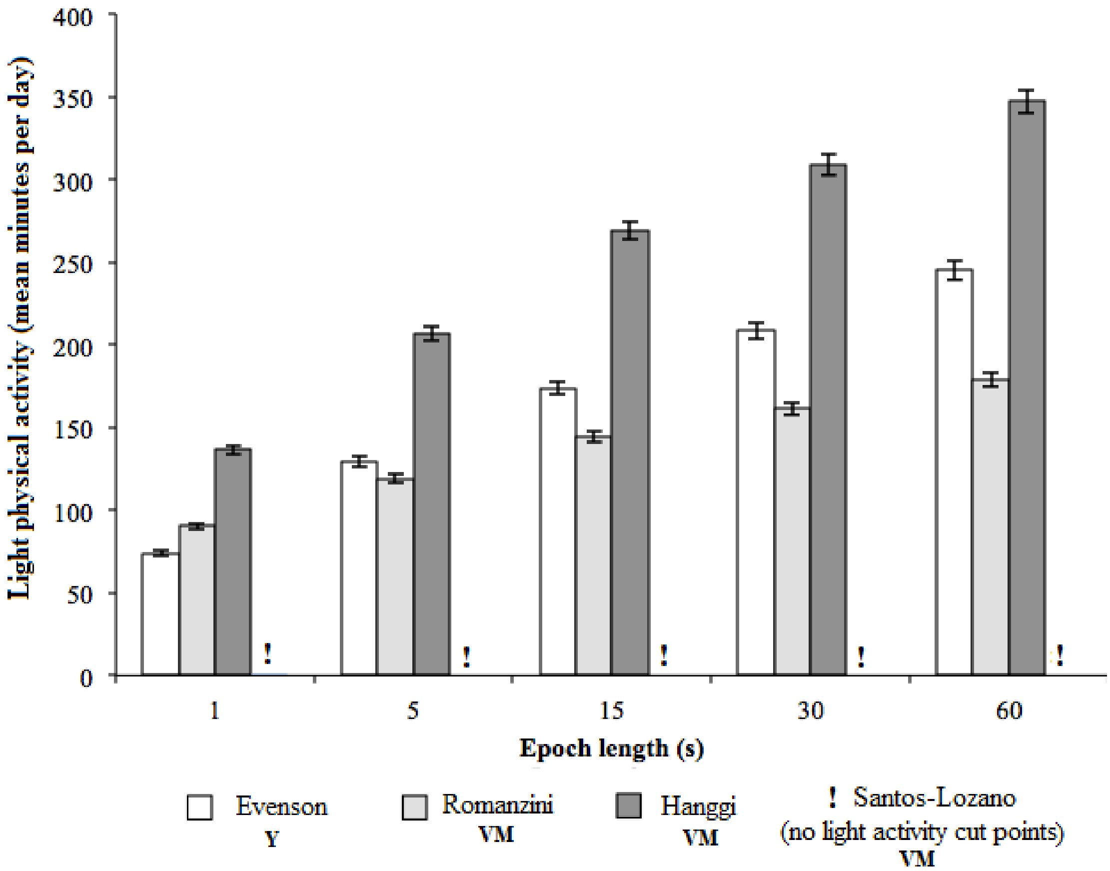


Figure 5: Mean minutes spent in light intensity physical activity per day interpreted using one vertical axis cut-point (Y) and three vector magnitude (VM) cut points at five different epoch settings (95% CI).

3.5.3 Moderate intensity physical activity

Using Evenson et al., Romanzini et al. and Santos-Lozano et al. cut points (Figure 6), significant differences ($p < 0.01$) were observed between times spent in moderate intensity physical activity within and between all epoch lengths with the exception of: 1 second epoch Evenson et al. with 5 second, 30 second and 60 second epoch Evenson et al. ($p > 0.05$); 5 second Evenson et al. with 15 second, 30 second and 60 second Evenson et al. ($p > 0.05$); 5 second epoch Evenson et al. with 60 second epoch Romanzini et al. ($p > 0.05$); 30 second epoch Evenson et al. with 60 second epoch Romanzini et al. ($p > 0.05$); 1 second epoch Santos-Lozano et al. with 5 second and 15 second epoch Santos-Lozano et al. ($p > 0.05$); 5 second epoch Santos-Lozano et al. with 15 second and 30 second epoch Santos-Lozano et al. ($p > 0.05$). Hänggi et al. moderate intensity physical activity cut points were not stratified from MVPA in their study [67]. Peak time in moderate activity was observed using 15 second epochs using Evenson et al. cut points (34 minutes), yet peaked with 5 second epochs using Santos-Lozano cut points (106 minutes). There was an overall decrease in moderate activity with increasing epoch length with Romanzini et al. cut points not seen using Evenson et al. and Santos-Lozano et al. cut points. A decrease of 7 minutes (17.3%) was observed between 1 second and 60 second epochs using Romanzini et al. cut points.

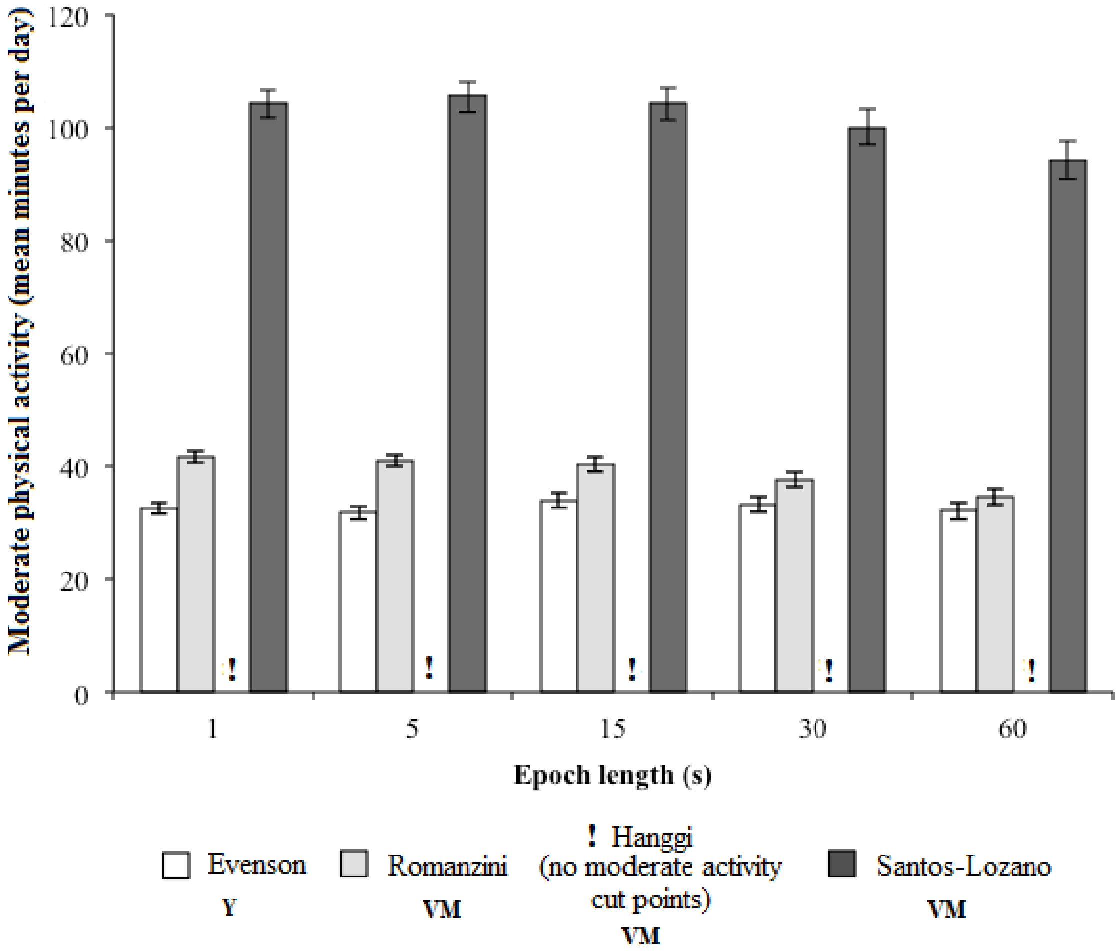


Figure 6: Mean minutes spent in moderate intensity physical activity per day interpreted using one vertical axis cut-point (Y) and three vector magnitude (VM) cut points at five different epoch settings (95% CI).

3.5.4 Vigorous intensity physical activity

Using Evenson et al., Romanzini et al. and Santos-Lozano et al. cut points (Figure 7), significant differences ($p < 0.01$) were observed between times spent in vigorous intensity physical activity within and between all epoch lengths with the exception of: 1 second epoch Evenson et al. with 5 second epoch Evenson et al. and 60 second epoch Romanzini et al. ($p > 0.05$); 5 second epoch Evenson et al. with 60 second epoch Romanzini et al. ($p < 0.05$) and 1 second epoch Santos-Lozano et al. ($p > 0.05$); 15 second epoch Evenson et al. with 1 second epoch Santos-Lozano et al. ($p > 0.05$); 60 second epoch Evenson et al. with 5 second epoch Santos-Lozano et al. ($p > 0.05$). Hänggi et al. vigorous intensity physical activity cut points were not stratified from MVPA in their study [67]. There was a decrease in time spent in vigorous physical activity with an increase in epoch length using each cut point. An 11 minute (57.2%), a 26 minute (48.2%) and a 14 minute (71.4%) decrease was observed between the 1 second and 60 second epoch for Evenson et al., Romanzini et al. and Santos-Lozano et al. cut points respectively.

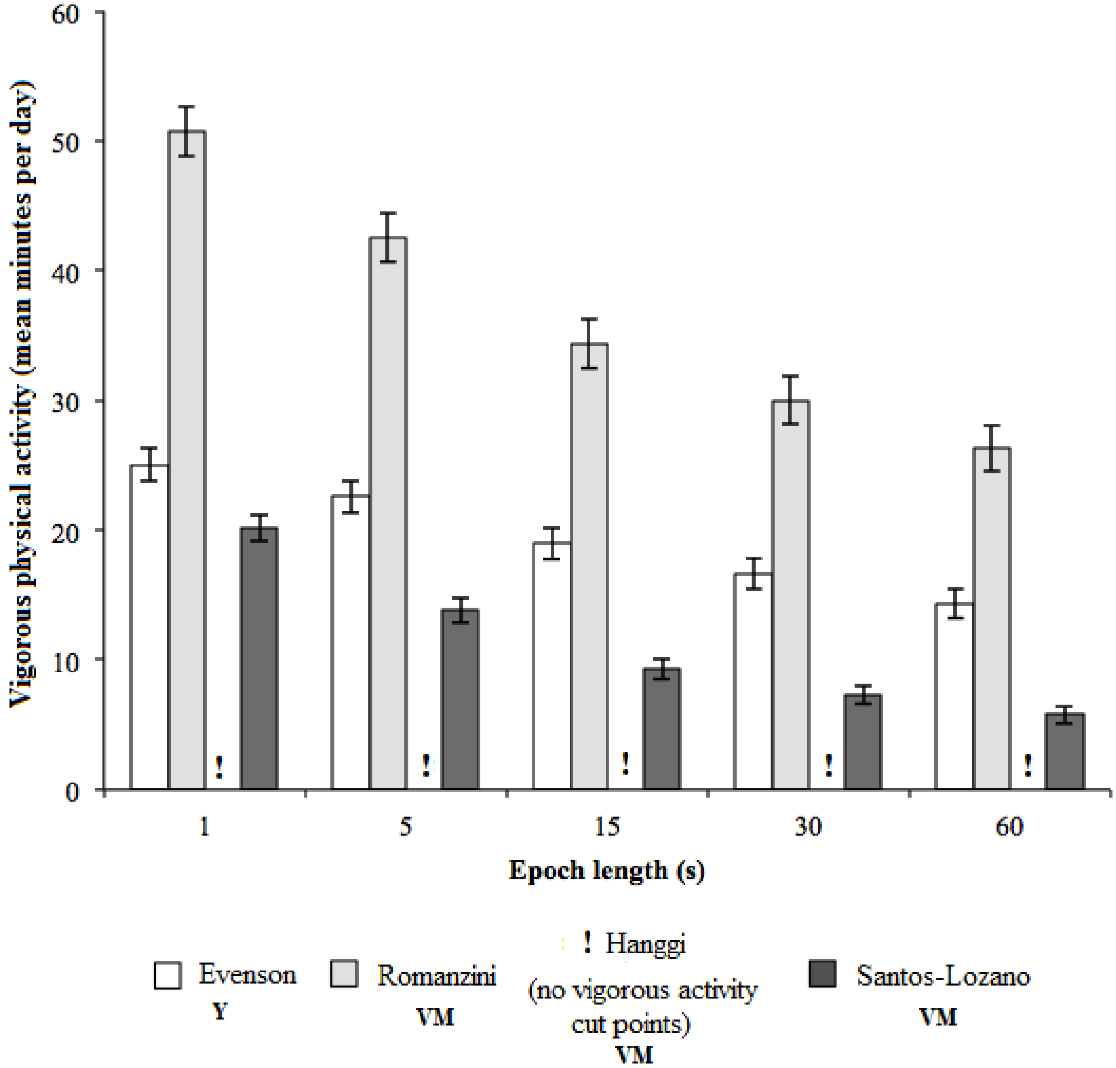


Figure 7: Mean minutes spent in vigorous intensity physical activity per day interpreted using one vertical axis cut-point (Y) and three vector magnitude (VM) cut points at five different epoch settings (95% CI).

3.5.5 Moderate-to-vigorous intensity physical activity

Mean minutes of MVPA per day (Figure 8) between all cut points and epoch lengths were statistically significantly different ($p < 0.01$) with the exception of: 1 second epoch Evenson et al. with 5 second epoch Evenson et al. and 30 second epoch Hänggi et al. ($p > 0.05$); 5 second epoch Evenson et al. with 15 second and 30 second epoch Evenson et al. ($p > 0.05$); 5 second epoch Evenson et al. with 60 second epoch Romanzini et al. ($p < 0.05$), 30 second and 60 second Hänggi et al. ($p > 0.05$); 30 second epoch Evenson et al. with 60 second epoch Hänggi et al. ($p > 0.05$); 1 second Santos-Lozano et al. with 5 second Santos-Lozano et al. ($p > 0.05$); 5 second Santos-Lozano et al. with 15 second Santos-Lozano et al. ($p > 0.05$). There was a decrease in time spent in MVPA with an increase in epoch length for each cut point. An 11 minute (19.5%), a 32 minute (34.3%), 30 minute (37.4%) and a 24 minute (19.6%) decrease was observed between the 1 second and 60 second epoch for Evenson et al., Romanzini et al., Hänggi et al. and Santos-Lozano et al. cut points respectively.

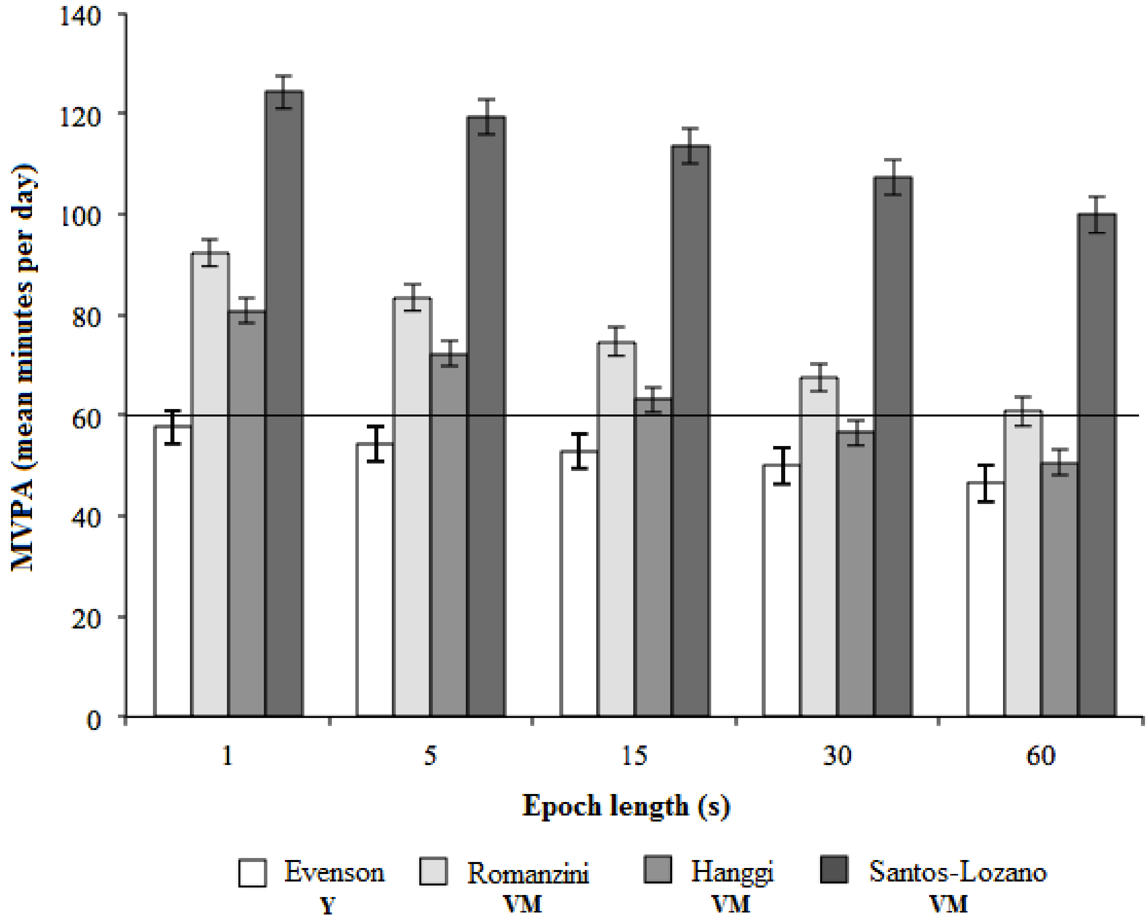


Figure 8: Mean minutes spent in moderate-to-vigorous intensity physical activity (MVPA) per day interpreted using one vertical axis cut-point (Y) and three vector magnitude (VM) cut points at five different epoch settings (with 95% CI). Current recommended physical activity levels of 60 minutes MVPA per day are represented by the black horizontal line.

3.6 Discussion

The absence of a standardised accelerometer data filter has confounded research efforts to fully understand adolescents' physical activity and its association with their health and wellbeing. This study shows the magnitude of difference in physical activity levels across epoch length and between VM cut points for the first time. We concurrently evaluated three factors that can influence the accelerometer quantification of adolescent's physical activity: 1) axis selection; 2) epoch length selection; and 3) cut point selection.

Recent technological advances in accelerometer and computer software technology have made it possible to analyse the data we present in a novel manner. Previous research may have been unable to compare accelerometer data in such a way due to insufficient accelerometer data storage, the inability to retrospectively analyse raw data through different epoch lengths, and through lack of defined VM cut points. As expected, our findings agree with previously published research, showing that VM produces more counts per minute compared with the vertical axis alone (Figure 3) [65]. Counter to expectations, we observed decreases in mean total counts per day from tri-axial measurement with increasing epoch length, whereas the vertical axis was unaffected by changes in epoch length. Whilst the vertical axis output may be considered as more stable across epoch lengths, it is likely that important movement is not captured by recording accelerations on one axis and therefore may mask the effects on acceleration counts that are otherwise seen with VM measurement. We therefore advise that caution must be taken when VM cut points are calculated to correspond with epoch length (if different from the epoch length used in cut point calibration), as this will potentially affect the validity of physical activity level measurement.

Reduction of epoch lengths to 1 second has previously been recommended for youth physical activity measurement [48,59], as it allows the accelerometer to most accurately record vigorous intensity accelerations [28]. The epoch lengths used in the design of our study are those most commonly used in physical activity research [27,41]. An expected 'diluting' effect was observed with an increased epoch length for vigorous intensity levels for all cut points used. Edwardson and Gorely [42] highlighted this issue using the ActiGraph GT1M, and concluded that research cannot compare studies using 5, 15 and 30 second epochs with those using 60 second epochs. To avoid the effect of epoch length on vigorous intensity dilution, Reilly et al. [48] suggest that MVPA may be used to classify moderate and vigorous activities together. Our study, however, has observed that epoch length affects MVPA as well as all individual physical activity intensities and sedentary time; therefore we advise that epoch length must be considered with MVPA. Furthermore, recent research is reporting independent associations of vigorous intensity activity with health outcomes [12,17,69], hence it is of importance to stratify for vigorous physical activity using 1 second epoch lengths.

An interesting distribution of data were observed with epoch length across the different intensities. Moderate activity appeared to be the most unchanged physical activity across all epoch lengths used for all cut points. This finding is in agreement with results seen in previous research [42]. Evenson et al. moderate activity levels peaked using 15 second epoch lengths, and Santos-Lozano et al. moderate activity levels peaked using 5 second epoch lengths, whereas Hänggi et al. cut points followed a more expected decrease in moderate activity levels with increasing epoch length. We postulate that that this may be an effect caused by the algorithm used to determine the cut points. Dramatically more moderate activity was observed using Santos-Lozano et al. cut points, which we speculate may be because of use of Artificial Neural Networks (ANN) to calibrate the cut points, whereas the other reported cut points were calibrated using receiver operating characteristic (ROC) curves. For sedentary time, light-, moderate-, and vigorous activity, Romanzini et al. cut points reported the least changeable physical activity levels across epoch lengths, however Santos-Lozano et al. cut points reported least unchangeable activity for MVPA across epoch lengths.

The present study also observed considerable variation in physical activity levels within each epoch length due to cut point selection. The differences in VM derived physical activity levels that we report are consistent with studies comparing vertical axis cut points in youth [49]. Cut points are calibrated in independent studies that relate the energy expenditure of activities, determined by indirect calorimetry, to the range of acceleration counts during the controlled activity task [50]. The activities are most commonly performed in laboratory settings to control for energy expenditure of the set task. There are no standardised activities that subjects must perform to calibrate these count ranges, nor are there standardised algorithms to determine cut points from acceleration count ranges when related to METs achieved during each activity. The Evenson et al. [51] vertical axis cut points used in the present study were chosen to best represent the vertical axis cut points used in adolescent accelerometer studies [50]. These cut points were determined using ROC curves [70]. For both Romanzini et al.

[66] and Hänggi et al. [67], VM cut points were determined using ROC curves and calibrated using the ActiGraph GT3X. There were discrepancies in the design of both these studies which affect cut point calibration: the length of epoch chosen when calibrating, and the different physical activity protocols used for determining energy expenditure of tasks. Romanzini et al. [66] recorded accelerations at 15 second epochs, whereas Hänggi et al. [67] recorded accelerations at 1 second epochs. Interestingly, Hänggi et al. [67] did not stratify for moderate or vigorous activity cut points from MVPA. This was reflected in their protocol design, which did not investigate energy expenditure of activities of intensities greater than ‘moderate running’. In contrast to Hänggi et al. [67], Romanzini et al. [66] used a range of intensities of activity from sedentary to vigorous in their calibration protocol. The resultant count ranges for both studies were different and therefore produced different physical activity level outcomes.

The cut points determined by Santos-Lozano et al. [65] were established using a novel ANN method, which involves a mathematical model that emulates some of the observed properties of the subjects’ biological nervous system. This method has the potential to be more accurate than establishing cut points with ROC curves determined in laboratory settings, since ANN account for a degree of free-living activity. Translation of laboratory-based cut points to free-living acceleration counts introduces a degree of error, therefore an aspect for future study is to calibrate cut points in free living conditions, possibly through observational analysis [71] and ANN. Research involving the application of ANN to accelerometer cut points is in its infancy and may require further research to improve on the techniques used by Santos-Lozano et al. [65]. However, due to the complexity of ANN design, replication of the calibration protocol may prove problematic. As indicated in their calibration study, Santos-Lozano et al. [65] described the ‘black-box’ nature of the ANN mathematical model, which may limit researchers’ ability to apply it to the field of accelerometry. The physical activity levels observed with Santos-Lozano et al. [65] cut points were the most changeable of all cut points used across epoch lengths, as there were large percentage differences between 1 second and 60 second epoch lengths for both moderate and vigorous physical activity levels. Moreover, these cut points used the largest acceleration count range to define moderate activity, which was reflected in our results by high levels of moderate activity compared with levels determined by the other cut points used (Figure 6).

Although it is desirable to provide recommendations for accelerometer data analysis, the aim of this study was to highlight the magnitude of difference in physical activity outcomes, with an emphasis on tri-axial accelerometry. Thus, we were unable to draw conclusions for best practice from our results. This research may not be conclusive in regard to practical application of VM cut points; however, we hope that attention is drawn to issues that are likely to evolve with the future utilisation of tri-axial accelerometry, especially concerning the comparison of physical activity outcomes using different epoch lengths.

3.7 Conclusions

Our findings specifically illustrate the differences in physical activity outcomes that occur between axis measurement, cut points and epoch length. Related to current physical activity guidelines they indicate that interpretation of accelerometer output must be critiqued in respect to whether populations are meeting publically espoused physical activity guidelines. Free-living physical activity is a challenging variable to measure, however steps must be taken to standardise accelerometer raw data wherever possible to allow for valid between-study comparisons to further our understanding of physical activity and its relationship with the health and wellbeing of adolescents. The magnitude of difference across epoch length must be considered in the interpretation of accelerometer data and seen as a confounding variable when comparing physical activity levels between studies. Future research should independently validate the VM cut points presently employed to better inform research as to the most appropriate application of accelerometer data filtering.

Chapter 4 - Exploring the relationship between adolescent physical activity and anthropometric parameters

4.1 Preface

Outcomes of the investigation in Chapter 3 highlight the influence of accelerometer data processing methods to determine physical activity levels. The current chapter draws from the knowledge gained from Chapter 3's accelerometer methodology study, to accurately determine adolescent physical activity levels and associate them with key body-measured health risk factors. This short-communication was conducted on a representative sample of New Zealand adolescents and highlighted the importance of vigorous intensity physical activity for adolescent health. The manuscript resulting from this chapter is published in the peer-reviewed journal Sports Sciences for Health.

4.2 Abstract

Purpose: This study investigated the contribution of objectively-measured light, moderate and vigorous physical activity to body mass index (BMI) and waist circumference-to-height ratio (WCHt) in adolescents.

Methods: A total of 694 adolescents (12-18 years) from six secondary schools in Auckland and two in Wellington, New Zealand, participated in the Built Environment and Physical Activity in New Zealand Adolescents (BEANZ) study between February 2013 and September 2014. Light, moderate and vigorous intensity physical activity was objectively assessed using ActiGraph GT3X+ accelerometers, which were worn for an eight-day period. Participants' weight, height and waist circumference were measured to calculate BMI and WCHt. Multiple linear regression was used to characterize independent continuous associations between the percentages of wear time spent in each physical activity intensity with BMI and WCHt.

