Making a HIIT:
High-intensity interval training interventions in educational settings

Stephanie Lynn Duncombe
MPH BSc

A thesis submitted for the degree of Doctor of Philosophy at
The University of Queensland in 2023

Faculty of Health and Behavioural Sciences
School of Human Movement and Nutritional Sciences

Abstract

High-intensity interval training (HIIT) is gaining interest in the school setting due to various factors, such as research associating higher intensity physical activity with lower cardiometabolic risk, its similarity with children's intermittent patterns of physical activity, and its time-efficient protocols. The aim of this thesis was to explore the effectiveness and feasibility of HIIT in schools.

The first study was a published systematic review and meta-analysis on school-based HIIT (*Chapter Two).* It determined that compared to a control group, the group completing HIIT had significant improvements to cardiorespiratory fitness, body composition, and blood biomarkers. However, it identified that current studies had limited involvement of end-users, minimal integration within school practice, and poorly documented evaluations of their intervention implementation.

The second study of this thesis, *Making a HIIT*, aimed to address these limitations. It was guided by self-determination theory and the theory of expanded, extended, and enhanced opportunities. *Chapter Three* provides its published protocol. In phase one, HIIT workouts were co-designed with students and teachers within the Health and Physical Education (HPE) curriculum. In phase two, these workouts were incorporated into HPE lessons for an 8-week intervention that was completed by students involved in the co-design process and additional students. A control group continued normal HPE lessons.

Chapter Four presents the co-design process used in five classes at three schools (121 students, aged 12 – 14 years) to design 33 HIIT workouts. This included: 1) identifying barriers and facilitators to exercise to create evaluation criteria for the HIIT workouts; 2) using heart rate monitors and engaging in pre-made HIIT workouts; 3) defining HIIT parameters (intensity and interval length); 4) creating HIIT workouts using the parameters and evaluation criteria; 5) trialling and modifying the HIIT workouts based on class feedback and intensity data. Analysis of teacher interviews and student discussions determined the methodology was feasible within the HPE curriculum and supported educative outcomes.

A comprehensive process evaluation of the *Making a HIIT* intervention is presented in *Chapter Five*. This was guided by the Framework for Effective Implementation. Three schools and 15 classes participated in phase two of *Making a HIIT*. Overall, 79% of eligible students (n = 308, $\bar{x}$ age: 13.0 ± 0.6 years, 148 girls) provided consent. The average number of HIIT workouts provided by teachers and attended by students was 10 ± 3 and 6 ± 2, respectively. During HIIT workouts, the percentage

of time students spent at ≥ 80% of heart rate maximum was 55% (interquartile range: 29% - 76%). On average, students rated their enjoyment of HIIT workouts as neutral to positive. Teachers found the workouts simple to implement but provided insights into the time implications of integrating the workouts into their lessons; elements that helped facilitate the HIIT workouts; and the use of HIIT within the classroom. This chapter identified areas for future focus, including methods for maximising dosage delivered, while providing promising insight into the satisfaction of HIIT expressed by students and teachers.

Chapter Six expanded on the fidelity of *Making a HIIT* as discussion on the quantification of heart rate data in the current literature was warranted. It presented evidence of variation in the heart rate data within-students, between-students, and over time. Further, it discussed considerations for fidelity measurement in the school setting and presented rating of perceived exertion (RPE) as an additional option for achieving this. The within-person correlation between heart rate and RPE data ($r = 0.39$; $p < 0.001$) suggests RPE is a suitable option when HR is unavailable.

Chapter Seven and *Chapter Eight* evaluated the effects of the HIIT intervention and the possible moderator role of the co-design process. The results of *Chapter Seven* indicate that the co-design process did not affect students' initial levels of enjoyment, autonomous motivation, self-efficacy, perceived competence, relatedness, or autonomy during HIIT. Similarly, there were no differences in the groups over time, which could be due to the use of workouts that were designed to: be engaging; modifiable for different abilities; and encourage social interactions. *Chapter Eight* demonstrated that students completing HIIT had significant improvements over time in cardiorespiratory fitness, muscular power, and inhibition, but that these were not significantly different from the control group. This could be as: 1) the control group was still completing high-intensity physical activity during their HPE lessons; 2) the intervention, which occurred in 'real-world' context, was not as effective as previous controlled studies; and 3) the dosage of HIIT was too low for additional improvements in the intervention group to occur.

This thesis makes significant and novel contributions to the literature on school-based HIIT through co-designing HIIT workouts, integrating *Making a HIIT* within the curriculum, and conducting an in-depth process evaluation. Combined, these enhance our understanding of school-based HIIT in an ecologically valid manner. Finally, this thesis identifies challenges that stem from 'real-world' implementation of HIIT interventions that warrant future investigation.

Declaration by author

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

I have clearly stated the contribution of others to my thesis as a whole, including statistical assistance, survey design, data analysis, significant technical procedures, professional editorial advice, financial support and any other original research work used or reported in my thesis. The content of my thesis is the result of work I have carried out since the commencement of my higher degree by research candidature and does not include a substantial part of work that has been submitted to qualify for the award of any other degree or diploma in any university or other tertiary institution. I have clearly stated which parts of my thesis, if any, have been submitted to qualify for another award.

I acknowledge that an electronic copy of my thesis must be lodged with the University Library and, subject to the policy and procedures of The University of Queensland, the thesis be made available for research and study in accordance with the Copyright Act 1968 unless a period of embargo has been approved by the Dean of the Graduate School.

I acknowledge that copyright of all material contained in my thesis resides with the copyright holder(s) of that material. Where appropriate I have obtained copyright permission from the copyright holder to reproduce material in this thesis and have sought permission from co-authors for any jointly authored works included in the thesis.

Publications included in this thesis

Peer reviewed journal articles

1. **Duncombe SL,** Barker AR, Bond B, Earle R, Varley-Campbell J, Vlachopoulos D, Walker JL, Weston KL, Stylianou M. (2022) School-based high-intensity interval training programs in children and adolescents: A systematic review and meta-analysis. *PLoS ONE*. 17(5): e0266427. https://doi.org/10.1371/journal.pone.0266427

2. **Duncombe SL**, Barker AR, Price L, Walker JL, Dux PE, Fox A, Matthews N, Stylianou M. (2022). Making a HIIT: study protocol for assessing the feasibility and effects of co-designing high-intensity interval training workouts with students and teachers. *BMC Pediatrics*. 22 (425). https://doi.org/10.1186/s12887-022-03440-w

3. **Duncombe SL,** AR Barker, Price L, Walker J, Liu Y, Paris D, and Stylianou (2023). Making a HIIT: Co-Design of High-Intensity Interval Training Workouts with Students and Teachers within the Curriculum. *BMC Public Health.* http://doi.org/10.1186/s12889-023-16613-8

Conference abstracts

1. **Duncombe SL**, Barker AR, Bond B, Earle R, Varley-Campbell J, Vlachopoulos D, Walker J, Weston K, Stylianou M. School-based high-intensity interval training programs in children and adolescents: A Systematic Review and Meta-Analysis. *Journal of Science and Medicine in Sport* 24: S78-79.

2. **Duncombe SL**, Barker AR, Price L, Walker J, Stylianou M. Making a HIIT: Co-design of high-intensity interval training workouts with students within the curriculum. 2022. *9th International Society of Physical Activity and Health Congress,* Abu Dhabi, United Arab Emirates, 23 – 26 October 2022.

3. **Duncombe SL**, Stylianou M, Price L, Walker J, Barker AR. Was it a HIIT? A process evaluation of a school-based high-intensity training intervention. 2022. *Journal of Science and Medicine in Sport* 25: S42

4. **Duncombe SL**, Stylianou M, Price L, Walker J, Barker AR. High intensity interval training in schools: methods for quantifying intensity and the validity of session rating of perceived exertion. 2022. *European College of Sport Science 27th Annual Congress,* Sevilla Spain, 30 August – 2 September 2022.

5. **Duncombe SL**, Barker AR, Price L, Walker J, Koep JK, Woodforde J, Stylianou M. Effect of a school-based HIIT intervention on students' cardiorespiratory fitness, muscular fitness, and executive function: Findings from Making a HIIT. 2023. *Asia-Pacific Society for Physical Activity Conference,* Wellington, New Zealand, 27 – 29 November 2023.

Submitted manuscripts included in this thesis

1. **Duncombe SL,** Stylianou M, Price L, Walker J, and Barker AR (2023). Making a HIIT: Methods for quantifying intensity in high-intensity interval training in schools and validity of session rating of perceived exertion.

Other publications during candidature

Peer reviewed journal articles

1. **Duncombe SL,** Barker AR, Bond B, Earle R, Varley-Campbell J, Vlachopoulos D, Walker JL, Weston KL, Stylianou M (2022) School-based high-intensity interval training programs in children and adolescents: A systematic review and meta-analysis. PLOS ONE. 17(5): e0266427. https://doi.org/10.1371/journal.pone.0266427

2. **Duncombe SL**, Barker AR, Price L, Walker JL, Dux PE, Fox A, Matthews N, Stylianou M (2022). Making a HIIT: study protocol for assessing the feasibility and effects of co-designing high-intensity interval training workouts with students and teachers. BMC Pediatrics. 22 (425). https://doi.org/10.1186/s12887-022-03440-w

3. **Duncombe SL,** AR Barker, Price L, Walker J, Liu Y, Paris D, and Stylianou (2023). Making a HIIT: Co-Design of High-Intensity Interval Training Workouts with Students and Teachers within the Curriculum. *BMC Public Health.* http://doi.org/10.1186/s12889-023-16613-8

4. Stylianou M, Woodforde J, **Duncombe, SL**, Kolbe-Alexander T, and Gomersall S (2021). School physical activity policies and associations with physical activity practices and behaviours: A systematic review of the literature. *Health and Place* 73 (5): 102705

5. Liu Y, Williams CA, Weston KL, **Duncombe, SL**, Malik AA, Barker AR (2023). Validation and calibration for embedding rating of perceived exertion into high-intensity interval exercise in adolescents: a lab-based study. *Pediatric Exercise Science.* Under Review.

Other Literature Contributions

1. **Duncombe SL** (2023) Vigorous Physical Activity: A promising option for a busy school day. *Sport Health.*

2. Gomersall S, **Duncombe SL**, Stylianou M. (2022) Organised Sport and Physical Activity Participation. In: Reboot! Reimagining Physically Active Lives: 2022 Australian Report Card on Physical Activity for Children and Young People. Melbourne, Victoria: Active Healthy Kids Australia. https://doi.org/10.21153/ahka2022

Contributions by others to this thesis

Dr. Michalis Stylianou and Associate Professor Alan Barker were lead investigators of this project and had substantial input into the conception and design of the project, interpretation of research data, and critical revision of all the work throughout this thesis. Dr. Lisa Price and Dr. Jacqueline Walker were involved in the design of the project and critical revision throughout the thesis. Dr. Bert Bond, Ms. Renae Earle, Dr. Jo Varley-Campbell, Dr. Dimitris Vlachopoulos, and Dr. Kathryn Weston were involved in the conception, data extraction, and critical revision of *Chapter Two*. Dr. Natasha Mathews, Professor Paul Dux, and Ms. Amaya Fox were involved in the design and interpretation of the executive function tests included in *Chapter Three* and *Chapter Eight*. Mr. James Woodforde and Ms. Jodie Koep were involved with data collection for *Chapter Five*, *Chapter Seven* and *Chapter Eight*. Mr. Yong Liu and Mr. Dewi Paris were involved in the data analysis in *Chapter Four*. Mr. Zebin Lyu was involved in the qualitative data analysis in *Chapter Five.*

Professor Mai Chin A Paw and Associate Professor Narelle Eather contributed to this thesis with valuable and constructive feedback during each yearly milestone. Journal reviewers and editors provided helpful feedback for the articles in *Chapter Two, Chapter Three, Chapter Four, and Chapter Five*.

Statement of parts of the thesis submitted to qualify for the award of another degree

No works submitted towards another degree have been included in this thesis.

Research involving human or animal subjects

All research presented in this thesis was approved by The University of Queensland's human research ethics committee (Project: 2020/HE002444) and relevant governing bodies and gatekeepers (Study 2; *Chapter Three – Chapter Eight*). Copies of the ethics approval letters are included in the thesis as Appendix 1.

Acknowledgements

This thesis would not have been possible without the support of countless people who have provided guidance, friendship, laughter, and encouragement. Between moving to Australia alone in 2020 and the covid lockdowns that followed, the last three years could certainly have been difficult. While they were not without challenges, when I reflect on this time, I am filled with gratitude for the people that made Brisbane home. It is near impossible to express my thanks to everyone and equally impossible to thank anyone properly in a short paragraph, but please know that this thesis exists thanks to every friend, family member, colleague, and mentor that got me across the line.

Thank you to the QUEX Institute for Excellence for providing me with this incredible opportunity that enabled me to travel to different countries, network with experts around the world, and conduct research with such an incredible team. To my unbelievable supervisory team: Michalis, Alan, Lisa, and Jacki, thank you for your endless support, consistent encouragement, and invaluable insight and knowledge. Michalis, thank you for always having time for a chat, whether it be PhD related or not, for your dedication to me and my studies, and for your always prompt and in-depth feedback – your attention to detail is unmatched. Alan, thank you for always being available over zoom, for your well-thought-out responses and contagious enthusiasm for science, and for helping me feel immediately welcomed at CHERC. I only wish I could have spent a few more months there. Lisa, thank you for taking time from your mat leave for coffee chats and for all your advice during my study design and analyses. Jacki, thank you for your insightful contributions and for making sure I had a desk during my data collection.

To everyone in HMNS for their friendship. From futsal Fridays and lunch upstairs to days at the beach and orphan Christmas; I am grateful for all the memories small and large that made working here so special. To everyone that welcomed me to Brisbane and gave me an outlet outside my PhD, thank you! To Di and Duncan, for being my family on this side of the world; to everyone on bikes, for all the adventures; and to Jodes, for being the best sister to share a home with for three years.

To Mom, Dad, and Dan – thanks for supporting me from afar and for always answering the phone. Forever wishing that you were over here with me, but grateful for our FaceTime calls that make you seem so much closer. To all my friends and family around the globe, thanks for the check-in calls & messages. Please come visit Australia soon. And lastly, to Jonathon, for moving around the world for me and for your endless love and support; I wouldn’t have gotten here without you.

Financial support

This research was supported by the QUEX Global Institute for Excellence and by a research grant from Sports Medicine Australia.

Keywords

School, physical activity, co-design, implementation, fidelity, fitness, executive functioning, enjoyment.

Australian and New Zealand standard research classifications (ANZSRC)

ANZSCR code: 110699

Human Movement and Sports Science, not elsewhere categorised, 50%

ANZSCR code: 111712

Health Promotion, 50%

Field of research (FoR) classification

FoR code: 1106

Human Movement and Sports Science, 50%

FoR code: 1117

Public Health and Health Services, 50%

Table of Contents

List of Figures

List of Tables

List of Abbreviations

ANOVA	Analysis of variance
BMI	Body mass index
CRF	Cardiorespiratory fitness
GRADE	Grading of Recommendations, Assessment, Development and Evaluation
HIIT	High-intensity interval training
HIIT-SQ	High-intensity interval training self-efficacy questionnaire
HOMA-IR	Homeostatic model assessment – insulin resistance
HPE	Health and physical education
HR	Heart rate
HR_{max}	Maximum heart rate
IAP2	International Association for Public Participation
ICC	Intraclass coefficient
LDL	Low-density lipoprotein
MAS	Maximal aerobic speed
MAV	Maximal aerobic velocity
MD	Mean difference
NR	Not reported
NS	Not significant
OMNI	omnibus
PACES	Physical activity enjoyment scale
PAQ-C	Physical activity questionnaire for children
PICO	Participant, intervention, comparison, and outcome
PHV	Peak height velocity
PLOC	Perceived locus of control

PRISMA	Preferred Reporting Items for Systematic Reviews and Meta Analyses
RCT	Randomised control trial
RPE	Rating of perceived exertion
ROB-2	Risk of Bias-2
ROBINS-I	Risk of Bias in Non-Randomised Studies
SDT	Self-determination theory
SMD	Standardised mean difference
sRPE	Session rating of perceived exertion
SRT	Shuttle run test
TRIMP	Training impulse
$\dot{V}O_2$	Maximal oxygen uptake

Chapter 1: Introduction and thesis structure

The purpose of this chapter is to provide a wider context of the research area, the thesis aims, and the general structure of the thesis document. Firstly, this chapter briefly introduces the area of school-based research and provides a description of co-design, which can be used to mitigate some of the challenges faced in this setting. Secondly, it provides a general overview of high-intensity interval training (HIIT) in children and adolescents, which was the type of physical activity delivered within the studies of this thesis. After, the theoretical framework that informed this thesis is presented. Finally, the overarching aims of this thesis and a summary of the research aims for each chapter are provided.

Physical activity levels in children and adolescents and the role of schools

Physical activity is essential for children and adolescents' health, wellbeing, and learning [1, 2]. Further, levels of activity in childhood and adolescence appear to track into adulthood and can have an impact on the general health of the population [3]. The Australian Department of Health published guidelines stating that children and adolescents aged 5 to 17 years should complete 60 minutes of moderate-to-vigorous physical activity each day to acquire health benefits [4]. However, Australia's 2022 Report Card on physical activity for children and young people provides evidence that physical activity levels in this population are low, with only a quarter meeting the recommended national guidelines [5, 6]. This is similar to international data from the 2022 Report Cards with Australia receiving a grade of D- for overall physical activity while the aggregate grade for all 57 participating countries was a D [7]. With this ongoing issue of physical inactivity in consideration, the World Health Organization launched their Global Action Plan on Physical Activity 2018 – 2030, which set a target of a reducing physical inactivity by 10% in 2025 and 15% by 2030 [8]. Both the World Health Organization Action Plan and the 2022 Report Cards recommended schools as an ideal setting to target physical inactivity, noting that quality physical education and inclusion of activity throughout the school day can provide physical and health literacy for long-lasting healthy lifestyles [6, 8]. Further, the International Society for Physical Activity and Health lists whole-of-school programs as one of their eight investment areas to promote physical activity [9]. Therefore, consistent with these recommendations, the studies within this thesis focused on the school setting and targeted physical activity during health and physical education (HPE) lessons.

Schools are consistently recommended as an opportune setting to combat physical inactivity for several reasons. They can reach a large proportion of the target population, they have infrastructure available at no cost to students, and they have staff who are, or can be, trained to facilitate physical activity interventions [10]. Numerous efficacy studies and systematic reviews have showcased the potential benefits of these interventions, including improved fitness, enhanced academic-related outcomes, and increased physical activity levels [11-14]. However, these findings are inconsistent, with other systematic reviews finding no positive impact on students' physical activity levels or body mass index (BMI) [14-16]. There is continually a call for future research to evaluate and report the level of implementation of these interventions to potentially explain some of the heterogeneity present in the studied outcomes [11, 15], especially as the implementation of interventions has been associated with their efficacy [17]. Further, there has been a call to evaluate the effectiveness of school-based physical activity interventions in real-world settings where the interventions are delivered by school employees as standard practice [12, 18]. The progression from efficacy trials to real-world interventions is known to result in decreased effectiveness and therefore, a greater understanding of the adoption by schools and the level of implementation is needed in this area to maximise impact on targeted outcomes [18, 19].

While schools enable the facilitation of interventions, they also pose unique challenges that must be considered, such as curriculum demands, time constraints, and teacher workloads [10, 17]. To address these challenges, there has been a strong push to include end-users (e.g., teachers and students) in the design of real-world trials [20, 21]. Additionally, the Australian Student Wellbeing Framework includes authentic student participation (student voice) as one of its five key elements, with the aim of enabling students to be active participants in their learning and wellbeing [22]. The work in this thesis aimed to address the lack of end-user participation in the literature through the process of co-design. Throughout this thesis, co-design is defined as collective creativity throughout the design process, and it is characterised by an active collaboration to design solutions to a pre-identified problem [23, 24]. It is distinguished from other forms of end-user engagement such as co-creation and co-production that have differing levels of end-user participation. Co-creation engages end-users before the problem is identified and necessitates the highest level of engagement from end-users, while co-production requires less engagement from end-users and involves them in the evaluation of potential solutions to a problem [24]. Due to the time and curriculum restraints of working in schools, co-design was deemed to enable sufficient and meaningful participation within this thesis, while complementing other curriculum demands.

High intensity interval training

Traditionally, moderate-to-vigorous physical activity was recommended as per the World Health Organization and national guidelines [4, 25]. However, recent studies have investigated moderate and vigorous physical activity separately and the evidence suggests that vigorous activity may be driving health benefits in addition to requiring less time than moderate activity [26-28]. Tarp *et al.* demonstrated that higher intensity physical activity was associate with a lower cardiometabolic risk score and lower body mass index (BMI) in children and adolescents and therefore, recommended the promotion of higher intensity activities [28]. Further, Gralla *et al*. suggested that vigorous intensity physical activity could yield benefits above those provided by moderate activities for outcomes such as adiposity and cardiorespiratory fitness in youth [27].

HIIT is a type of vigorous physical activity characterised by short bouts of exercise followed by recovery periods of either rest or low intensity exercise and follows a similar pattern to children's intermittent style of physical activity acquisition [29, 30]. Acute bouts of high-intensity interval exercise can elicit positive health effects in children and adolescents including improved vascular function, blood glucose and insulin, executive function, and well-being [31-36]. According to multiple systematic reviews, chronic HIIT has also been associated with benefits such as favourable changes to cardiovascular disease biomarkers, cardiorespiratory fitness, body composition, executive function, and wellbeing [35, 37-39]. HIIT interventions are increasingly used within the school setting and have had promising results. A comprehensive appraisal of school-based HIIT is provided in the literature review in *Chapter Two*. There is a large interest in school-based HIIT interventions to investigate if the results obtained from controlled acute and chronic studies are present in real-world settings, such as schools.