Results: Vigorous activity was inversely independently associated with WCHt ($R^2 = 0.013$, $p < 0.01$), whereas both light ($R^2 = 0.053$, $p < 0.01$) and moderate ($R^2 = 0.036$, $p < 0.01$) physical activity show significant, positive independent relationships with WCHt and BMI.

Conclusion: Only vigorous intensity physical activity was associated with key positive health outcomes in adolescents. Our data support the concept of emphasizing the importance of vigorous activity in youth physical activity guidelines.

4.3 Introduction

Chronic metabolic disorders such as type 2 diabetes and cardiovascular disease typically manifest during adulthood; however, the cardio-metabolic processes underlying these diseases begin early in life [25]. The development of such diseases can be mitigated through the uptake of healthy lifestyle behaviours such as physical activity [72,73]. Adolescence is a key stage in the development of physical activity behaviours which are continued throughout adulthood [1], thus it is important for youth to achieve physical activity levels beneficial to health.

Physical activity guidelines recommend that children and adolescents undertake at least 60 minutes of moderate-to-vigorous-intensity physical activity (MVPA) daily [10]. However, recent accelerometer-derived population measures of physical activity show evidence that the inverse correlation between MVPA and cardio-metabolic risk factors are driven by the time spent specifically in vigorous intensity physical activity [12,16,17,74-76]. For example, Hay et al. [16] observed that vigorous activity was inversely associated with waist circumference, body mass index (BMI) and systolic blood pressure, and positively associated with aerobic fitness, whereas moderate intensity physical activity was not significantly associated with cardio-metabolic risk factors.

The purpose of this study was to investigate the contribution of objectively-measured light, moderate and vigorous physical activity to health indices in adolescents.

4.4 Methods

4.4.1 Study population

Participant recruitment and data collection procedures are described in detail elsewhere [18]. Briefly, six secondary schools in Auckland and two in Wellington, New Zealand, participated in the Built Environment and Physical Activity in New Zealand

Adolescents (BEANZ) study between February 2013 and September 2014. Adolescents (aged 12-18 years) were eligible to participate if they resided in either a high or low walkability neighbourhood, calculated from environmental variables surrounding their residential addresses using Geographic Information Systems. A total of 694 adolescents consented to participate in this research. After data reduction, 632 subjects (366 males; 266 females) were eligible for analysis. Each participant and their legal guardian provided written informed consent. Ethical approval was gained from our institutional ethics committee.

4.4.2 Measures

Height and weight were assessed using a portable stadiometer and digital scales (Model Seca 217 and 770, Seca, Hamburg, Germany). Participants wore light clothing and removed shoes whilst measurements were taken. BMI was calculated as weight (kg) divided by squared height (m^2). Waist circumference was measured against the skin at the mid-point between the lower rib and the iliac crest to the nearest 1mm using a flexible tape measure. Waist circumference-to-height ratio (WCHt) was calculated as waist circumference (cm) divided by height (cm).

All participants were asked to wear an ActiGraph GT3X+ (ActiGraph™, Pensacola, FL) accelerometer for 8 days during waking hours. Each accelerometer was initialized with a start and end time and set to collect raw vertical acceleration signals at 30 Hz. Accelerometers were attached to an elasticated belt and positioned on the waist at the right hip. Raw data were uploaded for processing and reduction using MeterPlus™, Version 4.3 (Santech Inc., San Diego, CA). A valid day was classified as ≥8 hours of monitoring per day [41,48,68]. Participants with less than 4 days of complete monitoring were excluded from the analysis [48]. Non-wear time was defined as ≥60 minutes of consecutive zeros [48]. Cut points developed by Evenson et al. [51] were reconfigured for one-second epoch lengths and applied to the valid data.

Subsequently, mean time per day spent in light, moderate and vigorous intensity physical activity was calculated. Further, the mean percentage of time spent in each intensity were calculated from the valid times the accelerometers were worn each day.

4.4.3 Statistical analysis

All statistical analyses were performed using SPSS version 22 (IBM Corporation, Armonk, NY). Descriptive statistics were calculated and all data were tested for normality using the Kolmogorov-Smirnov test. Initially, Pearson correlation coefficients were used to explore relationships between physical activity variables. Multiple linear regression was then used to characterize independent continuous associations between the percentages of wear time spent in each physical activity intensity with WCHt and BMI. A $p < 0.05$ was considered statistically significant.

4.5 Results

Table 4: Participant demographic and physical activity characteristics

Measure	Total (N = 632)	Males (N = 366)	Females (N = 266)
Demographic			
Age (years)	16.2 ± 1.53	16.0 ± 1.54	16.4 ± 1.47
Height (cm)	167.7 ± 8.86	170.4 ± 9.47	164.0 ± 6.27
Weight (kg)	60.8 ± 12.57	62.1 ± 14.0	59.0 ± 10.06
Waist circumference (cm)	71.5 ± 8.64	73.0 ± 8.95	69.3 ± 7.72
BMI (kg m^{-2})	21.5 ± 3.68	21.2 ± 3.74	21.91 ± 3.56
WCHt	0.4 ± 0.05	0.4 ± 0.07	0.4 ± 0.06
Physical activity data			
Sedentary behaviour			
mean min per day	657.9 ± 88.19	648.4 ± 91.29	671.1 ± 82.11
mean % time	82.7 ± 4.33	81.7 ± 4.58	84.1 ± 3.53
Light physical activity			
mean min per day	74.5 ± 19.73	78.1 ± 20.68	69.6 ± 17.19
mean % time	9.5 ± 2.54	9.9 ± 2.59	8.8 ± 2.16
Moderate physical activity			
mean min per day	32.1 ± 13.09	32.7 ± 10.66	31.2 ± 9.61
mean % time	4.0 ± 1.36	4.1 ± 1.43	3.9 ± 1.26
Vigorous physical activity			
mean min per day	25.9 ± 13.09	29.0 ± 13.49	21.6 ± 11.19
mean % time	3.3 ± 1.64	3.7 ± 1.67	2.7 ± 1.41

Abbreviations: BMI, body mass index; WCHt, waist circumference-to-height ratio. Data are presented as mean ± SD

Physical activity data are presented as both mean minutes per day and as the mean percentage of daily valid accelerometer wear time (Table 4). No interaction effect was observed between sex and physical activity for both WCHt and BMI; therefore data from males and females were pooled for all further analyses.

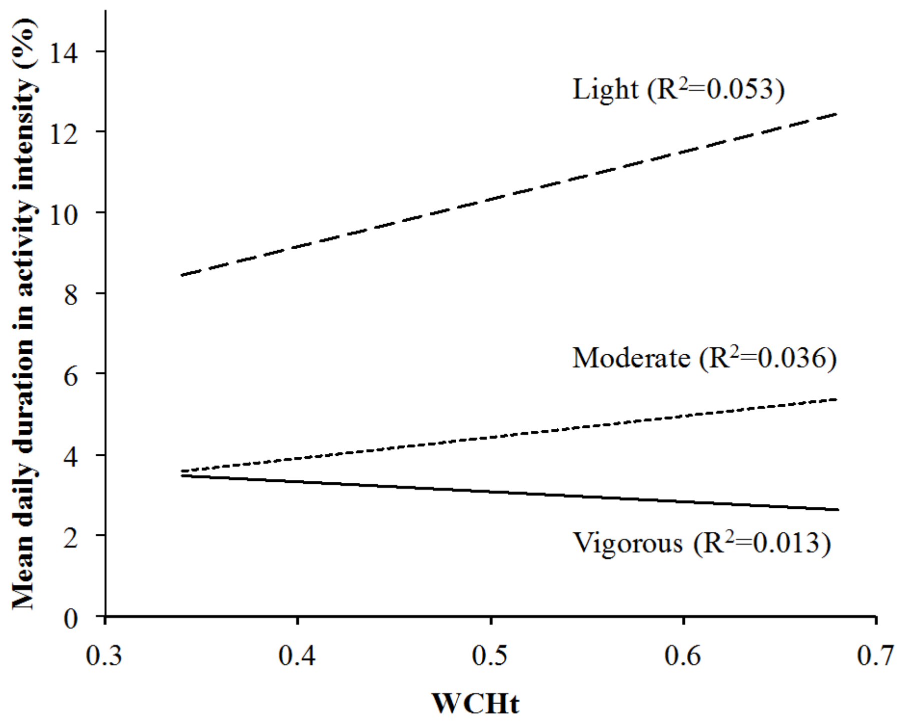


Figure 9: Linear regression relationships of light, moderate and vigorous physical activity intensity with WCHt

Figure 9 presents the linear regression relationships of mean percentage of time in light, moderate and vigorous intensity physical activity with WCHt. Regression slopes and their y-axis intercepts were significantly different ($p < 0.01$), therefore the combined male and female data show significant, positive independent relationships between WCHt and light ($R^2 = 0.053$, $p < 0.01$) and moderate ($R^2 = 0.036$, $p < 0.01$) physical activity. Vigorous activity was inversely independently associated with WCHt ($R^2 = 0.013$, $p < 0.01$) in the combined male and female data. Similar significant relationships were observed across activity intensities for BMI (not shown); however WCHt is a stronger predictor of adiposity in children and adolescents [77,78].

4.6 Discussion

This study provides novel insight into the relationships between time spent in objectively-measured physical activity intensities and key health outcomes in a large cross-sectional sample of New Zealand adolescents. Our data show that vigorous physical activity was inversely related to WCHt and BMI, whereas both light and moderate activity were positively associated with these health outcomes. Results from this study highlight the importance of vigorous intensity physical activity as an independent determinant of health risk factors in adolescents and strongly support the inclusion of including vigorous physical activity targets within current physical activity guidelines.

Our results are in agreement with those published by Hay et al. [16], whereby vigorous physical activity was the only intensity that was associated with reduced BMI and waist circumference in youth. To contextualize this relationship, our data show that an increase of 4.2% in proportion of daily duration in vigorous intensity activity is associated with a reduction in WCHt from the 75th centile to the 25th centile in adolescents. Hence, the clinical implication of our results suggest that an increase in daily vigorous activity by an average of 1.1 minutes each day is associated with a 0.05 reduction in WCHt in the adolescent cohort. Whilst it would be expected that time spent all intensities of physical activity would benefit health to different degrees, our data showed that WCHt and BMI increased with light and moderate activity in both males and females. Hay et al. [16] only observed this relationship between BMI and increasing duration of light (but not moderate) intensity activity across tertiles.

This study has several strengths. Firstly, we recorded accelerometer data using high-resolution 1-second epoch lengths. Reduction of the accelerometer epoch duration prevented the dilution and misclassification of activity intensity [42]. Secondly, we have nominated to present physical activity data as a mean percentage of the valid accelerometer wear time per day. This approach is potentially more meaningful than the conventional terminology of mean minutes per day, since the reported minutes are only representative of the time the accelerometer is worn. Finally, this study used a large, ethnically diverse sample of adolescents taken from two New Zealand cities. Despite these strengths, we acknowledge some limitations. Potentially confounding variables such as dietary intake and pubertal status were not measured. Whilst WCHt and BMI are useful surrogate markers for adiposity and metabolic health, future studies may consider using more detailed body and cardio-metabolic health measures. Due to the cross-sectional nature of this study, the direction of causality of these relationships cannot be determined. However, in a longitudinal study by Carson et al. [12], vigorous activity at baseline was the primary predictor of favourable cardio-metabolic profiles in 315 youth two years later, thus strengthening the argument for a causal association between vigorous activity and health in adolescents.

4.7 Conclusion

In summary, only vigorous intensity physical activity was associated with key positive health outcomes in adolescents. Our data support the concept of emphasising the importance of vigorous activity in youth physical activity guidelines.

Chapter 5 - A review of adolescent high-intensity interval training

5.1 Preface

Identification of the beneficial associations of vigorous intensity physical activity with adolescent health were determined from the cross-sectional population-level study in the previous thesis chapter. Following this, high-intensity interval training was identified as a practical method to deliver vigorous intensity exercise in the adolescent cohort. The purpose of Chapter 5 was to provide a narrative review, summarising the central characteristics of HIIT intervention trials involving adolescents, whilst focussing on HIIT's impact on metabolic health. The review is concerned with studies that investigate key parameters of the metabolic condition: glycemia and insulinemia, blood lipids, body composition, aerobic fitness and inflammation. Where possible, the efficacy of HIIT was compared to continuous aerobic exercise as a control for the aforementioned variables, in order to weigh the health effects of HIIT against traditionally recommended steady-state exercise (SSE). Findings from this review identified a significant gap in the literature, regarding the optimum strategy and HIIT dose to deliver cardio-metabolic health benefits in youth. This review also highlights scope for research to examine the palatability of HIIT as a stimulating exercise modality for adolescents, through investigating perceived enjoyment during and after HIIT, and psychological factors that may influence long-term exercise adherence. The manuscript resulting from this chapter was published in the peer-reviewed journal, Sports Medicine.

5.2 Abstract

Background: Despite the promising evidence supporting positive effects of high-intensity interval training (HIIT) on the metabolic profile in adults, there is limited research targeting adolescents. Given the rising burden of chronic disease, it is essential to implement strategies to improve the cardio-metabolic health in adolescence, as this is a key stage in the development of healthy lifestyle behaviours. This review summarises evidence of the relative efficacy of HIIT regarding the metabolic health of adolescents.

Methods: Due to the limited number of studies found examining HIIT in youth and the variety of metabolic measures and exercise protocols used, a narrative style was chosen over systematic or meta-analysis in order to portray pertinent information.

Results: A total of 13 studies met the criteria for review.

Conclusions: Methodological inconsistencies confound our ability to draw conclusions, however there is meaningful evidence supporting HIIT as a potentially efficacious exercise modality for use in the adolescent cohort. Future research must examine the effects of various HIIT protocols to determine the optimum strategy to deliver cardio-metabolic health benefits. Researchers should explicitly show between-group differences for HIIT intervention and steady-state exercise or control groups, as the magnitude of difference between HIIT and other exercise modalities is of key interest to public health. There is scope for research to examine the palatability of HIIT as an exercise modality for adolescents through investigating perceived enjoyment during and after HIIT, and consequent long-term exercise adherence.

5.3 Introduction

Early development of cardio-metabolic risk factors in youth have been associated with increased risk of premature mortality [2]. Insufficient physical activity, overweight and obesity, poor diet, low cardiorespiratory fitness, hypertension, chronic inflammation and dyslipidaemia are evident in youth and can track into adulthood [79-81]. Adolescence, in particular, is a key stage in the development of health behaviours. According to a systematic review of 26 cross-sectional studies by Dumith et al. [8], physical activity decreases by 65% (on average) during the adolescent years. Given the rising burden of chronic disease, it is essential to implement strategies to improve the cardio-metabolic health in youth.

In spite of the well-established health benefits of physical activity, the majority of youth are not meeting current activity recommendations [82]. Current international physical activity guidelines recommend that all children and young people should accumulate at least 60 minutes of moderate-to-vigorous physical activity each day, and have acknowledged that vigorous-intensity activities provide further health benefits [10]. Moderate-intensity, high-volume continuous aerobic exercise has been recommended for the inactive public, yet the nature of youth activity is spontaneous and intermittent bursts of high intensity activity [13]. Movement away from the idea of accumulating at least 10-minute bouts of moderate-intensity aerobic activity to fulfil the current physical activity recommendations has lead research to investigate more nuanced approaches to achieve the health benefits of physical activity. These new advances in research aim to understand the importance of light intensity incidental body movement and the impact of reducing sedentary behaviour, but equally look to understand the benefits of higher intensities of activity [12].

There has been recent interest in HIIT as an alternative to continuous aerobic exercise in adults [83,84]. These intense sprint bouts of short duration with recovery intervals at low-to-moderate intensity have been espoused as a time efficient method to achieve the health benefits of exercise, since lack of time has often been cited as a key barrier to exercise participation [84,85]. Further, HIIT has been shown to improve the cardio-metabolic risk profile to a greater extent than continuous aerobic exercise in healthy, obese and type 2 diabetic individuals, as well as being implemented as a more effective method in restoring vascular function in heart disease patients [86-90]. Emerging research is uncovering the benefits of vigorous intensity physical activity in the regulation of healthy metabolic profiles regardless of weight loss and energy expenditure, indicating underlying metabolic mechanisms sensitive to high intensity body movement [91].

Despite the promising evidence supporting HIIT in adults, there is limited research targeting youth, specifically in the key age group of adolescence. Adolescents may find short bouts of high-intensity exercise more natural, appealing and easier to adhere to than traditionally recommended moderate intensity exercise [92-94]. Further, engaging youth in activities that they perceive as enjoyable may aid in the development of self-directed physical activity to be continued into adulthood [92]. The aim of this narrative review is to summarise the central characteristics of HIIT intervention trials involving adolescents, focussing on HIIT's impact on metabolic health. This review is concerned with studies that investigate key parameters of the metabolic condition: glycemia and insulinemia, blood lipids, body composition, aerobic fitness and inflammation. Where possible, the efficacy of HIIT is compared to continuous aerobic exercise as a control for the aforementioned variables.

5.4 2. Literature search methodology

To perform this review, English-language literature searches of the PubMed, Web of Science, Scopus and Google Scholar databases were conducted for all time periods up to March 2014. A combination of the following search terms were used: 'adolescence', 'youth', 'high intensity', 'intermittent training', 'interval', 'exercise', 'sprint interval training', 'continuous training', 'obese', 'overweight', 'metabolic', cardio-metabolic', 'insulin', 'vigorous', 'physical activity', and 'health'. In addition, references from the extracted publications were examined. Non-English papers and studies examining HIIT for sport performance were excluded from this review. Due to the limited number of studies found examining HIIT in youth and the variety of metabolic measures and exercise protocols used, a narrative style was chosen over systematic or meta-analysis in order to portray pertinent information. A total of 13 studies met the criteria for review (Table 5). Percentage changes were calculated for each of the health outcome values from pre- to post-intervention and percentage difference for each variable between HIIT and control groups was calculated, where possible, using the following formula: $((post_{HIIT}/pre_{HIIT})/(post_{control}/pre_{control})-1)x100\%$. Key results from the relevant studies are summarised in Tables 6-10.

Table 5: Characteristics of studies investigating high-intensity interval training and health in adolescents

Study	Subjects/ intervention duration	Intervention group	Group size	Modality/ intensity	Repeated bouts/ frequency	Exercise bout duration	Recovery duration between bouts	Protocol duration (including recovery)	Total exercise intervention duration
Barker et al. [95]	Healthy, recreationally active male adolescents; N=10 (15 ± 0.3 years of age) 2 weeks	HIIT protocol	N=10	Cycle ergometer (100% peak power)	4, increased to 7 on the final session (3 times weekly)	30 seconds	4 minutes	Up to 27 minutes and 30 seconds	Up to 2 hours and 31 minutes
		SSE protocol	-	-	-	-	-	-	-
		Control	-						
Baquet et al. [96]	Adolescent secondary school children; N=551 (287 male, 264 female; 12-15 years of age) 7 weeks	HIIT protocol	N=503	Shuttle runs (100-120% maximum aerobic speed)	2 exercise bouts. Sets are repeated 3 times and interspersed with 3 minutes rest (once weekly)	10 seconds	10 seconds	33 minutes	2 hours and 50 minutes
		SSE protocol	-	-	-	-	-	-	-
		Control	N=48, active control						

Study	Subjects/ intervention duration	Intervention group	Group size	Modality/ intensity	Repeated bouts/ frequency	Exercise bout duration	Recovery duration between bouts	Protocol duration (including recovery)	Total exercise intervention duration
Buchan et al. [108]	Healthy adolescent secondary school children; N=57 (47 male, 10 female; 16.4 ± 0.7 years of age) 7 weeks	HIIT protocol	N=17	Shuttle runs during a 20-MSFT (maximal effort sprint)	Up to 6 (3 times weekly)	30 seconds	30 seconds	Up to 5 minutes 30 seconds	Up to 42 minutes
		SSE protocol	N=16	Continuous running (70% $VO_{2\ max}$)	3 times weekly	20 minutes	-	20 minutes	Up to 7 hours
		Control	N=24; active control						
Buchan et al. [97]	Healthy adolescent school children; N=41 (35 male, 6 female; 15-17 years of age) 7 weeks	HIIT protocol	N=17	Shuttle runs during a 20-MSFT (maximal effort sprint)	Up to 6 (3 times weekly)	30 seconds	30 seconds	Up to 5 minutes 30 seconds	Up to 42 minutes
		SSE protocol	-	-	-	-	-	-	-
		Control	N=24; active control						

Study	Subjects/ intervention duration	Intervention group	Group size	Modality/ intensity	Repeated bouts/ frequency	Exercise bout duration	Recovery duration between bouts	Protocol duration (including recovery)	Total exercise intervention duration
Buchan et al. [94]	Healthy adolescent secondary school children; N=89 (64 male, 25 female; 16.7 ± 0.6 years of age) 7 weeks	HIIT protocol	N=42	Shuttle runs during a 20-MSFT (maximal effort sprint)	Up to 6 (3 times weekly)	30 seconds	30 seconds	Up to 5 minutes 30 seconds	Up to 42 minutes
		SSE protocol	-	-	-	-	-	-	-
		Control	N=47; active control						
Burns et al. [98]	Normal-weight healthy adolescents; N=10 (15-18 years of age) Single session	HIIT protocol	N=10	Cycle ergometer (maximal effort sprint)	2	30 seconds	4 minutes active recovery	1 minute 30 seconds	60 seconds
		SSE protocol	-	-	-	-	-	-	-
		Control	N=10; passive control						
Cockcroft et al. [99]	Healthy adolescent males; N=9 (14.2 ± 0.4 years of age) 3 treatments performed in 3 single sessions	HIIT protocol	N=9	Cycle ergometer (90% peak power)	-	1 minute	Low intensity recovery lasting 1 minute 15 seconds	Up to 20 minutes	-

Study	Subjects/ intervention duration	Intervention group	Group size	Modality/ intensity	Repeated bouts/ frequency	Exercise bout duration	Recovery duration between bouts	Protocol duration (including recovery)	Total exercise intervention duration
		SSE protocol	N=9	Cycle ergometer (90% gas exchange threshold)	-	HIIT matched mechanical workload determined duration	-	-	-
		Control	N=9; passive control						
Corte de Araujo et al. [100]	Obese Brazilian children; N=30 (4 male, 14 female; 8-12 years of age) 12 weeks	HIIT protocol	N=15	Treadmill running (100% maximum velocity sprints)	Up to 6 (twice weekly)	60 seconds	3 minutes active recovery at 50% maximum velocity	Up to 21 minutes	Up to 144 minutes
		SSE protocol	N=15	Continuous treadmill walking/ running (80% peak heart rate)	Twice weekly	30 minutes (increased by 10 minutes every 3 weeks)	-	-	Up to 360 minutes
		Control	-						
Ingul et al. [101]	Obese adolescents; N=10 (14.8 ± 1.2 years of age), compared with healthy, lean adolescents; N=10 (14.9 ± 1.3 years of age) 13 weeks	HIIT protocol	N=10	Treadmill walking/ running (90-95% maximum heart rate)	4 (twice weekly)	4 minutes	3 minutes	25 minutes	3 hours 20 minutes

Study	Subjects/ intervention duration	Intervention group	Group size	Modality/ intensity	Repeated bouts/ frequency	Exercise bout duration	Recovery duration between bouts	Protocol duration (including recovery)	Total exercise intervention duration
		SSE protocol	-	-	-	-	-	-	-
		Control	N=10; passive control						
Koubaa et al. [102]	Obese adolescent Tunisian males; N=29 (13 ± 0.8 years of age) 12 weeks	HIIT protocol	N=14	Running (80% VO_{2max}, increased by 5% every 4 weeks)	Unknown (3 times weekly)	2 minutes	1 minute	Unknown	Up to 72 minutes
		SSE protocol	N=15	Continuous running (60-70% VO_{2max})	3 times weekly	30 minutes	-	-	18 hours
		Control	-						
Racil et al. [103]	Obese adolescent Tunisian females N=34 (15.9 ± 0.3 years of age) 12 weeks	HIIT protocol	N=11	Shuttle runs (HIIT:100-110% maximum aerobic speed; MIIT: 70-80% maximum aerobic speed)	Two blocks of up to 8 bouts (3 times weekly)	30 seconds	30 seconds active recovery at 50% maximum aerobic speed with 4 minutes rest between blocks	Up to 20 minutes	Up to 88 minutes
		SSE protocol	-	-	-	-	-	-	-
		Control	N=12; passive control						

Study	Subjects/ intervention duration	Intervention group	Group size	Modality/ intensity	Repeated bouts/ frequency	Exercise bout duration	Recovery duration between bouts	Protocol duration (including recovery)	Total exercise intervention duration
Thackray et al. [104]	Healthy adolescent males; N=15 (11-12 years of age) Single session	HIIT protocol	N=15	Treadmill sprinting (100% maximum aerobic speed)	10 (one session only)	1 minute	1 minute	20 minutes	10 minutes
		SSE protocol	-	-	-	-	-	-	-
		Control	N=15						
Tjonna et al. [93]	Overweight and obese adolescents, N=54 (26 male, 28 female; 14 years of age) 3 months	HIIT protocol	N=28	Treadmill walking/ running (90-95% maximum heart rate)	4 (twice weekly)	4 minutes	3 minutes	25 minutes	3 hours 20 minutes
		SSE protocol	-	-	-	-	-	-	-
		Control	N=26; multi-treatment group						

HIIT = high-intensity interval training; SSE = steady state exercise; MIIT = moderate-intensity interval training; VO_{2max} = maximal oxygen consumption; 20-MSFT = 20 metre multi-stage fitness test; - = not applicable

5.5 High-intensity interval training studies involving adolescents

Scientific interest in the use of HIIT to improve health in youth began in the last decade, focussing on cardiovascular fitness as a primary health outcome. An early study [96] investigated the effects of HIIT on the aerobic fitness of 11–16 year olds using the shuttle-run European physical fitness test battery (EUROFIT). A large sample of 551 adolescents was allocated to an intervention group (n = 503) or a passive control (n = 48). Once a week for 10 weeks, subjects completed three sets of two, 10-second repeated sprints at 100-120% maximal aerobic speed with 10 seconds rest between bouts and 3 minutes rest between sets, during a one-hour period. Interestingly, for both male and female participants in the HIIT group, there were significant increases from baseline in BMI and percentage body fat, although the percentage differences between the control group was small for both BMI (male: 2.0%; female: 0.01%) and percentage body fat (male: 2.5%; female: 3.7%). There was, however, a larger and significant improvement in aerobic fitness, as measured by the maximum distance run in a 7-minute period, with 7% difference between control and HIIT groups. The discrepancies between improved fitness and small changes in body composition may be explained in part by the frequency of the exercise session, as the HIIT protocol was only performed once weekly. Also, as there were far fewer subjects in the control group, there is a limited accuracy of comparison between groups. This study is one of the first to associate HIIT with improvements in adolescent fitness, and indirectly with traditional cardiovascular risk parameters. Dietary analysis and self-identified sexual maturation status were not accounted for in this study. Both diet and sexual maturation can have great effects on metabolic outcomes; accounting for any changes in these variables during experimental interventions is vital to the validity of results. Most commonly, classification of the pubertal status of youth is performed using a self-identified Tanner Stage scale, however dietary analysis differs between studies and should be tailored to the study population. In order to understand the processes of energy substrate metabolism and the subsequent effects on underlying glycaemic and lipid regulation, more detailed physiological testing must be performed with HIIT intervention studies. These elements are fundamental to the improvement of the cardio-metabolic profile. Tables 6-10 summarise the key variables investigated in existing youth HIIT studies.