The enjoyment of HIIT is an important area of consideration, with increased enjoyment associated with increased adherence, and adherence necessary for HIIT to have the benefits described above [40, 41]. However, the enjoyment of HIIT is an area of controversy in the literature. Critiques of HIIT argue that high-intensity physical activity, defined as activity above the ventilatory threshold, will elicit displeasure due to the body varying from its homeostatic baseline, which will cause low levels of adoption and maintenance [42-44]. However, it is worth nothing that this conclusion is based on predictions from incremental and continuous exercise and therefore may not appropriately apply to HIIT, which includes intervals of high-intensity interspersed with recovery periods [42]. Further, there is a paucity of information on the enjoyment of HIIT in children and adolescents, with only a few studies investigating this outcome [45-47]. Malik et al. demonstrated that a laboratory-based HIIT protocol including 8 x 1-minute running intervals at 90% of maximum aerobic speed did not elicit displeasure in 13 adolescent boys and produced a greater level of enjoyment post-exercise when compared to moderate intermittent exercise [45]. Another laboratory-based study on nine adolescent boys determined that enjoyment was no different between a HIIT protocol of 8 x 1-minute cycling intervals at 90% of peak power and a moderate intensity exercise protocol of continuous cycling at 90% of participants' gas exchange threshold even though HIIT elicited greater physiological and perceptual stress than the moderate intensity exercise [46]. One school-based study (n = 31, mean age = 16 years) reported that students' overall enjoyment of a HIIT program that included 8 weeks of 8-10-minute sessions with a work-to-rest ratio of 30s-to-30s was 4 out of 5 [47]. Overall, current findings on the enjoyment of HIIT in pediatric populations are based on small studies with traditional exercise protocols (e.g., running or cycling-based with constant interval lengths) and are mainly laboratory-based warranting further research with larger school-based studies as. Another critique of HIIT is that participants are not working at an appropriate intensity for the exercise to be considered high-intensity [48], which could lead to overestimating the enjoyment and adherence to HIIT. The intensity of HIIT within lab-based pediatric studies has been documented rigorously, enabling certainty that the protocol was implemented as intended [45, 46]. However, further research into the intensity of HIIT conducted outside of laboratories is necessary as current systematic reviews and meta-analyses on HIIT in children and adolescents have not reported on these process outcome data [35, 37-39]. Although, one review does acknowledge that due to the variance across studies, a protocol for standard practice remains ambiguous [38].

With these considerations in mind, HIIT was used as the mechanism of physical activity delivery for the work conducted in this thesis. The HIIT workouts were co-designed with students and teachers in HPE lessons to utilize the knowledge of end-users and alleviate some of the burden of school-based research by positioning the lessons within the curriculum. Both the co-design process and use of HIIT workouts align with several Year 7 and 8 Australian HPE content descriptors, such as understanding the benefits of physical activity for health, measuring heart rate, and designing fitness plans [49]. The studies in this thesis aimed to bring discourse to the effectiveness and level of implementation of school-based physical activity interventions in real-world settings (*Chapter Five* and *Chapter Six*) and to expand our understanding of students' enjoyment of HIIT and the effect of being involved with co-designing workouts (*Chapters Five – Chapter Seven*). They considered the self-efficacy and perceived competence of students as studies have demonstrated that both these attributes have been associated with the enjoyment of HIIT in children and adolescents (*Chapter Seven*) [50, 51].

Theoretical grounding

To increase the likelihood that the intervention conducted as part of this thesis was implemented with the potential for success and sustainability, it was guided by a theoretical framework grounded in two relevant and evidence-based theories. The purpose of adopting a theoretical framework was three-fold. It: 1) justified the significance of the work [52]; 2) provided the structure for the philosophical and methodological approach in the experimental studies; and (3) served as a guide during the development of the intervention used in *Chapter Three* to *Chapter Eight* [53]. As presented in Figure 1, the structure of the theoretical framework informing the work in this thesis is aligned with the socio-ecological model, which was identified as a promising framework for our intervention as it is holistic, contains multiple engagement points and stakeholders, and can account for the numerous correlates and agents involved in physical activity [54, 55]. For physical activity interventions in schools, many factors must be considered, including the school climate, teachers' perceptions, and motivation of individual students [56]. The theory of expanded, extended, and enhanced opportunities states that physical activity levels can be increased if students are provided with more opportunities for physical activity, more time for them, and higher quality opportunities [57]. It aligns with interpersonal and organisational layers of the socio-ecological model (Figure 1). It was chosen because the work in this thesis aimed to target the enhancement of opportunities for physical activity acquisition by introducing curriculum content focusing on vigorous physical activity and co-designed workouts to increase engagement. Complementing this, self-determination theory also guided the work in this thesis and aligned with the intrapersonal and interpersonal layers of the socio-ecological model (Figure 1) [58]. Study two of this thesis included components that supported the basic psychological needs (autonomy, relatedness, and competence) to promote increased motivation and engagement in the co-designing of workouts and the intervention [59].

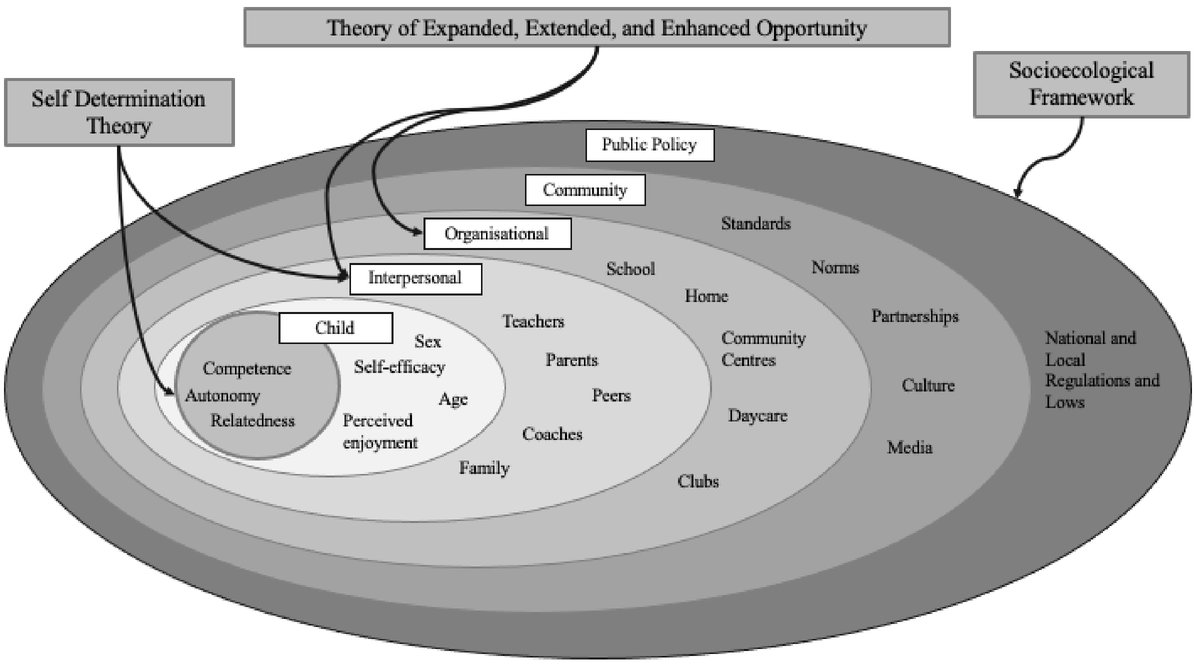


Figure 1. *Schematic of the theoretical framework underpinning the work undertaken in this thesis.*

This thesis will combine self-determination theory and the theory of expanded, extended, and enhance opportunity within the socioecological framework to provide the theoretical grounding for the work conducted in the experimental chapters of this thesis. This modified socio-ecological model is adapted from the Centers for Disease Control and Prevention (CDC).

Thesis aims and structure

The overarching aim of this thesis was to explore potential impact and feasibility of HIIT in schools, which was completed through two major studies. The first was a Systematic Review of the literature to identify the effect of HIIT on a range of outcomes and understand the process outcomes within these studies (*Chapter Two*). The second was an effectiveness trial in schools conducted in two phases (*Chapter Three – Chapter Eight*). In phase one, HIIT workouts were co-designed with students and teachers and the feasibility of this process was assessed. In phase two, an intervention was conducted to understand the effect of HIIT on health-related outcomes and the effect of co-design on student motivation and enjoyment during the intervention. A breakdown of each of the following chapters along with the primary aims are provided in Figure 2.

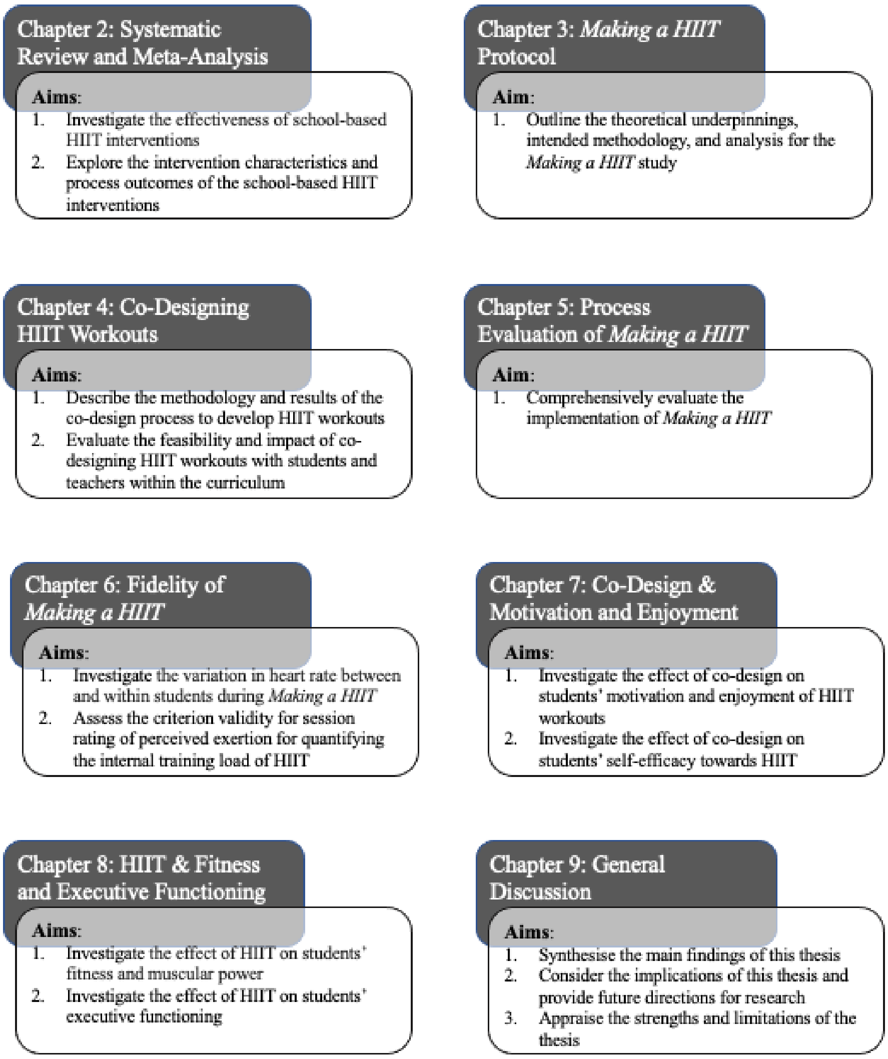


Figure 2. *Chapter summary of this thesis.*

The chapters included in this thesis along with their primary aims.

Chapter 2: Literature Review

The following publication has been incorporated as chapter two:

> **Duncombe SL**, Barker AR, Bond B, Earle R, Varley-Campbell J, Vlachopoulos D, Walker JL, Weston KL, Stylianou M. (2022) School-based high-intensity interval training programs in children and adolescents: A systematic review and meta-analysis. *PLOS ONE*. 17(5): e0266427 https://doi.org/10.1371/journal.pone.0266427

Author contributions:

	Statement of Contribution			
	Conception & design	**Data extraction**	**Analysis & interpretation**	**Drafting & critical review**
Ms. Stephanie Duncombe	22.5	50	84	78
A/Prof. Alan Barker	22.5	16	7	5
Dr. Bert Bond	5	3	0	2
Ms. Renae Earle	5	3	0	2
Dr. Jo Varley-Campbell	5	3	2	2
Dr. Dimitris Vlachopoulos	5	3	0	2
Dr. Jacqueline Walker	5	3	0	2
Dr. Kathryn Weston	5	3	0	2
Dr. Michalis Stylianou	22.5	16	7	5

Justification of chapter within the thesis

This chapter includes a comprehensive systematic review and meta-analysis on school-based high-intensity interval training (HIIT), which is provided in place of a traditional literature review. This review, which encompasses 54 papers and 42 unique studies, provides the context required for this thesis as it examines the effect of school-based HIIT on a wide range of outcomes in comparison to both control groups and other exercise modalities. Additionally, it expands on previous reviews by investigating both health and wellbeing outcomes instead of health outcomes only and examines the implementation of the interventions. While previous reviews have been completed on HIIT within children and adolescents, before this one, none focused entirely on the school setting. School-based HIIT is a growing area of interest and warranted further investigation due to the unique considerations of schools, which are further discussed in this chapter. This systematic review and meta-analysis identified several gaps in the literature, which informed the design of the *Making a HIIT* study presented in subsequent chapters.

School-based high-intensity interval training programs in children and adolescents: A systematic review and meta-analysis

Abstract

Purpose: 1) To investigate the effectiveness of school-based high-intensity interval training (HIIT) interventions in promoting health outcomes of children and adolescents compared with either a control group or other exercise modality; and 2) to explore the intervention characteristics and process outcomes of published school-based HIIT interventions.

Methods: We searched Medline, Embase, CINAHL, SPORTDiscus, and Web of Science from inception until 31 March 2021. Studies were eligible if 1) participants aged 5-17 years old; 2) a HIIT intervention within a school setting ≥ 2 weeks duration; 3) a control or comparative exercise group; 4) health-related, cognitive, physical activity, nutrition, or program evaluation outcomes; and 5) original research published in English. We conducted meta-analyses between HIIT and control groups for all outcomes with ≥ 4 studies and meta-regressions for all outcomes with ≥ 10 studies. We narratively synthesised results between HIIT and comparative exercise groups.

Results: Fifty-four papers met eligibility criteria, encompassing 42 unique studies (35 randomised controlled trials; 36 with a high risk of bias). Meta-analyses indicated significant improvements in waist circumference (mean difference (MD) = -2.5cm), body fat percentage (MD = -1.7%), body mass index (standardised mean difference (SMD) = -1.0), cardiorespiratory fitness (SMD = +1.0), resting heart rate (MD = -5bpm), homeostatic model assessment – insulin resistance (MD = -0.7), and low-density lipoprotein cholesterol (SMD = -0.9) for HIIT compared to the control group. Our narrative synthesis indicated mixed findings between HIIT and other comparative exercise groups.

Conclusion: School-based HIIT is effective for improving several health outcomes. Future research should address the paucity of information on physical activity and nutrition outcomes and focus on the integration and long-term effectiveness of HIIT interventions within school settings.

Introduction

Recent evidence suggests that vigorous physical activity, as opposed to moderate physical activity, could be driving health benefits, such as reduced cardiometabolic risk, in youth [27, 60, 61]. Consequently, there has been an interest in high-intensity interval training (HIIT), defined as short bouts of vigorous exercise followed by recovery periods [29], as a potential method to acquire vigorous physical activity. For example, recent physical activity guidelines have called for research evaluating the effectiveness of HIIT [62, 63]. Available reviews in this area have demonstrated that HIIT can promote favourable changes in cardiometabolic risk, cardiorespiratory fitness (CRF), cognition and wellbeing in youth [20, 35, 37-39, 64-67]. However, these reviews are confounded by the inclusion of studies conducted within different paediatric groups (e.g., athletic, or clinical populations) and in various settings (e.g., laboratory, school, clinical, and sports settings), introducing heterogeneity [37, 38, 68].

HIIT interventions conducted in the school setting need to be evaluated independently. Schools are an ideal setting for physical activity promotion as they can help reach a large percentage of children and adolescents with their policies and practices, existing infrastructure, and personnel who are or can be trained to support physical actvity [10]. Additionally, school-based interventions have the potential to be scalable and tend to be low cost [69]. However, this setting presents unique challenges, including time constraints, curriculum demands, and teacher workload and training [17]. Previous school-based physical activity interventions have had limited success at increasing physical activity levels [15, 16, 70, 71], suggesting that novel approaches and improved delivery are necessary. HIIT may be a promising approach to use in schools given it aligns to habitual physical activity patterns in youth and the intermittent style of most modern sports [30, 72]. It is also associated with greater post-exercise enjoyment than continuous exercise and does not elicit unpleasant feelings [45]. Two recent reviews focused on HIIT in schools [20, 73]; however, recommendations for informing policy advocate for a systematic review with a meta-analysis [74]. Delgado-Floody *et al.* did conduct a meta-analysis but only focused on HIIT delivered in physical education classes in a population classified as overweight or obese, leading to the inclusion of only six studies [73]. Further, both reviews focused solely on cardiometabolic and fitness outcomes and did not consider outcomes related to psychological wellbeing, learning, nutrition, or program feasibility and sustainability [20, 73]. It is important to assess these outcomes to understand the uptake and sustainability of HIIT programs within the school setting.

Therefore, the objectives of this systematic review were to: 1) investigate the effectiveness of school-based HIIT interventions in promoting physical health, cognitive health, and psychological wellbeing of children and adolescents (5-17 years old); and 2) explore the intervention characteristics and process outcomes of published school-based HIIT interventions.

Methods

This review follows the Preferred Reporting Items for Systematic Reviews and Meta Analyses (PRISMA) guidelines and was registered with the International Prospective Registry of Systematic Reviews (registration number CRD42018117567).

Search strategy

We conducted a structured electronic search from inception until March 2021 via MEDLINE, EMBASE, CINAHL, SPORTDiscus, and Web of Science using subject headings and keywords related to "high intensity interval training", "high intensity interval exercise", "sprint interval training", "children", and "adolescents" (Appendix 2). These terms were selected based on relevant papers and a participant, intervention, comparison, and outcome (PICO) statement [75]. They were trialled and refined with the support of a librarian. Using forward citation chasing, we scanned reference lists of included full-text articles and systematic reviews for additional articles.

Study selection and inclusion and exclusion criteria

After duplicate removal through Endnote (Clarivate Analytics, Philadelphia, USA) and Covidence software (Veritas Health Innovation, Melbourne Australia), titles and abstracts and subsequently full-text articles were screened independently by two reviewers. Discrepancies were resolved with a third reviewer. Articles were considered eligible for inclusion if they: 1) included 5–17-year-olds; 2) examined a HIIT intervention that occurred within a school setting at any point in the school day or before or after school; 3) had a minimum duration of two weeks; 4) had a control or a comparative exercise group; 5) examined outcomes related to health, cognition, physical activity, nutrition, or program evaluation; and 6) were original research articles published in English in peer-reviewed journals. Both randomised control trials (RCTs) and quasi-experimental studies were included as randomisation is not always feasible in school-based studies and informative literature could have been missed if only RCTs were included. We excluded studies if they focused on a specific disease or condition, or the youth athlete. Articles on children classified as obese or overweight were included. We placed no restrictions on the type of activity, intervention frequency, or cut-off intensity for "high-intensity", if an interval component was included. However, interventions had to be defined as "high-intensity" by the original authors. We attempted to contact authors when information was missing. If authors did not reply within two months, articles were excluded.

Data extraction

Data extraction was conducted by one reviewer and verified by another. We extracted: 1) key characteristics about the study (study design, country), participants (inclusion/exclusion criteria, age, sex), and intervention (HIIT protocol and modality, adherence, attendance, location and time within the school, individual leading the intervention); 2) outcomes examined as specified in our protocol; and 3) results. For study results, we extracted the mean and standard deviation pre- and post-intervention for each group. When reported, we also extracted the mean difference, effect size, group significance, time significance, and group x time significance.

Risk of bias and certainty of evidence

For our risk of bias assessment, we combined and adapted two tools recommended by the Cochrane Collaboration [75]. We used the Risk of Bias-2 (ROB-2) tool, which is designed for randomised studies, and for non-randomised quasi-experimental studies, we included a section of the Risk of Bias in Non-Randomised Studies (ROBINS-I) tool. For missing data, we used a cut-off of 15% based on quality assessments of other exercise interventions [76]. We modified the risk of bias due to deviations from the intended intervention section to appropriately reflect targeted interventions by evaluating adherence (attendance), adverse events, and program fidelity (meeting the desired exercise intensity). Each category received a bias score of "low", "some concerns", or "high". Overall bias was determined using the ROB-2 algorithm. Each study was assessed independently by two reviewers and discrepancies were resolved with a third reviewer. The certainty of evidence for each outcome included in a meta-analysis was assessed using the approach proposed by the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) working group [77]. The evidence was classified into one of four levels of certainty: "high", "moderate", "low", or "very low". The certainty of the evidence was downgraded due to a high risk of bias, inconsistency within the results (unexplained heterogeneity), indirectness of the findings (lack of generalisability and/or external validity), imprecision (small sample sizes and/or wide confidence intervals) or detected publication bias. The certainty of evidence was upgraded for large effect sizes or if all plausible bias would reduce the determined effect size.

Data synthesis and meta-analyses

For comparisons between the HIIT and control groups, we conducted meta-analyses for outcomes included in four or more studies and narratively synthesised the results for remaining outcomes that were reported in more than one study. For comparisons between HIIT and other exercise groups, we narratively synthesised available results reported in more than one study due to the heterogeneity among comparative group protocols.

Meta-analyses were conducted in R (Version 3.6.2; The R Foundation for Statistical Computing, Vienna, Austria) using the "meta" package. As this review included both randomised and quasi-experimental studies, we used change scores to analyse the effect of HIIT compared with control groups. When change score standard deviations were not reported, they were calculated from standard errors or confidence intervals, or imputed from correlation coefficients derived from other studies [78]. Random effect models were used to allow for variations between studies. For variables with measurements reported on multiple scales, a standardised mean difference (SMD) with inverse proportion weighting was used. For all other variables, the mean difference (MD) was used. Alpha was set at 0.05. We calculated heterogeneity using the I^2 statistic, with values between 0% to 40%, 30% to 60%, 50% to 90% and 75% to 100% representing trivial, moderate, substantial and considerable heterogeneity, respectively [75]. We used funnel plots to visually assess publication bias and Egger's test to quantify asymmetry and determine significance [79, 80].

We conducted meta-regressions and sub-analyses on unadjusted data to determine if the effects of the intervention differed due to intervention characteristics, including: 1) HIIT volume (minutes), defined as the total time performing HIIT including recovery periods but excluding warmup and cooldown, and 2) study duration (weeks). Additionally, meta-regressions were conducted on several participant characteristics: 1) mean age (years); 2) weight status classification (overweight and obese); and 3) sex (percentage of females). We removed the six studies where this percentage was not reported. Lastly, meta-regressions were conducted to understand the effect of study design and bias as follows: 1) RCTs vs quasi-experimental studies; 2) high, some concerns, or low risk of overall bias; and 3) high, some concerns, or low bias due to deviations from the intended intervention. These sensitivity analyses were only completed for meta-analyses with an $n > 10$ to ensure there was adequate power and to limit false positives [81]. Alpha was set at 0.05 for moderator effects and only significant moderators are reported.

Results

Study characteristics

Fifty-four articles [47, 78, 82-133] were eligible for inclusion in the review (Figure 3), consisting of 42 unique studies after combining the papers by Buchan et al. [92, 93], Costigan et al. [47, 96, 97], Cvetković et al. [98, 99], Arariza and Ruiz-Ariza et al. [85, 127], Van Biljon et al. [129, 130], Mucci et al. and Nourry et al. [120, 122], Lambrick et al. and McNarry et al. [108, 117], FIT-First study papers [101, 109] and Burn2Learn study papers [106, 110, 111, 133]. Thirty-nine of 42 studies included a control group, 13 contained an additional comparative group. The majority of the comparative groups included continuous exercise, but two studies used football and two used moderate intensity intervals. Four studies contained two different HIIT protocol groups, of which one combined HIIT and nutritional counselling. Three studies included only a HIIT group with a comparative exercise group. Studies used a variety of modalities within their protocols, including running, cycling, dance, resistance training, circuits, games, strength training, and sports drills. The most common modality was running, and interval lengths within the interventions spanned from 10 seconds to a 4-minute bout of HIIT games. Summary study and HIIT program characteristics are reported in Table 1, with additional details available in Table 2.

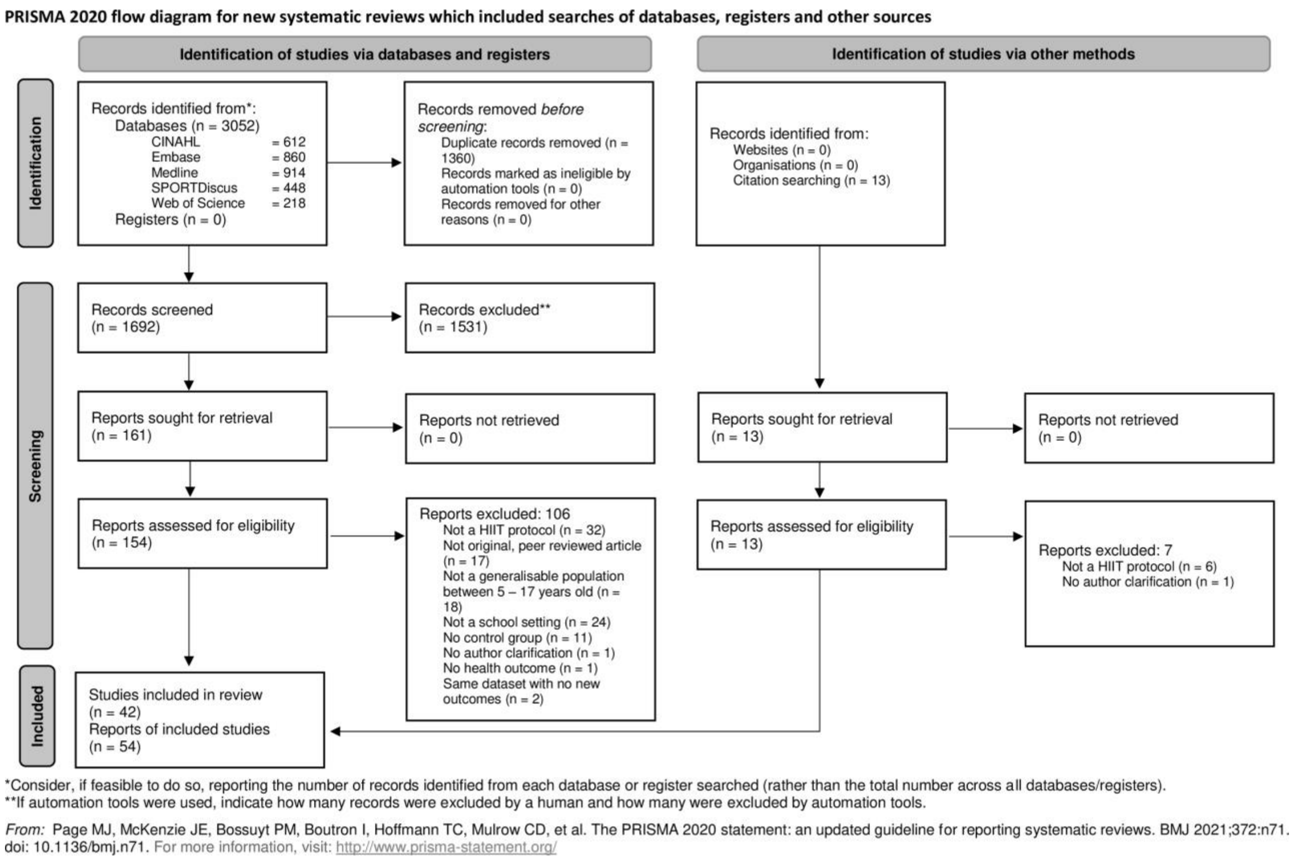


***Figure 3**. Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram.*

A flowchart describing the identification, screening, eligibility, inclusion, and exclusion of studies in the systematic review and meta-analysis.

Table 1. *Summary of study and program characteristics.*

Characteristic	Category	*N*	%
	Europe	25	59.5
	Africa	6	14.3
Continent	Australia/New Zealand	4	9.5
	Asia	4	9.5
	South America	3	7.1
Study Design	Randomised	35	83.3
	Non-randomised	7	16.7
Sex	Male and Female	22	52.3
	Males only	7	16.7
	Females only	8	19.1
	Not Reported	5	11.9
Sample Size	<100	30	71.4
	> 100	12	28.6
Intervention Length	2 – 7 weeks	13	30.9
	8 – 12 weeks	23	54.8
	> 12 weeks	6	14.3
Intervention Timing	Before or after school	4	9.5
	During school hours	7	16.7
	During HPE	24	57.1
	Not reported	7	16.7
Intervention Frequency	1 – 2 times/week	11	26.2
	3 times/week	28	66.7
	4 – 5 times/week	3	7.1
Intervention Facilitator	External Trainers	5	11.9
	Researchers	6	14.3
	HPE teachers	7	16.7
	Researchers and HPE teachers	4	9.5
	Not Reported	20	47.6
Intensity Results Reported	Heart Rate	20	47.6
	Rating of Perceived Exertion	1	2.4
	Percentage of one repetition maximum	1	2.4
	Not reported	20	47.6
Adverse Events	Yes	2 (2 students)	4.8
	No	16 (969 students)	38.1
	Not reported	24	57.1
Attendance Reported	Yes	15	35.7
	No	27	64.3

N = number of studies; HPE = health and physical education; % = the percentage of studies (N / 42) with rounding completed to the nearest 10th

Table 2. *Study characteristics.*

Author (Year) Location, Study Design	Sample Size, Age, ^ Sex Ratio (Girls/Boys) [a]	<u>HIIT:</u> Duration, Modality, Frequency, Total Volume of HIIT, [b] Bout Summary and Intensity	<u>Comparative Exercise Group:</u> Duration, Modality, Frequency, Total Volume of Exercise, [b] Bout Summary and Intensity	<u>Control Group:</u> Protocol Summary
Abassi et al. (2020) [82], Tunisia, RCT	24, 16.5 ± 1.1, 100.0 / 0.0	12 weeks, Running, 3 x week, 900 minutes 6 – 8 x (30/30)) @ 100 – 100% MAV	12 weeks, Running, 3 x week, 900 minutes 2 x (6 to 8 x (30/30)) @ 70 – 80% MAV	Told to maintain daily living
Adeniran et al. (1988) [83], Nigeria, RCT	76, 15.6 ± 1.4, 100.0 / 0.0	8 weeks, Running, 3 x week, 768 minutes 4 x (240/240) @ > 90% HR_{max}	8 weeks, Continuous Running 3 x week 576 minutes 3 miles (@ ≈ 8 min/mile) @ 80 – 85% HR_{max}	Not Recorded
Alonso-Fernandez et al. (2019) [84], Spain, RCT	28, 15 – 16, 46.4 / 53.6	7 weeks, Body Weight Exercises, 2 x week, 92 minutes 8 x (20/10) @ NR	NA	Attended regular HPE class
Arariza (2018)/ Ruiz Arirza et al. (2019) [85, 127], Spain, RCT	184, 13.7 ± 1.3, 46.7 / 53.3	12 weeks, Circuit Exercises, 2 x week, 408 minutes 4 x (20/40) or (25/35) or (30/30) or (35/25) or (40/20) @ > 85% HR_{max}	NA	Static Stretching
Baquet et al. (2001) [87], France, Non-RCT	551, 13.0 ± 1.0, 47.4 / 52.6	10 weeks, Running, 3 x week, 306 minutes 10 x (10/10) @ 100 – 120% MAV	NA	Attended regular HPE class
Baquet et al. (2002) [86], France,	53,	7 weeks, Running,	NA	Attended regular HPE class

Non-RCT	9.9 ± 0.4, 56.6 / 43.4	2 x week, 420 minutes 10 x (10/10) or 5 x (20/20) @ 100 – 130% MAV		
Baquet et al. (2004) [89], France, RCT	100, 9.8 ± 0.6, 54.0 / 46.0	7 weeks, Running, 2 x week, 420 minutes 10 x (10/10) or 5 x (20/20) @ 110 – 130% MAV	NA	Attended regular HPE class
Baquet et al. (2010) [88], France, RCT	72, 9.8 ± 1.2, 47.2 / 52.8	7 weeks, Running, 3 x week, 492 minutes 10 x (10/10) or 5 x (20/20) or 5 x (15/15) or 10 x (15/10) or 5 x (30/30) @ 100 – 130% MAV	7 weeks, Continuous Running, 3 x week, 446 minutes 6 to 20 minutes @ 80 - 85% MAV	Attended regular HPE class
Ben-Zeev et al. (2020) [78], Israel, RCT	40, 12 - 13 0.0 / 100.0	12 weeks, Running and resistance training, 3 x week, 720 minutes, 2 x (30s aerobic / 30s resistance) @ NR	NA	Attended regular HPE class
Boddy et al. (2010) [90], England, RCT	72, 9.8 ± 1.2, 47.2 / 52.8	3 weeks, Dance, 4 x week, 90 minutes 6 x (30/45) @ NR	NA	Not Reported
Bogataj et al. (2020) [91], Serbia, RCT	66 15.7 ± 0.6 100.0 / 0.0	8 weeks, Body weight exercises 3 x week, + nutritionist 2 x week 360 minutes, 10 x (30s/15s) @ 80% HR_{max}		Attended regular HPE class
Buchan et al. (2011) [92, 93], Scotland, Non-RCT	47, 16.3 ± 0.5, 21.2 / 78.8	7 weeks, Running, 3 x week, 105 minutes 4/5/6 x (30/30) or 6 x (30/20) @ NR	7 weeks, Continuous Running, 3 x week, 700 minutes 20 minutes @ 70% VO_2	Attended regular HPE class
		8 weeks,	8 weeks,	NA

Camacho-Cardenosa et al. (2016) [94], Spain, RCT	47, 16.3 ± 0.5, 21.2 / 78.8	Running, 3 x week, 125 minutes 3/4/5/6 x (20/60) or 4/5/6 x (20/40) or 4 x (20/20) @ NR		Continuous Running, 3 x week, 125 minutes Equivalent time to HIIT workout @ 65 – 75% HR_{max}		
Cheunsiri et al. (2018) [95], Thailand, RCT	48, 11.0 ± 0.3, 0.0 / 100.0	12 weeks, Cycling, 3 x week 864 minutes 8 x (120/60) @ > 90% peak power output		12 weeks, Cycling, 3 x week, 144 minutes 8 x (20/10) @ > 170% peak power output		Told to maintain daily living
Costigan et al. (2015/ 2016/2018) [47, 96, 97], Australia, RCT	65, 15.6 ± 0.6, 30.8 / 69.2	8 weeks, Running, 3 x week (2 in PE, one at lunch), 213 minutes 8/9/10 x (30/30) @ > 85% HR_{max}		8 weeks, HIIT Resistance Training, 3 x week (2 in PE, one at lunch), 213 minutes 8/9/10 x (30/30) @ 85% HR_{max}		Attended regular HPE class
Cvetkovic et al. (2018) [98, 99], Serbia, RCT	42, 11 - 13, 0.0 / 100.0	12 weeks, Running, 3 x week, 660 minutes 5 x (10/10) or 8 x (15/15) or 10 x (20/20) @ 100% MAV		12 weeks, Football, 3 x week, 1080 minutes 4 x 8 minutes of playing @ NR		Not Reported
Delgado Floody et al. (2018) [100], Chile, Non-RCT	197, 8.4 ± 1.2, 54.8 / 45.2	28 weeks, Running, Jumps, Throws 2 x week, NR (≈ 1512 minutes) 2/3/4 x (30-60/30-60) @ 80 – 95% HR_{max}		NA		Attended regular HPE class
Elbe et al. (2016)/ Larsen et al. (2017) [101, 109], Denmark, RCT	300, 9.3 ± 0.4, 52.6 / 47.4	44 weeks, or Running, or 5 x week, or 2640 minutes 8 x (60/30) @ NR	44 weeks Strength and Games 3 x week, 5280 minutes 6-10 x (30/45) @ NR	44 weeks, or Football, or 5 x week, 2640 minutes Continuous play	44 weeks, Football, 3 x week, 5280 minutes Continuous play	Attended regular HPE class
Espinoza-Silva et al. (2019) [102], Chile, Non-RCT	274, 7 – 9, 56.2 / 43.8	28 weeks, Running, Jumps, Throws 2 x week, NR (≈ 1960 minutes) NR x (30-60/60-120) and 3-4 x (240/60-120) @ 8 – 10 RPE		NA		Attended regular HPE class

Gamelin et al. (2009) [103], France, RCT	38, 9.6 ± 1.2, 50.0 / 50.0	7 weeks, Running, 3 x week, 492 minutes 10 x (10/10) or 5 x (20/20) or 5 x (15/15) or 10 x (15/10) or 5 x (30/30) or 2o x (5/15) @ 100 – 130% MAV	NA	Not Recorded
Granacher et al. (2011) [104], Switzerland, RCT	34, 8.6 ± 0.5, 43.8 / 56.2	10 weeks, Strength Training, 2 x week, 1400 minutes 3 x (10-12 reps/180-240s) @ 70 – 80% 1 rep max	NA	Attended regular HPE class
Haghshenas et al. (2019) [105], Iran, RCT	100, 14.0 ± 1.0, 0.0 / 100.0	8 weeks, Running, 3 x week, 430.5 minutes 2 – 4 (60-120/240/300) @ NR MAV	NA	Active walks in the school yard
Ketelhut et al. (2020) [107], Germany, RCT	46, 10.8 ± 0.6, 45.7 / 54.3	12 weeks, Games, Circuits, Choreographies 2 x week, 480 minutes 2-6 x (20-120/30-90) @NR	NA	Attended regular HPE class
Lambrick et al. (2016)/ McNarry et al. (2015) [108, 117], England, RCT	55, 9.2 ± 0.8, 45.5 / 54.5	6 weeks, Games 2 x week, 408 minutes 6 x (360/120) games and 4 min circuit @> 85% HR_{max}	NA	Attended regular HPE class
Logan et al. (2016) [108], New Zealand, RCT	24, 16.0 ± 1.0, 0.0 / 100.0	8 weeks, Aerobic and Resistance 3 x week (2 HIIT, 1 resistance), 173.3 minutes 1 x (4 x 20/10); 234.7 minutes 2 x (4 x 20/10); 296.0 minutes 3 x (4 x 20/10); 357.3 minutes 4 x (4 x 20/10); 418.7 minutes [c] 5 x (4 x 20/10) Resistance = 3 x 8-12 of 3 compound movements @ 90 – 100% HR_{max} for HIIT and 70% 1RM for Resistance		NA
Lubans et al. (2021)/ Kennedy et al. (2020)/ Leahy et al. (2019)/	670, 16.0 ± 0.4,	52 weeks, Aerobic, Resistance, Dance, Boxing 3 x week (½ year: 2 in PE, one own time, ½ year: all own time),	NA	Attended regular HPE class

Leahy et al. (2020) [106, 110, 111, 133], Australia, RCT	44.6 / 55.4	≈ 1248 minutes (using 8 min average/session and 52 weeks) 8 – 16 x (30/30) @> 85% HR_{max}		
Martin et al. (2015) [113], Scotland, RCT	49, 16.9 ± 0.4 24.5 / 75.5	7 weeks, Running, 3 x week, 108 minutes 4 - 6 x (30/30) @ NR	NA	Attended regular HPE class
Martin-Smith et al. (2018) [114], Scotland, RCT	56, 17 ± 0.3 37.5 / 62.5	4 weeks, Running, 3 x week, 66 minutes 5 - 6 x (30/30) @ NR (used a sprint pacer)	NA	Attended regular HPE class
McManus et al. (1997) [115], England, RCT	45, 9.6 ± 0.5 100.0 / 0.0	8 weeks, Running, 3 x week, 304 minutes 3 – 6 x (10/30) and 3 – 6 x (30/90) @ NR (used a distance)	8 weeks, Continuous Cycling, 3 x week, 320 minutes 20 minutes @ 80 – 85% HR_{max}	Not Reported
McManus et al. (2005) [116], Hong Kong, RCT	45, 10.4 ± 0.5 0.0 / 100.0	8 weeks, Cycling, 3 x week, 320 minutes 7 x (30/165) @ Peak Power elicited during VO_2 test	8 weeks, Continuous Cycling, 3 x week, 320 minutes 20 minutes @ 70 – 85% HR_{max}	Not Reported
McNarry et al. [d] (2020) [118], Wales, RCT	33, 13.5 ± 0.8 45.4 / 55.6	26 weeks, Circuits and Games, 3 x week, 1890 minutes (10-30/10-30) @ > 90% HR_{max}	NA	Not Reported
Moreau et al. (2017) [119], New Zealand, RCT	305, 9.9 ± 1.7 61.3 / 38.7	6 weeks, Video Workouts, 5 x week, 150 minutes 1 x (20/20) and 1 x (20/30) and 1 x (20/40) and 1 x (20/50) and 1 x (20/60) @ NR	NA	Board Games

Mucci et al. (2013)/ Nourry et al. (2005) [120, 122], France, RCT	18, 10.0 ± 0.7 38.9 / 61.1	8 weeks, Running, 2 x week, 198 minutes 10 x (10/10); 5 x (20/20); 5 x (15/15); 10 x (15/10); 5 x (30/30) @ 100 – 130% MAV	NA	Not Recorded
Muntaner-Mas et al. (2017) [121], Spain, RCT	80, 15.8 ± 0.5 NR	16 weeks, Circuit, 2 x week, 320 minutes 10 x (45/15) @ > 85% HR_{max}	NA	Attended regular HPE class
Racil et al. (2013) [123], Tunisia, RCT	36, 15.9 ± 1.2 100.0 / 0.0	12 weeks, Running, 3 x week, 672 minutes 6 – 8 x (30/30) @ 100 – 100% MAV and 50% MAV on rest	12 weeks, Running 3 x week, 672 minutes 6 – 8 x (30/30) @ 70 – 80% MAV and 50% MAV on rest	Not Recorded
Racil et al. (2016a) [124], Tunisia, RCT	47, 14.2 ± 1.2 100.0 / 0.0	12 weeks, Running, 3 x week, 440 minutes 4 – 8 x (15/15) @ 100 MAV and 50% MAV on rest	12 weeks, Running 3 x week, 440 minutes 4 – 8 x (15/15) @ 80% MAV and 50% MAV on rest	Not Recorded
Racil et al. (2016b) [125], Tunisia, RCT	75, 16.6 ± 0.9 100.0 / 0.0	12 weeks, Running, 3 x week, 672 minutes 6 – 8 x (30/30) @ 100% MAV and 50% MAV on rest	12 weeks, Running and Plyometrics 3 x week, 996 minutes 4 x (15/15) for plyometrics 6 – 8 x (30/30) for sprints @ 100% MAV and 50% MAV on rest	Not Recorded
Reyes Amigo et al. (2021) [126], Chile, RCT	48, 9.5 ± 0.5 66.7 / 33.3	11 weeks, HIIT Games, 2 x week, 510 minutes, 4 x (6-minute intermittent game) @75 – 95% HR_{max} or 6 – 8 / 10 RPE	11 weeks, Moderate Intensity Games, 2 x week, 510 minutes, 4 x (6-minute continuous game) @60 – 74% HR_{max} or 4 – 5 / 10 RPE	NA
Segovia et al. (2020) [128],	154	6 weeks, Games and Circuit,	NA	Played Ringo In regular