Table 6: Aerobic fitness measures

Study	Measured outcome	Baseline HIIT (mean ± SD)	HIIT (% change from baseline)	Control (% change from baseline)	Between-group difference (%)	Between-group p-value
Barker et al. [95]	Aerobic fitness ($ml.kg^{-1}.min^{-1}$)	53.5 ± 8.3	5.0	-	-	-
Baquet et al. [96]	Aerobic fitness (meters covered during 7 min shuttles)	1173 ± 219	7.5**	0.5	7.0	-
Buchan et al. [108]	Aerobic fitness (20-MSFT)	82 ± 25.8	8.3**	26.8**	-14.6	-
Buchan et al. [97]	Aerobic fitness (20-MSFT)	82 ± 25.8	-3.0*	-5.9	9.9	-
Buchan et al. [94]	Aerobic fitness (20-MSFT)	79 ± 25	6.3**	-4.9	11.8	N.S.
Koubaa et al. [102]	Aerobic fitness ($ml.kg^{-1}.min^{-1}$)	38.7 ± 1.2	10.9**	4.5*	6.0	-
Racil et al. [103]	Aerobic fitness ($ml.kg^{-1}.min^{-1}$)	36.9 ± 1.8	7.6**	5.1*	2.3	N.S.
Tjonna et al. [93]	Aerobic fitness ($ml.kg^{-1}.min^{-1}$)	32.3 ± 5.8	9.3**	0.0	9.3*	$p < 0.05$

Significantly different from baseline (*$p < 0.05$, ** $p < 0.01$); - = not stated; HIIT = high-intensity interval training; N.S. = not statistically significant; 20-MSFT = 20 metre multi-stage fitness test

In an attempt to investigate the effects of sprint interval training on post-exercise substrate utilisation and blood pressure in free-living subjects, Burns *et al.* [98] used a protocol of two 30-second bouts of 'all out' effort cycling separated by 4-minute rest intervals. Ten adolescent subjects of 15-18 years of age were recruited and split into a HIIT or passive control group in a crossover design. Post-exercise, subjects were seated for 90-minutes and wore a respiratory mask for respiratory exchange ratio (RER) analysis. No dietary analysis was undertaken, though subjects performed the experiment after a 10-hour overnight fast. Self-identified sexual maturation and ethnicity were accounted for in this study. This study is the first to show significant elevations in oxygen consumption post-HIIT, and an increased fat oxidation 30 to 60 minutes post-exercise in adolescents. It is important to note that a total of only 60 seconds of exercise was performed, emphasising the very short duration of activity needed to induce metabolic changes. These preliminary findings suggest that enhanced fat oxidation from HIIT is achievable in youth populations. Whilst metabolic differences were observed post-HIIT from the rested state, the study did not compare HIIT with steady state aerobic exercise (SSE). Building on the evidence for enhanced fat oxidation in adolescents using HIIT, Barker et al. [95] investigated the effects of the established HIIT protocol, first used by Burgomaster et al. [105], on the health outcomes of male adolescents. Like the study by Burns et al. [98], the HIIT protocol uses 30-seconds of ‘all out’ effort cycling followed by 4 minutes of rest, although in Barker et al.’s study the number of bouts is increased by up to seven repeats. The ten male participants aged between 14 and 16 completed six sessions of HIIT in the 2-week intervention and there was no control group used in the study. Subjects had sexual maturity adjusted anthropometric measurements taken, underwent maximal aerobic fitness testing in the form of maximal aerobic uptake (VO_{2max}) and had expired gas analysed during submaximal exercise pre- and post intervention. Subjects also had their dietary macronutrient intake analysed, and blood pressure taken both at baseline and follow up. Using novel statistical analysis [106], the researchers reported possibly beneficial effects seen from 2 weeks of HIIT in VO_{2max} (5% increase), submaximal exercise energy expenditure (-5.5%), submaximal exercise fat oxidation (23.8%), submaximal carbohydrate oxidation (-18.1%) and RER (-3.3%), though there was no effect seen with HIIT and blood pressure. These results show that positive beneficial effects can occur from just six sessions of HIIT, however, although metabolic health outcomes can be inferred from aerobic fitness and substrate utilisation, direct sampling of plasma glycaemic, inflammatory and lipid markers provide more valuable information for understanding the effects and physiological processes that HIIT has on the metabolic condition.

Table 7: Body composition and blood pressure measures

Study	Measured outcome	Baseline HIIT (mean ± SD)	HIIT (% change from baseline)	Control (% change from baseline)	Between-group difference (%)	Between-group p-value
Barker et al. [95]	BMI (kg/m^2)	21.5 ± 2.6	0.5	-	-	-
Baquet et al. [96]	Male BMI (kg/m^2)	19.3 ± 3.4	1.6**	3.7**	-2.0	-
Baquet et al. [96]	Female BMI (kg/m^2)	19.7 ± 3.6	2.0**	2.0**	0.1	-
Buchan et al. [108]	BMI (kg/m^2)	21.6 ± 2.2	-1.4*	-1.3**	0.0	-
Buchan et al. [97]	BMI (kg/m^2)	21.6 ± 2.2	-1.4	-1.3	-0.1	-
Buchan et al. [94]	BMI (kg/m^2)	21.5 ± 2.4	-0.9	-1.3	1.0	N.S.
Corte de Araujo et al. [100]	BMI (kg/m^2)	32 ± 3	-6.3*	-3.3*	-3.0	-
Koubaa et al. [102]	BMI (kg/m^2)	30.2 ± 3.6	-2.6**	-7.5*	5.2	-
Racil et al. [103]	BMI (z-score)	2.9 ± 0.2	-13.8**	-9.7*	-4.6*	p < 0.05
Tjonna et al. [93]	BMI (kg/m^2)	33.2 ± 6.1	-2.1**	0.6	-1.5	N.S.
Baquet et al. [96]	Male body fat (%)	17.7 ± 8.3	7.9**	5.3**	2.5	-
Baquet et al. [96]	Female body fat (%)	17.5 ± 6	10.3**	6.3**	3.7	-
Buchan et al. [97]	Body fat (%)	18.7 ± 7.7	2.9	-10.6*	15.1	-
Buchan et al. [97]	Body fat (%)	16.9 ± 5.1	1.8	-5.0	7.1	-
Corte de Araujo et al. [100]	Body fat (%)	38 ± 5	-2.6	-2.7	0.1	-
Racil et al. [103]	Body fat (%)	37.2 ± 1.2	-7.8*	-5.2*	-2.7*	p < 0.05
Tjonna et al. [93]	Body fat (%)	40.6 ± 5.3	-3.2**	-0.7	-2.5	N.S.
Barker et al. [95]	Submaximal exercise carbohydrate oxidation (g.min^{-1})	1.2 ± 0.2	-18.1	-	-	-

Study	Measured outcome	Baseline HIIT (mean ± SD)	HIIT (% change from baseline)	Control (% change from baseline)	Between-group difference (%)	Between-group p-value
Barker et al. [95]	DBP (mmHg)	65 ± 10	3.1	-	-	-
Buchan et al. [108]	DBP (mmHg)	67 ± 7	-3.0	0.0	-3.0	-
Buchan et al. [97]	DBP (mmHg)	82 ± 25.8	-3.0	-5.9	-1.9	-
Buchan et al. [94]	DBP (mmHg)	69 ± 11	-1.4	-5.7	-1.7	N.S.
Corte de Araujo et al. [100]	DBP (mmHg)	66 ± 8	-6.1	-7.6	1.6	-
Koubaa et al. [102]	DBP (mmHg)	87 ± 5	-3.4*	-2.4	-1.1	-
Tjonna et al. [93]	DBP (mmHg)	70.4 ± 7.5	-7.8**	2.7	-10.3	N.S.
Barker et al. [95]	Submaximal exercise energy expenditure ($kcal.min^{-1}$)	6.86 ± 0.56	-5.5	-	-	-
Barker et al. [95]	Submaximal exercise fat oxidation ($g.min^{-1}$)	0.21 ± 0.07	23.8	-	-	-
Barker et al. [95]	Submaximal exercise RER	0.91 ± 0.04	-3.3	-	-	-
Barker et al. [95]	SBP (mmHg)	115 ± 10	0.9	-	-	-
Buchan et al. [108]	SBP (mmHg)	112 ± 10	-5.4*	-2.7	-1.9	-
Buchan et al. [97]	SBP (mmHg)	112 ± 10	8.3*	-1.5	-1.9	-
Buchan et al. [94]	SBP (mmHg)	119 ± 13	-4.2**	-2.5	-1.7	N.S.
Corte de Araujo et al. [100]	SBP (mmHg)	115 ± 10	-7.8*	0.0	-7.8	-
Koubaa et al. [102]	SBP (mmHg)	134 ± 3	-2.2**	3.0*	-0.7	-
Tjonna et al. [93]	SBP (mmHg)	128.8 ± 12.8	-7.3*	-2.0**	-5.4	N.S.
Buchan et al. [108]	WHR	0.9 ± 0.3	-2.3	0.0	-4.7*	p < 0.01

Study	Measured outcome	Baseline HIIT (mean ± SD)	HIIT (% change from baseline)	Control (% change from baseline)	Between-group difference (%)	Between-group p-value
Buchan et al. [97]	WHR	0.8 ± 0.1	0.0	0.0	0.0	-
Buchan et al. [94]	WC (cm)	75.3 ± 6.7	0.0	2.0**	-2.0	N.S.
Corte de Araujo et al. [100]	WC (cm)	99 ± 10	-3.0	-7.1	4.3	-
Koubaa et al. [102]	WC (cm)	98.2 ± 9.4	-1.9**	-5.8	4.1	-
Racil et al. [103]	WC (cm)	93.7 ± 4.8	-3.6*	-3.2	-0.5	N.S.
Tjonna et al. [93]	WC (cm)	105.3 ± 10.5	-0.4*	2.8	-3.1	N.S.

Significantly different from baseline (*p < 0.05, ** p < 0.01); - = not stated; HIIT = high-intensity interval training; BMI = body mass index; DBP = diastolic blood pressure; N.S. = not statistically significant; RER = respiratory exchange ratio; SBP = systolic blood pressure; WHR = waist-to- hip ratio; WC = waist circumference

One of the first studies investigating the direct cardio-metabolic outcomes from HIIT in adolescents was performed by Tjonna et al. [93]. Overweight and obese Norwegian adolescent males and females were randomly assigned to a 3-month high intensity aerobic interval training or multi-treatment group. A follow-up was performed post 3-month intervention and after a further nine months. The HIIT protocol involved subjects walking or running uphill on a treadmill, repeating 4 minutes of 90% maximal heart rate exercise four times, interspersed with active recovery of 3 minutes at 70% maximal heart. This protocol was performed twice weekly. Those assigned to the multi-treatment group met fortnightly for teaching from a physician, psychologist, clinical nutritionist and physiotherapist for 12 months, though only participated in three activity sessions. Both groups kept a 3-month food diary for the intervention period. Sexual maturation was not accounted for in this study. Using the chronological age of adolescents, especially of those around 14 years of age should not be considered sufficiently accurate to account for pubertal status. At the end of the 3-month trial, the group who completed HIIT significantly improved several known markers of the metabolic condition from their baseline measures; BMI, percentage body fat, VO_{2max}, mean arterial pressure, high-density lipoprotein cholesterol (HDL) and reduced fasting glucose more than observed in the multi-treatment group. In addition, the exercise group improved their diet more so than the control. Although not significantly different from the multi-treatment group, one of the most promising findings was the 25.5% greater between-group improvement in insulin sensitivity with HIIT, using homeostasis model assessment (HOMA). Increasing insulin sensitivity has direct effect on blood glucose disposal, reducing plasma insulin and better regulating lipid metabolism, and is key to the healthy metabolic control for the prevention of chronic disease state [107]. Another benefit seen in the HIIT group was that these outcomes improved or were maintained after a 12-month period to a greater degree than the control, suggesting that the adolescents adhered to the activity protocol to a greater extent than health advice alone. Informal comments from the adolescents indicated that the feeling of improved fitness motivated them to continue the exercise after the 3-month intervention. This aspect of HIIT may be key for implementation of a successful public health strategy to improve and sustain health benefits in adolescents. Unique to this study, with regards to HIIT and adolescents, is that endothelial function using flow-mediated dilation (FMD). They saw that there was a 5.1% increase in FMD with aerobic interval training compared to a 3.9% increase with the multi-treatment group. Further, after 12 months FMD increased by 6.3% from baseline, whereas the control group's improvements on completion of the intervention returned to baseline after the 12-month follow-up. Further research is required to fully understand the effects HIIT may have on the cardiovascular system, specifically regarding endothelial function and cardiac-ventricular improvements.

Continuing from the work conducted by Tjonna et al. [93], Ingul et al. [101] used the same HIIT protocol for a 3-month period to investigate its ability to restore cardiac function in obese adolescents. Ten lean adolescent counterparts were used as a healthy control to which the obese HIIT treatment group were compared. Cardiac function was measured using echocardiography and was seen to be restored to normal function in the obese group after exercise treatment. Interestingly, aerobic fitness and BMI did not significantly improve after the HIIT intervention and were -36.3% and 62.7% different from the lean group, respectively. Nutritional information was not collected; therefore, the effects of diet on body measurements cannot be accounted for. The study acknowledges that the study uses a small sample size (n=20) and that a larger multicentre study must be conducted to verify the results. Also, it is necessary to compare the efficacy of other HIIT protocols on cardiac function and metabolic control.

Table 8: Blood glucose and insulin measures

Study	Measured outcome	Baseline HIIT (mean ± SD)	HIIT (% change from baseline)	Control (% change from baseline)	Between-group difference (%)	Between-group p-value
Buchan et al. [108]	Fasting glucose ($mmol.L^{-1}$)	4.7 ± 1.3	-9.0	2.1	-10.9	-
Buchan et al. [94]	Fasting glucose ($mmol.L^{-1}$)	4.9 ± 1.3	2.0	4.0	-1.9	N.S.
Corte de Araujo et al. [100]	Fasting glucose ($mmol.L^{-1}$)	92 ± 6	-3.3	-4.3	1.1	-
Racil et al. [103]	Fasting glucose ($mmol.L^{-1}$)	4.6 ± 0.5	-2.2	-2.2	0.0	N.S.
Thackray et al. [104]	Fasting glucose ($mmol.L^{-1}$)		-	-	-1.3	-
Tjonna et al. [93]	Fasting glucose ($mmol.L^{-1}$)	5.2 ± 0.4	-5.8**	-2.0*	-3.9	N.S.
Tjonna et al. [93]	2 h post-glucose load ($mmol.L^{-1}$)	6.3 ± 1.5	-11.6*	-5.1	-6.8	N.S.
Corte de Araujo et al. [100]	HbA_{1c} (%)	5 ± 0	0.0	0.0	0.0	-
Tjonna et al. [93]	HbA_{1c} (%)	5.8 ± 0.2	-2.4**	-2.3**	-0.2	N.S.
Corte de Araujo et al. [100]	HOMA	5 ± 3	-40.0*	-40.0*	0.0	-
Racil et al. [103]	HOMA-IR	4.4 ± 0.7	-29.5*	18.2*	-13.9	N.S.
Tjonna et al. [93]	HOMA (%S)	42.1 ± 26.3	56.8*	24.9*	25.5	N.S.
Buchan et al. [108]	Fasting insulin ($\mu IU.mL^{-1}$)	5.2 ± 3.3	112.2	-66.6*	534.6	-
Buchan et al. [94]	Fasting insulin ($\mu IU.mL^{-1}$)	7.9 ± 7.5	7.6	-20.5	35.4	N.S.
Corte de Araujo et al. [100]	Fasting insulin ($\mu g.mL^{-1}$)	21 ± 9	-28.6*	-27.3*	-1.8	-
Racil et al. [103]	Fasting insulin ($\mu g.mL^{-1}$)	21.3 ± 2.4	-27.2*	-17.9*	-11.4*	$p < 0.05$
Thackray et al. [104]	Fasting insulin ($\mu g.mL^{-1}$)		-	-	-2.3	-
Tjonna et al. [93]	Fasting insulin ($\mu g.mL^{-1}$)	186.4 ± 134	-29.1*	-19.1	-12.4	N.S.
Tjonna et al. [93]	Insulin (2 h glucose load) ($\mu g.mL^{-1}$)	634.7 ± 558	-27.3*	-41.4*	24.0	N.S.

Significantly different from baseline (*$p < 0.05$, ** $p < 0.01$); - = not stated; HIIT = high-intensity interval training; HbA_{1c} = glycosylated haemoglobin; HOMA = homeostasis model assessment; -IR = for insulin resistance; N.S. = not statistically significant; %S = percentage sensitivity

Where Tjonna et al. [93] compared physiological effects of HIIT to a multi-treatment programme and Ingul et al. [101] to a lean control group, Buchan et al. [108] investigated the differences between HIIT and traditionally advised moderate intensity exercise in healthy adolescents. This is an important comparison, needed in order to provide evidence-based support for HIIT as an alternative to current exercise guidelines. A total of 57 youths were randomly assigned to a HIIT, moderate intensity aerobic exercise or a passive control group. Sexual maturation was accounted for using the self-reported Tanner criteria for pubic hair development. Diet was reported using a self-reported food diary and a food frequency questionnaire, and nutrition was further analysed using computer software. Free-living physical activity was also accounted for using the seven-day physical activity questionnaire for adolescents (PAQ-A). The HIIT group completed four to six repeats of maximal sprint running within a 20-metre area lasting 30 seconds, interspersed with 30-second rest periods between bouts. The moderate exercise group performed a single 20-minute bout of steady state running at 70% VO_{2max}. Both groups significantly improved several metabolic conditions from baseline, though greater mean percentage differences in improvements were observed between groups in aerobic fitness (14.6%), percentage body fat (15.1%), fasting plasma insulin (534.6%), fibrinogen (32.5%), and plasminogen activator inhibitor-1 (PAI-1) (2.0%) concentrations in favour of moderate exercise. Though the extent of cardio-metabolic benefits were not as great, the HIIT group was able to improve their cardiovascular risk in 15% of the overall time the moderate exercise group took to achieve similar benefits over the 7-week period; those following the HIIT protocol spent a maximum of 42 minutes exercising in total over the intervention period, whereas the continuous exercise group spent a total of 7 hours exercising, thus emphasising the time efficiency aspect of HIIT.

In a study using a similar HIIT protocol, Buchan et al. [97] saw improvements in aerobic fitness after 7 weeks of HIIT intervention when compared with an active control group in a healthy cohort of adolescents. Participants completed PAQ-A questionnaires to account for their physical activity, however diet and sexual maturation were not considered in this study. Traditional markers of cardiovascular disease such as BMI, waist-hip ratio, percentage body fat and aerobic fitness capacity were measured. Again, significant changes in measures other than aerobic fitness were not seen in this healthy adolescent study group. Whilst low cardiorespiratory fitness is a strong predictor of cardiovascular morbidity and mortality, more detailed cardio-metabolic markers are likely to give a clearer understanding of the health benefits of HIIT [109].

The most recent study by Buchan et al. [94] sought to investigate the effects of HIIT on cardio-metabolic risk profile in healthy Scottish adolescents. Participants completed PAQ-A to account for free living physical activity over the intervention period, as well as self-reported dietary diaries and food frequency questionnaires. Sexual maturation was considered using the Tanner stage scale. Again, using the same HIIT protocol as in their previous studies, participants were randomly assigned to the HIIT intervention group or to an active control group and had anthropometric, metabolic and inflammatory measures taken both before and after intervention. Contrary to the investigators' hypothesis, there were no significant differences in any of the nine metabolic blood sample measures between the experimental and control groups, although HIIT was observed to be an effective strategy to enhance aerobic fitness in the adolescent cohort, a factor which has been strongly associated with reduced cardiovascular risk in youth [110]. It is unsurprising that limited differences between control and intervention groups occurred as the participants were recruited from physical education (PE) classes. It was recognised that a 7-week trial may be too short a period to see significant reductions in cardiovascular risk profile in healthy subjects and the investigators recommended that future studies include a longer-duration intervention. The three studies by Buchan et al. [94,97,108] show that cardio-metabolic improvements occur with HIIT in healthy individuals; however, the subjects volunteered from a PE class and so both exercise groups and control groups were likely to have been physically active both in school and leisure time. It is therefore possible that health benefits were also achieved through physical activity externally from the experimental protocol. A degree of self-selection is likely to have occurred: these youth may have chosen to participate in school PE classes, whereas sedentary, inactive adolescents are likely to avoid school-based activity [111]. Sampling from a PE class is therefore not representative of population level adolescents and recruitment from different schools and classes is likely to provide a more accurate picture regarding the health benefits of HIIT to the general population. Future study should seek to find the potential benefits of HIIT to a low-active adolescent cohort. Inactive youth are likely to show a greater degree of cardio-metabolic improvement from baseline than active individuals using HIIT [112].

Table 9: Blood lipid measures

Study	Measured outcome	Baseline HIIT (mean ± SD)	HIIT (% change from baseline)	Control (% change from baseline)	Between-group difference (%)	Between-group p-value
Buchan et al. [108]	Adiponectin ($ng.mL^{-1}$)	8633 ± 699	-51.1**	-13.0	-42.8	-
Buchan et al. [94]	Adiponectin ($ng.mL^{-1}$)	9.4 ± 6.1	-19.1	-8.6	-11.5	-
Racil et al. [103]	Adiponectin ($ng.mL^{-1}$)	7.4 ± 1.5	33.8*	14.9*	16.4	N.S.
Tjonna et al. [93]	Adiponectin ($ng.mL^{-1}$)	6.5 ± 1.3	27.4	19.3	6.8	-
Buchan et al. [108]	HDL ($mmol.L^{-1}$)	1.5 ± 0.5	20.4	6.3	13.3	-
Buchan et al. [94]	HDL ($mmol.L^{-1}$)	1.4 ± 0.3	28.6	21.4	5.9	N.S.
Corte de Araujo et al. [100]	HDL ($mg.dL^{-1}$)	43 ± 6	7.0	7.0	0.0	-
Koubaa et al. [102]	HDL ($mmol.L^{-1}$)	0.99 ± 0.04	4.0*	15.5**	-9.9	-
Racil et al. [103]	HDL ($mmol.L^{-1}$)	1.02 ± 0.06	5.9*	7.9*	-1.9	N.S.
Tjonna et al. [93]	HDL ($mmol.L^{-1}$)	1.13 ± 0.29	9.7	-7.3	18.4	-
Corte de Araujo et al. [100]	Leptin ($mg.dL^{-1}$)	47 ± 14	-8.5	-16.3	9.3	-
Buchan et al. [108]	LDL ($mmol.L^{-1}$)	1.9 ± 0.8	-24.1	-10.9	-14.8	-
Buchan et al. [94]	LDL ($mmol.L^{-1}$)	2.5 ± 1.5	-40.0*	-39.3**	-1.2	N.S.
Corte de Araujo et al. [100]	LDL ($mg.dL^{-1}$)	102 ± 24	2.0	6.4	-4.2	-
Koubaa et al. [102]	LDL ($mmol.L^{-1}$)	2.8 ± 0.2	-1.8	-5.9	4.4	-
Racil et al. [103]	LDL ($mmol.L^{-1}$)	2.5 ± 0.3	-12.4**	-7.9*	-4.9*	$p < 0.01$
Tjonna et al. [93]	Oxidised LDL ($mmol.L^{-1}$)	34.2 ± 10.5	1.8	7.4	-5.2	-
Buchan et al. [108]	Total cholesterol ($mmol.L^{-1}$)	3.8 ± 1.4	3.1	-3.4	6.8	-
Buchan et al. [94]	Total cholesterol ($mmol.L^{-1}$)	4.5 ± 1.8	-15.6	-16.7*	1.3	N.S.
Corte de Araujo et al. [100]	Total cholesterol ($mg.dL^{-1}$)	156 ± 26	0.6	5.1	-9.7	-
Koubaa et al. [102]	Total cholesterol ($mmol.L^{-1}$)	4.4 ± 0.1	-1.1	-5.1	0.0	-
Racil et al. [103]	Total cholesterol ($mmol.L^{-1}$)	3.8 ± 0.3	-7.1*	-3.7	-3.5*	$p < 0.05$
Buchan et al. [108]	TAG ($mmol.L^{-1}$)	0.8 ± 0.3	64.9**	43.2*	15.2	-
Buchan et al. [94]	TAG ($mmol.L^{-1}$)	1 ± 0.3	10.0	10.0	0.0	N.S.
Corte de Araujo et al. [100]	TAG ($mg.dL^{-1}$)	93 ± 25	-9.7	0.0	-9.7	-
Koubaa et al. [102]	TAG ($mmol.L^{-1}$)	1.4 ± 0.2	-5.9*	-5.1	-0.9	-

Study	Measured outcome	Baseline HIIT (mean ± SD)	HIIT (% change from baseline)	Control (% change from baseline)	Between-group difference (%)	Between-group p-value
Racil et al. [103]	TAG (mmol.L^{-1})	1.4 ± 0.1	-7.1*	-2.2	-5.1	N.S.
Thackray et al. [104]	TAG (mmol.L^{-1})		-	-	-9.4	-
Tjonna et al. [93]	TAG (mmol.L^{-1})	1.3 ± 0.8	-11.2	-8.8	-2.6	-
Thackray et al. [104]	TAG (total area under the curve) (mmol.L^{-1})		-	-	-12.5	-
Corte de Araujo et al. [100]	VLDL (mg.dL^{-1})	19 ± 5	-10.5	5.6	-15.2	-

Significantly different from baseline (*p < 0.05,** p < 0.01); - = not stated; HIIT = high-intensity interval training; N.S. = not statistically significant; HDL = high density lipoprotein cholesterol; LDL = low density lipoprotein cholesterol; N.S. = not statistically significant; TAG = triacylglyceride; VLDL = very low density lipoprotein cholesterol

Following the work performed on cardio-metabolic parameters in youth, the health benefits of both HIIT and endurance training in obese Brazilian children aged 8-12 years old was examined [100]. Although not adolescent specific, the study involved youth in the later ages of childhood and included subjects at early stages of puberty, measured using the self-reported Tanner scale. Thirty children were randomly allocated to either a HIIT group or a SSE group and took part in exercise training for 12 weeks. The HIIT intervention involved up to six bouts of 60-second treadmill sprints at 100% peak velocity, interspersed with 3 minutes of active recovery, twice a week; endurance exercise involved a single bout of treadmill walking or running at 80% peak heart rate (HR) for 30 minutes (increased by 10 minutes after every 3 weeks). Diet was assessed at baseline and post intervention using 24-hour dietary recalls and subsequent energy and macronutrient intakes were analysed. Significant improvements in BMI and insulin sensitivity were observed in both exercise groups. Furthermore, between-group improvements favoured HIIT with respect to BMI (3.3%), insulinemia (1.8%) and systolic blood pressure (SBP) (7.8%). In spite of a lack of statistical significance, there was a 9.7% greater improvement in triacylglycerol (TAG) with HIIT. Although there was no control group present in this study, this research provides worthy comparisons of traditionally recommended moderate exercise with HIIT in a young cohort. Those in the HIIT group undertook a maximum of 144 minutes at high intensity exercise, whereas those in the continuous exercise group completed 360 minutes of moderate exercise, thus cardio-metabolic risk factors were improved to a similar or greater extent in 40% of the time. The researchers did not include a control as it was deemed unethical to have children recruited from a medical hospital refrain from first line exercise treatment. It remains to be seen whether HIIT confers more long-term adherence benefits and consequent health outcomes in youth when compared with SSE and so warrants further study.