Spain, RCT	10.7 ± 0.8 47.4 / 52.6	2 – 3 x week, 195 minutes 1 x 300 – 420 for games 5 – 8 x (40/20) for circuit @85 – 90%			HPE class
Van Biljon et al. (2018) [129, 130], South Africa, Non-RCT	120, 11.1 ± 0.8 61.4 / 38.6	5 weeks, Running, 3 x week, 337.5 minutes 10 x (60/75) @ > 80% HR_{max}	5 weeks, Walking, 3 x week, 495 minutes 33 minutes @ 65 – 70% HR_{max}	5 weeks, Alt. Running and Walking 3 x week, 400.5 minutes 3 weeks of sprints 2 weeks of walking	Not Recorded
Weston et al. (2016) [131], England, Non-RCT	101, 14.1 ± 0.3 37.6 / 62.4	10 weeks, Dance, Soccer, Boxing, Basketball 3 x week (2 in PE, 1 after school/at lunch), 119.3 minutes 4 – 7 x (45/90) @ >90% HR_{max}		NA	Attended regular HPE class
Williams et al. (2000) [132], England, RCT	45, 10.0 ± 0.2 0.0 / 100.0	8 weeks, Running, 3 x week, 330 minutes 3 – 6 x (10/30) and 3 – 6 x (30/90) @ 100% MAV and 50% MAV on rest		8 weeks, Cycling 3 x week, 420 minutes 20 minutes @ 80 – 85% HR_{max}	Normal everyday activities

Study characteristics including participant characteristics (sample size, age, sex ratio), protocol characteristics for HIIT and the comparative exercise group (duration – in weeks, modality – style of exercise, frequency – number of times per week, total time, and a general description with intensity), and protocol characteristics for the control group; HPE = health and physical education; HIIT = high intensity interval training; HR_{max} = maximum heart rate; MAV = maximal aerobic velocity; NA = not applicable; NR = not recorded; RCT = randomised control trial; 1RM = 1 repetition maximum

ˆ reported as mean and standard deviation (x ± x), or where not provided as range (x – x)

[a] reported as frequency (%)

[b] time in intervention excluding warm up and cool down

[c] This study compares 5 different HIIT protocols with different volumes of HIIT

[d] Data extracted only for healthy children

Process outcomes

Over half of the studies (24 of 42) were completed during health and physical education (HPE) class but only 11 documented that HPE teachers played a role in their delivery, while 20 studies did not provide information on the intervention facilitator. Attendance data was reported in only 35.7% of studies (Table 1). It varied across studies from 63% [110] to above 90% [78, 91, 104, 107, 108, 120, 123-126, 129]. Different intensity targets were set for participants in interventions. Four studies did not specify a target and instead used terminology such as "suitably high" and "sprint maximally" [78, 90, 93, 119]. For all other studies, a target threshold for heart rate, speed, power, or rating of perceived exertion (RPE) was provided to participants. The lowest intensity target among any study was 75% of maximum heart rate during high intensity games with both work and rest included [126]. Assessment of whether these targets were achieved (fidelity) only occurred in 47.6% studies, with heart rate as the most commonly used tool. Session intensity was most often reported as an average heart rate across all participants and sessions. Five studies [94, 113, 114, 131, 132] used the average heart rate during only work intervals whereas other studies used an average that included both work and rest intervals or did not specify what was included. One study [109] reported the average time spent in different heart rate zones by participants and one study reported the number of students that achieved the desired heart rate during sessions in addition to the average and maximum heart rate [106]. Among the studies that reported session intensity, two studies did not use heart rate, with one using an RPE scale [100] and the other using a percentage of a one maximum repetition [104].

Risk of bias and certainty of evidence

Thirty-six of the 42 studies had a "high" risk of bias (Table 3), mostly related to deviation from the intended intervention and missing data. High bias related to randomisation was noted least often. Four studies were classified as having "some concerns", and only two as having a "low" risk of bias. Using the GRADE approach, the certainty of the outcomes ranged between "very low" and "moderate" (Table 4). The most common reasons for downgrading the evidence were risk of bias and inconsistency within the findings. The certainty of evidence for body fat percentage, body mass index (BMI), low-density lipoprotein (LDL), and CRF was upgraded by one point due to large effect sizes within the findings.

Table 3. *Risk of bias assessment based on ROB-2 and ROBINS.*

	Randomised Control Trials					
	Randomisation and Selection Bias	Bias due to Missing Data	Measurement Bias	Bias due to Deviations from the Intended Intervention	Bias due to Analysis and Selection of Reported Results	Overall Risk of Bias
Abassi et al. (2020) [82]	Some Concerns	High	Some Concerns	High	High	High
Adeniran et al. (1988) [83]	Low	Low	Some Concerns	High	Some Concerns	High
Arariza (2018)/Ruiz Arirza et al. (2019) [85, 127]	Low	Low	Low	Low	Some Concerns	Some Concerns
Alonso-Fernandez et al. (2019) [84]	Low	High	Some Concerns	High	Some Concerns	High
Baquet et al. (2004) [89]	Low	Some Concerns	Some Concerns	High	Some Concerns	High
Baquet et al. (2010) [88]	Low	Some Concerns	High	High	High	High
Boddy et al. (2010) [90]	Some Concerns	Some Concerns	Low	Some Concerns	High	High
Ben-Zeev et al. (2020) [78]	High	Low	Some Concerns	High	Some Concerns	High
Bogataj et al. (2020) [91]	Some Concerns	Low	Low	High	Some Concerns	High
Buchan et al. (2011) [92, 93]	High	Low	Some Concerns	Low	High	High
Camacho-Cardenosa et al. (2016) [94]	Low	Low	Some Concerns	Some Concerns	Some Concerns	Some Concerns
Cheunsiri et al. (2018) [95]	Some Concerns	High	Some Concerns	High	Some Concerns	High
Costigan et al. (2015/2016/2018) [47, 96, 97]	Low	Low	Low	Low	Low	Low
Cvetkovic et al. (2018) [98, 99]	Some Concerns	High	Some Concerns	Some Concerns	Some Concerns	High
Elbe et al. (2016)/Larsen et al. (2015) [101, 109]	Low	High	Some Concerns	High	Low	High
Gamelin et al. (2009) [103]	Low	Some Concerns	Some Concerns	High	Some Concerns	High
Granacher et al. (2011) [104]	Low	Low	Some Concerns	Low	Some Concerns	Some Concerns
Haghshenas et al. (2019) [105]	Low	Low	Some Concerns	High	Some Concerns	High
Lambrick et al. (2016)/McNarry et al. (2015) [108, 117]	Some Concerns	Some Concerns	Some Concerns	Low	Some Concerns	High
Ketelhut et al. (2020) [107]	Low	High	Some Concerns	High	Some Concerns	High
Lubans et al. (2021)/Leahy et al. (2018)/Leahy et al. (2020)/Kennedy et al. (2020) [106, 110, 111, 133]	Some Concerns	Low	Some Concerns	High	Low	High
Logan et al. (2016) [112]	High	Low	Some Concerns	Low	Some Concerns	High
Martin et al. (2015) [113]	Low	High	Some Concerns	High	Some Concerns	High
Martin-Smith et al. (2018) [114]	Low	Low	Some Concerns	High	Low	High
McManus et al. (1997) [115]	High	High	Some Concerns	High	Some Concerns	High
McManus et al. (2005) [116]	Some Concerns	High	Some Concerns	High	Some Concerns	High

McNarry et al. (2020) [118]	Low	High	Some Concerns	Some Concerns	Some Concerns	High
Moureau et al. (2017) [119]	Some Concerns	Low	Low	Low	Low	Low
Mucci et al. (2013)/Nourry et al. (2005) [120, 122]	Some Concerns	Some Concerns	Low	High	Some Concerns	High
Racil et al. (2013) [123]	Some Concerns	Low	Some Concerns	High	Some Concerns	High
Racil et al. (2016a) [124]	High	Low	Some Concerns	Some Concerns	Some Concerns	High
Racil et al. (2016b) [125]	Some Concerns	Low	Some Concerns	High	Some Concerns	High
Reyes Amigo et al. (2021) [126]	High	Low	Some Concerns	High	Some Concerns	High
Segovia et al. (2020) [128]	Low	High	Some Concerns	High	Some Concerns	High
Williams et al. (2000) [132]	Some Concerns	Low	Some Concerns	Low	High	High

Quasi-Experimental Studies

	Bias due to Confounding	Bias due to Missing Data	Measurement Bias	Bias due to Deviations from the Intended Intervention	Bias due to Analysis and Selection of Reported Results	Overall Risk of Bias
Baquet et al. (2001) [87]	Some Concerns	High	Some Concerns	High	Some Concerns	High
Baquet et al. (2002) [86]	Low	High	Some Concerns	Some Concerns	Some Concerns	High
Delgado Floody et al. (2018) [100]	High	High	Some Concerns	High	Some Concerns	High
Espinoza-Sliva et al. (2019) [102]	Low	High	Some Concerns	High	High	High
Muntaner-Mas et al. (2017) [121]	High	High	Some Concerns	High	High	High
Van Biljon et al. (2018) [129, 130]	High	Low	Some Concerns	Low	Some Concerns	High
Weston et al. (2016) [131]	Low	Low	Some Concerns	Some Concerns	Some Concerns	Some Concerns

Risk of bias assessment for each study included in the review.; Bias due to missing data uses a 15% cut-off; Bias due to deviations from the intended intervention was modified to reflect an exercise intervention by assessing the fidelity of attaining high intensity, the attendance, the adverse events, and the qualifications of the person leading the intervention. ROB-2 = risk of bias; ROBINS = risk of bias in non-randomised studies; RCT = randomised control trial

Table 4. *Certainty of Evidence based on Grading of Recommendations, Assessment, Development and Evaluation.*

	Outcome	Risk of Bias	Inconsistency	Indirectness	Imprecision	Publication Bias	Large Effect Size	Overall
Body Composition	Waist Circumference	-1	0	0	0	0	0	⊕⊕⊕
	Body Fat Percentage	-1	-1	0	0	-1	+1	⊕⊕⊕
	Body Mass Index	-1	-1	0	0	-1	+1	⊕⊕
	Lean Mass	-1	-1	0	-1	0	0	⊕
	Muscle Mass	-1	0	0	-1	0	0	⊕⊕
Cardiovascular	Systolic Blood Pressure	-1	0	0	0	0	0	⊕⊕⊕
	Diastolic Blood Pressure	-1	-1	0	0	0	0	⊕⊕
	Resting Heart Rate	-1	-1	0	0	0	0	⊕⊕
Blood Profile	Glucose	-1	0	0	0	0	0	⊕⊕⊕
	Insulin	-1	-1	0	-1	0	0	⊕
	HOMA-IR	-1	0	0	0	0	0	⊕⊕⊕
	Triglycerides	-1	-1	0	-1	0	0	⊕
	Total Cholesterol	-1	-1	0	-1	0	0	⊕
	High-density Lipoprotein	-1	0	0	-1	0	0	⊕⊕
	Low-density Lipoprotein	-1	0	0	-1	0	+1	⊕⊕⊕

Fitness	Cardiorespiratory Fitness	-1	-1	0	0	-1	+1	⊕⊕
	Cardiorespiratory Fitness (VO2)	-1	-1	0	0	0	+1	⊕⊕⊕
	Cardiorespiratory Fitness (shuttles)	-1	-1	0	-1	-1	+1	⊕
	Standing Long Jump	-1	-1	0	0	0	0	⊕⊕
	Countermovement Jump	-1	-1	0	0	0	0	⊕⊕

Certainty of Evidence classified as either “very low”, “low”, “moderate”, or “high”. The certainty could be downgraded due to a high risk of bias, inconsistency (unexplained heterogeneity), indirectness (lack of generalisability or external validity), imprecision (small sample size or wide confidence intervals), or the presence of publication bias. The certainty of evidence could be upgraded due to a large effect size.
HOMA-IR = homeostatic model assessment – insulin resistance.

⊕ = very low, ⊕⊕ = low, ⊕⊕⊕ = moderate, ⊕⊕⊕⊕ = high

Physical health outcomes

Table 5 reports results for all outcomes examined in two or more studies comparing HIIT to a control group. Forest plots for all meta-analyses are presented in Appendix 3. HIIT was favoured in meta-analyses for waist circumference, body fat percentage, BMI, CRF, resting heart rate, homeostatic model assessment – insulin resistance (HOMA-IR), and LDL. Publication bias was significant for body fat percentage (p = 0.049), BMI (p = 0.003) and CRF (p = 0.001). According to the meta-regression results, having an entire population classified as overweight or obese significantly moderated the results for waist circumference (n = 7, β = -0.56, p = 0.009), body fat percentage (n = 9, β = -2.11, p < 0.0001), and BMI (n = 9, β = -1.38, p < 0.0001), with a greater decrease noted in this population. Additionally, there was a greater increase in CRF in these studies (n = 5, β = 1.01, p = 0.007). Having an entire population classified as overweight or obese also explained some of the heterogeneity present in the model for waist circumference (Residual heterogeneity: I^2 = 36%, p = 0.06). Studies with a higher volume of HIIT were associated with a greater decrease in body fat percentage (β = -0.002, p < 0.0001) and BMI (β = -0.001, p = 0.0014). Studies with a longer protocol duration had a greater decrease in body fat percentage (β = -0.12, p = 0.0004). Including a higher percentage of girls was also associated with a greater decrease in body fat percentage (β = -0.01, p = 0.0377) and BMI (β = -0.01, p = 0.0109). Studies with a high risk of bias due to deviations from the intended intervention had a significantly greater increase in CRF compared to studies with low bias (β = 1.03, p = 0.013). When only the 5 studies with low bias were included in the analysis, heterogeneity was not significant (I^2 = 14%, p =0.32) and the random effects model was still significant (SMD = 0.41, 95% CI = 0.12 to 0.70) [47, 93, 108, 130, 132]. The method used to assess CRF (20 m shuttle run, cycle ergometer, or treadmill ergometer) and body fat percentage (Dual X-ray absorptiometry, bioelectrical impedance, or skinfold estimation) did not significantly moderate the results.

Table 6 reports findings for all outcomes examined in two or more studies comparing HIIT and comparative exercise groups, with no significant differences reported between the two groups for most health outcomes. Across all health outcomes, only three studies had results that favoured HIIT [123, 124, 129], while one study had results that favoured continuous exercise [93].

Table 5. *Summary of outcomes between HIIT and control groups for all outcomes reported in ≥ 2 studies.*

	Outcome	**Participants (Studies)**	**Analysis**	**Certainty of the Evidence (GRADE)**	**Key Finding**	**Heterogeneity**
Body Composition	Waist circumference	1175 (14)	MA + MR	⊕⊕⊕⊖	Favoured HIIT, MD = -2.5 cm (-3.1 to -1.9) [47, 82, 90, 100, 102, 108, 114, 121, 123-125, 128, 129, 131]	I^2 = 47%, p = 0.01
	Body fat percentage	1893 (19)	MA + MR	⊕⊕⊖⊖	Favoured HIIT, MD = -1.7 % (-2.3 to -1.1) [82, 84, 86, 87, 89-91, 93, 95, 99, 100, 102, 108, 121, 123-125, 128, 131]	I^2 = 93%, p < 0.01
	Body Mass Index	2450 (22)	MA + MR	⊕⊕⊖⊖	Favoured HIIT, SMD = -0.9 (-1.3 to -0.6) [47, 82, 84, 87, 88, 90, 91, 93, 95, 99, 100, 102, 108, 113, 118, 121, 123-125, 130, 131, 133]	I^2 = 92%, p < 0.01
	Muscle mass	264 (5)	MA	⊕⊕⊖⊖	Summary statistic NS [91, 95, 99, 108, 131]	I^2 = 43%, p = 0.12
	Lean mass	297 (4)	MA	⊕⊖⊖⊖	Summary statistic NS [90, 99, 109, 124]	I^2 = 90%, p < 0.01
	Hip circumference	126 (3)	Narrative		NS in 3 studies [90, 108, 114]	
	Bone density and content	300 (2)	Narrative		NS in 2 studies [90, 109]	
Cardiovascular Health	Systolic blood pressure	872 (11)	MA	⊕⊕⊕⊖	Summary statistic NS [90, 93, 95, 99, 100, 102, 107, 114, 124, 129, 131]	I^2 = 29%, p = 0.14
	Diastolic blood pressure	872 (11)	MA	⊕⊕⊖⊖	Summary statistic NS [90, 93, 95, 99, 100, 102, 107, 114, 124, 129, 131]	I^2 = 68%, p < 0.01
	Resting heart rate	381 (6)	MA	⊕⊕⊖⊖	Favoured HIIT, MD = -5 bpm (-7 to -2) [95, 99, 100, 103, 124, 129]	I^2 = 52%, p = 0.03
	Heart rate variability	147 (2)	Narrative		Favoured HIIT in 1 study [130], NS in 1 study [103]	
	Aortic pulse wave velocity	166 (2)	Narrative		Favoured HIIT in 1 study [107], NS in 1 study [129]	
Blood Profile	Glucose	447 (10)	MA	⊕⊕⊕⊖	Summary statistic NS [82, 93, 98, 113, 114, 123-125, 130, 131]	I^2 = 0%, p = 0.81
	Insulin	321 (8)	MA	⊕⊖⊖⊖	Summary statistic NS [82, 93, 113, 114, 123-125, 130]	I^2 = 93%, p < 0.01
	HOMA-IR	211 (5)	MA	⊕⊕⊕⊖	Favoured HIIT, MD = -0.7 (-1.1 to -0.4) [113, 114, 123-125]	I^2 = 95%, p < 0.01
	Triglycerides	279 (6)	MA	⊕⊖⊖⊖	Summary statistic NS [93, 95, 99, 114, 123, 131]	I^2 = 84%, p < 0.01
	Total cholesterol	279 (6)	MA	⊕⊖⊖⊖	Summary statistic NS [93, 95, 99, 114, 123, 131]	I^2 = 84%, p < 0.01
	High-density lipoprotein	254 (5)	MA	⊕⊕⊖⊖	Summary statistic NS [93, 95, 99, 114, 123, 131]	I^2 = 36%, p = 0.18
	Low-density lipoprotein	153 (4)	MA	⊕⊕⊕⊖	Favoured HIIT, SMD = -0.9 (-1.2 to -0.5) [93, 95, 114, 123]	I^2 = 0%, p = 0.53

	Leptin	152 (3)	Narrative		Favoured HIIT in 2 studies [124, 125], NS in 1 study [95]	
	Adiponectin	206 (4)	Narrative		Favoured HIIT in 3 studies [93, 123, 125], NS in 1 study [95]	
	C-reactive Protein	265 (3)	Narrative		Favoured HIIT in 1 study [129], NS in 2 studies [93, 131]	
Aerobic & Muscular Fitness	Cardiorespiratory fitness (all methods)**	2099 (25)	MA + MR	⊕⊕⊖⊖	Favoured HIIT, SMD = 1.0 (0.7 to 1.3) [47, 82, 84, 86-88, 90, 91, 93, 95, 103, 108, 113-116, 118, 122-125, 130-133]	I^2 = 83%, p < 0.01
	Cardiorespiratory fitness (relative VO_2) †	403 (11)	MA	⊕⊕⊕⊖	Favoured HIIT, MD = 3.1 ml/min/kg (2.4 to 3.8) [86, 88, 90, 95, 103, 108, 116, 120, 123, 125, 132]	I^2 = 50%, p = 0.03
	Cardiorespiratory fitness (shuttles) ‡	299 (5)	MA	⊕⊖⊖⊖	Favourite HIIT, MD = 10.4 shuttles (1.9 to 18.9) [47, 93, 110, 113, 131]	I^2 = 88%, p < 0.01
	Standing long jump	1428 (5)	MA	⊕⊕⊖⊖	Summary statistic NS [47, 87, 89, 121, 133]	I^2 = 84%, p < 0.01
	Countermovement jump	212 (5)	MA	⊕⊕⊖⊖	Summary statistic NS [91, 92, 98, 104, 125]	I^2 = 53%, p = 0.07
	Push ups	735 (2)	Narrative		Favoured HIIT in 1 study [133], NS in 1 study [47]	
	Handgrip Strength	146 (2)	Narrative		NS in 2 studies [91, 121]	
	Sit ups	624 (2)	Narrative		NS in 2 studies [87, 89]	
	Sprint time	331 (3)	Narrative		Favoured HIIT in 2 studies [92, 109], NS in 1 study [98]	
	Flexibility	693 (3)	Narrative		NS in 3 studies [87, 89, 98]	
	Balance	334 (2)	Narrative		NS in 2 studies [104, 109]	
Cognition and Wellbeing	Inhibition	1199 (4)	Narrative		Favoured HIIT in 3 studies [78, 85, 119], NS in 1 study [133]	
	Memory	1199 (4)	Narrative		Favoured HIIT in 2 studies [78, 119], NS in 2 studies [85, 133]	
	Wellbeing	919 (3)	Narrative		Favoured HIIT in 1 study [127], NS in 2 studies [97, 133]	
	Motivation levels	126 (2)	Narrative		NS in 2 studies [97, 133]	
Physical activity and Nutrition	Vigorous Physical Activity	791 (3)	Narrative		Favoured HIIT in 2 studies [96, 114], NS in 1 study [133]	
	Moderate Physical Activity	791 (3)	Narrative		Favoured HIIT in 1 study [114] NS in 2 studies [96, 133]	
	Moderate-to-Vigorous Physical Activity	843 (3)	Narrative		Favoured HIIT in 1 study [131] NS in 2 studies [90, 133]	
	Step Count	790 (3)	Narrative		Favoured HIIT in 1 study [133], NS in 2 studies [90, 95]	

Caloric intake	71 (3)	Narrative	NS in 2 studies [113, 125]

Participants (studies) = number of participants (number of studies) included. HOMA-IR – homeostatic model assessment – insulin resistance; MA – meta-analysis; MR – meta-regressions; HIIT – high intensity interval training; NS – not significant; MD – mean difference; SMD – standardised mean difference.

** cardiorespiratory fitness was examined using either 20 m shuttle runs, cycle ergometer, or treadmill ergometer and it was reported either as the number of shuttles completed, or as VO_2, which was either measured by a metabolic cart or estimated using an equation. The type of measurement did not significantly moderate the results.

† Body mass relative maximum oxygen consumption directly assessed by metabolic cart

‡ Number of shuttles completed in the 20 m shuttle run test using a mean difference.

Table 6. *Summary of outcomes between HIIT and comparative exercise groups for all outcomes reported in ≥ 2 studies.*

	Outcome	**Participants (studies)**	**General Finding**
Body Composition	Waist circumference	137 (4)	Favoured HIIT in 1 study [129], NS in 3 studies [82, 123, 124]
	Body fat percentage	168 (6)	Favoured HIIT in 1 study [123], Favoured comparator in 1 study [93], NS in 4 studies [82, 94, 99, 124]
	BMI	235 (7)	NS in 7 studies [82, 88, 93, 99, 123, 124, 129]
Cardiovascular Health	Systolic blood pressure	145 (4)	Favoured HIIT in 1 study [129], NS in 3 studies [93, 99, 124]
	Diastolic blood pressure	145 (4)	NS in 4 studies [93, 99, 124, 130]
	Resting heart rate	112 (2)	Favoured HIIT in 1 study [130], NS in 1 study [99]
Blood Profile	Glucose	191 (6)	NS in 6 studies [82, 93, 98, 123, 124, 130]
	Insulin	170 (5)	Favoured HIIT in 2 studies [123, 124], Favoured comparator in 1 study [93], NS in 2 study [82, 129]
	HOMA-IR	79 (3)	NS in 3 studies [82, 123, 124]
	Triglycerides	76 (3)	Favoured HIIT in 1 study [123], NS in 2 studies [93, 99]
	Total cholesterol	76 (3)	NS in 3 studies [93, 99, 123]
	High-density lipoprotein	55 (2)	NS in 2 studies [93, 123]
	Low-density lipoprotein	55 (2)	NS in 2 studies [93, 123]
Aerobic & Muscular Fitness	Cardiorespiratory fitness	225 (7)	Favoured HIIT in 1 study [130], NS in 6 studies [82, 88, 115, 116, 123, 124, 132]
	Countermovement jump	220 (2)	NS in 2 studies [92, 98]

Participants (studies) = number of participants (number of studies) included. HOMA-IR = homeostatic model assessment – insulin resistance; HIIT = high intensity interval training; NS = not significant

Psychosocial and cognitive outcomes

As shown in Table 5, there were heterogeneous results for inhibition and memory when comparing HIIT and control groups in the four studies where these outcomes were examined. A variety of tests were used to investigate these two outcomes, with no two studies using the same battery of tests so no meta-analyses were performed. Two studies demonstrated no improvement to wellbeing after HIIT [97, 133], while one found an improvement in inactive children only [127]. No between-group difference was present for motivation levels towards completing the HIIT workouts [97, 133].

HIIT intervention enjoyment

Enjoyment of HIIT was examined in four studies [47, 95, 101, 106]. Two [95, 101] used the validated Physical Activity Enjoyment Scale (PACES) questionnaire and determined that team sports elicited significantly greater enjoyment than individual sports [101], that 20-second bouts were enjoyed more than 120-second bouts [95], and that enjoyment was significantly associated with improvement in running performance [101]. Two studies [47, 106] used Likert questions to examine enjoyment alongside motivation, fatigue, and satisfaction, and found that students and teachers were satisfied with the HIIT workouts, and the majority intended to continue using the workouts.

Physical activity levels and energy intake

Five studies used accelerometers to quantify physical activity outcomes for HIIT and control groups [90, 96, 114, 131, 133], one used a pedometer [95], and one used the Physical Activity Questionnaire for Children [95]. Physical activity outcomes were reported using different outcome variables (Table 4), with no more than three studies reporting the same variable, therefore meta-analyses were not performed. Heterogeneous findings were present for physical activity variables and no significant differences existed between the HIIT and control groups for caloric intake in the two studies examining the outcome (Table 5).

Comparing HIIT protocols

Four studies compared different HIIT protocols. Two compared aerobic training to aerobic training plus resistance or plyometric training [47, 125]. A third compared a shorter bout length of higher intensity to longer bouts of lower intensity [95], and the last looked at different doses of HIIT by changing the number of sets [112]. No clear effect of dose or bout length was found in these studies [95, 112] and heterogenous findings were reported when resistance training was added to aerobic training [47, 125].

Discussion

This systematic review advances the findings of previous reviews [37-39] by investigating a broader range of outcomes associated with school-based HIIT interventions through comprehensive statistical analysis. The results of this review demonstrate that school-based HIIT is an effective strategy for improving various health outcomes compared with control groups. However, there are heterogenous findings when HIIT is compared to other exercise modalities. Overall, most studies had a high risk of bias, therefore the results need to be interpreted cautiously. Although findings support HIIT can be a useful tool within schools to promote a range of health benefits, they also highlight that further research is needed to examine the meaningful integration of these interventions within schools.

Physical health outcomes: HIIT compared with control

Youths with obesity have an increased risk of developing cardiometabolic conditions [134-136], making it an important outcome to monitor. Improvements to body composition were documented across the included studies in this review with moderate (waist circumference, body fat percentage) or low (BMI) certainty according to GRADE when comparing HIIT with control groups. Our body fat percentage summary effect (1.7%) is similar to another meta-analysis on HIIT, where a 1.6% (95% CI: 0.5% to 2.9%) change was noted in favour of HIIT compared to a combination of non-training controls and moderate intensity groups [37]. While our summary effect for BMI differs to a systematic review on all school-based physical activity interventions that reported no significant change [16], it is equivalent to a previous meta-analysis (n = 8) that compared HIIT to both control groups and moderate intensity comparative groups across various settings [37]. Our findings also have the potential to be clinically meaningful. For example, while we do not have individual data points in this synthesis, a summary effect demonstrating a decrease in waist circumference of 2.5 cm (1.9 to 3.1 cm) is equitable to a decrease from the 90th to 85th percentile in 16-year-old boys or a decrease from the 90th to 80th percentile in 7-year-old girls [136], but this could be influenced by baseline values. In our review, studies that only included students classified as overweight or obese had significantly greater health benefits as a result of HIIT. As increased adiposity is associated with future disease related morbidity and mortality [137], decreasing adiposity, especially in populations classified as obese and overweight, is critical to prevent disease [138]. No significant differences were seen for lean mass, muscle mass, or hip circumference within our systematic review. However, this could be due to the smaller sample sizes for these outcomes.

We can say with moderate certainty that CRF is significantly improved as a result of HIIT interventions compared with a control group. The large effect size (d = 0.9) established in this study mirrors that of two previous meta-analyses on HIIT (d = 1.05 in adolescents and d = 1.11 in adolescents classified as obese or overweight) [37, 66]. Relevant literature shows a positive association between vigorous activity and CRF, corroborating this finding [139]. According to our findings, there was an increase of 3.1 ml/kg/min (2.4 to 3.8 ml/kg/min) in the HIIT group after the intervention compared with the control group in the 11 studies that directly determined peak $\dot{V}O_2$, maximum oxygen consumption. This difference has the potential to be clinically meaningful as a lower CRF is associated with higher cardiometabolic risk in children, independent from physical activity and adiposity [140]. Further, children and adolescents in the lowest quartile for fitness have a greater risk for developing cardiovascular disease compared with those in the highest quartile for fitness [141]. Muscular fitness was examined in fewer studies than CRF, with no difference between the HIIT and control group noted for jumping, handgrip strength or sit-ups through meta-analyses and narrative synthesis. These will be important outcomes to study in more detail as HIIT protocols diversify and further involve different muscle groups. HIIT could have effects on muscular fitness with current research demonstrating a link between vigorous activity and a variety of muscular fitness test outcomes [142, 143].

The LDL and HOMA-IR blood biomarkers were significantly improved following HIIT compared with control groups in this review. However, the studies within these meta-analyses comprised of mainly populations classified as overweight or obese (50% and 60% of studies, respectively), which could be driving this change. The lack of change to other biomarkers for cardiometabolic health, including blood pressure, fasting glucose, triglycerides, and total cholesterol, could be reflective of the fact that baseline measures were within normal thresholds. We might expect to see changes for these variables in populations where the initial levels are elevated, such as in students who are classified as overweight or obese. This is consistent with findings from a recent review that demonstrated that while physical activity interventions in youths classified as obese are capable of producing favourable changes in biomarkers, the same dose is not effective for non-obese youths [144]. However, it is still important to encourage physical activity in all students regardless of their body composition as there is a strong positive association between total physical activity and blood biomarkers in youths [144] and puberty is a crucial period for the development of hypertension later in life [145].

HIIT protocols and comparative exercise

More research is needed to determine if differences exist between HIIT and comparative exercise protocols in the school setting. Our narratively synthesised results did not detect any differences between HIIT and moderate continuous exercise or other comparative exercise protocols, such as moderate intensity intervals or football. However, HIIT provides educators with another option for promoting physical activity and has several unique characteristics that may make it effective in this setting. It can be short and simple to conduct, enabling it to be performed in a classroom setting [110, 146], while partly alleviating concerns that it will compete for time with curricular demands, which is a common reason compromising the effectiveness of school-based interventions [17].

Process outcomes

Overall, process outcomes were documented poorly throughout these studies. The lack of fidelity and attendance data makes it difficult to assess if students received the intended HIIT intervention, which is critical as the intensity of exercise is likely to be important in driving physiological changes. Even for studies that stated that the desired intensity was achieved, this was most often based on an average heart rate across all participants and sessions, which does not allow provide readers with information on how many students successfully completed the intervention. Further, mean peak heart rate was occasionally reported as an outcome measure, which does not capture the variability within sessions. It will be important for future studies to appropriately document the attendance and fidelity of these interventions for proper evaluation [147]. This could help inform readers of HIIT protocols that are more likely to achieve high intensity in this setting. The intervention timing and facilitators varied between studies, and this could have implications on the reach, maintenance, and scalability of studies. However, the variation in the HIIT protocols across studies suggests that there are opportunities to tailor protocols to specific classes or students to appropriately engage and challenge them, and in turn optimise associated outcomes. There was no evidence of integration within the school curriculum in these studies, even though integration can mitigate the overloading teachers and provide staff with appropriate resources, which are shown to improve implementation [17] and should be a focus of future studies.

Future Directions

High-quality studies are needed in this area to be able to reach more robust conclusions as significant limitations were identified in the studies included in this review. Specifically, the lack of power calculations and documentation whether the intervention took places as was intended, along with the high levels of missing data that were unaccounted for in the analyses lead to studies with high risk of bias. Future studies should focus on 1) providing justification for their sample size; 2) reporting adherence, fidelity, and whether blinding occurred to determine deviations from the intended intervention; 3) and performing statistical analyses that account for any missing data.

The body of work focusing on school-based HIIT would benefit from additional studies examining cognitive, physical activity and nutrition outcomes. Our findings for cognitive outcomes are similar to those of a systematic review focusing on the impact of HIIT in adolescents across all settings that determined that HIIT may improve cognitive function but highlighted the need for more relevant studies [35]. These outcomes are important to assess, especially within the school setting, as they are related to academic success and improvements in this domain are likely to encourage schools to engage with HIIT [1]. Our narrative synthesis included heterogenous findings for the few studies that examined physical activity levels. More studies investigating physical activity levels and nutritional intake will be useful to help understand the impact of HIIT on these outcomes and whether incorporating HIIT leads to any compensatory behaviours in these domains, as recommended by a recent expert statement [148]. This expert statement also calls for further research into the benefits that are specific to students classified as overweight or obese [148]. Our meta-regressions demonstrated that studies including only those classified as overweight or obese moderated the results for waist circumference, body fat percentage, BMI, and CRF. Moving forward, this will be important to also assess for other variables. As the body of evidence grows, it will be important to investigate potential sex and pubertal differences. Future studies should ensure that they report participants' pubertal stages in addition to their sex. Further, it will be important for future studies to report results stratified by sex and maturity status to enable the effects of these variables to be understood. Additionally, beyond sex and maturity, studies should aim to investigate these health outcomes are present across schools in different contexts with varying physical activity policies and practices as these vary greatly between countries, school systems, and individual schools.

While this review supports the effectiveness of HIIT interventions in schools, factors related to their feasibility and maintenance must also be considered to improve meaningful short-term and long-term outcomes. It will be important to further investigate enjoyment and affect among HIIT protocols in schools to understand the likelihood for future engagement in these programs [40]. Current research on HIIT has displayed favourable results on enjoyment during and after exercise compared to moderate-intensity continuous training [149]. One strategy to facilitate high levels of student enjoyment may be involving students in the design of HIIT protocols. Affording students ownership in the design of HIIT protocols has the additional potential to also enhance students' accountability, participation, confidence and perceived competence in completing the workouts when the interventions reach the implementation phase [150]. This may be particularly useful for girls given they are less likely to enjoy school physical education and have on average a lower self-perceived physical ability [151]. Beyond students, studies should consider engaging other key stakeholders (e.g., teachers, parents, principals, local policy makers) in designing the intervention to increase the likelihood that interventions are maintained. Co-designing relevant interventions with teachers and integration of the interventions within the curriculum and with relevant educative outcomes could mitigate common reasons for implementation failure such as time constraints, competing curricular demands and overburdened teachers [17, 152].

Strengths and Limitations

This is the first systematic review to comprehensively synthesise the effects of school-based HIIT interventions across a wide range of health and wellbeing outcomes. The review has conducted a rigorous assessment of the risk of bias of included studies and available evidence, which allows the results to be interpreted with the required caution. Further, the review includes several meta-analyses and subsequent meta-regressions, which provide novel insights into the impact of HIIT in this setting along with associated factors. A limitation of this review includes the potential publication bias from only using articles published in English and omitting literature that was not peer-reviewed. Additionally, the papers included within this systematic review were mainly studies with small sample sizes and were classified as having a high risk of bias. Therefore, the results may need to be interpreted with caution.

Conclusion

HIIT is an effective strategy for improving various health outcomes within the school setting, with our meta-analyses indicating meaningful improvements in markers of body size and composition, cardiovascular disease blood biomarkers, and CRF when compared to a non-exercise control group. However, our risk of bias results highlight that more high-quality studies are needed in this area. Currently, there is insufficient evidence to suggest that HIIT is superior to moderate continuous exercise or other types of comparative exercise. It is recommended that future research addresses the paucity of information on cognitive, physical activity, and nutrition outcomes associated with school-based HIIT interventions. It is also recommended that future research examines the effectiveness of these interventions over longer periods and how the interventions can be best developed and integrated within school practice to ensure engagement and maintenance.

Chapter 3: *Making a HIIT* Protocol and Methodology

The following publication has been incorporated as chapter three:

> **Duncombe SL**, Barker AR, Price L, Walker JL, Dux PE, Fox A, Matthews N, Stylianou M. (2022). Making a HIIT: study protocol for assessing the feasibility and effects of co-designing high-intensity interval training workouts with students and teachers. *BMC Pediatrics*. 22 (425). https://doi.org/10.1186/s12887-022-03440-w

Author contributions:

	Statement of Contribution	
	Conception & design	**Drafting & critical review**
Ms. Stephanie Duncombe	60	70
A/Prof. Alan Barker	12	8
Dr. Lisa Price	5	4
Dr. Jacqueline Walker	5	4
Professor Paul Dix	2	2
Ms Amaya Fox	2	2
Dr. Natasha Matthews	2	2
Dr. Michalis Stylianou	12	8

Justification of chapter within the thesis

Making a HIIT was designed to overcome several of the gaps identified in the systematic review and meta-analysis from *Chapter Two,* including: 1) the involvement of end-users through the process of co-designing HIIT workouts; 2) the integration of HIIT within the curriculum; and 3) a detailed evaluation of the intervention's implementation. This chapter includes a detailed protocol of the *Making a HIIT* study. It outlines the rationale, objectives, methodology, justification of the chosen outcomes, and the data analysis that informed the second study of this PhD presented in the succeeding chapters of this thesis. As this chapter was written as a protocol paper, the methods are comprehensively described, aiming to improve the reproducibility of this work. Protocol papers are recommended practice for intervention studies to encourage transparency, limit publication bias, fully explain the study rationale, and ensure correct sample size reporting. Additionally, this study was registered with the Australian New Zealand Clinical Trials Registry, which is in accordance with standard practice.

Making a HIIT: Study Protocol for Assessing the Feasibility and Effects of Co-designing High-Intensity Interval Training Workouts with Students and Teachers

Abstract

Background: High-intensity interval training (HIIT) is an effective strategy for improving a variety of health outcomes within the school setting. However, there is limited research on the implementation of school-based HIIT interventions and the integrating of HIIT within the Health and Physical Education (HPE) curriculum. The aims of the *Making a HIIT* study are to: 1) describe the methodology and evaluate the feasibility of co-designing HIIT workouts with students and teachers in HPE; 2) determine the effect of co-designed HIIT workouts on cardiorespiratory and muscular fitness, and executive function; 3) understand the effect of co-design on students' motivation, enjoyment, and self-efficacy towards the workouts; and 4) evaluate the implementation of the intervention.

Methods: Three schools will participate. Within each school, three different groups will be formed from Year 7 and 8 classes: 1) Co-Designers; 2) HIIT Only; and 3) Control. The study will include two phases. In phase one, Group 1 will co-design HIIT workouts as part of the HPE curriculum using an iterative process with the researcher, teacher, and students as collaborators. This process will be evaluated using student discussions, student surveys, and teacher interviews.

In phase two, Groups 1 and 2 will use the co-designed 10-minute HIIT workouts in HPE for 8-weeks. Group 3 (control) will continue their regular HPE lessons. All students will participate in cardiorespiratory fitness, muscular fitness, and executive function assessments before and after the HIIT program. Students will complete questionnaires on their motivation, enjoyment, and self-efficacy of the workouts. Differences between groups will be assessed using linear regressions to account for covariates. Heart rate and rating of perceived exertion will be collected during each HIIT session. The implementation will be evaluated using the Framework for Effective Implementation. Ethical approval was granted by the University of Queensland Human Research Ethics Committee and other relevant bodies.

Discussion: This study will be the first to co-design HIIT workouts with teacher and students within the HPE curriculum. As this study relies on co-design, each HIIT workout will differ, which will add variability between HIIT workouts but increase the ecological validity of the study.

Introduction

Physical inactivity is an important global issue as a high proportion of children and adolescents are not achieving the recommended levels of physical activity for health benefits [153, 154]. Evidence suggests that increasing vigorous physical activity is particularly important as it could be driving health benefits [27, 28]. High-intensity interval training (HIIT) is a method of acquiring vigorous physical activity and includes short bouts of high-intensity exercise interspersed with recovery periods [29]. HIIT is becoming a popular tool for physical activity acquisition in schools and HIIT interventions have been linked with improvements for markers of body size and composition, blood biomarkers, and cardiorespiratory fitness [155]. HIIT is also structured similarly to children's intermittent patterns of physical activity [30] and can offer opportunities to facilitate learning in health and physical education (HPE) lessons [156].

Schools are an opportune environment to implement HIIT interventions as they can reach a large proportion of adolescents, have existing facilities, and staff capable of facilitating HIIT sessions [10]. Yet, research in schools can present several challenges, including the risk of overburdening teachers or taking away valuable time from the curriculum [10]. To date, most HIIT interventions have not adapted to these challenges and have been conducted during HPE lesson time with no links to the curriculum [155]. Further, very few HIIT interventions have incorporated student and teacher input into the workouts used and none have investigated designing the workouts within the curriculum [155]. Therefore, reviews focused on the topics of school-based HIIT and HIIT in children and adolescents have recommended consulting students and teachers on the design and evaluation of the intervention, and investigating the integration of HIIT within the curriculum [20, 37, 155].

Inherently, integrating HIIT into the curriculum requires the involvement of teachers and students. According to the International Association for Public Participation, engaging end-users in programs exists across a 5-stage continuum ranging from informing to empowering [157]. While stage 5 (empowering) enables the highest level of engagement, it is not always feasible in the curriculum due to time constraints and assessment requirements. However, lower levels of participation, such as involvement or collaboration, where end-users are involved in each phase of the process, are still viewed as beneficial. This active collaboration is often referred to as co-design, which is defined as collective creativity across the entire design process [23, 158]. In the current study, co-design presents a unique opportunity to combine the expertise and lived experiences of researchers, teachers, and students on 1) the topic of HIIT; 2) the curriculum and school setting; and 3) their physical activity participation. Co-designing HIIT workouts within the curriculum has the potential to support educative outcomes and aligns with several Australian HPE curriculum content descriptions for Year

7 and 8 including, designing personal fitness plans, measuring heart rate, and predicting the benefits of physical activity for health [49, 156]. Further, collaboration with students and teachers in designing the workouts and intervention could increase the chances of implementation and engagement in the school setting as it is tailored to meet the needs and interests of end-users [158].