Recently, Cockcroft et al. [99] investigated the acute metabolic response of HIIT and a work-matched bout of SSE in healthy adolescent boys. In a within-measures crossover design, nine boys completed HIIT, SSE and acted as a passive control on three separate occasions. HIIT was performed on a cycle ergometer at 90% of peak power for eight bouts lasting one-minute, interspersed with low-intensity recovery for 1.25 minutes. The SSE work intensity was calculated at 90% of the gas exchange threshold for each participant and the mechanical work done during HIIT determined overall duration. Work duration during HIIT was 8 minutes, whilst SSE lasted 22.8 minutes. Results from a post-exercise oral glucose tolerance test (OGTT) revealed that the improvements in glucose tolerance and insulin sensitivity were similar after HIIT and SSE. Interestingly, participants also found both exercise protocols to be equally enjoyable according their physical activity enjoyment scale score despite HIIT eliciting greater physiological and perceptual stress, which may have implications for long-term exercise adherence.

Elevated postprandial TAG in the blood has been associated with increased development of atherosclerosis. Recently, a study sought to investigate the effects of HIIT on postprandial TAG using fifteen healthy 11-12 year old males [104]. Subjects were randomly recruited to a control group or undertook a single session of HIIT comprising of 10 bouts of 1-minute 100% maximal aerobic speed treadmill runs interspersed with 1-minute active recovery between bouts. After the HIIT session, participants ate an evening meal. The following day, capillary blood samples were taken in the fasted state and following a high fat breakfast. The test was repeated after 14 days with those previously assigned to the control group undertaking HIIT and vice versa. All participants recorded their dietary intake and physical activity during the 48-hour period before the first experimental condition, having been asked to minimise their physical activity during this period. A single session of HIIT performed the day before standardised test meals attenuated postprandial plasma TAG concentrations by 12.5%, likely indicating an acute increased skeletal muscle lipoprotein lipase activity mediated through an increase in insulin sensitivity and reduction in plasma insulin. A limitation to this study was a lack of comparison between HIIT with moderate-intensity exercise.

Future study should seek to determine the difference in postprandial TAG between these two exercise intensities and also the accumulative effects of more than one session of HIIT on postprandial lipemia in the adolescent age group.

Table 10: Inflammatory markers

Study	Measured outcome	Baseline HIIT (mean ± SD)	HIIT (% change from baseline)	Control (% change from baseline)	Between-group difference (%)	Between-group p-value
Buchan et al. [108]	CRP ($mg.L^{-1}$)	1.4 ± 0.6	34.1	33.8	0.2	-
Buchan et al. [94]	CRP ($mg.L^{-1}$)	1.3 ± 1.2	23.1	0.0	7.7	N.S.
Buchan et al. [108]	Fibrinogen ($mg.dL^{-1}$)	119.5 ± 105.7	-17.5	37.7*	32.5	-
Buchan et al. [108]	IL-6 ($pg.ml^{-1}$)	3.8 ± 5.9	-36.2	-5.0	-32.9	-
Buchan et al. [94]	IL-6 ($pg.ml^{-1}$)	3.4 ± 4.1	-14.7	2.6	-16.9	N.S.
Buchan et al. [108]	PAI-1($ng.ml^{-1}$)	19.8 ± 9	-51.0	-50.0*	-2.0	-

Significantly different from baseline (*$p < 0.05$, ** $p < 0.01$); - = not stated; HIIT = high-intensity interval training; CRP = C-reactive protein; IL-6 = interleukin-6; N.S. = not statistically significant; PAI-1 = plasminogen activator inhibitor-1

Duration-matched interval bouts of moderate and high intensity on cardio-metabolic risk markers in obese female adolescents were recently investigated in Tunisia [103]. This research is unique, in that the protocol for high- and moderate-intensity interval training (MIIT) was the same in both intervention groups for all parameters except for the intensity of exercise bout. The HIIT group initially performed two blocks consisting of six bouts of 30-second sprints at 100% maximal aerobic speed with 30 seconds active recovery between bouts at 50% peak velocity. Between the two blocks there was a 4-minute passive rest period. This training was undertaken three days per week for 12 weeks. The MIIT followed the same training structure, except running bouts were performed at 70% peak velocity. A non-exercising control group was also present in the study. The study participants carried out 4-day dietary records; subsequently, daily energy intake and nutrient composition were established. Within groups, significant improvements were observed in BMI-z score, aerobic fitness and cardio-metabolic risk markers in both exercise intensities. HIIT provided significantly greater benefits in plasma low-density lipoprotein cholesterol (LDL) (4.9%) and total cholesterol (3.5%) than equivalent duration moderate intermittent exercise, with an additional 13.9%

improved insulin sensitivity using homeostasis model assessment of insulin resistance (HOMA-IR). Fasting insulin levels post-HIIT were significantly lower than in MIIT (11.4%), suggesting an increased insulin sensitivity with exercise intensity. Percentage body fat and BMI-z score were significantly lesser (2.7% and 4.6% respectively) following HIIT compared with MIIT. Increased insulin sensitivity is likely to mediate a reduction in plasma TAG through decreasing plasma insulin concentrations, which increase the availability of fat for utilisation as an energy substrate. The intricate hormonal response of insulin to exercise is a key mechanism in the regulation of energy storage and utilisation, thus the improvements in insulin sensitivity are likely to have influenced the body fat reduction observed with increased exercise intensity [113]. The authors encourage future research to optimise the HIIT protocol for health benefits to occur and to investigate its effects on motivation and perceived enjoyment.

Another recent study [102] investigated metabolic risk factors after intermittent interval training and continuous exercise bouts in obese Tunisian male adolescents over a 12-week period. The intermittent protocol consisted of 2-minute sprints at 80% VO_{2max} with 1-minute recovery periods. Sprint intensity was increased by 5% of the participant's VO_{2max} after every 4 weeks. The study does not reveal how many sprints were repeated in one session, nor the nature of the recovery period (i.e. passive/active recovery). The continuous exercise group were asked to run for 30-40 minutes at 60-70% VO_{2max} in one single session, three times weekly. Primary outcomes were body composition, aerobic fitness and blood lipid profiles. Dietary assessment was not performed on any of the study participants. Both exercise groups significantly decreased their body fat, though there was a 10.1% greater fat mass reduction and 4.1% greater waist circumference reduction in the SSE group than the intermittent group. Interestingly, blood lipid profile favoured the continuous exercise group, with very large standardised effect differences in HDL, though significant reductions in TAG were only observed after HIIT exercise intervention. In line with the majority of HIIT versus SSE studies, the greatest improvements from HIIT were in aerobic fitness. Unfortunately, the researchers have not revealed the total single-session duration of HIIT; therefore parallels cannot be directly drawn between each training mode's exercise duration and cardio-metabolic risk. Further, it may be possible that the HIIT group did not participate in exercise of high enough intensity to induce metabolic benefits as seen in other adolescent HIIT studies critiqued in this review. The researchers conclude that a mixture of continuous and intermittent exercise may produce the best results in cardio-metabolic health. Whilst this may indeed be true, a main attraction of HIIT is its perception of time-efficiency, which may be diluted if combined with SSE and so may affect exercise adherence.

5.6 Discussion

Initial research has established promising reductions in cardio-metabolic risk factors using HIIT in the adolescent age group, supporting short bouts of high-intensity exercise as an alternative approach to achieve the health benefits of physical activity in this cohort. Improvements in aerobic fitness, insulin sensitivity, adiponectin, HDL and reductions in BMI, percentage body fat, systolic blood pressure, waist circumference, fasting plasma glucose and insulin, LDL, and TAG were common themes throughout the reviewed literature. Further, aerobic fitness, insulin sensitivity, fasting plasma insulin, TAG and adiponectin were improved to a greater extent with HIIT than moderate intensity SSE; yet it is inconclusive as to whether HIIT provides greater changes in BMI, percentage body fat, waist circumference, fasting plasma glucose and HDL than comparable SSE in adolescents. Where these studies compared cardio-metabolic risk factors post intervention for HIIT against SSE, there was a large discrepancy in the total duration spent in each exercise protocol. Thus, HIIT delivers similar or greater benefits to the cardio-metabolic profile than SSE in adolescents after a much shorter total duration of exercise.

5.6.1 HIIT enjoyment

An important influence on physical activity adherence is the level of perceived exercise enjoyment. Few HIIT studies have quantified enjoyment, especially in youth, though research performed on adults has observed HIIT as a more enjoyable exercise modality than SSE protocols [114-118]. We have reviewed all child and adult studies identified in our literature search in an attempt to form an impression of the level of enjoyment adolescents may experience with HIIT.

Anecdotal comments in studies where enjoyment was not a main focus have also noted greater enjoyment with HIIT [93,119]. In recognition of the potential associations of HIIT enjoyment and adherence, a recent study [115] directly asked overweight and obese men ‘‘how enjoyable would it be for you to do high intensity interval training 3 days per week?’’. Participants scored highly for intention to implement HIIT after completion of the study as rated on a 7-point Likert scale, supporting preliminary reports of HIIT enjoyment. Little et al. [114] also used a 9-point Likert scale for subjective assessment of HIIT enjoyment in their study on a type 2 diabetic adult cohort that primarily investigated exercise effects on hyperglycaemia and muscle mitochondrial capacity. Although there was no comparative control group, HIIT enjoyment was rated highly; however, there was no speculation on the influences of enjoyment on adherence.

Three HIIT studies have been conducted where enjoyment was the primary measure. Bartlett et al. [116] conducted a randomised crossover design study involving eight healthy, active men assigned to either a HIIT group or a moderate exercise (SSE) group. The HIIT group undertook six bouts of 3-minute runs at 90% VO_{2max}, the SSE group ran for 50 minutes at 70% VO_{2max}. After 7 days, participants completed the opposite training protocol. Using the seven-point bipolar Physical Activity Enjoyment Scale (PACES), perceived enjoyment was measured immediately after exercise [120]. Significantly greater enjoyment was experienced in the HIIT group compared to the moderate exercise group ($p = 0.004$). The results from this study cannot be directly translated to youth, though do provide promising implications for adolescent HIIT enjoyment. In agreement with these findings, Jung et al. [118] observed greater enjoyment from HIIT than both 30 and 60 minutes of continuous exercise in four type 2 diabetic subjects. Prior to intervention, subjects perceived 30 minute SSE as being more enjoyable, however after 2-weeks of exercise training, HIIT was rated most enjoyable of the three forms of activity, as was self-efficacy to perform HIIT. Interestingly, a study [117] related the perceived enjoyment of three exercise protocols to the intention to implement the exercise for two days per week but did not observe significant differences between HIIT and SSE. The study was performed on 11 young adults. Enjoyment and implementation intentions were both rated on a scale from one (low) to seven (high) and emotional state was measured on a 10-point scale. Both HIIT and SSE were rated significantly higher than MIIT, and were correlated with the emotional response midway through the exercise protocol. Longer duration studies using larger numbers of participants must be performed to more accurately assess the differences in enjoyment between HIIT and SSE.

When investigating the effects of adding sprints to continuous moderate exercise, Crisp et al. [92] did not observe any significant improvement in PACES with increasing exercise intensity, though higher intensity exercise was reported to be more enjoyable. The 8-12 year old participants were involved in either continuous light-to-moderate exercise, cycling at 40-50% VO_{2max} or exercised at the same intensity interspersed with 4-second sprints every 2 minutes. Whilst this protocol contains intermittent sprinting, the total duration of activity is matched to the continuous exercise group, thus it is longer in total exercise duration than other HIIT protocols. However, the researchers state that the protocol is reflective of child physical activity behaviour. It was noted that all those who were of normal weight, and all but two of those overweight, enjoyed the intermittent protocol more than the continuous training. A partial explanation as to why it was less enjoyable in the overweight cohort may be because the sprint protocol used in this study is not reflective of other HIIT studies, containing longer duration aerobic element. This study is the first to explore enjoyment of HIIT in youth. Adolescents are likely to be hedonistically motivated to participate in exercise, thus increasing the perception of exercise enjoyment through the use of HIIT may target intrinsic motivation, however insufficient literature confounds our ability to draw conclusions. There is scope for research to examine HIIT palatability in the adolescent cohort through investigating perceived enjoyment during and after exercise.

5.7 Summary

Future study must examine the effects of various HIIT protocols to determine the optimum strategy to deliver cardio-metabolic health benefits. Also, the minimum duration and frequency of HIIT bout must be determined if it is to be used as an alternative to current physical activity recommendations. In order for this to happen, literature must state both the duration of exercise and rest bouts as well as total session duration. Clearly stating the total duration of activity undertaken in in the intervention, without reader extrapolation, is essential as time efficiency is of key interest regarding HIIT. It is of great importance to determine the duration in which health benefits occur with HIIT, especially when compared with longer duration SSE. Exercise intensity measures must also be stated and easily translated to practice by the subjects. Intensity and bout-duration cut-offs must also be agreed upon to develop a clear definition as to what constitutes HIIT.

Research practitioners should explicitly show between-group differences for HIIT intervention and SSE or control groups, as the magnitude of difference of HIIT to other exercise modalities is of key interest in public health. To further understand the effect of HIIT on the metabolic condition, using a suite of cardio-metabolic measures is recommended. Diet and physical activity undertaken beyond the exercise intervention must also be accounted for to eliminate confounding metabolic variables. Further, research must be performed on inactive and overweight/obese adolescents and those at high metabolic risk of developing chronic diseases. In addition, study must seek to quantify the impact of HIIT on the full age spectrum of adolescents, ideally accounting for the gender differences and hormonal implications of puberty on metabolism. The perceived enjoyment of exercise youth feel is integral to our understanding of whether HIIT has potential for long-term exercise adherence.

Effective protocols used to improve the metabolic profile in adolescents include: four to six repeats of 30-second sprints interspersed with 30-second rest bouts [94,108]; four repeated runs at 90% maximum heart rate with 3 minutes of active recovery between bouts [93]; six repeats of 60-second sprints at 100% peak velocity interspersed with 3 minutes of active recovery between bouts [100]; 10 repeats of 60-second sprints at maximal aerobic speed with 60 seconds of active recovery between bouts [104] and two blocks consisting of six bouts of 30-second sprints at 100% maximal aerobic speed with 30 seconds active recovery between bouts [103]. Future studies and practitioners may choose to adapt these effective protocols or create new training programmes for youth. The paucity of literature concerning HIIT in adolescence thus far leaves prospective research to further our understanding of its effects on the metabolic condition and perceived enjoyment of exercise.

Chapter 6 - Low-active male adolescents: A dose-response to high-intensity interval training

6.1 Preface

Paucity in the literature exposed in Chapter 5 gave opportunity to investigate the dose-response relationship of HIIT with cardio-metabolic risk factors in adolescents. The current chapter is specifically concerned with delivering an 8-week HIIT intervention to determine the efficacy of incremental HIIT doses on the cardio-metabolic health of low-active male adolescents. Males were chosen for the exercise intervention study for several reasons: firstly, the influence of hormonal fluctuations on the measured metabolic variables would be minimised; secondly, maximising the homogeneity of the study cohort was appropriate for the study design; and finally, the candidate had an invested interest in male health. Low-active individuals were identified to participate, since it is of key interest to investigate HIIT as an alternative to the steady-state exercise (SSE) that youth are exposed to through current public health recommendations.

Another important variable that we wished to explore was the environment in which the exercise was performed. Undertaking the exercise intervention in a school environment (i.e. the use of a real-world setting) allowed for increased translatability of research. The investigation into training adaptations elicited by HIIT have primarily been conducted under laboratory conditions; however, it essential to understand the efficacy of HIIT on adolescent health outside of a closely controlled environment. The manuscript resulting from this chapter has been published in the peer-reviewed journal Medicine & Science in Sport & Exercise.

6.2 Abstract

Background: High-intensity interval training (HIIT) is a potential alternative to traditionally recommended steady state exercise for providing health benefits in adolescents, yet its dose-response relationship in this cohort remains unclear, as does its translatability to real-world, non-clinical settings. The present study adopts a novel dose-response design to investigate the effects of undertaking 8 weeks of HIIT on the cardio-metabolic health of low-active male adolescents.

Methods: Twenty-six male adolescents (age 16 ± 1 years), identified as low-active by non-participation in structured sport and physical education classes, were randomly assigned to one of five treatment groups. Corresponding with their group numbers (1-5), participants completed a number of HIIT 'sets' which consisted of 4 repeated bouts of 20 seconds of near-maximal exertion interspersed with 10 seconds of passive recovery. Participants performed two HIIT sessions and one resistance training session each week for 8 weeks. Baseline and follow-up health measures consisted of VO_{2peak} with an incremental ramp test to volitional exhaustion, body composition (including visceral fat mass, body fat and lean tissue mass) with dual-energy X-ray absorptiometry, and lipid profile, glucose, insulin, and interleukin-6 from blood analysis. All health outcomes were analysed as percentage changes and data were modelled using a quadratic function to explore dose-response relationships.

Results: Significant improvements were observed for VO_{2peak} (~6%), body fat percentage (~4%), visceral fat mass (~10%), and waist circumference-to-height ratio (~3%), but there was no clear effect of dose across groups.

Conclusions: Low-active adolescent males performing a single HIIT set twice-weekly, in addition to one resistance training session, gained meaningful improvements in fitness and body composition. Performing additional HIIT sets provided no additional improvements to those of the lowest dose in this study.

6.3 Introduction

The development of healthy lifestyle behaviours, including physical activity, typically begin in childhood and continue into adulthood [1,2]. Preventing the decline of physical activity throughout youth is of key importance in reducing the development of chronic cardio-metabolic diseases such as type 2 diabetes, metabolic syndrome, cardiovascular disease and obesity [25,121]. Public health guidelines suggest that children and adolescents undertake at least 60 minutes of MVPA each day to achieve health benefits [10]; however, more than 80% of adolescents globally fail to achieve this recommended threshold of activity [9]. Given that adolescents report difficulty starting and adhering to traditional exercise programs [8], there is a need to explore and develop engaging alternatives for youth to achieve the many health benefits related to regular physical activity.

Recent research has indicated that vigorous intensity activity may drive the inverse association between physical activity and cardio-metabolic risk factors [12,16]. Therefore higher intensity activities performed in short repeated bouts, interspersed with periods of recovery, may be an achievable and enjoyable alternative to high-volume continuous exercise for adolescents [122]. Adopted as a time-efficient method of achieving the health benefits of physical activity, HIIT has become a popular alternative to the traditionally recommended steady-state aerobic exercise [84]. The majority of HIIT research has been conducted using adults, but it is widely accepted as an exercise model effective in improving aerobic fitness, body composition, insulin sensitivity, blood lipid profile, blood pressure and cardiovascular function [88,123,124]. Research studying the efficacy of HIIT on the health-related outcomes of adolescence, however, has been limited, although initial studies indicate similar or superior health benefits using HIIT when compared with continuous aerobic exercise [122,125].

Conventionally, HIIT research has been performed in laboratory settings, but to fully investigate its efficacy as an alternative to currently recommended exercise it should also be considered in a real-world setting. Recently, Buchan et al. [94] reported the efficacy of HIIT on the health and fitness of healthy Scottish adolescents when performed in school physical education (PE) classes. Whilst it is of interest to understand the feasibility and efficacy of HIIT during PE, it important to understand the effects of HIIT on the health of low-active youth who are disengaged from PE, structured sports and extracurricular physical activity. Our research adopts the approach of using a non-clinical, school-based setting for inactive adolescents to undertake HIIT outside of PE class.

In view of the uncertainty of the quantity of HIIT needed to improve inactive adolescents' cardio-metabolic health, our research attempts to establish a dose-response relationship for the first time. To investigate the efficacy of different treatments, the conventional approach is to conduct a repeated-measures crossover study, whereby each study participant receives all treatments or doses. This study design is impractical when considering many health outcomes, as exercise interventions produce long-lasting effects, thus preventing subjects from receiving more than one treatment [20]. In the current study we have addressed this issue by adopting the novel dose-response design reported by Stepto et al. [19] and Barnes et al. [20]. Using this study design, participants receive only one treatment and individual responses are plotted with the overall dose-response effect represented as a quadratic function.

To our knowledge no study has yet investigated the dose-response of HIIT on the health of adolescents, hence the purpose of this study was to investigate the efficacy of incremental doses of HIIT on inactive adolescents' health related outcomes after an 8-week school-based exercise intervention. We hypothesise that increasing the dose of HIIT, through the addition of exercise sets (or intervals), will elicit a greater benefit in several key health outcomes in low-active male adolescents.

6.4 Methods

6.4.1 Participants

The present study involved three recruitment and three 8-week intervention phases from two secondary schools in Auckland, New Zealand, and was conducted between July 2014 and June 2015. After approval from the institution ethics advisory committee, male students were recruited from school years 11, 12 and 13. For these school years PE classes are not compulsory for students. Individuals were eligible to participate provided they were males aged 12-18 years, did not take PE, were not involved in extracurricular structured-sport and were identified as disengaged with physical activity by school teaching staff. Students were unable to participate if they had any diagnosed metabolic, hormonal, orthopaedic or cardiovascular condition. An information session was delivered by the researchers, whereby students were informed on the design and aims of the study. All participants and their guardian(s) provided written informed assent and consent, respectively.

6.4.2 Experimental design

A pre–post parallel-groups design was adopted, with an exercise intervention period lasting 8 weeks. Prior to the intervention, participants' baseline measures were taken on three separate occasions separated by one day. The first testing session involved blood sample collection; secondly a peak oxygen uptake (VO_{2peak}) test was performed; and finally dual-energy X-ray absorptiometry (DXA) and anthropometry was carried out. Three days after the completion of the final training session, each participant repeated the same set of tests in the same order as pre-intervention testing.

6.4.3 Blood analysis

Blood samples were collected through venipuncture of the anticubital vein after a 12-hour fasting period. Serum was isolated by centrifugation at 1500 rcf at 4°C for 10 minutes and subsequently frozen at -80°C within two hours of collection. Analysis was completed within three months of collection. Fasting glucose, insulin, triglyceride (TG), high-density lipoprotein cholesterol (HDL), low-density lipoprotein cholesterol (LDL), and interleukin-6 (IL-6) were measured using specific assays on a Roche Modular E170 at Auckland University of Technology's Roche Diagnostic Laboratory. Homeostasis model assessment was used to estimate overall insulin sensitivity (HOMA2%S). Due to its clinical relevance as a marker to identify the development of cardiovascular disease in youth, TG/HDL ratio was calculated [126].

6.4.4 Testing of maximal oxygen uptake, blood pressure and maximal heart rate

Prior to exercise testing, blood pressure was measured twice after five minutes of rest in a sitting position using an automated monitor (Microlife BP A100, Microlife Corp., Taipei, Taiwan). Before testing, subjects were instructed that they were to exercise to their maximum limit. Participants undertook an incremental ramp test to volitional exhaustion on a bicycle ergometer (Lode Excalibur Sport, Lode, Groningen Netherlands) and expired gasses were measured continuously using a metabolic cart (ParvoMedics TrueOne 2400, Salt Lake City, UT, USA) for determination of VO_{2peak}. Heart rate was recorded every second throughout the test (Polar RS800sd, Polar Electro, Finland) and maximum heart rate (HR_{max}) was recorded at time of exhaustion. Rate of perceived exertion (RPE) was noted at the end of each minute during testing. A plateau of VO_2 despite an increased workload, a respiratory exchange ratio > 1.05, and an RPE of 20 were used as criteria for reaching the true VO_{2peak}; this was achieved by all individuals in the present study.

6.4.5 Anthropometry

Participants were initially measured for height on inspiration (± 0.1cm), weight (± 0.1kg) and waist circumference on expiration (± 1.0cm) using a standardized protocol. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared.

Participants wore light clothing and removed all jewellery to undergo whole-body DXA scanning (GE-Lunar iDXA, GE Healthcare, Madison, WI). GE-Lunar enCORE™ software (version 15) was used to determine body fat percentage, lean tissue mass and visceral fat mass [127].

6.4.6 Dietary registration and physical activity monitoring

Prior to the exercise intervention, participants were instructed not to modify their dietary or lifestyle behaviours other than when delivered during the intervention period. Daily dietary intake was estimated with a validated self-reported food frequency questionnaire [128], which listed food types and meals typical of a New Zealand diet, and was administered at baseline and follow-up screening. Leisure time physical activity was recorded 1 week prior to and 1 week after the 8-week exercise intervention. All participants wore an accelerometer (ActiGraph GT3X+) during waking hours for the duration of each week and the daily and total counts were registered. The average time spent in MVPA was calculated using cut points developed by Evenson et al. [51] at 1-second epochs. A valid day was classified as ≥8 hours of monitoring per day [41] and non-wear time was defined as ≥60 minutes of consecutive zeros [48]. All participants achieved the threshold of ≥4 days of valid monitoring [48].

6.4.7 Exercise intervention

During the course of the 8-week intervention period, all participants undertook three group-based exercise sessions each week, which consisted of two HIIT sessions and one resistance training session. Participants were scheduled to perform HIIT sessions on Mondays and Fridays, and resistance training sessions on Wednesdays to allow a period of 48 hours of recovery between sessions. There were frequent deviations from the schedule due to participant school commitments and aberrations in school timetabling; however, sessions were rescheduled to other days during the affected week and participants were ensured a minimum of 24 hours recovery between sessions. During intervention Phase 1, 12 sessions were rescheduled; in Phase 2, seven sessions were rescheduled; and in Phase 3, three sessions were rescheduled. All sessions were supervised by a New Zealand Registered Exercise Professional (NZREPs) and performed in the school gym during weekday lunch intervals. In order to deliver varying doses of HIIT, participants were randomly allocated to one of five exercise groups, determined by approximately even distribution of VO_{2peak} calculated from baseline testing.