A limited number of studies have conducted process evaluations to assess the implementation of HIIT interventions in schools [106, 159]. Other studies have reported only selected aspects of process evaluations within their overall results, such as the dosage delivered and received, which could potentially lead to biased results [20, 155]. Process evaluations are important for understanding the connection between implementation and any null, negative, or positive findings [17]. For intervention studies employing co-design, evaluating both the process of co-design and the implementation of the intervention is necessary to draw appropriate conclusions.

Aims and Objectives

The *Making a HIIT* study aims to examine the process and effectiveness of co-designing and implementing HIIT workouts with secondary school students and teachers within HPE. *Making a HIIT* will be conducted in two phases with the following objectives in each phase:

Phase one:

1. To describe the methodology and results of the co-design process to develop HIIT workouts in the HPE curriculum, using the framework outlined by *Leask et al*. [160].
2. To evaluate the feasibility of co-designing HIIT workouts with students and teachers as part of the HPE curriculum.

Phase two:

1. Determine the effect of a HIIT intervention on cardiorespiratory fitness, muscular fitness, and executive function.
2. Determine the effect of the co-design process on students' enjoyment, self-efficacy, affect, basic psychological needs, and motivation towards the workouts.
3. Evaluate whether the intervention was implemented as intended through a process evaluation using the framework described by *Durlak and DuPres* [161].

Methods

Overview

Making a HIIT will be completed in two phases, occurring during two subsequent terms in the same school year for each participating school. In phase one, students will co-design HIIT workouts with teachers and researchers as a part of their HPE curriculum (Figure 4). The process will be evaluated using student discussions, student written feedback, and teacher interviews.

In phase two, the HIIT workouts designed in phase one will be implemented using an intervention and quasi-experimental design. All consenting students will participate in cardiorespiratory fitness, muscular fitness, and executive function assessments before and after the HIIT intervention. They will also complete questionnaires on their motivation, enjoyment, and self-efficacy towards HIIT as displayed in Figure 4.

Grounding theories

The theory of expanded, extended, and enhanced opportunities states that more physical activity can be accrued if students are provided with more opportunities, more time for these opportunities and higher quality opportunities for routine physical activity [57]. In line with this theory, *Making a HIIT* aims to enhance HPE lessons by introducing curriculum content targeting high-intensity physical activity and using co-design, which could potentially enhance student engagement throughout the intervention [57]. *Making a HIIT* also includes components that support the basic psychological needs (autonomy, competence, and relatedness) described within self-determination theory (SDT), including the co-design process, exercise modifications, and partner and group workouts [58, 59]. The combined use of these two theories to inform the study aim to support meaningful opportunities for physical activity and foster students' motivation to participate.

Recruitment and participants

Schools in greater Brisbane will be recruited to *Making a HIIT* through purposeful sampling. Schools with known contacts will be identified and contacted one by one until three schools agree to participate. The aim is to consecutively recruit one co-educational school, one boys' school, and one girls' school. The first school will be used as a pilot school to trial the co-design lessons and adapt them if needed before starting in the next two schools. It will include all of phase one activities and the questionnaires pertaining to students' motivation, enjoyment, and self-efficacy towards HIIT. The range of included schools aims to help understand potential sex and school-based differences to comprehensively evaluate the integration of co-designing HIIT within HPE.

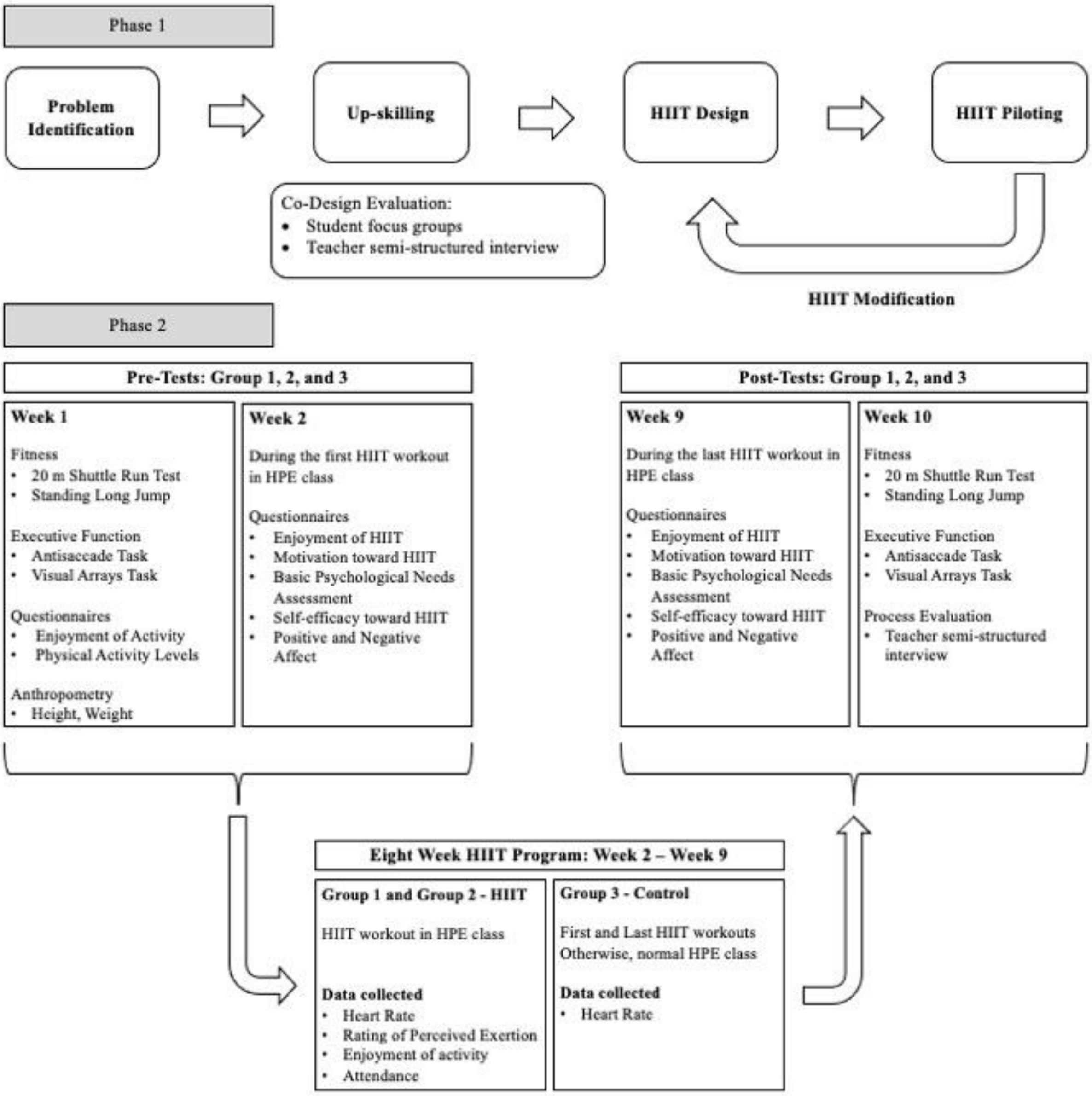


Figure 4. *Overall Making a HIIT Schematic*

Overall study schematic outlining the lesson topics that will be used in phase one to co-design HIIT workouts with Group 1 and the intervention using the HIIT workouts in phase two. The pre-test and post-test measures are listed under their respective weeks. The data that will be collected during the intervention for the groups performing HIIT (Group 1 and 2) and for the control group (Group 3) are displayed under the eight-week HIIT program. HIIT = high intensity interval training; HPE = health and physical education.

The head of the HPE department and HPE teachers will be informed of the study and will be involved in class selection for the study. Interested teachers will need to provide informed consent to participate. All students in the classes of consenting teachers will be eligible to participate as *Making a HIIT* will be conducted as part of the curriculum. However, only students who provide parental consent and student assent will have their data collected as part of the study. Students will be excluded if they are unable to participate in the HIIT workouts due to injuries or other reasons. Students will be in either Year 7 or Year 8 (aged 12 – 14 years) as these two years share the same curriculum content descriptions [49]. The flexibility of using Year 7 or 8 allows schools to meaningfully integrate the work conducted as part of the study in their curriculum according to their local needs.

Within each school, *Making a HIIT* will recruit three groups of participants: **Group 1)** HPE classes involved in the co-design of the HIIT workouts in phase one and who use the HIIT workouts in phase two (Co-Designers); **Group 2)** HPE classes that use the HIIT workouts in phase two but are not involved in the co-design (HIIT only); and **Group 3)** HPE classes that continue normal HPE lessons in phase two and are not involved in the co-design (control group). In the pilot school, one class will be recruited for each group. In school two and three, two classes will be recruited for each group.

Sample size calculation

The sample size calculation was based on the main outcome of phase two, which is cardiorespiratory fitness using the 20-meter shuttle run test (20mSRT). An achievable and meaningful difference has previously been reported as between 5 and 6 laps in adolescents for HIIT-based interventions [110, 131]. Six laps will be used in this study. The standard deviation of the 20 m SRT test was 22 laps in a sample of 100 school children aged 13 – 15 years [131]. Using 3 groups, an α of 0.05, and a power of 80%, we anticipate needing 44 students in each of the three groups based on a G*Power calculation (Critical F = 3.066, df = 2) [162]. Based on expected recruitment rates (75% – 80%), typical class sizes (25 – 30 students), attrition (5%), and data loss due to absence or abstaining from specific measures (10 – 15%) [131, 133, 159], two classes will be recruited to each group in schools two and three.

Phase one

Phase one will use a co-design process with researchers, teachers, and students. Only students in **Group 1** will participate in this phase. The co-design will be conducted as part of the HPE curriculum. The Australian curriculum includes content descriptions related to designing fitness plans and modifying systems to allow students to enjoy and succeed [49], which are aligned with the co-design of HIIT workouts.

The development of the HIIT workouts will take place during obligatory HPE lessons. Students will complete approximately 6 lessons focused on problem identification, upskilling, design, and modification in an iterative process as recommended in the Framework by *Leask et al*. [160]. The number of lessons can be adjusted to meet the needs of participating schools but will encompass the topics outlined in Table 7. The pedagogical strategies will also be modifiable based on the needs of schools and teachers. The lessons may occur during different content units depending on the school and teacher. The same researcher will facilitate the lessons during the co-design process in each participating class.

Table 7. *Topics covered in HIIT co-design.*

Topic	Key Actions
Problem Identification	• Students brainstorm their barriers and facilitators to exercise • Students group their barriers and facilitators into main themes visually with sticky notes • Collectively, students, teachers, and researchers, use the barriers and facilitators to create evaluation criteria that can be used to design and evaluate HIIT workouts
Upskilling	• In groups, students discuss what they already know about HIIT • Students explore their heart rate using monitors and Polar GoFit software that shows intensity levels in different colours • Students partake in several HIIT workouts, reflect on their heart rate, and rate the workouts using their class criteria
HIIT Design	• Collectively decide, with students, teachers, and researchers, the percentage of heart rate maximum to be classified as high-intensity, and the minimum and maximum interval lengths prior to starting the workout design (HIIT parameters) • In groups, students identify potential themes for HIIT workouts and exercises that fit the theme • In groups, students create HIIT workouts that meet both the HIIT parameters and their evaluation criteria
HIIT Piloting	• Each group presents their workout to the class with the aid of the teacher and researchers • Students provide feedback on other groups' HIIT workouts based on their evaluation criteria, and teachers and researchers to provide one or two comments • Heart rate for each pilot is recorded
HIIT Modification	• Each group modifies their workouts based on 1) their own reflection of their pilot; 2) feedback from the other students, researchers, and teachers; and 3) the heart rate summary data from their pilot

The co-design team will include the researcher, the teacher, and students in each class. The aim and purpose of the sessions will be discussed by each co-design team and students and teachers will be able to provide feedback on the activities and pedagogical strategies used. Each member of the co-design team will be encouraged to share their experiences and expertise through activities designed to elicit collaboration. The co-design team will collectively define the parameters for the HIIT workouts (high intensity threshold and interval length) and criteria for an enjoyable HIIT workout. Based upon these parameters, students will co-design HIIT workouts in small groups, and will subsequently have the opportunity to trial their workouts and receive feedback from the co-design team based on the criteria established and heart rate data. To complete phase 1 activities, the student groups will have an opportunity to modify their workouts based on the feedback they receive.

At the end of the phase one, students will reflect on the co-design process through group discussions and individual written feedback to explore their thoughts about educative outcomes from the lessons, lesson aspects that were enjoyable or beneficial and in what way, their intentions to use the workouts in the future, and suggestions for any changes to the process used. Semi-structured interviews will be conducted with teachers to understand their thoughts on how the co-design lessons related to the curriculum and supported educative outcomes, their intentions to use co-design in the future, and their thoughts on student engagement during the co-design lessons.

Data collected

Throughout phase 1, the following data will be collected to support the reporting of the methods and results of the co-design process: 1) the criteria created by students to evaluate the workouts; 2) students' evaluations of pre-made HIIT workouts using their criteria; 3) students' decisions on HIIT parameters (intensity and interval length); 4) draft HIIT workouts; 5) peer feedback using the criteria on the draft HIIT workouts; 6) heart rate data on draft HIIT workouts; and 7) finalised HIIT workouts.

To evaluate the co-design process, both student and teacher feedback will be collected throughout the process. After each lesson, students will have the opportunity to reflect on the activities and pedagogical strategies used and ask questions or provide suggestions and requests for future lessons, either verbally or written anonymously on an index card. At the end of the process, audio recordings of teacher interviews, notes from student discussions, and individual written feedback from students will be collected to examine the feasibility of co-designing HIIT workouts within the HPE curriculum and relevant outcomes.

Data analysis

Descriptive statistics will be used to report the methods and results of the co-design process at each school. For example, they will be used to summarise student evaluations of the various HIIT workouts, highlight differences between schools in the created criteria, HIIT parameters, and HIIT workouts. To evaluate the co-design process, a thematic analysis will be completed using students' feedback about the lesson, notes from student group discussions, individual student written feedback, and semi-structured teacher interviews at the end of the term. The thematic analysis will include familiarisation with the dataset, coding during a re-read of the dataset, and theme development [163, 164]. At least two authors will be involved in refining the themes. Participating teachers will be involved in member checking for feedback on the generated themes. Lastly, the themes will be presented beside quotes which exemplify each theme [163].

Phase two

Phase two will use quasi-experimental design.

Intervention

The intervention will consist of the HIIT workouts designed by Group 1 in phase one. Decisions about the delivery, including the number of HIIT sessions per week and the types of lessons where HIIT is delivered (e.g., theory and/or practical lesson), will be made with teachers, and informed by the local school context. The aim is to have two workouts per week completed in practical and/or theory lessons for a duration of 8 weeks within a single 10-week term. Each HIIT workout will take approximately 10-minutes to complete and will be led by the HPE teacher of each class. For teachers who were not involved in the co-design process, a meeting will be scheduled to discuss the HIIT workouts and expectations for the intervention. All involved teachers will also receive a booklet with the HIIT workout (intervals, exercises with descriptions and modifications, and necessary equipment) for each week. The intervention will be completed by **Groups 1 (Co-Designers)** and **2 (HIIT only)**. Following the HIIT workout, HPE lessons will continue as normal. **Group 3 (Control)** will complete the first and last HIIT workout in the 8-week intervention to be able to appropriately respond to the questionnaires focused on HIIT but will otherwise continue with normal HPE lessons.

Pre-intervention and post-intervention measurements

All intervention measures will be collected by research assistants blinded to group allocation. Baseline measurements will include anthropometry, general enjoyment of physical activity, and self-reported physical activity levels (Figure 1). These measurements will take place the week prior to the intervention and require approximately 15 minutes to complete. Measurements for cardiorespiratory fitness, muscular power, and executive function will be conducted one week prior to and one week post intervention and require 60 minutes to complete. Questionnaire data relating to motivation, basic psychological needs, enjoyment, positive and negative affect, and self-efficacy will be collected after the first and last HIIT workout for all groups and will be completed in 10 minutes. Data will be collected using the same protocols at both timepoints. These data will be collected in all 3 groups during HPE lessons.

Anthropometry

Students will be asked to remove shoes, hats, and any heavy or bulky clothing. Stature will be measured using a stadiometer. Students will be asked to stand with their feet together and have their heels against the back of the stadiometer while keeping their knees straight. They will be instructed to breathe in and stand tall. Their stature will be recorded to the nearest 0.01 m. Body mass will be measured using a calibrated scale. Students will be asked to stand on the scale facing forward with their arms by their side. Their body weight will be recorded to the nearest 0.1 kg. Body mass index (BMI) will be calculated as (body mass (kg) divided by stature (m) squared). To determine students' weight categories, age and sex specific BMI cut points will be used [165]. Based on discussions with key stakeholders (school gatekeepers and teachers), these measures will only be collected at the baseline visit and will be used as covariates in the study to understand differences based on body weight status.

General physical activity levels

Baseline general physical activity level data will be collected using the physical activity questionnaire for children (PAQ-C) questionnaire, a self-administered, 7-day recall instrument that generates a physical activity score based on eight items scored on a 5-point scale [166]. The questionnaire is reliable (ICC = 0.96) [167], and its convergent validity is supported through relationships with an activity rating question, a teacher's rating of physical activity, and moderate to vigorous physical activity assessed by a separate inventory (r=0.45 to r=0.63) [168, 169]. Further, the PAQ-C is quick to complete (approximately 5 minutes), [170] and is one of three physical activity measures that received majority support within an expert group [169]. This questionnaire will only be completed prior to the intervention to understand participants baseline general physical activity levels, which will be used as a covariate in data analysis.

Cardiorespiratory fitness

The 20m SRT will be used to measure cardiorespiratory fitness [171]. The test involves continuous running between two lines in time to recorded beeps with speed that increases by 0.5 km/hr at each level. It requires minimal equipment and can be administered to a large number of students simultaneously [172]. It is easy to administer and is time efficient, with a maximum test option lasting 22 minutes [172]. Additionally, it is a test that students typically engage with during HPE as part of the curriculum. The 20 m SRT is the most used field test for cardiorespiratory fitness [173]. It has a moderate to high criterion-related validity against peak oxygen uptake (r_p = 0.62-0.84) in adolescents according to both a relevant meta-analysis [174] and systematic review [173]. The number of laps each participant completes will be recorded. The 20 m SRT will be used as an outcome variable examining differences between groups over time.

Muscular fitness

The standing long jump will be used to measure muscular power. This jump involves a two-foot take-off and landing. Students will stand behind a line with both feet and will be encouraged to bend their legs and swing their arms for maximum forward movement. The distance of the jump will be recorded from the line to the back of the student's foot. Each student will have three attempts. The standing long jump is a practical, time-efficient, and low-cost test [175, 176]. It is valid (r = 0.7 with 1 repetition leg extension) and strongly associated with other lower body strength tests (r = 0.83 – 0.86) and upper body strength tests (r = 0.69 – 0.85), making it a general indicator of muscular fitness in youth [175-177]. It is commonly used within the HPE curriculum [47, 87, 89, 110, 121]. The standing long jump will be used as an outcome variable examining differences in groups and time.

Executive function

An antisaccade task and a visual array task will be conducted on computers using PsychoPy software [178]. These tasks will be used to assess students' selective attention, inhibition, and working memory and will take approximately 30 minutes to complete [179]. The tasks were pilot tested with Year 8 students and modified appropriately.

The antisaccade task measures inhibitory control of attention and has previously been used in an exercise intervention trial with adolescents [180]. The task will be conducted as previously described [179]. In brief, students will focus on a fixation cross in the centre of their screens. After a visual cue, an asterisk will appear on one side of the screen, followed by a Q or O on the opposite side that is immediately covered by "##". Students will be told to ignore the asterisk and respond to the Q or O. Due to the classroom setting, the original audio cue for this task was replaced with a visual cue to minimise distraction to other students. Prior to starting the task, students will receive a practice round. They will receive feedback throughout the task on their answers and will be provided with a break in the middle of the 72 responses. This task has good internal consistency (R = 0.92) and test-retest reliability (R = 0.71) [179]. The number of correctly identified target letters will be used as the outcome variable from the antisaccade task to examine differences between groups over time.

The visual arrays task, which provides a measure of the capacity of working memory and selective attention ability, will also be completed as previously described [179]. Students will see an array of blue and red rectangles flash on screen after being told to focus on one of the two colours. Subsequently, only the colour they were told to remember will appear on screen with one rectangle labelled using a white dot. Students will be asked if that rectangle has changed orientation from the original display. During pilot testing, each array contained five or seven rectangles of each colour. Based on the results and student feedback, an array with three rectangles of each colour was included to ensure an appropriate dosage curve. Before the task begins, students will have two practice rounds. This includes one round with a longer initial flash and one round at full speed. Students will receive feedback throughout the practice, but not during the actual task. The visual arrays task has good internal consistency (R = 0.75) and test-retest reliability (R= 0.67) [179]. It has previously been used in children as young as ten years old.[181] The outcome variable of interest from the visual array task is the capacity score *(k)*, which provides a measure of working memory capacity. It is calculated from $N \times (\text{Hits} + \text{Correction} + \text{Rejections} - 1)$, where *N* is the set-size for that array [179].

Motivation

Motivation towards HIIT will be measured using the perceived locus of causality (PLOC) questionnaire that was developed by Goudas *et al* [182] based on the original questionnaire by Ryan and Connell [183]. It has been used extensively to assess motivation in HPE [184]. The questions are administered using a 7-point Likert scale. For this study, we changed the stem from “I take part in PE/sport” to “I take part in HIIT workouts…”. The questions are based on SDT and assess motivation, external regulation, introjected regulation, identified regulation, and intrinsic regulation to gain an understanding of what motivates students to participate in HIIT [182]. The PLOC will be used as an outcome variable examining differences in groups and time.

Basic psychological needs

Three innate psychological needs are encompassed within SDT: autonomy (the need to be self-governed), relatedness (need to feel connected and accepted by others), and competence (the need to succeed in various tasks) [59]. The basic needs theory within SDT hypothesizes that when these needs are met students will have improved intrinsic motivation, wellbeing, and health [59, 185, 186]. Five 7-point Likert scale questions will be used to assess each need. Autonomy during the HIIT workout will be assessed using the questions collated by Standage *et al.* (2003), who demonstrated internal reliability of the questions in an HPE setting [187]. Relatedness during the HIIT workout will be assessed using a subscale of the Need for Relatedness Scale [188], which has previously been used in HPE with acceptable internal reliability [187, 189]. Lastly, HIIT competence will be assessed using 5 questions from the perceived competence subscale of the intrinsic motivation inventory [190], which has also been shown to be reliable in an HPE setting [187, 191]. The basic psychological needs will be used as an outcome variable examining differences in groups and time.

Enjoyment

Enjoyment of general physical activity will be measured for all groups using physical activity enjoyment scale (PACES) before the intervention [192]. The version used in adolescents and youth includes the prompt "When I am active" and 16 phrases that students rank on a 5-point Likert scale from 1 (Disagree a lot) to 5 (Agree a lot) [193]. The overall score is calculated by summing the 16 responses and dividing by the number of questions, with a higher score demonstrating greater enjoyment. It has been validated for both children and adolescents [194]. Enjoyment of general physical activity will be used as a covariate for understanding enjoyment of HIIT specifically.

Enjoyment of HIIT will be also measured using the PACES questionnaire. The stem of the questionnaire will be changed from "When I am active" to "When I am participating in HIIT". Enjoyment has previously been shown to mediate the effects of school-based physical activity interventions and will be a key variable to examine in this study [195]. The PACES questionnaire on HIIT will be used as an outcome variable examining differences in groups and time.

Positive and negative affect

A 9-item questionnaire will be used to assess affect using the prompt "During this workout, I felt". Students will respond on a 5-point Likert scale from 1 (Not at all) to 5 (Extremely). Five items on the scale are related to positive affect (e.g., proud) and four to negative affect (e.g., unhappy). This is a short-form of the original positive and negative affect scale (PANAS) that was developed to be used in children and has shown to be reliable [196]. This questionnaire will be used as an outcome variable examining differences in groups and time.

Self-efficacy

Self-efficacy toward HIIT will be measured using the HIIT-SQ, which has previously been used with and validated for adolescents [197]. It includes 6 questions on a 10-point Likert scale. It will be an outcome variable used to understand differences in students' confidence in relation to performing HIIT workouts between groups and over time.

Intervention measurements

Heart rate

Heart rate will be monitored throughout the HIIT sessions and the remainder of the HPE lessons to evaluate intensity for **Groups 1 and 2** using Polar H10 monitors (Polar H10, Polar Electro, Finland). Heart rate will also be monitored throughout the HPE lesson in **Group 3.** Polar H10 monitors will be provided to students and the Polar GoFit system (https://polargofit.com/) will be used to collect data. This will be done anonymously using a number assigned to each student. Students' maximum heart rates will be determined during the baseline 20 m SRT. Heart rate will be used to assess the fidelity of the HIIT workouts through the calculation of average and peak heart rate, the percentage of students above the thresholds of 80% and 90% of maximum heart rate, and the percentage of time students spend in various deciles (>80% maximum heart rate, >90% maximum heart rate).

Rating of perceived exertion

The omnibus (OMNI) children's rating of perceived exertion (RPE) scale will be administered at the end of each HIIT workout for **Groups 1 and 2** and at the end of the first and last HIIT workout for **Group 3**. Students will reflect on how tired they were throughout the entire HIIT session using the prompt "During this workout, I felt". They will respond using a pictorial scale from 0 (not tired at all) to 10 (very, very tired) [198]. The OMNI-RPE scale has demonstrated strong criterion validity for walking/running against both heart rate and peak oxygen consumption in children aged 11-12 and ≥ 13 years ($r \geq 0.82$) [199]. A sessional score will be calculated by multiplying the RPE by the duration of the session to represent the load for the entire session. The sessional RPE will be used to assess the fidelity of the HIIT workouts.

Enjoyment of HIIT workout

One 5-point Likert scale question will be used to assess students' enjoyment at the end of each HIIT workout for **Groups 1 and 2.** Students will rate their enjoyment using the following prompt: "I enjoyed participating in today's HIIT session" between 1 (strongly disagree) and 5 (strongly agree). A similar style question has previously been used to assess student satisfaction of HIIT workouts [47]. This will be used to understand changes over time in enjoyment and enjoyment of specific workouts and student responsiveness.

Process outcomes

The process evaluation will be guided by the Framework for Effective Implementation [161]. The number of schools and students contacted about the study will be tallied to inform the recruitment rate. The number of HIIT workouts delivered by teachers and attended by students will be recorded to inform the dosage delivered and received. Heart rate and RPE will be recorded to assess fidelity to high intensity. Heart rate will also be used to monitor intensity during regular HPE lessons in the control group. Enjoyment of each workout will be recorded to understand student responsiveness. Any adverse events will be recorded by a researcher in a logbook. Any modifications made to the workouts will be recorded by a researcher. Semi-structured interviews will be completed with teachers at the end of phase two on the topic of implementation to investigate adaption and quality.

Data analysis

Data entry will be completed by one researcher with at least 10% checked by a second researcher. All data will be checked prior to analysis using range to assess any outliers or errors in data entry. To describe the population, descriptive statistics will be reported for each school separately. To determine the effect of the HIIT intervention on cardiorespiratory fitness, muscular fitness, and executive function, general linear models will be used to assess changes in the dependent variables with group (HIIT or control), timepoint, and group x time interaction included as independent variables. To determine the effect of involvement in co-design on students' motivation, enjoyment, self-efficacy, feelings, and basic psychological needs, generalised linear models will be used to assess changes in the dependent variable, with group (Co-Design or not), timepoint, and group x time interaction included as dependent variables. Potential covariates, such as sex, age, BMI, involvement in co-design, baseline physical activity levels, baseline physical activity enjoyment, and baseline levels of the dependent variable will be identified using two-by-two tests and included in the model where appropriate.

The implementation of *Making a HIIT* will be evaluated using the Framework for Effective Implementation [161] across 8 components: 1) program reach – number of consenting schools and students; 2) dosage – number of HIIT workouts delivered and completed; 3) fidelity – students' heart rate and RPE during HIIT workouts; 4) quality – variation in heart rate between students; 5) monitoring of control group – via heart rate ; 6) responsiveness – student enjoyment and teacher perspectives; 7) adaption – modifications of the HIIT workouts by teachers; 8) differentiation – uniqueness of study.

Ethical Considerations and dissemination

Making a HIIT has been approved by The University of Queensland's human research ethics committee (Project: 2020/HE002444) and school organisations as necessary (Appendix 1). All researchers involved in the study will have to complete appropriate checks and training to ensure child safety. Consent for participating schools will be provided by school gatekeepers (e.g., principals). Involved teachers will also provide consent. All students will partake in designing and participating in the HIIT workouts as it will be completed as part of the curriculum. However, only students who have both parental/guardian consent and student assent will have their data collected as part of this study. All data collected will be stored anonymously on a secure server. Results of *Making a HIIT* will be disseminated through publications in peer-reviewed journals and conference presentations.

Discussion

This chapter presents the protocol for the *Making a HIIT* study. *Making a HIIT* will include the novel component of co-designing HIIT workouts with students and teachers within the HPE curriculum. Further, it will examine if co-designing HIIT workouts affects student engagement during the workouts and if it moderates any outcome variables. *Making a HIIT* will include three different school types (co-educational school, boys' school, and girls' school) to provide insight into the integration of this type of work within a variety of schools and HPE units to support the HPE curriculum and to investigate potential gender differences. Currently, there are limited process evaluations on HIIT interventions in schools [155]. *Making a HIIT* will aim to comprehensively evaluate the extent to which the intervention was completed as intended. This is pertinent to understanding the link between implementation and outcomes, especially given evidence supporting that high-intensity exercise could be driving health benefits. This study does not include randomisation as it is not feasible in our protocol based on school timetables and preferences for class involvement. However, quasi-experimental designs are widely used in school-based research and are useful for comparing groups and measuring change when randomisation is not possible [200]. Overall, the results of this study will provide useful insights into the meaningful implementation of school-based HIIT interventions that support both educative and health outcomes.

Chapter 4: Co-Designing HIIT Workouts

The following submitted manuscript has been incorporated as chapter four:

> **Duncombe SL**, Barker AR, Price L, Walker J, Liu Y, Paris D, and Stylianou M (2023). Making a HIIT: Co-Design of High-Intensity Interval Training Workouts with Students and Teachers within the Curriculum. *BMC Public Health*. http://doi.org/10.1186/s12889-023-16613-8

Author contributions:

	Statement of Contribution			
	Conception & design	**Data Collection**	**Analysis & interpretation**	**Drafting & critical review**
Ms. Stephanie Duncombe	70	90	80	82
A/Prof. Alan Barker	10	0	2	5
Dr. Lisa Price	5	0	0	2
Dr. Jacqueline Walker	5	0	0	2
Mr. Yong Liu	0	0	8	2
Mr. Dewi Paris	0	0	8	2
Dr. Michalis Stylianou	10	10	2	5

Justification of chapter within the thesis

The lack of end-user participation in school-based high-intensity interval training (HIIT) research was identified in both *Chapter One* and *Chapter Two* of this thesis. Therefore, *Making a HIIT* followed a co-design approach that included teachers and students in the design of HIIT workouts. This chapter expands on *Chapter Three* by providing a detailed description of the co-design approach used to create the HIIT workouts and its results during phase one of *Making a HIIT*. This process is novel to school-based HIIT, and a detailed description of the methods was warranted to enable future research to use this methodology. Additionally, it was important to describe the unique and varying HIIT workouts that were created and subsequently used in the intervention discussed in *Chapters Five to Eight*. Further, it provides an evaluation of the feasibility of incorporating the co-design process within the curriculum to guide future work that incorporates end-users in this type of research

Making a HIIT: Co-design of High-Intensity Interval Training Workouts with Students & Teachers within the Curriculum

Abstract

Background: High-intensity interval training (HIIT) interventions are becoming more common in schools. However, limited input has been sought from end-users, which can help design interventions that are more engaging and context appropriate, therefore increasing their potential for successful implementation. One method of engaging end-users is co-design, which involves an active collaboration to design solutions to pre-specified problems. This paper aimed to: 1) describe the methodology and results of the co-design process in *Making a HIIT* to develop HIIT workouts for a school-based intervention; and 2) evaluate the feasibility and impact of co-designing HIIT workouts with students and teachers within the health and physical education (HPE) curriculum.

Methods: The development of the HIIT workouts occurred during obligatory HPE lessons with year seven and eight students. The co-design process included: 1) identifying barriers and facilitators to exercise to create evaluation criteria for creating the HIIT workouts; 2) exploring HIIT; 3) defining HIIT parameters (intensity and interval length); 4) creating HIIT workouts using the parameters and evaluation criteria; 5) trialling and modifying the HIIT workouts based on class feedback and intensity data. To evaluate the feasibility and impact of the co-design process, a thematic analysis was completed using teacher interviews, student discussions, and student surveys.

Results: Five classes comprised of 121 students (12-14 years; 49% female) and five teachers were involved in the co-design process across three schools in Queensland, Australia. A total of 33 HIIT workouts were created aimed at satisfying the HIIT parameters and variations of the following evaluation criteria: 1) fun; 2) social; 3) achievable skill level; 4) feeling accomplished; and 5) beneficial for health. From the thematic analysis, three themes (acceptability; implementation; integration) and 12 codes contributed to the overarching understanding of the feasibility of the lessons within the curriculum and a further three themes (perceived changes to lessons; educative outcomes; personal and social capabilities) and three codes contributed towards understanding their impact.

Conclusion: Overall, co-designing HIIT workouts was feasible within the HPE curriculum and may have contributed to positive educative outcomes. Using this methodology could improve the implementation of HIIT interventions within HPE while supporting educative benefits.

Introduction

Most children and adolescents are not acquiring the amount of moderate-to-vigorous physical activity recommended for health benefits [153, 201, 202]. Recent evidence has demonstrated that vigorous physical activity specifically could be driving some of the health benefits, such as improved cardiorespiratory fitness and body composition [27, 28], suggesting that developing interventions that focus on promoting vigorous physical activity are necessary. High-intensity interval training (HIIT) is a form of vigorous physical activity that incorporates alternating bouts of high-intensity exercise and recovery [29]. HIIT follows a similar intermittent pattern to children's habitual physical activity and has been used in school-based interventions [30, 155].

Schools are an important setting for acquiring physical activity. They can reach a high percentage of children and adolescents with their policies, infrastructure, and trainable personnel [10]. However, the school environment also presents unique challenges, including time constraints, teacher workload, and curriculum demands [17]. Currently, most school-based HIIT interventions have demonstrated limited consideration of these challenges and have had minimal input from students and teachers to tailor the interventions for student enjoyment or to curriculum units [155]. Of the 42 studies identified in a systematic review on school-based HIIT [155], only two had included any engagement with end-users during design and implementation [131, 133]. Therefore, contemporary reviews have recommended integrating HIIT within the curriculum and consulting teachers and students [20, 37, 155]. The Australian Health and Physical Education (HPE) curriculum includes standards and elements related to fitness and the benefits of physical activity for health [49], which presents an opportunity for the integration of HIIT and active involvement of students and teachers while still focusing on educative outcomes.

Participation with end-users, such as teachers and students, occurs on a 5-stage continuum outlined by the International Association for Public Participation (IAP2), which includes informing, consulting, involving, collaborating, and empowering [157]. While integrating interventions within the curriculum has the potential to alleviate some of the challenges outlined above, time restraints and assessment requirements restrict student involvement, limiting the feasibility of stage 5 (empowering) [203]. Young people have previously been included in the development of school-based physical activity interventions; however, this rarely occurs beyond stage 1 (consultation) [204]. Including students and teachers at higher levels on the IAP2 continuum can provide several benefits, including: 1) providing students with a voice to express their needs [205]; 2) increasing students' confidence [205]; 3) increasing skill acquisition for students [205]; and 4) enhancing relevant projects through a better understanding of student and teacher needs by involving them as experts [203].

However, it is important to ensure that the involvement of end-users is authentic, which can be fostered through practical strategies and frameworks that guide the process [160, 206].

The *Making a HIIT* study described in this paper was designed to enable authentic end-user participation through co-design. Co-design is defined as a collective creativity across the entire design process and involves an active collaboration with end-users to design solutions to pre-specified problems [23, 24]. It is distinguished from other forms of end-user engagement such as co-creation and co-production that have differing levels of end-user participation. Co-creation engages end-users before the problem is identified and necessitates the highest level of engagement from end-users [24]. Conversely, co-production requires less engagement from end-users and involves them in the evaluation of potential solutions to a problem [24]. In this instance, co-design was deemed to enable sufficient and meaningful participation from end-users, while complementing other curriculum demands. For the *Making a HIIT* study, it enabled the expertise and lived experiences of researchers, teachers, and students to be combined to create and use HIIT workouts within the HPE curriculum. If done appropriately, the co-design process has the potential to lead to the development of HIIT workouts that are more engaging and useful to students and teachers by bringing together different views, contributions, and expertise [158].

This paper presents the co-design approach from the *Making a HIIT* study where HIIT workouts were co-designed within the HPE curriculum by students, teachers, and researchers. This paper aims to: 1) describe the methodology and results of the co-design process; and 2) evaluate the feasibility and impact of co-designing HIIT workouts with students and teachers as part of the HPE curriculum.

Methods

The overall study design of *Making a HIIT* has previously been described in *Chapter Three* [207]. This chapter focuses on phase one of the study. This phase was completed within obligatory HPE lessons and involved co-designing HIIT workouts with students and teachers within the curriculum, which were subsequently used in an intervention in phase two of *Making a HIIT*. A brief overview of the topics covered in the lessons is presented in Table 8.

The co-design process was guided by the framework and recommendations from Leask *et al.* [160] and adapted at each school to meet their specific needs. This framework was designed to systematically guide the development of public health interventions using participatory methods and was informed by several case studies, including one focused on physical activity in secondary schools with students as the end users [160]. While this framework has a focus on participatory action research, which aims to change social reality by means of participatory research [208], it includes four main stages, which are all relevant to co-design: 1) planning; 2) conducting; 3) reporting; and 4) evaluating. These stages are presented in Table 9, where they are linked to the corresponding information of the co-design process for *Making a HIIT*.

Table 8. *Topics covered in the HIIT co-design lessons.*

Topic	Key actions
Problem Identification Theory lesson	• The co-design team listed their three main barriers and facilitators to exercise on individual sticky notes. • The co-design team visually grouped their barriers and facilitators into themes to understand which ideas were the most common. • The co-design team used the common barriers and facilitators to collectively create workout criteria that represented their shared thoughts.
Upskilling Practical lesson	• Students used heart rate monitors to familiarise themselves with heart rate and high-intensity and experiment with achieving different heart rate zones. • The co-design team partook in several HIIT workouts, reflected on their heart rate, and rated the workouts using the criteria developed during problem identification.
HIIT Design Theory and practical lesson	• The co-design team collectively decided on the percentage of heart rate maximum that was classified as high-intensity, and the minimum and maximum interval lengths that could be used in their workouts. • In small groups, students identified potential themes for their HIIT workout and exercises that fit the theme. • Using their identified themes and exercises, the small groups created a HIIT workout that abided by the established HIIT parameters and attempted to satisfy the criteria developed during problem identification.
HIIT Piloting Practical lesson	• Each small group led their HIIT workout for the co-design team with the aid of the teacher and researcher. • The co-design team provided feedback on other groups' HIIT workouts using the criteria developed during problem identification. • Heart rate for each pilot was recorded.

HIIT Modification
Theory lesson
	• All groups modified their workouts based on:
	  o their own opinion of their pilot.
	  o the feedback provided by the co-design team during the pilot.
	  o the heart rate summary data from their pilot.

Table 9. *Operationalisation of the Leask et al. framework for the co-design of HIIT workouts.*

			HIIT Workout Co-Design
Planning	Aim of Study	Problem	A low percentage of students are meeting the recommend minutes of physical activity to acquire health benefits
		Objective	To co-design high intensity interval training (HIIT) workouts in health and physical education (HPE) lessons that can be used in HPE
		Design	Co-design
		End Users	HPE teachers and students
		Co-designers	Researchers, HPE teachers, students
		Evaluation	The process was evaluated with individual student surveys, student discussions, and teacher interviews
		Scalability	Two outputs from this study have the potential to be scaled for further school-based HIIT interventions: 1. The co-design process and the associated lessons plans that can be integrated in the HPE curriculum across multiple schools, which were refined throughout the three consecutive schools in *Making a HIIT* 2. The HIIT workouts designed by the co-design team that focused on incorporating facilitators to exercise and alleviating barriers can be shared between teachers to be used as brain breaks, warmups, or in HPE
	Recruit/ Sampling Procedure	Criteria	All students within the co-design classes at participating schools were eligible to participate
		Setting	HPE lessons in three greater Brisbane schools
		No. of creators	A researcher, one class of Year 7 or 8 students, and the class teacher formed an independent co-design team
		Demographics/characteristics	Broad and generalisable schools: a co-educational state school, a girls' catholic school, and a boys' independent school with different levels of socio-educational advantage (Table 3)
Conducting	Ownership	Manifesting Ownership	Ownership was established using several methods: 1. The HIIT parameters were decided using participation from all team members with each team member receiving a vote. 2. Depending on the class, students were given the opportunity to decide whether to form groups themselves or have their groups formed by a teacher 3. Groups decided on a team name and theme collectively that reflected shared interests and the personality of the group 4. Groups had the final decision on the theme and exercises included in their workouts based on input from the rest of the co-design team 5. Index cards at the end of the lessons were provided for anonymous student feedback that could be discussed the following session
	Procedural Components	Level of participation	Team-based design with the researcher as facilitator and teacher as facilitator/collaborator with all members of the team treated as experts
		How was the aim presented?	The objective for the co-design process was discussed with all co-designers at the start of the first session along with the proposed lesson plans. The co-design team (students and teachers) was asked to provide feedback on the aims and activities
		Purpose of each meeting presented	Each lesson commenced with a "what, why, how" discussion to ensure that it had a clear purpose
		Rules and responsibilities agreed upon?	All co-designers were of equal status and had the right to contribute ideas. This was actioned by: 1. Ensuring each team member had a vote for the creation of the criteria and HIIT parameters

			2. Ensuring each team member in the HIIT creation groups had an agreed upon role and provided ideas for included exercises
	Procedural Methods	Upskilling	Student co-designers deepened their understanding of HIIT by: 1. Increasing their understanding of heart rate intensity zones using heart rate monitors 2. Discussing 1) high intensity; 2) intervals; and 3) the relationship between rest, work, and intensity 3. Discovering a range of workouts that fall under the definition of HIIT
		How was previous evidence reviewed?	1. A systematic review and meta-analysis of school-based HIIT was completed by researchers that identified a lack of student and teacher voice and integration within the curriculum (in *Chapter Two*) 2. Lived experiences around barriers and facilitators to exercise were discussed with the co-design team and the most common barriers and facilitators were identified visually with sticky notes
		Prototype Process	To design the HIIT workouts: 1. Co-design teams made their 1st iteration of the HIIT workouts 2. The HIIT workouts were piloted with the co-design team 3. Each group received the heart rate data from their HIIT workout and feedback from the co-design team based on the class criteria 4. The teams modified their HIIT workouts based on the feedback and heart rate data
		Frequency and duration of lessons	The lessons varied between schools based on decisions with teachers and head of department. They were: 1. School 1: 6 x 70-minute lessons 2. School 2: 6 x 50-minute lessons 3. School 3: 6 x 60-minute lessons
		Interactive techniques used	1. Active participation through brainstorming and discussions enabled all team members to partake 2. Each co-design member provided input into the creation of the HIIT parameters by standing along a continuum line to indicate their preference and discussing and debating with other team members
		Fieldwork techniques used	1. Heart rate exploration was completed in the upskilling lesson 2. Pre-made HIIT workouts were trialled in the upskilling lesson 3. Groups piloted their HIIT workouts with their peers, teacher, and researcher
		How did iteration occur?	1. Criteria for creating the HIIT workouts were developed, piloted, and revised/finalised 2. HIIT workouts were developed, piloted, and revised/finalised
Evaluation	Process Evaluation	Co-design process evaluated?	Evaluation of the feasibility and impact of the co-design process was completed using qualitative analysis. Data included: 1. An individual written survey completed by students 2. Student discussions with researchers in their small groups 3. Semi-structured interviews with co-design teachers The co-design process was implemented at each school consecutively with feedback from one school used at the following
		Results reported to stakeholders/public?	1. The final HIIT workouts were shared with the teachers involved in the co-design process and the head of the HPE department to distribute and use as they preferred. 2. The feasibility and impact of the process was discussed with stakeholders (teachers) and the findings of the discussions was relayed to other stakeholders (e.g., the head of the department) 3. Dissemination of the methods and findings of the study was completed via journal articles and conference presentations.