The HIIT protocol used was an adaptation of that developed by Tabata et al. [129], and was favoured due to its short exercise bouts and brief overall duration [130]. Each 'set' consisted of four bouts of 'all-out' maximal exercise (90-100% HR_{max}) lasting 20 seconds, interspersed with 10 seconds of passive rest periods. Achieving the correct exercise intensity is a critical factor in HIIT, and given that the intervention was performed in a school setting, we ensured all participants scored an RPE of at least 18 and a minimum of 90% HR_{max} towards the end of each set for the entire 8-week trial. Heart rate was measured on completion of each set, due to a delay in HR response; that is, HR_{max} was achieved during the final exercise bout of each set. In addition to this, participants were informed of their own HR_{max} and aimed to reach it as a 'goal' at the end of each set.

Groups were rank-ordered 1-5 by their corresponding number of HIIT sets to complete, which presented a linear increase in HIIT dose (

Table 11). Individuals were notified that they were to undertake a different number of sets of HIIT based on their allocated exercise groups and all groups exercised simultaneously during the exercise sessions. Three-minutes of warm up and cool down (50-60% HR_{max}) were undertaken at the start and on completion of every exercise session. For groups completing more than one set, HIIT sets were separated by two-minute periods of passive recovery.

Table 11: Details of the five group exercise treatments (two HIIT sessions/week)

	Group 1 (n = 5)	Group 2 (n = 5)	Group 3 (n = 6)	Group 4 (n = 5)	Group 5 (n = 5)
No. of sets per session (4 x 20s work:10s rest)	1	2	3	4	5
HIIT protocol duration	1 min 50s	3 min 40s	5 min 30s	7 min 20s	9 min 10s
Total duration in HIIT over 8-weeks	29 min 20s	58 min 40s	88 min	117 min 20s	146 min 40s

To simulate how HIIT may be undertaken outside of a controlled laboratory setting, a mixed exercise modality approach was adopted, whereby participants elected their desired form of exercise before the session began. Participants had the choice of completing the training using a rowing machine, cycle ergometer, treadmill, cross-trainer, performing shuttle-runs, repeated box-jumps or by non-contact boxing. Those assigned to groups completing more than one set of HIIT were given the option of changing exercise modality for the following set. Participants were familiarised with the exercise protocol during the first week of training by completing one set of HIIT. Over the following sessions sets were incrementally increased until each group satisfied their required HIIT dosage.

In addition to HIIT, resistance training sessions were included in the exercise intervention for partial fulfilment of the current youth physical activity guidelines [131]. Supervised weight training was performed once weekly, consisting of simple, compound push, pull and squat/ lunge movements to target large muscle groups. During the familiarization phase, each participant completed a maximal repetition (1RM) test on a chest-press, seated row and leg press machine. Individual's 1RM were calculated and weights corresponding to 70% of participants' 1RM were assigned to each resistance machine. The overall resistance training volume was standardized for all participants. All participants performed three sets of 8-12 repetitions for each of the three compound push, pull and squat/ lunge movements, and the last repetition on the final set was performed to failure.

6.4.8 Statistical analysis

All statistical analyses were performed using SPSS version 22 (IBM Corporation, Armonk, NY). Simulations were performed to determine the sample size that would give an acceptable confidence interval for VO_{2peak}, predicted with a quadratic model. In these simulations, the training protocol was a variable that ranged from 1 for the shortest duration through to 5 for the longest duration. Data were generated that had no real polynomial effects, since data without effects need the largest sample sizes to define the magnitude of the effects with acceptable precision. With 25 subjects, an error of measurement for an individual's VO_{2peak} of 2%, and a quadratic model, the 95% confidence interval was acceptable.

To calculate the efficacy of each group's HIIT dose, all health outcome measures were analysed as percentage changes. The data were modelled as a quadratic function of the rank-ordered duration of the HIIT treatments to determine the dose-response relationship. Confidence intervals for the measures derived from the quadratic model were produced by bootstrapping (x 1000). Data were considered suitable for analysis since group means were not skewed, therefore bootstrapping was conducted. The difference in error between the bootstrapped and non-bootstrapped confidence intervals was minor, but bootstrapped intervals were preferred as they were considered to be nearer the true population estimates. Finally, in order to make conclusions about the overall efficacy of HIIT on each health variable, all five groups' data were combined. After the normality and homogeneity of the variance were confirmed, the dependent variables were compared at pre-intervention and post-intervention using paired Student's *t*-tests. The significance was set at $p < 0.05$. Each groups' standardized differences were utilised to determine effect size (0.1-0.3, small effect; 0.3-0.5, moderate effect; 0.5-0.7, large effect) [132].

6.5 Results

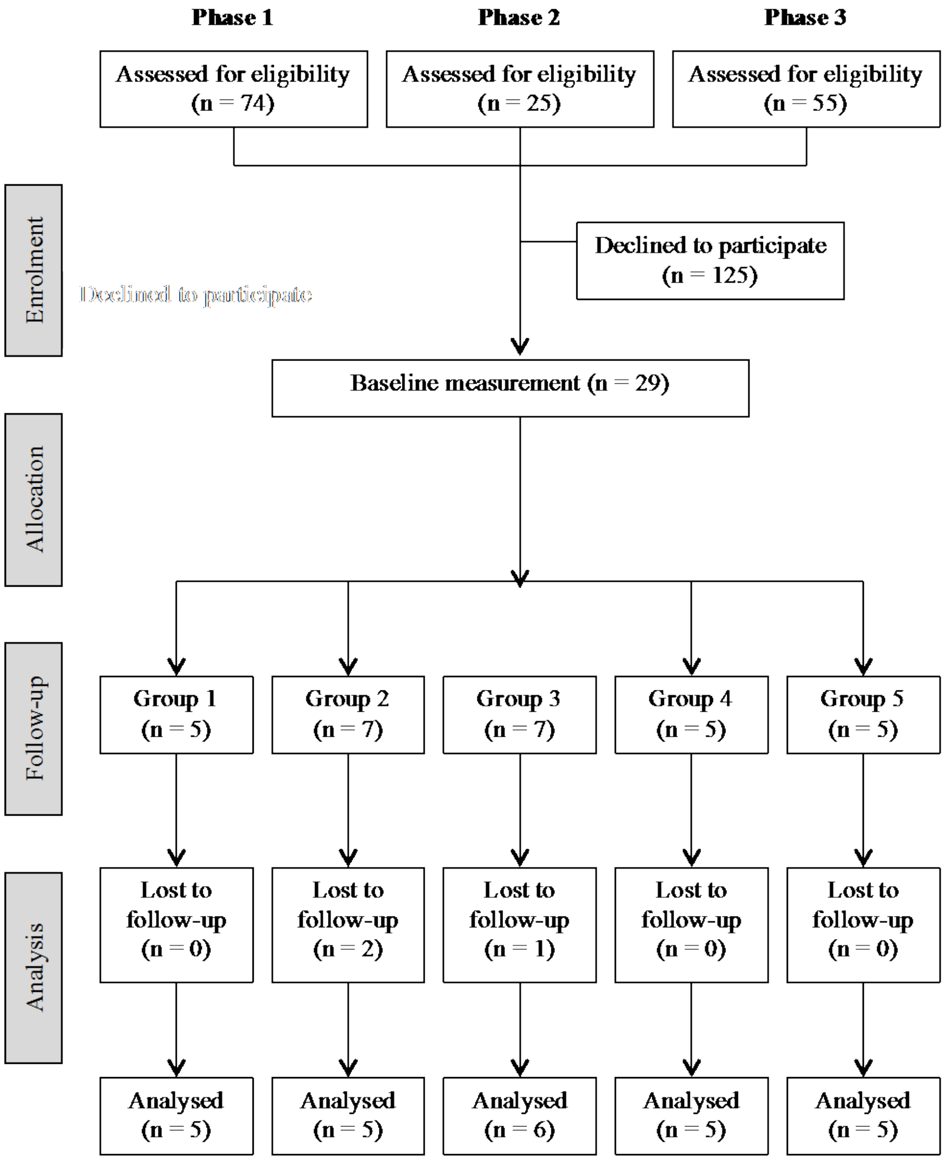


Figure 10: Participant recruitment and retention

Of the 154 eligible individuals identified, 29 agreed to participate (19% recruitment rate). Subjects' data were eligible for analysis provided they completed 85% of the exercise sessions. During the study, two participants withdrew and one failed to meet compliance due to illness. The flow of participants in the study is shown in Figure 10. As a result, data were valid for analysis for 26 participants (mean ± SD; age 16 ± 1 years, body mass 71 ± 17 kg, height 174 ± 7 cm, BMI 23 ± 5 kg·m^{-2}, body fat 25 ± 9%, VO_{2peak} 38.7 ± 7.4 mL·kg^{-1}·min^{-1}, systolic blood pressure [SBP] 130 ± 11 mmHg, diastolic blood pressure [DBP] 79 ± 8 mmHg). Heart rate responses to HIIT were recorded throughout the intervention and all groups achieved the desired intensity of ≥90% HRmax: mean %HRmax ± SD; Group 1, 93.6 ± 2.1; Group 2, 93.8 ± 2.6; Group

3, 93.9 ± 2.6; Group 4, 92.6 ± 1.6; 92.6 ± 0.9. No changes were observed in any of the participant’s diet or leisure time physical activity from baseline to the final week of intervention.

Table 12: Intervention effects on aerobic fitness, physical activity and anthropometric variables

Variable	Group	Baseline values	Mean percentage change		Overall mean pre-post comparison for all groups combined	
		median (min, max)	(bootstrapped 95% CL)		Effect size	p-value
VO_2peak (mL·kg^{-1}·min^{-1})	1	40.9 (29.7, 45.1)	5.0	(-1.34, 13.2)	0.29 (Small)	**p < 0.001**
	2	34.4 (28.8, 41.6)	7.0	(2.9, 11.9)		
	3	39.3 (27.0, 52.7)	3.4	(-1.9, 9.5)		
	4	33.8 (31.1, 52.4)	8.6	(3.9, 12.8)		
	5	40.3 (29.2, 49.7)	7.1	(2.5, 12.7)		
MVPA (min·day^{-1})	1	22 (13, 31)	0.7	(-7.9, 9.3)	<0.01 (Trivial)	p = 0.898
	2	11 (8, 33)	3.9	(-4.6, 12.5)		
	3	21 (13,42)	-3.4	(-8.8, 1.9)		
	4	24 (7, 30)	15.2	(-2.3, 32.8)		
	5	16 (6, 26)	7.7	(-9.3, 24.7)		
BMI (kg·m^{-2})	1	20 (18, 23)	-2.1	(-3.2, -1.1)	<0.01 (Trivial)	p = 0.649
	2	22 (19, 33)	0.9	(-1.1, 4.1)		
	3	25 (18, 30)	-0.1	(-2.5, 2.1)		
	4	23 (19, 35)	0.1	(-1.3, 1.6)		
	5	19 (18, 23)	0.9	(-0.3, 2.5)		
Body fat (%)	1	19 (12, 29)	-0.9	(-4.0, 2.3)	-0.11 (Small)	**p < 0.001**
	2	30 (16, 36)	-4.3	(-8.1, -0.4)		
	3	29 (14, 43)	-6.2	(-9.1, -4.2)		
	4	31 (16, 44)	-1.7	(-4.5, 2.0)		
	5	18 (15, 34)	-5.5	(-10.0, -0.3)		
Diastolic blood pressure (mmHg)	1	73 (62, 86)	0.8	(-5.4, 6.7)	-0.63 (Large)	**p < 0.001**
	2	83 (75, 87)	-2.7	(-10.4, 3.5)		
	3	77 (64, 88)	2.6	(-4.8, 11.0)		
	4	82 (66, 95)	-13.1	(-21.4, -4.4)		
	5	76 (71, 82)	-9.9	(-13.1, -6.5)		
Systolic blood pressure (mmHg)	1	132 (119, 141)	-6.3	(-9.5, -3.1)	-0.3 (Moderate)	p = 0.183
	2	132 (122, 143)	-5.7	(-19.1, 7.7)		
	3	135 (120, 142)	4.5	(0.6, 4.9)		
	4	133 (123, 153)	-4.3	(-11.3, 3.5)		
	5	127 (109, 130)	-2.8	(-7.0, 0.3)		
Lean tissue mass (kg)	1	45 (41, 51)	3.6	(1.1, 6.0)	0.23 (Small)	**p < 0.001**
	2	50 (36, 67)	7.3	(3.8, 11.1)		
	3	53 (42, 72)	6.8	(3.9, 9.5)		
	4	49 (40, 52)	1.1	(-1.0, 3.1)		
	5	49 (30, 50)	2.5	(1.6, 3.3)		

Variable	Group	Baseline values	Mean percentage change		Overall mean pre-post comparison for all groups combined	
		median (min, max)	(bootstrapped 95% CL)		Effect size	p-value
Visceral fat mass (g)	1	215 (165, 368)	-10.1	(-18.8, -2.1)	-0.13 (Small)	**p = 0.004**
	2	275 (134, 687)	-3.9	(-18.0, 8.3)		
	3	364 (237, 644)	-24.8	(-42.4, -8.4)		
	4	298 (82, 1439)	3.9	(-4.3, 11.6)		
	5	190 (104, 471)	-14.2	(-42.1, 16.4)		
WCHt	1	0.42 (0.39, 0.50)	-2.2	(-4.2, -0.6)	-0.15 (Small)	**p = 0.024**
	2	0.47 (0.40, 0.58)	-3.0	(-8.4, 1.0)		
	3	0.48 (0.41, 0.56)	-3.3	(-4.9 -1.7)		
	4	0.48 (0.38, 0.61)	-0.9	(-8.0, 4.6)		
	5	0.41 (0.36, 0.49)	-2.6	(-6.6, -0.7)		

CL, confidence limit; VO_2max, maximal aerobic capacity; MVPA, moderate-to-vigorous physical activity; BMI, body mass index; WCHt, waist circumference-to-height ratio

Table 12 and Table 13 summarize group baseline data and show the percentage changes in fitness, physical activity, anthropometric, and blood variables as a result of the exercise intervention. Additionally, effect size and p-values are shown, illustrating the overall efficacy of HIIT for all groups' combined data.

Table 13: Intervention effects on blood-related health variables

	Group	Baseline values median (min, max)	Mean percentage change (bootstrapped 95% CL)		Overall mean pre-post comparison for all five groups combined: Effect size	p-value
Fasting glucose ($mmol{\cdot}L^{-1}$)	1	4.8 (4.3, 5.3)	8.2	(4.0, 12.5)	0.03 (Trivial)	p = 0.873
	2	4.9 (4.0, 6.0)	1.4	(-9.5, 14.5)		
	3	4.6 (2.9, 5.0)	9.9	(-5.3, 34.5)		
	4	5.3 (4.9, 5.6)	-12.4	(-18.9, -8.4)		
	5	4.8 (3.9, 5.3)	4.3	(-10.0, 23.2)		
Fasting insulin ($pmol{\cdot}L^{-1}$)	1	54.8 (37.8, 74.7)	-11.8	(-33.4, 8.5)	0.01 (Trivial)	p = 0.716
	2	56.9 (44.4, 208.8)	21.1	(-19.5, 70.6)		
	3	80.7 (40.4, 247.8)	-7.1	(-29.4, 22.8)		
	4	63.0 (11.63, 68.9)	53.2	(-32.6, 167.6)		
	5	53.7 (33.6, 132.1)	81.13	(-22.0, 196.7)		
HOMA2%S (%)	1	97.2 (56.4, 126.5)	9.2	(-17.3, 27.7)	0.18 (Trivial)	p = 0.338
	2	92.8 (26.3, 120.9)	-0.28	(-39.3, -42.4)		
	3	64.9 (25.3, 162.1)	3.6	(-18.6, 25.9)		
	4	79.4 (76.8, 259.7)	20.8	(-34.6, 85.8)		
	5	106.8 (41.1, 120.5)	-9.9	(-55.9, 40.7)		
LDL ($pg{\cdot}mL^{-1}$)	1	2.2 (2.1, 4.0)	-1.7	(-15.7, 12.1)	-0.37 (Moderate)	p = 0.053
	2	3.1 (3.1, 3.5)	-7.2	(-16.2, 15.0)		
	3	2.7 (1.7, 4.2)	-1.0	(-11.5, 11.7)		
	4	2.9 (1.2, 9.9)	-41.6	(-61.6, -26.2)		
	5	2.4 (1.6, 3.2)	-24.9	(-46.4, -8.6)		
TG/HDL	1	0.41 (0.27, 0.77)	56.5	(-5.3, 127.4)	0.02 (Trivial)	p = 0.959
	2	0.71 (0.44, 0.80)	42.0	(-15.0, 124.6)		
	3	0.78 (0.70, 1.14)	8.7	(-24.7, 52.6)		
	4	0.72 (0.20, 1.50)	-10.4	(-32.8, 7.9)		
	5	0.57 (0.33, 1.48)	-14.1	(-58.1, 36.0)		
IL-6 ($pg{\cdot}mL^{-1}$)	1	2.9 (2.2, 3.9)	15.8	(-0.6, 32.4)	0.45 (Moderate)	**p < 0.001**
	2	3.5 (2.8, 3.8)	18.1	(24.9, 33.2)		
	3	3.9 (2.9, 5.0)	5.3	(-3.4, 11.3)		
	4	1.8 (1.6, 2.9)	57.3	(31.2, 84.5)		
	5	1.7 (1.6, 2.7)	62.2	(27.6, 97.6)		

CL, confidence limits; HDL, high-density lipoprotein cholesterol; HOMA2%S, homeostasis model assessment percentage sensitivity; IL-6, interleukin-6; LDL, low-density lipoprotein cholesterol; TG, triacylglyceride

Figure 11 presents participants' percentage changes and quadratic trends with bootstrapped confidence limits on selected health measures. Quadratic modelling showed a weak trend in VO_{2peak} ($R^2 = 0.018$) and we observed wide variation in individual responses in all five groups. Only Groups 4 and 5 improved aerobic fitness in all participants. There was an overall significant ($p < 0.001$) increase in VO_{2peak} by ~6% for all HIIT groups data combined.

As for anthropometric measurements, there was a wide spread in individual responses, yet significant improvements for percentage body fat ($p < 0.001$), WCHt ($p = 0.024$) and visceral fat ($p = 0.004$), and overall beneficial changes of ~4%, ~3%, and ~10% were elicited for each variable respectively. There was no further improvement in visceral fat and WCHt from Groups 1-5. Percentage body fat however, decreased incrementally across Groups 1-3 and showed no further improvement in Groups 4 and 5. All groups experienced a significant ($p < 0.001$) beneficial response in lean muscle mass, and a strong ($R^2 = 0.212$) curvilinear dose-response relationship was observed; percentage change increased to the greatest extent in Groups 2 and 3 for this variable. No significant effect ($p = 0.469$) was observed with BMI. There were significant ($p = 0.009$) favourable changes in DBP (~3%).

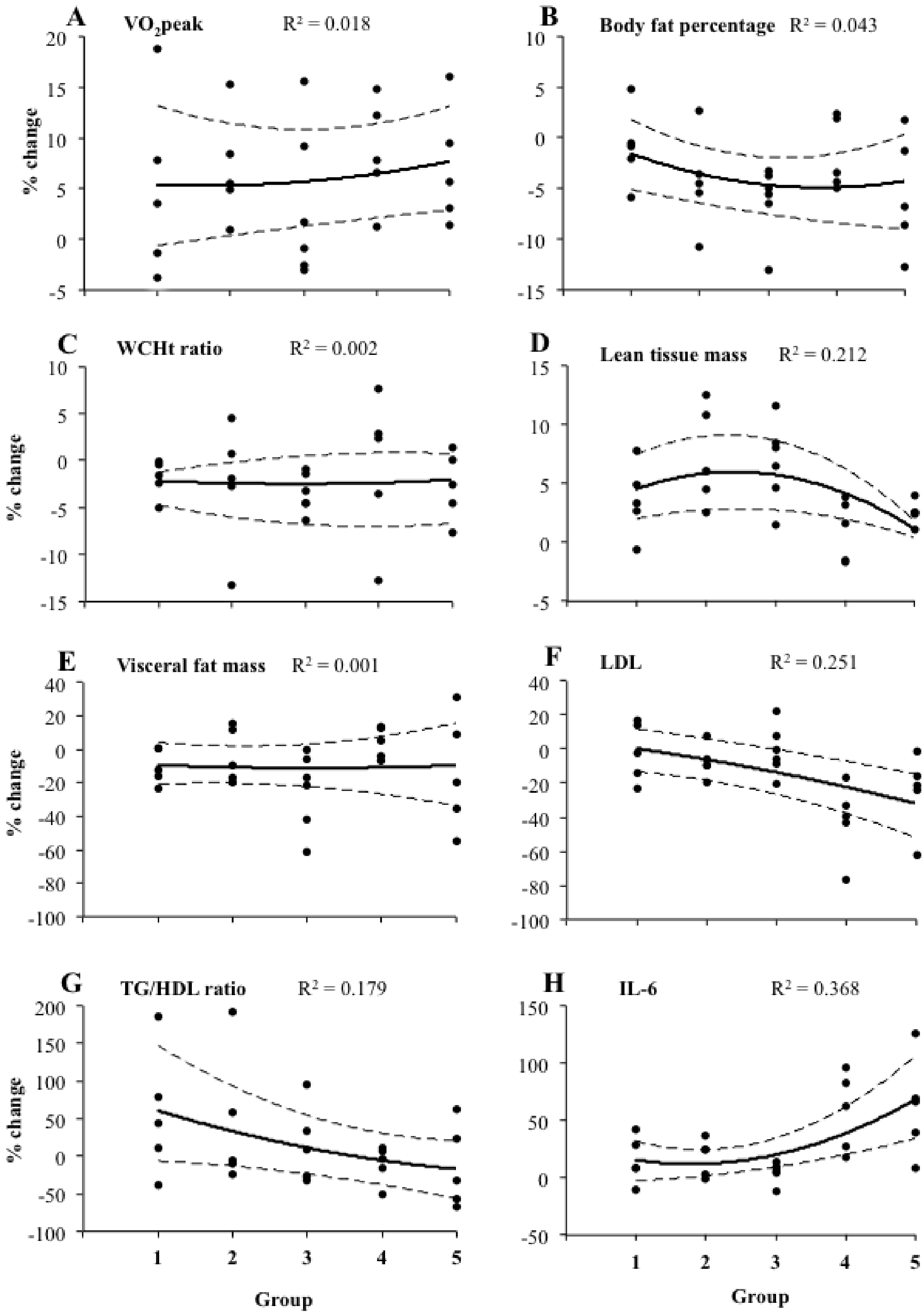


Figure 11: Percentage changes in selected cardio-metabolic health variables for all five HIIT treatment groups. Black dots express individual changes in inactive male adolescents. Solid curved lines denote means from quadratic modelling. Dashed lines represent associated confidence limits derived from bootstrapping (x1000). HDL, high-density lipoprotein cholesterol; IL-6, interleukin-6; LDL, low-density lipoprotein cholesterol; TG, triacylglyceride; VO_{2peak}, peak aerobic capacity; WCHt, waist circumference-to-height ratio

Blood-measured variables revealed curvilinear relationships for LDL, and IL-6 with increasing HIIT dose. There was no significant overall change ($p = 0.959$) in TG/HDL and plotted results revealed that Groups 4 and 5 did not experience change. An inverse LDL response was observed with increasing HIIT dose, however the overall effect was not significant ($p = 0.053$), whereas a significant ($p < 0.001$) moderate unfavourable effect was experienced with IL-6, which was greatest amongst Groups 4 and 5. Responses for fasting glucose, insulin and HOMA2%S were not significant, showed no clear quadratic trend, and therefore were not graphically represented.

6.6 Discussion

The purpose of this study was to assess the effectiveness of an 8-week school based HIIT intervention on several physiological health indices in low-active male adolescents. For the first time, we have established dose-response (perhaps more accurately termed 'dose-adaptation') relationships between HIIT and selected cardio-metabolic health measures using a novel study design, based on an approach previously adopted by Stepto et al. [19] and Barnes et al. [20]. The present study demonstrates that 8-weeks of twice-weekly HIIT and once-weekly resistance training elicits improvements in: (i) maximal oxygen uptake, and (ii) body composition (body fat percentage, lean tissue mass, visceral fat, WCHt). However, the main outcome from this study was that the degree of improvement was not dependent on the HIIT dose for several key indicators of metabolic health.

We predicted that higher doses of HIIT would elicit greater improvements in fitness; however, there was no extra benefit to VO_{2peak} from the lowest to the highest HIIT dose. All but five participants across all groups achieved positive adaptations in fitness, and the overall enhancement of ~6% in VO_{2peak} agrees well with other studies that have implemented HIIT interventions in the adolescent cohort [93,108]. Although there was a slightly greater (~1%) trend in adaptation in VO_{2peak} for Groups 4 and 5, the individual variation experienced across all groups confounds our ability to assume any further benefits to fitness at a higher dose. For example, a participant who undertook the lowest HIIT dose experienced the greatest increase in VO_{2peak} (19%) of all participants, yet the greatest percentage change at the highest dose was 16%.

The relationships between dose and change in visceral fat and WCHt were similar to those observed with VO_{2peak}. These two known cardiovascular disease risk factors [78,127] may have been expected to improve relatively more with increasing volumes of HIIT; however we have shown that participants performing 3 minutes and 40 seconds of HIIT and one resistance training session weekly improved visceral fat and WCHt similarly to the group performing 18 minutes and 20 seconds of HIIT. The weak relationship of HIIT dose and body fat percentage ($R^2 = 0.043$) resultant from the breadth of individual responses limits our ability to quantify optimal dose. A stronger relationship existed with lean tissue mass ($R^2 = 0.212$) suggesting a trend for the greatest improvement to lie between Groups 2 and 3; however, as with VO_{2max}, differences in improvements between Groups 1 to 3 were ~1%, and therefore minimal.

We observed no clear improvements for glucose and insulin in this cohort. Previous studies have shown similar results for fasting insulin, glucose and HOMA2%S [100,103,108]. Regarding lipid control in this adolescent population, TG, in particular may be sensitive to exercise induced improvement [133]. We found slight increases in TG/HDL in Groups 1-3 but all values were within a desirable range [134]. An increase in IL-6 was seen with increasing dose, however, as with TG/HDL values were within the normal range. A moderate favourable effect was seen with LDL, whereby the degree of benefit improved with incremental doses, however, when we considered the overall effect for all HIIT doses combined, the improvement was not significant ($p = 0.053$). This is an unsurprising outcome, considering that only two studies have shown significant beneficial responses in LDL from HIIT interventions in adolescents [94,103], whereas several others have reported unclear responses [93,97,100]. As there was no nutritional intervention in the present study, it is perhaps expected that there was no great change in fasting insulin, glucose or the blood lipid profile [135].

Our findings suggest that adolescent males may perform a single HIIT set, twice weekly, and a once weekly session of resistance training to gain meaningful health benefits. Given that physical activity and diet did not change significantly ($p < 0.01$) during the intervention, we can ascribe the beneficial adaptations to the combination of HIIT and resistance training. The addition of a once-weekly resistance training session allowed for current physical activity guidelines [10], however there were limitations to its inclusion; we were unable to disentangle its metabolic effects from those of HIIT, although since all participants undertook the same resistance training, a true dose-response relationship remained. We postulate that the positive health response seen may be attributed to the potency of the vigorous exercise bout during HIIT, and in consideration of the many possible combinations of exercise bout, rest bout and overall session duration used to constitute HIIT, we recognise that the dose-response relationships observed may not be limited to the protocol used in the present study. However, a short exercise bout and overall HIIT duration may be more favourable HIIT protocols over longer duration sessions, as individuals are able to train at near-maximal intensities, eliciting a potent health response with a minimum time constraint [136]. It may be that such time-efficiency is an appealing aspect that represents an exercise option more likely to be adhered to in this cohort [137]. An encouraging indication that participants were engaged was reflected in the high attendance rate: 90% of those who volunteered completed the exercise intervention. Whilst this is a promising sign, further examination into the so-called affective response is needed to investigate the psychological components that may motivate individuals to undertake and adhere to HIIT.

To our knowledge, this is the first time a dose-response relationship has been presented for the health effects of HIIT using low-active adolescents. The reporting of all individual results has also served to detail the spectrum of responses across all variables in all groups. The study design enabled us to establish treatment effects with a relatively small sample size; however, the generalizability would benefit from a larger number of participants. We must also highlight the strength of the measures used: DXA has provided high-sensitivity quantification of body fat and visceral fat mass, and aerobic fitness was assessed using a laboratory controlled maximal VO_{2peak} test. Potentially confounding influences to health, such as leisure time physical activity and diet were monitored; however the contribution of sexual maturity was not investigated and is therefore considered a limitation. There were no adverse effects or injuries reported during the intervention, strengthening the evidence for HIIT's safety in untrained populations [138]. All of the participants, with the exception of one, were non-smokers, and to our knowledge did not smoke during the intervention period. The single participant who disclosed to our research team that he began smoking during the intervention (for unknown reasons) and that revealed that he only smoked e-cigarettes. Due to the recent technology of e-cigarettes (or vapour cigarettes), resultant metabolic health effects in the adolescent cohort are unknown, therefore we cannot speculate the degree of influence this may have on the magnitude of change in outcomes such as VO_{2peak}.

The use of a school-based location has allowed us to illustrate the efficacy of HIIT outside of a closely regulated laboratory environment. The study was limited to 8-weeks exercise intervention as the pre- and post- measures needed completion within school term time, thus it is of interest to understand the effects of HIIT dose-response over a longer duration. A mixed exercise modality approach gave participants variety during sessions that reflects how adolescents may perform HIIT at school or during leisure time. We are aware of the potential differences in metabolic response that exercise modality may elicit; however, the aim of our study was not to disentangle the effects of each exercise modality, but observe the effect of overall session adaptation for exercise intensity at a prescribed level. We elected to offer participants a choice of modality during each HIIT set and between sessions, providing individuals with a degree of control over the HIIT session, yet the prescribed exercise intensity and HIIT framework remained intact. Performing HIIT using a researcher-nominated modality, either for the HIIT set or session duration, would no doubt influence perceived enjoyment, motivation, and compliance, and therefore is an important consideration when applying a translatable approach to HIIT. Anecdotally, we are able to report that participants changed exercise modality between and during sessions, rarely staying with the same exercise modality in succession, allowing a relatively even distribution of modality use. Heart rate monitoring provided a useful method of monitoring exercise intensity in the field, and participants responded well to the 'goal' of aiming to achieve near HR_{max} at the end of each set. The positive participant responses in both adherence and informal feedback endorse the feasibility of undertaking HIIT-based exercise during school time.

6.7 Conclusions

In summary, low-active adolescent males performing a single HIIT set twice-weekly, in addition to one resistance training session, gained meaningful improvements in fitness and body composition. Performing additional HIIT sets provided little additional improvements to those of the lowest dose in this study.

Chapter 7 - Modelling the effects of high-intensity interval training dose on physical self-perception in low-active male adolescents

7.1 Preface

Establishing the dose-response effects of HIIT with physiological health indices was an essential step in the previous chapter. Having observed meaningful health improvements with HIIT, it was then critical to further understand the translatability of this form of vigorous intensity exercise, and whether it could contribute to physical activity adherence. Thus, individuals' affective responses and psychological determinants of exercise adherence were investigated.

The purpose of Chapter 7, therefore, was to investigate physical self-concept and exercise enjoyment, using data collected from the same exercise intervention study described in Chapter 6. A three-month follow-up investigation into HIIT adherence and uptake was attempted, but due to a poor response rate in this element of the study data could not be analysed. Improvements and high scores physical self-description and exercise enjoyment inferred intent for future HIIT utilisation for all doses of HIIT that were undertaken. The manuscript resulting from this chapter is under review in the peer-reviewed Journal of Sports Science and Medicine.

7.2 Abstract

Background: High-intensity interval training (HIIT) has proven effective in improving the physiological health and fitness of adolescents; however, there is paucity of research regarding the psychological outcomes that influence exercise adherence. Our aim was to explore the effects of undertaking 8 weeks of five different HIIT doses on the physical self-perceptions of low-active male adolescents.

Methods: Participants (n = 26, mean age = 16 ± 1 years) were randomly allocated to one of five training groups, and undertook twice-weekly HIIT and once-weekly resistance training sessions for 8 weeks. To explore the effect of HIIT dose, groups competed either 1, 2, 3, 4, or 5 HIIT 'sets', consisting of 4 repeated bouts of 20-seconds near-maximal exertion interspersed with 10-seconds of passive recovery. Using the Physical Self Description Questionnaire short form (PSDQ-S), 11 sub-domains of physical self-perception were quantified pre- and post- intervention and score changes were calculated.

Results: For all five groups' combined data there were significant improvements with large effect sizes elicited in perceived Activity ($p = 0.007$), Global Physical Self-concept ($p < 0.001$), and Strength ($p < 0.001$), with moderate effect sizes elicited in Flexibility ($p = 0.008$) and Sport ($p = 0.011$), and a small effect size elicited in Coordination ($p = 0.039$). There were trends showing incremental improvements in Activity ($R^2 = 0.227$), Flexibility ($R^2 = 0.036$), Global Physical ($R^2 = 0.082$), Strength ($R^2 = 0.154$), and Sport ($R^2 = 0.114$) with HIIT dose, and each group reported beneficial responses.

Conclusion: Low-active adolescent males performing HIIT twice weekly, in addition to a once weekly resistance training session, gained meaningful improvements in several sub-domains of physical self-perception, regardless of HIIT dose.

7.3 Introduction

Given that many adolescents fail to achieve the recommended 60 minutes of moderate-to-vigorous intensity physical activity daily [9], an alternative approach based on brief, potent bouts of semi-structured intense exercise may represent an expedient option towards general health for inactive youth [84,95,139]. A range of high-intensity interval training (HIIT) protocols have proven effective in improving physiological health and fitness outcomes in adolescents [122]; however, the affective response, and consequent exercise adherence to HIIT in youth remain unclear.

Adolescence has been identified as a crucial life stage in the development of physical self-perception, which has also been identified as an essential contributor to global self-esteem during this critical formative period [140,141]. Research investigating the relationship between physical activity and self-perception has identified self-esteem as an important influence on youth behaviours in a range of contexts [142]. Several cross-sectional studies have modelled physical self-perception and its subdomains (including self-esteem) as determinants of physical activity [143-147]; however, few interventions have explored the effect of exercise on youth physical self-concept [148-150]. Existing exercise intervention studies investigating physical self-perception have implemented aerobic activity [148,151,152], resistance training [149,153], or a combination of both exercise modes [154,155]. A resistance training study by Lubans et al. [149] saw that female adolescents improved their perceived body attractiveness over eight weeks from undertaking free-weight exercise, whilst Schneider et al. [148] observed that youth enhanced global physical self-concept when positive changes in fitness occurred after aerobic activity; a finding also observed in a cross-sectional study by Lubans & Cliff [147]. Some studies have reported null findings, to which ‘ceiling effects’ caused by high levels of initial self-perception have been attributed [156]; however, Lubans et al. [149] suggest that exercising at an insufficient intensity and poor study compliance are also possible explanations for the failure of studies to elicit a meaningful training effect.

Characterized by short, intense exercise bouts, interspersed with light-active or passive recovery periods, HIIT is a potent and time-efficient alternative to achieve meaningful health benefits of exercise in adolescents [122]. Furthermore, the very-vigorous nature of exercise the bouts performed ensure individuals achieve activity intensities high enough for a meaningful affective response [157]. To date, research has investigated acute affective responses to HIIT in order to provide insight into its tolerability and enjoyment [116,118,158,159]; however, the effects of HIIT on youth physical self-perception are currently unknown.

A positive self-concept promotes individuals to feel good about themselves and their capabilities, resulting in strong resilience to life challenges, facilitating positive changes in mood and motivation [160,161]. Self-concept is considered to be a hierarchical construct consisting of physical, social and academic dimensions [162]. The branch of self-concept known as *physical* self-perception (or physical self-concept), relates to an individual's perceived physical ability and appearance, and is considered to be a key determinant of behaviours influencing physical activity [163]. Of specific interest are the effects that HIIT may elicit on the physical self-perceptions of low-active adolescents who are at high risk of developing future lifestyle related health issues due to a chronic lack of engagement with physical activity [164]. Additionally, examining physical self-concept exercise response in adolescents outside of laboratory settings may offer understanding into the potential for uptake and adherence to HIIT in translational, real-world settings [165].

To our knowledge, no existing study has examined the relationship of HIIT dose with physical self-perception; hence, we adopted a novel dose-response design to investigate the effects of eight weeks of an in-school, combined HIIT and resistance training intervention on the physical self-perception of low-active male adolescents.

7.4 Methods

7.4.1 Participants

The present study was conducted between July 2014 and June 2015, and involved three recruitment and three 8-week intervention phases from two secondary schools in Auckland, New Zealand. After approval from the institution ethics advisory committee, male students were recruited from school years 11, 12 and 13, where PE classes were not compulsory for students. Individuals were eligible to participate provided they were males aged 12-18 years, did not take PE, were not involved in extracurricular structured-sport and were identified as low-active by school teaching staff. Students were unable to participate if they had any diagnosed metabolic, hormonal, orthopaedic or cardiovascular condition. An information session was delivered by the researchers, whereby students were informed on the design and aims of the study. All participants and their guardian(s) provided written informed assent and consent, respectively.

7.4.2 Experimental design

A pre–post parallel-groups design was adopted, with an exercise intervention period lasting 8 weeks. In order to deliver varying doses of HIIT, participants were randomly allocated to one of five exercise groups, determined by approximately even distribution of peak oxygen uptake (VO_{2peak}) calculated from baseline testing (Table 14).

7.4.3 Height and weight

Height and weight were assessed using a portable stadiometer and digital scales (Model Seca 217 and 770, Seca, Hamburg, Germany). Participants wore light clothing and were measured for height (±0.1 cm) and weight (±0.1 kg) using a standardised protocol. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared.

7.4.4 Maximum oxygen uptake and maximum heart rate testing

Prior to the intervention, a baseline a VO_{2peak} test was performed. Before testing, subjects were instructed that they were to exercise to their maximum limit. Participants undertook an incremental ramp test to volitional exhaustion on a bicycle ergometer (Lode Excalibur Sport, Lode, Groningen Netherlands) and expired gasses were measured continuously using a metabolic cart (ParvoMedics TrueOne 2400, Salt Lake City, UT, USA) for determination of VO_{2peak}. Heart rate was recorded every second throughout the test (Polar RS800sd, Polar Electro, Finland) and maximum heart rate (HR_{max}) was recorded. Rate of perceived exertion (RPE) was noted at the end of each minute during testing. A plateau of VO_2 despite an increased workload, a respiratory exchange ratio > 1.05, and an RPE of 20 were used as criteria for reaching the true VO_{2peak}; this was achieved by all individuals in the present study.

7.4.5 Exercise intervention

All participants undertook three group-based exercise sessions consisting of two HIIT sessions and one resistance training session each week over an 8-week intervention period. Exercise sessions were supervised by a New Zealand Registered Exercise Professional (NZREPs) and performed in the school gym during weekday lunch intervals.

While we acknowledge the large spectrum of HIIT protocols available, which range in duration and intensity, an adaptation of the so-called ‘Tabata’ [166] model was utilised. We theorized that the potent nature of the short duration, very high intensity exercise bouts of this protocol would elicit positive changes in physical self-perception [149]. Each ‘set’ consisted of four bouts of ‘all-out’ maximal exercise (90-100% HR_{max}) lasting 20 seconds, interspersed with 10 seconds of passive rest periods. Given that the intervention was performed in a school setting and not in a laboratory environment, we ensured all participants scored an RPE of at least 18 and a minimum of 90% HR_{max} towards the end of each set for the entire 8-week trial. Ensuring individuals achieve the correct exercise intensity is a critical factor in HIIT, and in addition to researchers monitoring intensity, participants were informed of their own HR_{max} and aimed to reach it as a ‘goal’ at the end of each set.

Through the rank-order of treatment groups, a linear increase in HIIT dose was established. As reported in Table 14, groups were numbered 1-5 corresponding with the increments in the number of HIIT sets to complete during the exercise session. Participants were notified to undertake the number of HIIT sets based on their allocated exercise group number. All groups exercised simultaneously during the exercise sessions. Three-minutes of warm up and cool down (50-60% HR_{max}) were undertaken prior to, and on completion of, every HIIT period. For groups completing more than one set, HIIT sets were separated by two-minute periods of passive recovery.

Table 14: Group baseline characteristics and details of HIIT exercise treatments (two sessions per week)

	Age (years) mean ± SD	Height (cm) mean ± SD	Weight (kg) mean ± SD	BMI ($kg{\cdot}m^{-2}$) mean ± SD	Mean VO_{2peak} ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$) mean ± SD	No. of HIIT sets per session (4 x 20s work:10s rest)	HIIT session duration	Total duration in HIIT over 8-weeks
Group 1 (n = 5)	16.6 ± 1.5	172.7 ± 2.1	61.0 ± 5.4	20.7 ± 2.1	39.5 ± 5.9	1	1 min 50 s	29 min 20 s
Group 2 (n = 5)	17.2 ± 1.3	175.5 ± 9.3	79.7 ± 24.0	25.7 ± 6.7	35.6 ± 5.4	2	3 min 40 s	58 min 40 s
Group 3 (n = 6)	15.7 ± 0.5	179.4 ± 5.8	83.3 ± 15.6	25.9 ± 4.6	39.5 ± 9.2	3	5 min 30 s	88 min
Group 4 (n = 5)	15.2 ±1.3	171.0 ± 8.8	70.3 ± 13.6	24.4 ± 6.4	39.5 ± 10.2	4	7 min 20 s	117 min 20 s
Group 5 (n = 5)	15.4 ± 1.1	173.9 ± 9.7	60.1 ± 11.1	19.8 ± 2.0	39.4 ± 7.6	5	9 min 10 s	146 min 40 s

A mixed-exercise modality approach was adopted to simulate how HIIT may be undertaken outside of a controlled laboratory setting [167], whereby participants elected their desired form of exercise before the session began. Participants chose to complete the training using a rowing machine, cycle ergometer, treadmill, cross-trainer, performing shuttle-runs, repeated box-jumps, or by non-contact boxing. Those assigned to groups completing more than one set of HIIT were given the option of changing exercise modality for the following set. Participants were familiarized with the exercise protocol during the first week of training by completing one set of HIIT. Over the following sessions, sets were incrementally increased until each group satisfied their required HIIT dosage.

Resistance training sessions were included in the exercise intervention for partial fulfilment of the current youth physical activity guidelines [131]. Supervised weight training was performed once weekly, consisting of simple, compound push, pull and squat/ lunge movements to target large muscle groups. During the familiarisation phase, each participant completed a maximal repetition (1RM) test on a chest-press, seated row and leg press machine. Individual's 1RM were calculated and weights corresponding to 70% of participants' 1RM were assigned to each resistance machine. The overall resistance training volume was standardized for all participants.

7.4.6 Physical self-perception measurement

Participants completed the Physical Self Description Questionnaire short form (PSDQ-S) [168] three days prior to commencing the exercise intervention, and three days after the completion of the final training session. The PSDQ-S is a multidimensional, physical self-concept instrument designed for high-school adolescents. Each PSDQ-S item is a simple declarative statement, and participants respond using a 6-point true-false response scale. The PSDQ-S comprises of a 40 item questionnaire that define 11 self-concept scales, characterized by Marsh [169] as:

- **Activity**: Being physically active, doing lots of physical activities regularly
- **Appearance**: Being good-looking, having a nice face
- **Body Fat**: Not being overweight, not being too fat
- **Coordination**: Being good at coordinated movements, being able to do physical movements smoothly

- **Endurance/Fitness**: Being able to run a long way without stopping, not tiring easily when exercising hard
- **Flexibility**: Being able to bend and turn your body easily in different directions
- **Global Esteem**: Overall positive feelings about oneself
- **Global Physical (Self-concept)**: Feeling positive about one's physical self
- **Health**: Not getting sick often, getting well quickly when you are sick
- **Sport**: Being good at sports, being athletic, having good sports skills
- **Strength**: Being strong, having a powerful body with lots of muscles

7.4.7 Exercise enjoyment and 3-month follow-up measurement

After completion of the follow-up PSDQ-S, participants were asked to complete one question regarding their overall enjoyment of the exercise used during the intervention. Specifically, participants were asked: 'How much did you enjoy the exercise that you have done over the last 8 weeks?' Responses were scored on a 7-point rating scale with anchors ranging from 'Hated it' (1), 'Neutral' (4), and 'Loved it' (7).

Follow-up telephone interviews were conducted 3-months after the completion of the final exercise session to question participants on their physical activity status, and utilisation of HIIT and resistance training. A research assistant who had no previous engagement with the participants asked four short questions with the choice of four possible answers. Participants were asked:

1) How often have you continued using the short, sharp exercise after the study finished?
2) How often have you continued using resistance exercise after the study finished?
3) Are you more active now than before the study started?
4) Do you enjoy exercising more now than before the study started?

Responses for questions 1 and 2 were scored on a 4-point rating scale ranging 'Never' (1), 'Not often' (2), 'Sometimes' (3), and 'Regularly' (4). For questions 3 and 4, responses were scored from 'Less' (1), 'The same' (2), 'A little' (3), and 'More' (4).

7.4.8 Statistical analysis

All statistical analyses were performed using SPSS version 22 (IBM Corporation, Armonk, NY). To calculate the efficacy of each group's HIIT dose on each of the 11 sub-categories of PSDQ self-concept, responses were analysed as overall change in score. The data were modelled as a quadratic function of the rank-ordered duration of the HIIT treatments to determine the dose-response relationship. Confidence intervals for the measures derived from the quadratic model were produced by bootstrapping (x 1000). Finally, in order to make conclusions about the overall efficacy of HIIT on each of the 11 PSDQ items, all five groups' data were combined. After the normality and homogeneity of the variance were confirmed, the dependent variables were compared at pre-intervention and post-intervention using paired Student's *t*-tests. The significance was set at $p<0.05$. Mean differences were utilised to determine effect size differences (0.1-0.3, small effect; 0.3-0.5, moderate effect; 0.5-0.7, large effect) [132]. In addition, a one-way ANOVA was conducted to examine differences in exercise enjoyment between the five exercise groups. Data for the four 3-month follow-up items were intended to be analysed in the same way, however due to low follow-up response rates, insufficient data confounded our ability to analyse responses.

7.5 Results

A 19% recruitment rate was achieved as 29 (phase 1, n = 5; phase 2, n = 10; phase 3, n = 4) of the 154 eligible individuals (phase 1, n = 74; phase 2, n = 25; phase 3, n = 55), agreed to participate. Subjects' data were eligible for analysis provided they completed 85% of the exercise sessions. During the study, two participants withdrew and one failed to meet compliance due to illness. As a result, PSDQ and exercise enjoyment data were valid for analysis for 26 participants (mean ± SD; age 16 ± 1 years, weight 71 ± 17 kg, height 174 ± 7 cm, BMI 23 ± 5 $kg{\cdot}m^{-2}$, VO_{2peak} 38.7 ± 7.4 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$). A low response rate (15%) was recorded for 3-month follow-up phone interviews, producing insufficient data for analysis.

Table 15 summarizes changes in PSDQ score for each of its 11 items; a negative change reflected perceived improvement in each of the self-concept sub-categories, whilst a positive value indicated an unfavourable change in self-perception. In addition, effect size and p-values are presented, representing the overall differences from pre- to post-intervention for all five groups' data combined.

Table 15: Intervention effects on the sub-domains of the PSDQ-S

Variable	Group	Baseline values	Mean score change		Mean pre-post comparison for all groups combined	
		median (min, max)	(bootstrapped 95% CL)		Effect size	p-value
Activity	1	3.2 (2.0, 4.8)	0.3	(-0.5, 1.2)		
	2	4.3 (1.8, 6.0)	-0.6	(-1.1, -0.3)		
	3	3.4 (1.3, 4.8)	-0.3	(-0.9, 0.3)	-0.5 (Large)	**0.007**
	4	3.3 (2.0, 5.3)	-1.2	(-2.3, -0.5)		
	5	3.3 (1.8, 4.3)	-1.2	(-2.0, -0.4)		
Appearance	1	3.3 (2.0, 4.3)	-0.1	(-0.7,0.4)		
	2	3.0 (2.0, 5.0)	-0.4	(-1.5, 0.5)		
	3	2.8 (2.3, 4.3)	-0.3	(-1.1, 0.4)	-0.2 (Small)	0.256
	4	4.0 (2.0, 4.7)	-0.1	(-0.9, 0.6)		
	5	3.0 (1.7, 5.7)	0	(-0.4, 0.6)		
Body fat	1	1.7 (1.0, 4.3)	-0.5	(-1.0, -0.1)		
	2	3.7 (1.0, 5.7)	-0.3	(-0.6, 0.0)		
	3	4.2 (1.0, 5.7)	-0.4	(-0.7, -0.1)	-0.1 (Trivial)	0.092
	4	3.0 (2.0, 5.3)	-0.3	(-0.8, 0.3)		
	5	1.3 (1.0, 2.0)	0.5	(0.1, 0.9)		
Coordination	1	3.2 (1.8, 3.4)	-0.2	(-0.3, -0.1)		
	2	2.6 (2.0, 3.4)	-0.2	(-1.0, 0.3)		
	3	2.3 (1.0, 2.6)	-0.1	(-0.7, 0.5)	-0.3 (Small)	**0.039**
	4	2.0 (1.8, 4.4)	-0.6	(-1.3, 0.2)		
	5	2.2 (1.8, 4.0)	-0.3	(-0.6, -0.1)		
Endurance	1	3.3 (2.3, 5.0)	0.7	(0.1, 0.4		
	2	4.0 (1.3, 5.0)	-0.7	(-1.8, -0.1)		
	3	3.7 (1.0, 5.7)	-0.2	(-0.5, 0.1)	-0.3 (Small)	0.052
	4	3.3 (2.0, 5.7)	-1	(-2.5, 0.2)		
	5	3.7 (1.7, 4.3)	-0.3	(-1.2, 0.2)		
Flexibility	1	4.0 (3.3, 4.7)	-0.3	(-0.8,0.1)		
	2	3.3 (3.0, 5.0)	-0.2	(-0.5, -0.1)		
	3	3.8 (1.0, 5.3)	-1.2	(-0.8, 0.6)	-0.4 (Moderate)	**0.008**
	4	2.7 (2.0, 5.0)	-1.1	(-2.0, -0.4)		
	5	2.7 (1.7, 5.7)	-0.5	(-1.3, 0.3)		
Global esteem	1	3.0 (2.6, 3.0)	-0.5	(-0.9, -0.1)	-0.4 (Moderate)	0.069

Variable	Group	Baseline values median (min, max)	Mean score change (bootstrapped 95% CL)	Mean pre-post comparison for all groups combined Effect size	p-value
	2	2.8 (1.6, 3.4)	0.2 (-0.1, 0.5)		
	3	2.4 (1.8, 3.0)	-0.4 (-0.9, 0.0)		
	4	2.0 (1.4, 2.8)	-0.4 (-0.9, 0.1)		
	5	2.6 (2.0, 3.4)	-0.1 (-0.7, 0.5)		
Global	1	3.0 (2.3, 4.3)	-0.3 (-1.1, 0.4)		
	2	2.7 (1.3, 3.7)	-0.5 (-1.2, -0.1)		
	3	3.2 (2.0, 6.0)	-0.9 (-2.3, 0.2)	-0.6 (Large)	**<0.001**
	4	3.0 (1.7, 4.3)	-1.3 (-2.2, -0.7)		
	5	3.0 (1.0, 5.7)	-0.6 (-0.9, -0.3)		
Health	1	1.4 (1.0, 3.0)	0.2 (-0.3, 1.3)		
	2	2.8 (2.2, 5.2)	-0.2 (-0.7, 0.4)		
	3	1.3 (1.0, 3.6)	0.3 (-0.1, 0.8)	-0.01 (Trivial)	0.927
	4	2.4 (1.8, 3.4)	-0.4 (-1.5, 0.4)		
	5	2.0 (1.0, 3.2)	-0.2 (-0.8, 0.5)		
Sport	1	3.3 (2.7, 4.0)	-0.1 (-0.5, 0.4)		
	2	4.0 (2.7, 6.0)	-0.3 (-0.8, 0.2)		
	3	3.3 (2.7, 4.0)	-0.4 (-0.1, 0.2)	-0.4 (Moderate)	**0.011**
	4	4.7 (2.3, 5.3)	-1.2 (-2.1, -0.5)		
	5	2.7 (2.3, 6.0)	-0.2 (-0.7, 0.2)		
Strength	1	3.0 (3.0, 4.0)	-0.1 (-0.7, 0.5)		
	2	3.0 (2.0, 4.7)	-0.7 (-1.5, -0.1)		
	3	2.8 (2.0, 4.7)	-0.7 (-1.4, 0.0)	-0.6 (Large)	**<0.001**
	4	3.7 (1.7, 4.7)	-1.1 (-2.1, -0.5)		
	5	3.0 (2.0, 6.0)	-0.9 (-1.3, -0.5)		

Figure 12 presents quadratic trends with bootstrapped confidence limits for the changes in score for six PSDQ items, selected for showing significant effects. A quadratic trend showed a relatively strong ($R^2 = 0.227$) relationship between the change in score for perceived Activity and increasing HIIT dose; significant ($p = 0.007$) improvements with large effect sizes were observed for all groups' combined data. There was no change in Activity score for Group 1, and a decreasing change in score was observed across groups. A similar response was seen for perceived Strength and large effect size was observed for all groups' combined data. Global Physical and Sport showed quadratic trends of a similar nature, indicating optima in response towards Group 4. Significant ($p < 0.001$) improvements with large effect sizes were observed for all groups' combined data for Global Physical. A significant ($p = 0.039$) change in score (~0.3) with a small effect size was seen in Coordination, and there was no further improvement across Groups 1-5. A significant (p = 0.008) score change with a moderate effect size was observed for Flexibility, and quadratic modelling showed a ~0.3 improvement between Groups 1 and 5.

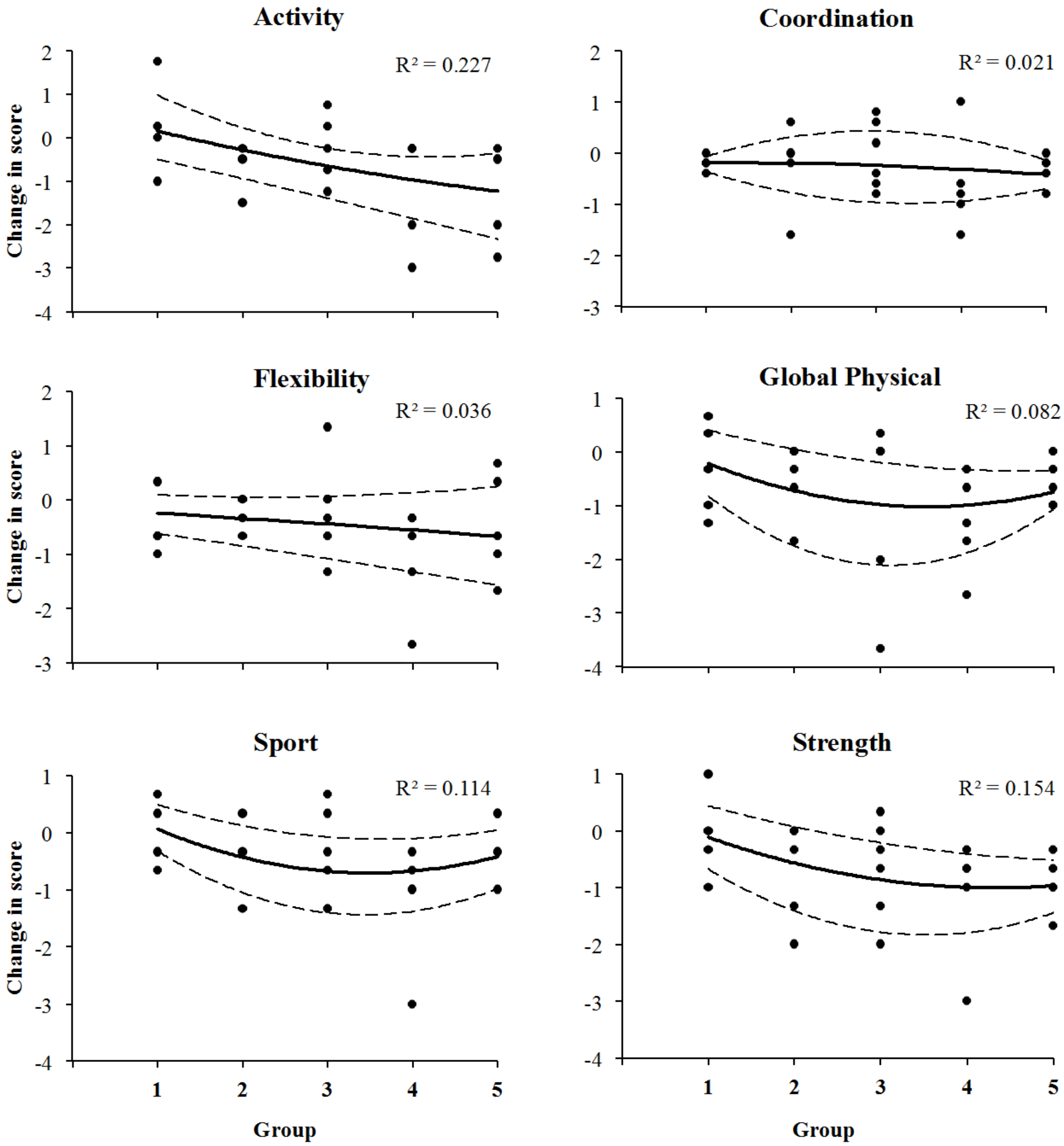


Figure 12: Score changes in selected physical self-perception sub-domains for all five HIIT treatment groups. Black dots express individual score changes in inactive male adolescents. Solid curved lines denote means from quadratic modelling. Dashed lines represent associated confidence limits derived from bootstrapping (x1000).

There were no significant differences (p = 0.215) between each of the five groups' enjoyment score, and all groups scored the exercise between 5 (slightly enjoyed it) and

7 (loved it): Group 1, 6.4 ± 0.5 (mean ± SD); Group 2, 6.6 ± 0.5; Group 3, 6.3 ± 0.8; Group 4, 6.8 ± 0.4; and Group 5, 5.8 ± 0.8.

7.6 Discussion

The primary aim of this study was to explore the effects of an 8-week combined HIIT and resistance training intervention on the physical self-perception profile of low-active male adolescents. In doing so, we have established dose-response relationships between HIIT and 11 sub-domains of physical self-perception, using a novel study design based on an approach previously adopted by Stepto et al. [19] and Barnes et al. [20]. We demonstrated that 8 weeks of twice-weekly HIIT and once-weekly resistance training positively changed perceived Activity, Coordination, Flexibility, Global Physical (Self-perception), Sport, and Strength.

Unsurprisingly, perceived Activity increased with increments of HIIT dose; although there was no change in Group 1, since four out of five participants experienced no change in perceived Activity. Interestingly, those in Group 1 improved self-perceived Coordination, Flexibility, Global Esteem, Global physical, Sport, and Strength, despite feeling no change in Activity. Unfortunately, due to a poor response rate during 3-month follow-up phone interviews, we were unable to assess the implications of perceived Activity change (and all other sub-domains of the PSDQ) with exercise adherence; however, we speculate that minimising the perceived burden of exercise duration may be appealing to this low-active cohort, and thus may influence adherence. The high levels of enjoyment towards the exercise intervention in all groups suggest a positive attitude towards future utilisation of HIIT and resistance training. Since enjoyment was measured three days after completion of the last exercise session, our intention was to quantify feelings toward the intervention on reflection, and not during or immediately post-exercise as has been previously investigated [116,118,159]. We acknowledge that exercising at very high intensities may evoke immediate negative affective response [170,171], however it is likely that perceived benefit on reflection is a potent motivational stimulus for adherence to HIIT and resistance training.

From quadratic modelling (Figure 12) we observed trends that indicated an effect of incremental doses of HIIT for Flexibility, Global Physical, Sport, and Strength. Encouragingly, the greatest changes elicited from the exercise intervention were seen in Global Physical and Strength, both of which returned large effect sizes. Since Global Physical (self-concept) is considered one of the key PSDQ sub-domains that we measured, it is promising that large favourable changes transpired in this low-active population. Such changes have been previously associated with future physical activity participation in young people, especially boys [163]. A recent study by Velez et al. [150] investigating the effects of 12 weeks of resistance training in Hispanic adolescents and reported small effect sizes in Global Physical, which when compared with our data, may suggest that combined HIIT and resistance training could elicit a greater effect than resistance training alone. Despite observing no significant changes in Body Fat and Appearance in the present study, Global Physical improved: this aligns well with research conducted by Lubans et al. [147] and Raustorp et al. [172], which suggest that males' perception of Strength is related to physical self-esteem and physical self-worth. It is likely that the resistance training element of our intervention influenced participants' perceived Strength; however, due to the relatively strong ($R^2 = 0.154$) relationship between HIIT dose and perceived Strength, it is likely that HIIT itself also had a positive influence on individuals Strength. Therefore, a combination of HIIT and resistance training may be deemed beneficial for both Strength and Global Physical self-concept.

While Global Esteem scores did not change significantly ($p = 0.069$), a moderate effect size was observed; a finding that is in line with a meta-analysis conducted by Spence et al. [173]. Explaining clinical significance in some interventions is relatively straightforward (e.g. in physiological health measurement), but identifying meaningful results in physical self-perception measurement can be more problematic. Hagger & Charzidarantis [174] state that statistical significance is highly dependent on the study sample size and recommend that researchers report effect sizes and discuss their findings in relation to practical or clinical significance. As such, we assume that significant changes in Global Esteem may have occurred if a larger sample size was used. Due to the low recruitment rate (19%), however, this was not possible. In spite of this, those who participated to completion achieved excellent compliance to the intervention, and only one individual failed to attend 80% of exercise sessions due to illness. This is a promising result, given the non-participatory nature of the low-active cohort. It is unfortunate that we were unable to determine follow-up utilisation and adherence, and reasons for a lack of response in 3-month follow-up interview are unknown.

Although the aim of the present study was to observe the effect of HIIT dose on physical self-perception, participants were informed that the main outcomes of our research were to improve their physical health. While this was true (Chapter 6), individuals were not led to believe that the study was also designed specifically to improve physical self-perception, thus there were no expectancy effects or demand characteristics which may have influenced results. In any case, there were no meaningful changes in perceived Health, which may be explained by initially high scores during baseline measurement (i.e. a ceiling effect).

7.6.1 Strengths and limitations

This is the first study to explore the effects of HIIT on physical self-perception. The PSDQ-S has been rigorously validated in adolescents in several countries [168], and served as robust measure of physical self-concept in our studied population. The reporting of all individual results has also served to detail the spectrum of responses across all variables in all groups. While recruitment of low-active youth proved challenging, the design of our study allowed us to determine treatment effects with a relatively small sample size. Nonetheless, the generalizability would benefit from a larger number of participants. We used a real-world approach [165] to deliver the exercise intervention, with the intention of gaining true-to-life affective responses from individuals, thus we have illustrated the efficacy of HIIT outside of a closely regulated laboratory environment. A mixed exercise modality method gave individuals variety during exercise sessions, which reflect how adolescents may perform HIIT at school or during leisure time. We were unable to disentangle the benefits participants gained in physical self-concept from resistance training; however, due to group differences in score change for some sub-domains of physical self-perception, it is clear that an independent response was elicited by HIIT. Potentially confounding influences to physical self-concept, such as socioeconomic status, sexual maturity and bullying were not accounted for in this study. Although we attempted to quantify long-term follow up, it remains unknown whether any changes in psychological outcomes persisted when the training stimulus was withdrawn, and whether they affected exercise adherence.

7.7 Conclusions

In summary, low-active adolescent males performing HIIT twice weekly, in addition to a once weekly resistance training session, gained meaningful improvements in several sub-domains of physical self-perception. Quadratic modelling indicated an effect of incremental HIIT dose on Activity, Flexibility, Global Physical, Sport, and Strength; however, until more data are obtained, practitioners can assume that performing any

HIIT dose in addition to resistance training improves physical self-perception. Unfortunately, in the present study we were unable to determine the implications of improved physical self-perception on long-term exercise adherence, but the high levels of enjoyment participants experienced could suggest intent for future HIIT and weight training utilisation.

Chapter 8 - Discussion

The large decline in physical activity levels over the course of adolescence is of great concern to the future health and wellbeing of youth [8]. Despite recognition from leading health agencies, such as the World Health Organisation, that physical inactivity is one of the foremost preventable risk factors for non-communicable disease and premature mortality [14], currently employed recommendations for physical activity are not achieved by as many as 80% of adolescents worldwide [9]. At present, physical activity guidelines promote aerobic steady state exercise (SSE) as the method to gain health benefits from physical activity. In doing so, an emphasis on continuous moderate intensity exercise has developed.

Alternative approaches should be explored to offer adolescents a choice of exercise modalities, which may best suit their lifestyle and activity preference. Clues to developing alternative strategies may lie in the intensity at which exercise is undertaken. Whilst physical activity guidelines are beginning to integrate vigorous intensity activity recommendations, the nature of activity remains focussed on SSE; it is currently promoted by suggesting that individuals can receive the health benefits of moderate SSE by undertaking vigorous activity (in the form of SSE) but reducing the overall duration by half [10,14]. It has been suggested that adolescents may prefer to exercise at vigorous intensity, since the nature of incidental youth activity is spontaneous, intermittent, and of high intensity [1,29,92,94], and emerging research is uncovering the benefits of vigorous intensity physical activity in the regulation of healthy metabolic profiles regardless of weight loss and energy expenditure, indicating that there are underlying metabolic mechanisms sensitive to high intensity body movement [91].

The overarching aim of this thesis was to conduct a cohesive investigation into the metabolic effects of vigorous intensity physical activity, using both an epidemiological level study, and a detailed exercise intervention on a sub-sample of adolescents. This thesis draws from, and adds knowledge to, the limited body of work regarding vigorous intensity physical activity and the metabolic health of adolescents, and offers a possible alternative approach to deliver the health benefits of traditionally recommended SSE, using HIIT.

8.1 Summary of research

This body of work makes a substantial contribution to the field of physical activity and adolescent health through cross-sectional investigation of activity intensity with health risk factors on a large epidemiological scale, and by detailed exploration of the adaptations elicited from an exercise intervention incorporating vigorous intensity physical activity. The first part of this thesis is concerned with the accurate measurement of adolescent physical activity levels, with specific interest in deriving associations of activity intensity with health indices. Using the knowledge gained from the investigation of physical activity intensity and health, the second part of this thesis exploits the use of vigorous intensity activity through delivery of an exercise intervention.

8.1.1 Measuring adolescent physical activity

Chapters 2-4 of this thesis are concerned with the accurate measurement of adolescent physical activity levels, with specific considerations paid to quantification of activity intensity. Accurately measuring physical activity levels is essential to derive associations of activity intensity with the health of youth; therefore, the narrative review in Chapter 2 is an exploration and critical appraisal of the available methods used to measure physical activity in adolescents. This review draws attention to the strengths and limitations of all activity assessment techniques and identifies the appropriate application and technological advances made for each method. The most commonly used methods for physical activity assessment in adolescent epidemiological studies were subjective self-report questionnaires and objective movement sensing devices. Accelerometers were found to be the most complete single method for activity assessment, providing detailed information on frequency, duration, and intensity of adolescent activity; however, the unstandardized processing of raw objective accelerometer data were deemed to be a concern, as there were several steps during researcher data processing which may influence youth physical activity levels, namely: choice of epoch length, axis selection, cut-point selection, removal of non-wear time, and inclusion of valid days.

In consideration of these issues regarding accelerometry data processing, Chapter 3 sought to investigate the effects of epoch length choice, axis selection, and cut point application on adolescent physical activity levels. Research conducted with older accelerometer models used uni-axial cut points and longer 60-second epochs (due to limited data storage) resulting in a ‘diluting effect’ of vigorous intensity activity [42]; however, advances in accelerometer technology have expanded device data storage and can measure on up to three axes, potentially enabling accelerometers to measure the intensity of movement more accurately. Chapter 3’s research was an investigation of methods study, which aimed to further knowledge of adolescent accelerometry data processing. This research was performed on 409 adolescents’ data from the overarching BEANZ study and was the first to simultaneously compare the effects of epoch length, axis selection, and cut points on physical activity levels across all intensities of adolescent physical activity. This was is an important consideration when choosing the filters for meaningful physical activity outcomes.

Chapter 3’s findings illustrated the differences in physical activity outcomes that occur between axis measurement, cut points and epoch length. Related to current physical activity guidelines (Figure 8), they indicated that interpretation of accelerometer output must be critiqued in respect to whether populations are meeting publically espoused physical activity guidelines. The magnitude of difference across epoch length must be considered in the interpretation of accelerometer data and seen as a confounding variable when comparing physical activity levels between studies. Free-living physical activity is a challenging behaviour to measure; however, steps must be taken to standardise accelerometer raw data wherever possible to allow for valid between-study comparisons to further understanding of physical activity and its relationship with the health and wellbeing of adolescents. As there was large variability in activity outcomes between cut points, future research should independently validate tri-axial cut points used in Chapter 3’s study to better inform research as to the most appropriate application of accelerometer data filtering.

Through exploring the effect of data processing on accelerometer derived physical activity levels, an informed approach was used to determine the physical activity levels in the cross-sectional study in Chapter 4. Using 1-second epochs allowed for high-resolution measurement of adolescent movement for a more accurate classification of exercise intensity. This was crucial for monitoring exercise undertaken in short bouts, which is typically how vigorous intensity activity is performed [12]. Whilst tri-axial acceleration technology promises to better measure youth activity and movement, the infancy of vector magnitude cut point development using ActiGraph models meant that uni-axial cut points developed by Evenson et al. [51] were employed [50]. Utilising the full cohort of participants from the BEANZ study, accelerometer and body-measured health outcome data were explored to associate physical activity intensity with health. The full spectrum of light, moderate and vigorous intensity activity data were analysed for a total of 694 adolescents. These data showed that vigorous physical activity was inversely related to WCHt and BMI, whereas both light and moderate activity were positively associated with these health outcomes. Results from this study draw attention to the importance of vigorous intensity physical activity as an independent determinant of health risk factors in adolescents, which strongly supported the inclusion of including vigorous physical activity targets within current physical activity guidelines.

8.1.2 Vigorous intensity physical activity intervention

Evidence of the beneficial associations of vigorous intensity physical activity with adolescent health determined in Chapter 4 warranted the investigation of an exercise intervention to deliver vigorous intensity activity. Chapters 5-7 are concerned with an investigation into HIIT, utilised as a time-efficient, alternative method for adolescents to achieve the cardio-metabolic health adaptations that are currently recommended with long-duration SSE.

The narrative review undertaken in Chapter 5 summarised the central characteristics of HIIT intervention trials involving adolescents, focussing on the impact of HIIT on metabolic health. This chapter was concerned with studies that investigated key parameters of the metabolic condition: glycemia and insulinemia, blood lipids, body composition, aerobic fitness and inflammation. The efficacy of HIIT was compared to continuous aerobic exercise as a control for the aforementioned health variables. Findings from this review identified a significant gap in the literature, exposing the possibility for future research to further explore a variety of HIIT protocols and delivery strategies, as well as investigate the effect of a HIIT dose-response, on cardio-metabolic risk factors in youth. This review also highlighted scope for research to examine the palatability of HIIT as a stimulating exercise modality for adolescents, through investigating perceived enjoyment during and after HIIT, and psychological factors that influence long-term exercise adherence.

Progressing from the literature review in Chapter 5, the studies performed in Chapters 6 and 7 explore the dose-response adaptations from an 8-week HIIT intervention using low-active male adolescents, delivered in a school environment. This HIIT intervention study utilised a novel dose-response study design, previously used by Stepto et al. [19] and Barnes et al. [20], whereby the efficacy of HIIT dose was explored across five treatment groups undertaking incremental HIIT doses. A resistance training element was included in the intervention, in recognition of current physical activity recommendations [10], and was standardised across all groups. This is the first time a dose-response relationship has been presented for the health effects of HIIT using low-active adolescents.

Firstly, Chapter 6 was concerned with the quantification of physiological, metabolic and body-measured health adaptations to HIIT dose. The findings from this research demonstrated that 8-weeks of twice-weekly HIIT and once-weekly resistance training elicited improvements in maximal oxygen uptake, and body composition (body fat percentage, lean tissue mass, visceral fat, WCHt). However, the main outcome from this study was that the degree of improvement was not dependent on the HIIT dose for several key indicators of metabolic health. The findings of this research suggest that adolescent males may perform a single HIIT set (comprising of 4 repeated bouts of 20 seconds of near-maximal exertion interspersed with 10 seconds of passive recovery), twice weekly, and a once weekly session of resistance training to gain meaningful health benefits. The addition of a once-weekly resistance training session allowed for current physical activity guidelines, however there were limitations to its inclusion; its metabolic effects were unable to be disentangled from those of HIIT. Since all participants undertook the same resistance training, however, a true HIIT dose-adaptation relationship emerged.

The positive health responses seen may be attributed to the potency of the vigorous exercise bout during HIIT, and in consideration of the many possible combinations of exercise bout, rest bout and overall session duration used to constitute HIIT, it is recognised that the dose-response relationships observed may not be limited to the protocol used in the Chapter 6's study. A short exercise bout and overall HIIT duration may be more favourable HIIT protocols over longer duration sessions, as individuals are able to train at near-maximal intensities, eliciting a potent health response with a minimum time constraint [136]. It may be that such time-efficiency is an appealing aspect that represents an exercise option more likely to be adhered to in this cohort [137]. An encouraging indication that participants were engaged with the exercise was reflected in the high attendance rate: 90% of those who volunteered completed the exercise intervention.

To further explore the determinants of the high levels of compliance and implications for exercise adherence, Chapter 7 was concerned with the quantification of affective response to HIIT dose. Physical self-concept was identified as a key factor that influences self-esteem, physical activity uptake and adherence. This research is the first to measure the effect of HIIT dose on both physical self-concept, and exercise enjoyment. Physical self-description was quantified pre- and post- intervention using the PSDQ-S and score changes for sub-domains of physical self-concept were explored across all treatment groups. Encouragingly, the greatest changes elicited from the exercise intervention were seen in Global Physical and Strength, both of which returned large effect sizes. Since Global Physical (self-concept) is considered one of the key PSDQ sub-domains that were measured, it is promising that large favourable changes transpired in this low-active population. Unfortunately, due to a poor response rate during 3-month follow-up phone interviews, assessment of the implications of PSDQ sub-domains with exercise adherence were confounded; speculatively, minimizing the perceived burden of exercise duration may appeal to this low-active cohort, and thus may influence adherence. Also, the high levels of enjoyment towards the exercise intervention in all groups suggest a positive attitude towards future utilisation of HIIT and resistance training. Through measuring physical self-description and exercise enjoyment, improvements and high scores inferred intent for future HIIT utilisation for all doses of HIIT that were undertaken.

8.2 Implications and practical application

The research outcomes from this thesis emphasise the importance of vigorous intensity physical activity for adolescent health. Implications and practical application drawn from study designs outcomes are generated from each investigative chapter of this thesis.

Firstly, through an in-depth investigation into adolescent accelerometer data processing in Chapter 3, issues surrounding the interpretation of physical activity levels were exposed. The results from this study highlighted the magnitude of variation in the physical activity levels across all intensities resulting from the application of epoch length, cut points, and selection of axis. This implies that results between studies using different epoch lengths, cut points, and axes cannot be validly compared. Furthermore, Chapter 3's outcomes suggest that the infancy of vector magnitude cut point calibration in ActiGraph accelerometers prevents potentially more accurate tri-axial accelerometry from being utilised in adolescents. Hence, from these results, it is apparent that a validated approach using high-resolution 1-second epochs with uni-axial Evenson et al. [51] cut points [175] must be utilised until further research is performed on vector magnitude cut point calibration and validation.

Conducting associations with a large, representative adolescent sample in Chapter 4 indicated the importance of vigorous intensity activity for adolescent health. Utilising accurate accelerometer quantification of physical activity determined from Chapter 3, only vigorous intensity physical activity was associated with key positive health outcomes in adolescents whereas light and moderate activity intensity activity were not. Thus, these data support the concept of emphasising the importance of vigorous activity in youth physical activity guidelines.

The most novel and important research outcomes resulting from this thesis came from the exercise intervention conducted in Chapters 6 and 7. Through performing structured vigorous intensity physical activity, findings revealed that HIIT was a potent, time-efficient, practically feasible, and metabolically efficacious alternative for adolescents to achieve meaningful benefits.

Whilst this HIIT research may be considered to be a first step towards integration of specific HIIT physical activity guidelines, school-based PE, or group HIIT sessions, a range of outcomes that were investigated support its future use. Psychological assessment showed that HIIT elicited positive responses in adolescent physical self-concept and perceptions of exercise enjoyment, implying future intent to utilise HIIT for physical activity adherence. The high rates of participant compliance also demonstrated that HIIT was engaging for participants, which may support implications of future activity uptake. It was unfortunate that a poor response rate during follow-up phone interviews confounded the ability to draw conclusions regarding medium to longer-term HIIT adherence, but the positive affective responses suggest that HIIT may an exercise option that participants choose to continue using, although the potential influence of supervision, or lack thereof, is of interest in respect to adherence.

The application of HIIT to a school gym environment has allowed illustration of its efficacy on health outcomes, and practical viability outside of a closely regulated laboratory environment. This important ‘real-world’ design served to integrate the element of translatability to this research, which is essential for the consideration of future HIIT application in the adolescent cohort.

Another aspect that this study incorporated was the use of a mixed exercise modality approach to HIIT. Focussing on the potency of the vigorous intensity exercise bouts, and not the specific responses elicited from certain exercise modalities, gave freedom to offer participants a range of activities that they could switch to in-between sets. This was a novel approach to HIIT that aimed to reflect the mixed exercise modality format that youth may undertake during real-world HIIT sessions, enhancing the translatability of the research outcomes. Informal participant feedback showed support for the mixed exercise modality approach, as individuals claimed to enjoy the variety of exercise sessions; therefore, this is a strategy which may be utilised in future HIIT application.

The low rate of participant recruitment was somewhat expected, as undertaking very vigorous intensity exercise may be a daunting prospect for individuals who avoid structured exercise. However, this research has shown that meaningful health and fitness improvements can be achieved across a range of short duration HIIT doses, which may be an encouraging reference for low-active individuals to undertake HIIT in future. Furthermore, a major outcome from this research was that the lowest HIIT dose used elicited a similar degree of health benefits to that of the highest dose. Promoting the lowest dose of HIIT may be a useful strategy in the campaign for vigorous intensity exercise for inactive youth, since the barriers of time and immediate negative affective response may be perceived as less of an imposition. Indicating that such improvements can be achieved through very short duration, non-competitive exercise may also attenuate the barrier of perceived athleticism needed to undertake exercise for health, and thus has potential to improve population activity levels.

Thus, implications from this body of work suggest that encouraging adolescents to undertake vigorous intensity exercise, using HIIT as an alternative method to achieve the health benefits of physical activity, is likely to be an effective strategy to improve adolescent health.

8.3 Study limitations and future research directions

The studies which form this thesis have been subject to several limitations that have assisted to guide directions for future research. As with all research, time, budget, and resource constraints dictated study design and participant sample size, and contributed to the main limitations of this research. Specific limitations, and resultant future research directions for each investigation are outlined forthwith.

The limitations in Chapter 3's research lie in the dissection of accelerometer data. Whilst three main influences to adolescent physical activity levels were investigated (epoch length, cut point, axis selection), other variables affecting activity quantification were not assessed, namely: removal of non-wear time, number of hours constituting a valid day, and number of valid wear days for inclusion in data analysis. Although these factors may affect overall data inclusion, their outcomes were not directly attributed to the resultant physical activity intensity measurement to which this thesis is concerned. Future study may investigate the contribution these additional factors to physical activity intensity. The ActiGraph GT3X+ accelerometer model was selected as it is the most recent device from the ActiGraph brand, most widely used in physical activity research [38]. Accelerometer research would benefit from a similar study to Chapter 3, conducted using other commonly used brands.

Although the most informed and up-to-date accelerometer data processing techniques were used to determine physical activity levels in Chapter 4, the research was limited to using uni-axial cut points developed by Evenson et al. [51], due to inadequate validation of, and the large magnitude of variation between, vector magnitude cut points (described in Chapter 3). Research was also limited to using body-measured health outcomes (BMI and WCHt) in the adolescent sample, due to the study of a large participant sample size with limited resources. Whilst WCHt and BMI are useful surrogate markers for adiposity and metabolic health, future studies may consider using more detailed body and cardio-metabolic health measures and associating them with high-resolution accelerometer derived physical activity data; however, constraints to conducting such research lie in the availability of budget and resources. Potentially confounding variables such as dietary intake, socio-economic status and pubertal status were not measured, and the influences of ethnicity were not analysed. Although the adolescent cohort used was intended to reflect the mixed ethnicity of the New Zealand population, the selected participant sample also accounted for the additional variable of neighbourhood walkability as a component of the overarching BEANZ study. Since participants were selected from neighbourhoods of both high and low walkability from two New Zealand cities, resultant physical activity data are likely to affect population representation, which requires further investigation.

Another possible avenue for future research is to investigate the effect of accelerometer measured vigorous intensity bout length. Although investigations have been conducted to quantify the influence of bout length on overall adolescent physical activity levels

[28,176], it is appropriate to further understand a dose-response relationship of accelerometer derived vigorous intensity bout length with health outcomes. It is plausible that the minimum duration leisure time vigorous activity bout length for health to be determined using accelerometry, and so warrants further investigation.

Due to the cross-sectional nature of Chapter 4's study, the direction of causality could not be determined, nor could a method to implement vigorous intensity physical activity be established; thus, a detailed investigation to explore the effect of a structured vigorous activity intervention was warranted. Chapters 5, 6, and 7 focussed on HIIT as an exercise protocol that could be used to deliver vigorous intensity exercise. It may be perceived as a limitation that only one method was investigated (i.e. HIIT); however, based on the investigated literature in Chapter 5, it was evident that HIIT was a promising alternative method to achieve the health benefits of physical activity for adolescents. Other plausible approaches to deliver vigorous intensity activity and improve adolescent health were considered, such as: high-intensity resistance training (HIRT) [177], CrossFit [178], aerobic interval training [93], single exercise bout [136], and mixed exercise approaches [179,180]. However, through the identification of a HIIT dose-response relationship with health, the HIIT protocol examined in Chapters 6 and 7 was utilised due to its potent, short duration, repeated vigorous exercise bouts. This investigation is considered to be a first step towards identifying an appropriate HIIT protocol and overall recommended duration for adolescent population consumption. While Chapters 6 and 7 provide strong evidence for promotion of the minimum HIIT dose that was investigated, research must also investigate the effect dose-adaptation relationships using a range of HIIT protocols.

It may be suggested that HIIT protocols should incorporate a low-duration, near maximum exertion, high-intensity bout strategy; however, it is also plausible that longer bouts of below maximal exertion may be used to elicit better compliance and long-term adherence. Near-maximum exertion HIIT exercise bouts are speculated to be the most appropriate approach for translation to real-world situations, since if heart rate monitoring is unavailable, reaching and maintaining the required intensity may be more feasibly achieved than if sub-maximum exertion intervals are performed.

The dose-response study design used enabled us to establish treatment effects with a relatively small sample size; however, the generalizability would benefit from a larger number of participants. Chapter 6's research was performed using a specific low-active cohort; it would be useful for similar research to be performed on a more heterogeneous adolescent cohort, provided participant sample size is adequate. Such research could not be performed during this PhD due to budgetary and resource constraints; however, it is hoped that this thesis is able to provide a platform for the development of HIIT research in youth.

There were several limitations to the investigation of psychological and affective outcomes to HIIT, as studied in Chapter 7. One of the main questions surrounding HIIT research involves the implications for using HIIT for long-term physical activity adherence. Clearly, a public health strategy that delivers a sustained beneficial effect is desired to maintain population health. As physical activity behaviour change involves numerous psychological processes, it is difficult to isolate all of the determinants that may contribute to exercise adherence. In Chapter 7, physical self-concept was identified as one of the key determinants for physical activity uptake and adherence specific to adolescents. This research attempted to quantify the change in adolescents' physical self-perception and relate it to 3-month follow-up HIIT adherence, but unfortunately a very low response during telephone interviews conducted post-intervention confounded the ability to analyse exercise adherence data. Nonetheless, positive physical self-concept has previously been associated with long-term physical activity compliance [143-147]; therefore, a positive change in physical self-perception implied likelihood for the continuation of HIIT and resistance training on completion of the exercise intervention. It is strongly recommend that future research attempts to quantify long-term adherence and physiological adaptations to HIIT if resources are available.

A clear limitation to the translatability of Chapter 6's research to adolescent physical activity recommendations was that the study was performed with male participants only. It is necessary for similar HIIT dose-response research to be conducted using female participants, since the metabolic and psychological outcomes may differ to those seen in males. If similar HIIT responses to those seen for males in Chapters 6 and 7 are established in females, dissemination and promotion of the benefits of HIIT to youth may elicit substantial and sustained benefits to physical activity levels and public health, especially if the minimum HIIT dose is endorsed.

8.4 Conclusion

This thesis details the importance of vigorous intensity physical activity for the metabolic health of adolescents. In summary, epidemiological research showed that only vigorous intensity physical activity was associated with key positive health outcomes in adolescents, supporting the concept of emphasising the importance of vigorous activity in youth physical activity guidelines. Further, investigation into HIIT as method to deliver the health benefits of vigorous activity showed that low-active adolescent males, performing a single HIIT set twice-weekly, in addition to one resistance training session, gained meaningful improvements in fitness and body composition. Undertaking additional HIIT sets provided little additional health improvements to those of the lowest dose in this study. In support for HIIT uptake and long-term adherence, participants also gained meaningful improvements in several sub-domains of physical self-perception and expressed high levels of enjoyment towards the exercise intervention. This research indicated an effect of incremental HIIT dose on the physical self-concept subdomains; thus, practitioners can assume that performing any HIIT dose in addition to resistance training improves physical self-perception. This body of work provides strong support for the promotion of vigorous intensity physical activity in adolescents, specifically endorsing the utilisation of HIIT as a potent and practical alternative method to deliver metabolic health benefits of exercise in youth.

Through addressing the overarching research question, '**What are the effects of vigorous intensity physical activity on the metabolic heath of adolescents?**' this thesis, as a whole, contributes new knowledge to the science of adolescent physical activity and health. The wider implications of this research may help to improve the lifelong health and wellbeing of adolescents by suggesting novel physical activity strategies that incorporate the promotion of vigorous intensity physical activity. Through implementing this research in the adolescent cohort, policy makers and exercise practitioners may be able to reduce the burden of chronic lifestyle related diseases to public health.

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Appendix A: AUTEC approval for the BEANZ study

UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

MEMORANDUM

Auckland University of Technology Ethics Committee (AUTEC)

To: Grant Schofield
From: Rosemary Godbold, Executive Secretary, AUTEC
Date: 31 July 2012
Subject: Ethics Application Number **12/161 Built environments and physical activity in New Zealand youth.**

Dear Grant

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 9 July 2012 and I have approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement by AUTEC at its meeting on 13 August 2012.

Your ethics application is approved for a period of three years until 31 July 2015.

I advise that as part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/research/research-ethics/ethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 31 July 2015;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/research/research-ethics/ethics. This report is to be submitted either when the approval expires on 31 July 2015 or on completion of the project, whichever comes sooner;

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are reminded that, as applicant, you are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

Please note that AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this. Also, if your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply within that jurisdiction.

To enable us to provide you with efficient service, we ask that you use the application number and study title in all written and verbal correspondence with us. Should you have any further enquiries regarding this matter, you are welcome to contact me by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 6902. Alternatively you may contact your AUTEC Faculty Representative (a list with contact details may be found in the Ethics Knowledge Base at http://www.aut.ac.nz/research/research-ethics/ethics).

On behalf of AUTEC and myself, I wish you success with your research and look forward to reading about it in your reports.

Yours sincerely

Dr Rosemary Godbold
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Erica Hinckson; Melody Oliver; Scott Duncan;Julia McPhee; Kate White

From the desk of ...
Dr Rosemary Godbold
Executive Secretary
AUTEC

Private Bag 92006, Auckland 1142
New Zealand
E-mail: ethics@aut.ac.nz

Tel: 64 9 921 9999
ext 8860
Fax: 64 9 921 9902
page: 1 of 1

Appendix B: AUTEC approval for the HIIT dose-response study

AUT UNIVERSITY TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU | AUTEC SECRETARIAT

30 June 2014

Nigel Harris
Faculty of Health and Environmental Sciences

Dear Nigel

Re Ethics Application: **14/161 The dose-response relationship of high-intensity interval training with the metabolic health of male adolescents.**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 30 June 2017.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 30 June 2017;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 30 June 2017 or on completion of the project.

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this. If your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply there.

To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

Kate O'Connor
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Greigh Logan glogan@aut.ac.nz; Scott Duncan; Erica Hinckson; Grant Schofield

Auckland University of Technology Ethics Committee
WA505F Level 5 WA Building City Campus
Private Bag 92006 Auckland 1142 Ph: +64-9-921-9999 ext 8316 email ethics@aut.ac.nz

Appendix C: Letter to the school board of trustees

HUMAN POTENTIAL CENTRE
AN AUT UNIVERSITY RESEARCH CENTRE

To The Board of Trustees,

RE: The dose-response relationship of high-intensity interval training with the metabolic health of male adolescents

Researchers at AUT University's Human Potential Centre are implementing a reasearch study titled **'The dose-response relationship of high-intensity interval training with the metabolic health of male adolescents'**.

New research has shown that high-intensiy interval training, or HIIIT, is a time-efficient way of exercising that delivers health benefits that exceed traditionally recommended long-duration moderate intensity aerobic exercise. In particular, initial studies have observed that HIIT is an effective and more enjoyable form of exercise for inactive, overweight and obese youth. The duration of exercise sessions using HIIT can be as short as 3 minutes; for this reason, we believe this is a palatable and engaging form of exercise for youth.

The primary aim of our study is to determine the efficacy of given doses (or quantities) of HIIT on measures of metabolic health in inactive adolescent males aged 16-18 years.

This research will generate credible evidence to inform researchers, physical education teachers and exercise practitioners as to the health benefits gained from different doses of very short duration, high intensity exercise. The outcomes of this study may influence physical activty guidelines by suggesting an alternative form of exercise to traditionally recommended exercise and help to improve physical activity uptake and adherence.

We hope to work alongside your secondary school to recruit participants, deliver the HIIT exercise intervention and measure students' metabolic health improvements. We will need to work closely a school staff member to coordinate times to conduct the research that suits your school. Research will be conducted in five phases. Each data collection phase is described in detali below.

Phase one: Participant recruitment

We will be seeking a total of 40 students to participate in the research. Males aged 16-18 years who were previously involved in the Built Environment and Physical Activity in New Zealand Adolescents (BEANZ) research, which took place in your school, will be invited to participate in the proposed study. These students' physical activity levels have been measured in the BEANZ study. Subjects will be eligible to participate if they do not adhere to current New Zealand physical activity guidelines and do not participate in school Physical

Education classes. All students will be provided with information sheets. Informed consent will be sought from interested students prior to commencing the study.

Phase two: Baseline measurements

Consenting participants will be invited to the Sports Performance Research Institute New Zealand (SPRINZ) laboratory located at AUT Millennium to undergo baseline measurements. Participants will perform a maximum aerobic fitness (VO_{2max}) test, have body measures taken, and blood drawn by a trained phlebotomist. Visceral fat will be measured on a separate occasion using state-of-the-art dual-energy x-ray absorptiometry (DXA) at Auckland Hospital's body composition laboratory.

Phase three: Exercise intervention

Subjects are randomly assigned to one of five exercise groups. All participants will undertake two sessions of low-volume high-intensity interval training and one session of resistance training each week, for ten weeks. Each exercise session will take a maximum of 20 minutes (60 minutes per week). Exercise sessions will be performed in your school gym hall and sports field, and also in AUT Millennium's SPRINZ laboratory. Trained exercise professionals will deliver exercise sessions which will involve running, cycling, weight training and non-contact boxing.

Phase four: Follow-up measurements

On completion of the exercise trial, subjects will have their fitness, body composition and metabolic health variables measured again. From the pre- and post-intervention results we can calculate the magnitude of change and hence quantify the health benefits that have occurred from the exercise training. As each of the five exercise groups will be given different doses of exercise, we will be able to see which dose produces the optimal benefits.

Phase five: 3-month follow-up

Immediately after, and 3-months after completion of the exercise trial, subjects will be asked a series of questions in as part of a telephone interview. The questions seek to understand how participants enjoyed the exercise intervention, what changes they would make and whether they would undertake the exercise in the future. Each interview will take a maximum of 10 minutes. In understanding participants perceptions of the exercise trial, we will be able to evaluate the study and translate our findings for use of the exercise in real-world settings.

AUT UNIVERSITY AUCKLAND, NEW ZEALAND

HUMAN POTENTIAL CENTRE
AN AUT UNIVERSITY RESEARCH CENTRE

This study is a good opportunity to involve your students in new and unique research which aims to improve their health and encourages them to be more physically active. With both school and student involvement, we hope to be able improve the health of New Zealand youth.

Please contact us should you have any questions around this research.

We look forward to working with you on this project.

Yours sincerely,

Greig Logan

Appendix D: Parent consent and participant assent form

Participant Assent Form

Project title: ***The dose-response relationship of high-intensity interval training with the metabolic health of male adolescents.***

Project Supervisor: ***Nigel Harris***

Researcher: ***Greig Logan***

- I have read and understood the information provided about this research project in the Participant Information Sheet dated 3rd December 2014.
- I have had an opportunity to ask questions and to have them answered.
- I understand that I may withdraw myself, my image, or any other information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- If I withdraw, I understand that all relevant information will be destroyed.
- I permit the researcher to use the data collected for all body composition measures, metabolic measures, and fitness measures.
- I permit the researcher to use voice recordings as part of the focus groups.
- I understand that all data will be used for academic purposes only and will not be published in any form outside of this project without my written permission.
- I agree to take part in this research.

Participant's signature: ....

Participant's name: ....

Participant's date of birth : ....

Participant's cell phone number: ....

Participant's email address: ....

Date: ....

If you are interested in participating in this research please complete this consent form and return it to Ms. Leijten's office by **Tuesday 9th December.**

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

HUMAN POTENTIAL CENTRE
AN AUT UNIVERSITY RESEARCH CENTRE

03 June 2015

Parent/Guardian Consent Form

Project title: ***The dose-response relationship of high-intensity interval training with the metabolic health of male adolescents.***

Project Supervisor: ***Nigel Harris***

Researcher: ***Greig Logan***

- I have read and understood the information provided about this research project in the Participant Information Sheet dated 3rd December 2014.
- I have had an opportunity to ask questions and to have them answered.
- I understand that I may withdraw my child/children, or any other information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- If I withdraw my child/children, I understand that all relevant information will be destroyed.
- I permit the researcher to use the data collected for all body composition measures, metabolic measures, and fitness measures.
- I permit the researcher to use voice recordings as part of the focus groups.
- I understand that all data will be used for academic purposes only and will not be published in any form outside of this project without my written permission.
- I agree for my child to take part in this research.

Parent/Guardian's signature: ....

Parent/Guardian's name: ....

Parent/Guardian's date of birth : ....

Parent/Guardian's Contact Details (if appropriate):

....

....

....

....

Date:

Appendix E: Participant information sheet

HUMAN POTENTIAL CENTRE
AN AUT UNIVERSITY RESEARCH CENTRE

Participant Information Sheet

Date Information Sheet Produced:

15th June 2014

Project Title

The dose-response relationship of high-intensity interval training with the metabolic health of male adolescents.

An Invitation

My name is Greig Logan, a researcher and PhD student at AUT University. I am inviting you to participate in a research project. Your participation in the study is voluntary and you may withdraw at any stage prior to the completion of data collection. Your relationship with AUT will not be advantaged or disadvantaged in any way based on whether or not you decide to participate in the study. Please read through the information below carefully before making your decision.

This research is funded by AUT Enterprises and the Faculty of Health and Environmental Sciences.

What is the purpose of this research?

It is recommended that youth undertake 60 minutes of moderate-to-vigorous physical activity per day to gain health benefits, however many adolescents do not reach these guideline levels. New research is beginning to show that short, repeated bouts of high-intensity interval training, or HIIT, provide greater benefits to health in considerably less time than current recommendations. Exercise involving HIIT can be as short as 3 minutes in duration! Some of these benefits include increased fitness, reductions in unhealthy body fat, weight loss and a better metabolic regulation. All of these health benefits can decrease the risk of developing lifestyle-related diseases.

You have the opportunity to be part of research that aims to find the minimum and optimum amount of exercise to produce health benefits for people your age.

How was I identified and why am I being invited to participate in this research?

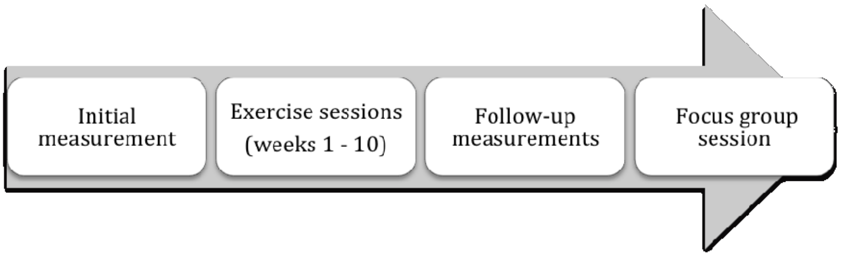
Your school has identified that you do not participate in structured exercise, Physical Education class or extracurricular sport. It is likely that you do not achieve current physical activity guidelines. We would like to give you the opportunity to be involved in low-volume (minimum duration) exercise training sessions that can benefit your health.

What will happen in this research?

This study will take place during school time. You will be given leave from class to undergo detailed exercise and health testing. Each in school term 3 weeks you will be delivered:

- high-intensity interval training sessions
- resistance training (weights) session

We will measure your fitness, metabolic profile and body composition, and at the end of term 3 we will quantify your health improvements.



1) Initial and follow-up health measures

   You will be invited to attend the Sports Performance Research laboratory at AUT Millennium where trained researchers will measure your fitness using a maximal aerobic fitness test (VO_{2max}). Your body composition will be measured using state of the art dual-energy x-ray absorptiometry (DXA) and your metabolic profile will be measured by blood analysis.

   DXA is a scanning or imaging method, which provides a quick and non-invasive measure of body composition (bone, fat, lean tissue). The scan takes about 10 minutes. You lie quietly on an open bed (you are not inside a 'tube' as you are for MRI scanning) and a scanning arm passes quickly over the top of you. You have to lie quietly without moving, but it is not an unpleasant measurement. As the scanning arm passes over you it emits very low dose x-rays, similar to the radiation dose that you would receive if you took a 1 hour flight – perhaps between Auckland and Wellington. At the end of the scan we will print a picture of you showing an image of the bone, fat and lean tissue in your body.

2) Exercise protocol and procedures

   You will be assigned to an exercise group where you will perform three sessions of exercise for 10 weeks. This exercise is very short in duration. For two sessions each week you will be delivered low-volume high-intensity interval training (HIIT) and one session per week will involve resistance exercise.

   The exercise sessions will be performed in AUT's exercise laboratory and at your school. It will involve running, cycling, weight training and non-contact boxing. You will be taught to perform the exercise safely and efficiently.

3) Focus group sessions

   After we have taken your final set of measurements we would like to interview you in groups to find out what you thought of the exercise you undertook (e.g. Did you like it? What changes would you make? Would you use it in the future?). There will be another focus group session 3-months after completion of the exercise trial.

What are the discomforts and risks?

You may experience slight discomfort (a) when you are being measured, (b) when blood is taken, and (c) during the intervention from exercising at higher intensities than you are used to. The dose of radiation used in DXA measurement is classified as 'trivial' and does not pose any risk to health.

How will these discomforts and risks be alleviated?

We will make sure you are comfortable and cater to your needs at every stage of the intervention. Trained exercise professionals will deliver the exercise sessions and prioritise your safety. Experienced research professionals will be involved in taking blood and body measurements to ensure comfort and safety at all times.

What are the benefits?

Research indicates that exercising at high intensities for very short durations can improve health to a greater extent than currently recommended long-duration moderate intensity steady state exercise. We are trying to find out what dose of high intensity exercise provides the optimal health benefits. By participating, you will improve your health and learn new skills to exercise efficiently. You will receive detailed feedback on all of the variables we measure. The findings from this study could benefit many individuals worldwide through employment of the most effective exercise for health benefits. You will also get real experience of what it is like to be a part of exercise science research, which may inspire you for future career options!

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

Due to the nature of the research your colleagues and schoolteachers will know that you are participating in the research. However, your data will be kept private and will not be shared with them. No names or contact details will be stored with the dataset.

What are the costs of participating in this research?

There are no financial costs of participating in the research.

You will be required to give up to 1 hour of your time for initial and follow-up measurements. Exercise sessions may last up to 20 minutes (1 hour per week). Follow-up focus groups may last up to 30 minutes.

What opportunity do I have to consider this invitation?

If you are interested in participating in the research please complete a consent form and return it to the research team by **Tuesday 10th June.**

Will I receive feedback on the results of this research?

Yes, once all the data collection has been completed all participants will receive a feedback report with their individual results for all health and fitness variables, as well as the main findings of the study.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Leader, Greig Logan (glogan@aut.ac.nz).

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Kate O'Connor, Tel: +64 9 921 9999 extn: 6038.

Whom do I contact for further information about this research?

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Appendix F: Physical self-description questionnaire

HUMAN POTENTIAL CENTRE
AN AUT UNIVERSITY RESEARCH CENTRE

PSDQ-S

All information supplied will be kept strictly confidential

Name:................................
Date:.................................
Age:...................................

This is not a test. The questions are about how you view yourself and exercise.

PLEASE ANSWER THESE QUESTIONS WITHOUT SPEAKING TO ANYONE ELSE.

Please **circle** the number that fits the statement for you.

EXAMPLE:

	1 True	2 Mostly True	3 Slightly True	4 Slightly False	5 Mostly False	6 False
I am a creative person. →	1	2	3	4	5	6

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1 True	2 Mostly True	3 Slightly True	4 Slightly False	5 Mostly False	6 False

1. I feel confident when doing coordinated movements. → 1 2 3 4 5 6

2. I am a physically strong person. → 1 2 3 4 5 6

3. I am quite good at bending, twisting and turning my body. → 1 2 3 4 5 6

4. I can run a long way without stopping. → 1 2 3 4 5 6

5. Overall, most things I do turn out well. → 1 2 3 4 5 6

→

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	1 True	2 Mostly True	3 Slightly True	4 Slightly False	5 Mostly False	6 False
6. I usually catch whatever illness (flu, virus, cold, etc.) is going around. →	1	2	3	4	5	6
7. Controlling movements of my body comes easily to me. →	1	2	3	4	5	6
8. I often do exercise or activities that make me breathe hard. →	1	2	3	4	5	6
9. My waist is too large. →	1	2	3	4	5	6
10. I am good at most sports. →	1	2	3	4	5	6

→

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HUMAN POTENTIAL CENTRE
AN AUT UNIVERSITY RESEARCH CENTRE

1 True	2 Mostly True	3 Slightly True	4 Slightly False	5 Mostly False	6 False

11. Physically, I am happy with myself. → 1 2 3 4 5 6

12. I have a nice looking face. → 1 2 3 4 5 6

13. I have lots of power in my body. → 1 2 3 4 5 6

14. My body is flexible. → 1 2 3 4 5 6

15. I am sick so often that I cannot do all the things I want to do. → 1 2 3 4 5 6

→

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HUMAN POTENTIAL CENTRE
AN AUT UNIVERSITY RESEARCH CENTRE

	1 True	2 Mostly True	3 Slightly True	4 Slightly False	5 Mostly False	6 False
16. I am good at coordinated movements. →	1	2	3	4	5	6
17. I have too much fat on my body. →	1	2	3	4	5	6
18. I am better looking than most of my friends. →	1	2	3	4	5	6
19. I can perform movements smoothly in most physical activities. →	1	2	3	4	5	6
20. I do physically active things (e.g. jog, dance, bicycle, aerobics, gym, swim) at least three times a week. →	1	2	3	4	5	6

→

HUMAN POTENTIAL CENTRE
AN AUT UNIVERSITY RESEARCH CENTRE

1 True	2 Mostly True	3 Slightly True	4 Slightly False	5 Mostly False	6 False

21. I am overweight. →	1	2	3	4	5	6
22. I have good sports skills. →	1	2	3	4	5	6
23. Physically, I feel good about myself. →	1	2	3	4	5	6
24. Overall, I am no good. →	1	2	3	4	5	6
25. I get sick a lot. →	1	2	3	4	5	6

→

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HUMAN POTENTIAL CENTRE
AN AUT UNIVERSITY RESEARCH CENTRE

	1 True	2 Mostly True	3 Slightly True	4 Slightly False	5 Mostly False	6 False
26. I find my body handles coordinated movements with ease. →	1	2	3	4	5	6
27. I do lots of sports, dance, gym, or other physical activities. →	1	2	3	4	5	6
28. I am good looking. →	1	2	3	4	5	6
29. I could do well in a test of strength. →	1	2	3	4	5	6
30. I can be physically active for a long period of time without getting tired. →	1	2	3	4	5	6

→

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HUMAN POTENTIAL CENTRE
AN AUT UNIVERSITY RESEARCH CENTRE

1 True	2 Mostly True	3 Slightly True	4 Slightly False	5 Mostly False	6 False

31. Most things I do, I do well. →	1	2	3	4	5	6
32. When I get sick, it takes me a long time to get better. →	1	2	3	4	5	6
33. I do sports, exercise, dance or other physical activities almost every day. →	1	2	3	4	5	6
34. I play sports well. →	1	2	3	4	5	6
35. I feel good about who I am physically. →	1	2	3	4	5	6

→

HUMAN POTENTIAL CENTRE
AN AUT UNIVERSITY RESEARCH CENTRE

	1 True	2 Mostly True	3 Slightly True	4 Slightly False	5 Mostly False	6 False
36. I think I would perform well on a test measuring flexibility. →	1	2	3	4	5	6
37. I am good at endurance activities like distance running, aerobics, bicycling or swimming. →	1	2	3	4	5	6
38. Overall, I have a lot to be proud of. →	1	2	3	4	5	6
39. I have to go to the doctor because of illness more than most people my age. →	1	2	3	4	5	6
40. Nothing I ever do seems to turn out right. →	1	2	3	4	5	6

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE.

Appendix G: Enjoyment scale

HUMAN POTENTIAL CENTRE
AN AUT UNIVERSITY RESEARCH CENTRE

Please CIRCLE the answer you feel is most appropriate to you.

1) How much did you enjoy the exercise that you have done over the last 8 weeks?

1 Hated it	2 Disliked it	3 Slightly disliked it	4 No feelings either way	5 Slightly enjoyed it	6 Really enjoyed it	7 Loved it