	Outcome Evaluation	Validity of outcome (HIIT Workouts)	1. The HIIT workouts included multiple iterations and modifications to increase the likelihood that they satisfied the HIIT parameters and class evaluation criteria 2. A second phased of *Making a HIIT* will embed the co-designed HIIT workouts in an experimental study and evaluate the fidelity and quality of the workouts
		Plan to test effectiveness/scalability of outcome?	1. A second phase of this study will embed the co-designed HIIT workouts in an experimental study comparing the motivation and enjoyment of co-designers to students not involved in co-design 2. A second phase of this study will embed the co-designed HIIT workouts in an experimental study comparing the fitness and executive function of students completing the co-designed HIIT sessions to a control group

The recommended framework outlined by Leask et al. [160] and the corresponding methods and activities completed in this study. HIIT = high-intensity interval training; HPE = health and physical education.

Recruitment and Sampling Procedure

Three metropolitan secondary schools in Queensland, Australia were recruited through purposeful sampling to participate in *Making a HIIT* and their characteristics are displayed in Table 3. The classes that participated in the co-design process were chosen in consultation with teachers based on lesson schedules. Each class constituted its own co-design team along with the teacher and researcher. Ethical approval for the study was granted by The University of Queensland's human research ethics committee (Project: 2020/HE002444) and relevant education organisations. All students and teachers in the partaking classes were eligible to participate. Informed consent was collected from teachers and school principals. Informed assent and consent were obtained from students and their parents / guardians. In total, 121 of a possible 129 students, and five teachers were involved in the co-design process across the three schools. No students or teachers withdrew from the process.

Procedural Components

While a similar lesson structure was observed across participating classes, a separate co-design process was conducted for each one with no influence from the other classes on the decisions made. The lesson plans were developed by the research team in consultation with the head of the HPE department and participating HPE teachers at each school, and in alignment with content descriptors from the Australian HPE curriculum for Years 7 and 8 (e.g., designing personal fitness plans and modifying systems to enable enjoyment and success) [49]. The lesson plans designed, including the activities and resources, are available from the research team upon reasonable request. The number of lessons for the co-design process was determined by the researchers and teachers prior to interacting with students as it needed to be decided before the start of the term so teachers could plan the remaining lessons and their assessments. At the beginning of the co-design procedure, the co-design team discussed the objectives and tentative lesson plans. Students were encouraged to provide their thoughts and feedback on the lessons throughout the co-design process, either through class discussions or anonymously using index cards that could be discussed during the next lesson. At the start of each lesson, the "what, why, and how" were discussed so that all members of the co-design team were clear on the purpose of the lesson, underlying rationale for the lesson, and associated activities. Researchers facilitated the lessons with support from the HPE teacher, who held a passive role throughout the lessons to minimise the influence of teacher-student power dynamics. Students' lived experiences and input were treated as equally important to that of researchers' and teachers', and as essential to co-designing the workouts.

***Table 10**. School and class characteristics.*

School	School Type	ICSEA percentile*	Language Other than English*	Class	Year Level (Mean age)	*N* (girls)	Agreed Upon HIIT Parameters		
							Intensity Threshold	**Min Interval Length**	**Max Interval Length**
One	State	41%	42%	A	8 (13.3 ± 0.3)	25 (11)	80% of HR_{max}	10 s	60 s
Two	Independent	87%	24%	B	7 (12.6 ± 0.3)	24 (0)	85% of HR_{max}	10 s	60 s
				C	7 (12.5 ± 0.3)	24 (0)	90% of HR_{max}	10 s	60 s
Three	Catholic Education	65%	5%	D	8 (13.3 ± 0.3)	23 (23)	80% of HR_{max}	10 s	60 s
				E	8 (13.4 ± 0.3)	25 (25)	80% of HR_{max}	10 s	60 s

The values presented in the school information columns were acquired from myschool.edu.au. The HIIT parameters for each class were decided by each co-design team. ICSEA = Index of Community Socio-Educational Advantage; SEA = socio-educational advantage; HIIT = high-intensity interval training; HR = heart rate; Max = maximum; Min = minimum; *N* = number of students.

* Based on 2021/2022 results from: https://myschool.edu.au/

Researchers facilitated the lessons with support from the HPE teacher, who held a passive role throughout the lessons to minimise the influence of teacher-student power dynamics. Students' lived experiences and input were treated as equally important to that of researchers' and teachers', and as essential to co-designing the workouts. Students were informed of their right to equal contribution on par with the researchers and teacher for all activities, such as the criteria creation, the selection of HIIT parameters, and the design of the HIIT workouts. Smaller teams (3 – 5 students) were formed to design the HIIT workouts with input from teachers and students. In school one, students voted on how to form the teams (i.e., by students or teacher) and chose to have the teacher make the decision. In schools two and three, this decision was based on teacher discretion, with students in one class forming their own teams and students in the second class being organised in teams by the teacher. Each team collectively decided their name, workout theme, and exercises to reflect their shared interests.

Procedural Methods

Frequency and Duration of Lessons

The intention was to conduct the co-design process across 6 HPE lessons as part of the curriculum. In school one, the co-design team met twice a week for three weeks and each HPE lesson was 70 minutes. In school two, one class completed six 50-minute lessons and one class completed only 5 lessons due to scheduling conflicts disrupting class time. The lessons in school two were completed across five weeks and occurred between one to three times per week. In school three, both classes met twice a week for three weeks and each HPE lesson was 60 minutes. In all three schools, the process was integrated within a fitness-related unit and was completed in both theory and practical lessons using the classroom and school gymnasium.

Problem Identification: HIIT Criteria Creation

Prior to beginning this study, the research team completed a systematic review of the school-based HIIT literature and identified a lack of student and teacher voice and integration within the curriculum [155]. With the purpose of creating workouts centred on student interests and enjoyment, the first lesson of the co-design process started with a focus on barriers and facilitators to general exercise to create criteria for engaging exercise as described in Table 8. Students used the created criteria to evaluate several pre-made HIIT workouts during the upskilling lesson. Subsequently, the class discussed what modifications, if any, were needed to properly represent their interests before the criteria were used to inform the design of their own HIIT workouts. Data collected on this topic included the sticky notes listing each student's individual barriers and facilitators, the draft class criteria, and the final class criteria.

HIIT Upskilling

Prior to designing the HIIT workouts, the second lesson was used to familiarise students in the co-design team with heart rate and HIIT. The co-design team discussed resting heart rate and calculated their estimated maximum heart rate in beats per minute. Each student was provided with a Polar H10 heart rate monitor (Polar H10, Polar Electro, Finland) and instructed on proper placement. Using Polar GoFit software (https://polargofit.com/), students heart rates were anonymously projected in the gymnasium (i.e., using assigned numbers instead of names). The GoFit software uses different coloured zones to denote 90%+, 80% - 89%, 70 – 79%, 60-69%, and <60% heart rate, so students could quickly determine their effort while working and resting. Students had a chance to freely move around the gymnasium and watch their heart rate response on screen with the goal of displaying all five heart rate zones.

To understand HIIT, the researchers then introduced the students in the co-design team to the concept of intervals and the co-design team discussed the relationship between intensity and interval length. The co-design team discussed how heart rate and intervals were relevant to HIIT and co-design team members identified any prior knowledge or experiences they had of HIIT from gyms, social media, or other sources. Students in the co-design team were never provided with a specific definition of HIIT (e.g., an intensity threshold) from the researcher so that they would be able to formulate their own definition based on their knowledge from this lesson. Students in the co-design team did trial a variety of HIIT workouts chosen by the research team to gain a greater understanding of the types of exercises in HIIT workouts and how they influenced heart rate. In school one this included a: 1) relay for points; 2) resistance workout; 3) dance-themed workout; 4) boxing themed workout; and 5) run/jog workout. Due to time constraints, the boxing and dance workouts were not completed in school two, and the dance workout was not completed in school three. Students used the criteria created in the first lesson to evaluate the workouts. The data collected in this lesson included the evaluation page that each student completed for each HIIT workout using the criteria created by each class.

HIIT Workout Parameters

During the third lesson, the co-design team collectively decided on: 1) the threshold for high intensity as a percentage of maximum heart rate; 2) the maximum interval length for work and rest; and 3) the minimum interval length for work and rest. Using their understanding of heart rate from the HIIT workouts in the upskilling lesson, students lined up on a continuum across the classroom to mark where they thought the threshold for high intensity should be set as a percentage of maximum heart rate ranging from 50% to 100%. They discussed their reasoning with others closest to them and subsequently shared their reasoning with the rest of the class, the teacher, and the researcher. This discussion was moderated by the researcher. Finally, students in the co-design team voted on the percentage of maximum heart rate to use as a threshold when designing their workouts. The researcher guided the voting process by establishing the thresholds that would be included in the vote based on the where on the continuum the largest proportions of students were standing. The percentage with the majority vote was used. The same process was used to set the maximum and minimum interval times for work and rest based on students' understanding of the relationship between heart rate and interval length. During the discussion on interval length, the researcher ensured that it was clear to students that they were able to use any interval length within the minimum and maximum constraints for designing the workouts and that these values were to be used as a guide. Field notes were collected by the researcher to document the discussions and decisions for each parameter. The length of the HIIT workout was predetermined by teachers and researchers based on student ability and time constraints with the intention of using the HIIT workouts in HPE lessons the following term. In school one, 10-minute workouts were created using intervals within the determined constraints. In schools two and three, researchers and teachers decided to have students design a 5-minute workout that would be repeated twice. This decision was based on teacher feedback from school one where teachers felt that students were too rushed during the design and would benefit from more time to focus on the interplay between heart rate and interval length for each of their chosen exercises.

HIIT Workout Creation

Small groups of three to five students created the HIIT workouts during the remaining three lessons using: 1) the criteria developed during the problem identification lesson; 2) the parameters established for the workouts (interval length, heart rate intensity); 3) a booklet of example exercises; and 4) relevant resources identified through the internet. The student groups started by discussing potential group names and themes for their workouts. Afterwards, they proceeded to research and list exercises related to the theme and modifications of the exercises to make them suitable for all levels of ability. They were encouraged to use their heart rate monitors to trial their exercises to ensure the interval length was appropriate and at the desired intensity.

After finalising the first iteration of workouts, the workouts were trialed by the class. Teachers and researchers aided the student groups in leading their workouts with varying levels of involvement based on teacher discretion. Heart rate information was collected, and peer feedback was collected using the criteria and a comment section. In a following lesson, student groups were provided with the feedback and heart rate data. Time was allotted for reviewing and discussing the feedback. Groups then made any changes they thought would be useful for their final HIIT workout based on feedback and their own experience leading the workout and documented their reasoning. Data collected during the HIIT workout design included the draft HIIT workout, the peer feedback, the heart rate data, the final HIIT workout, and the reasoning for any modifications made by each group.

Student Ownership

Students were informed of their right to equal contribution on par with the researchers and teacher for all activities, such as the criteria creation, the selection of HIIT parameters, and the design of the HIIT workouts. Smaller student groups (3 – 5 students) were formed to design the HIIT workouts with input from teachers and students. The insight of the teachers into the class dynamics was a valued contribution to the co-design team and enabled them to make an informed decision on how groups should be created. In school one, students were able to vote on how to form the student groups (i.e., by students or teacher) and chose to have the teacher make the decision. In schools two and three, group formation was based on teacher discretion, with students in one class forming their own student groups and students in the second class being organised in student groups by the teacher. Each student group collectively decided their name, workout theme, and exercises to reflect their shared interests.

Evaluation of Feasibility and Impact

Qualitative data were collected to evaluate the feasibility and impact of the co-design process. Student data include: 1) discussions between each group and a researcher about the co-designed process based on a semi-structured guide (All schools) and 2) individual written surveys (Schools one and three). A semi-structured interview was completed with each teacher once the lessons were completed to understand the implementation and integration of the process within the HPE lessons (All schools). It was led by the researcher involved in the co-design process and recorded for subsequent analysis. The teacher interviews were between 20 – 25 minutes in length, while discussions with student groups lasted approximately 10 – 15 minutes each. The survey and discussion guides are provided in Appendix 4. *Making a HIIT* was completed at each school consecutively and feedback from students and teachers was incorporated into the subsequent school's co-design process.

Data Analysis

To describe the results of the co-design process (Aim 1), data were collected during each lesson. This data included: 1) the facilitators and barriers to exercise from individual students; 2) the original and modified class criteria; 3) the evaluations of each trialed HIIT workout during the upskilling lesson using the class criteria, which were descriptively analysed; 4) the established HIIT parameters from each class; 5) the heart rate data and evaluations of each pilot HIIT workout, which were descriptively analysed; 6) the themes, time in work, and types of exercises used in each HIIT workout, which were tallied to understand variation between workouts.

To evaluate the feasibility and impact of co-designing HIIT workouts with students and teachers as part of the HPE curriculum (Aim 2), a thematic analysis was completed using the student discussions, student surveys, and teacher semi-structured interviews [163, 209]. Student written responses and discussion notes were collated shortly after the final lesson and teacher interviews were transcribed verbatim within a week of completion by the first author. This was done to increase familiarity with the data. Any personal or identifiable information was deleted. After familiarisation with the data, two authors (S.L.D. and Y.L.) developed the first iteration of the coding framework based on relevant literature on feasibility studies and program evaluations (deductive) and a subset of data from one co-design team (inductive) with a focus on the explicit (semantic) meaning of the text [163]. This was used to code a second subset of data (S.L.D., Y.L., and D. P.) and the coding framework was adjusted based on new content in the data. The coding framework was applied to the rest of the dataset using NVivo (Version R1) over five iterations (S.L.D., Y.L. and D. P.) and discussed until all authors were satisfied with the codes. S.L.D. organised the codes into larger categories in a hierarchical fashion and drafted a thematic map that was discussed and revised by all the authors. The themes were presented with quotes that exemplified each theme.

Results

Co-Designing the HIIT Workouts

HIIT Criteria

Compiling the sticky notes of individual student barriers and facilitators identified similar themes among the classes. These included facilitators such as: enjoyment, socialising, and fitness goals; and barriers that included: lacking motivation, feeling tired, being injured, and having no time. Therefore, the criteria for all five co-designed teams included several common elements: 1) fun; 2) social; 3) achievable skill level; 4) feeling accomplished at the end; and 5) beneficial. However, the manifestation of these criteria differed slightly. For example, the definition of fun for one class included a statement that the exercises shouldn't be repetitive, while for another class it was expressed as a desire to do the workout. Further, what type of benefit was sought differed in the criteria between classes from health benefits to fitness or skill levels. Compared to the co-educational and girls' schools, the boys' school noted competition or a challenge as a facilitator more often, which was reflected in their created criteria (Appendix 5).

After trialling the criteria with the HIIT workouts in the upskilling lesson, two of the five classes modified their evaluation sheets. Originally, the criteria form used a 5-point Likert scale. However, class A at school one determined it would be better to use a 10-point scale to further understand the variability within the feedback and make comparisons among the workouts. This class also added in an additional criterion, “I would do this HIIT workout again”, to inform if a successful HIIT workout had been created. Class D at school three initially only created 4 criteria. However, after trialling the HIIT workouts, they chose to add in a criterion focused on being able to complete the workout at an appropriate level of difficulty. Additionally, they expanded the criterion regarding the required benefits of the HIIT workout to include supporting their physical activity habits.

HIIT Workout Assessments

Among schools, there were minimal differences in the assessment of the various types of HIIT participated in or trialled in the upskilling lesson. Overall, students in four of five classes rated the relay HIIT workout as the most fun and social (Appendix 6). However, one class in the girls’ school rated the boxing workout as the most fun. Students in all five classes disagreed that the sprint-based workout was fun. However, the sprint-based workout had the highest proportion of “agrees” for a sense of accomplishment in both classes in the boys’ school.

Defining HIIT Parameters

The parameters of the HIIT workouts are displayed in Table11. Students who argued for a lower heart rate threshold (e.g., 80% of maximum heart rate) felt that it could be more enjoyable and easier to achieve for a greater number of students. They also stated that those who wished to push themselves to a higher heart rate would still have the opportunity as this was only a minimum threshold. Those that defended a higher threshold (e.g., 90% of maximum heart rate) maintained that it would be most suitable for benefits and would enable students to feel more accomplished.

Students that argued for longer work and rest interval maximum lengths reasoned that it didn’t negate the potential to use shorter intervals if they were preferred and they thought it would be wise to have more freedom for the interval lengths. They also argued that for certain exercises there might not be enough time to increase heart rate or to have an appropriate amount of rest after a hard exercise if the maximum interval length was too short. Those in favour of shorter intervals were predominately worried about becoming bored during certain exercises.

HIIT Workouts

Overall, the co-design teams created thirty-three HIIT workouts (Table 4). All the workouts followed a HIIT format with work and rest intervals that met the HIIT criteria. The percentage of time in work ranged from 50% to 75%. The themes of the workouts are listed in Table 4. Sport warm-ups and general fitness were prominent themes. All the workouts included aerobic components, and 25 included resistance components. The most common resistance exercises included push-ups, sit-ups, and squats. Thirteen workouts included partner exercises. The workouts at school one included music and equipment such as skipping ropes and soccer balls; however, based on feedback from teachers in school one, the use of music and equipment added additional time to complete the workouts during the intervention in the second phase of *Making a HIIT*. Accordingly, and based on consultation with the teachers in schools two and three, music and equipment were removed from these schools.

Based on feedback from the co-design team and heart rate data collected during the first pilot, modifications were made to the original HIIT workouts during the second iteration. Most groups changed their interval lengths to add or reduce rest; make it easier to lead /follow if intervals were on the minute. In school one, four of seven groups decided to change the order of their exercises to maintain a higher heart rate as they noticed different exercises produced a different heart rate response. In school two, no groups discussed changing the order of their exercises. Instead, to maintain intensity, three groups discussed adding a goal to the workout interval (e.g., a push-up every couple of seconds for the interval) to encourage their peers to maintain their effort. In school three, five groups changed some of the exercises in their workouts due to difficulty and to include more variety and partner activities to improve the workout's ability to satisfy the class criteria.

Table 11. HIIT workout characteristics.

School	Class	Team	Theme	Exercise Included			Time in Work
				Partner	Resistance	Aerobic	
One	A	1	Soccer	x		x	65%
One	A	2	Bedroom Workout		x	x	57%
One	A	3	General Fitness	x	x	x	65%
One	A	4	Core & Cardio	x	x	x	53%
One	A	5	Soccer			x	58%
One	A	6	Things Tom Likes	x		x	67%
One	A	7	Volleyball	x		x	68%
Two	B	1	Swimming/Rugby		x	x	67%
Two	B	2	Yard Workout		x	x	57%
Two	B	3	Muscle Burner		x	x	68%
Two	B	4	Football Warmup		x	x	63%
Two	B	5	Home Workout		x	x	62%
Two	B	6	Contact Sports	x	x	x	72%
Two	C	1	General Themed			x	75%
Two	C	2	At Home/Backyard		x	x	63%
Two	C	3	Rugby Themed	x		x	70%
Two	C	4	Volleyball			x	63%
Two	C	5	Team Workout	x	x	x	62%
Two	C	6	General Themed		x	x	72%
Two	C	7	AFL Themed			x	65%
Two	C	8	Send it!		x	x	50%
Three	D	1	Core & Fitness	x	x	x	67%
Three	D	2	Netball		x	x	67%
Three	D	3	Circuit	x	x	x	70%
Three	D	4	Athletics		x	x	57%
Three	D	5	80s Aerobics		x	x	75%
Three	D	6	Work with Friends	x	x	x	67%
Three	E	1	Random		x	x	70%
Three	E	2	Bedroom Workout	x	x	x	75%
Three	E	3	Core		x	x	65%
Three	E	4	Random		x	x	73%
Three	E	5	Everything	x	x	x	53%
Three	E	6	A challenge		x	x	50%

The co-designed high intensity interval training (HIIT) workouts by school, class, and team along with their theme, exercise styles, and the percentage of time each had in work intervals. An ‘x’ in the columns for partner, resistance or aerobic exercises indicates that the workout included at least one exercise in the category.

Feasibility and Impact of Co-Designing HIIT in the Curriculum

Feasibility

The thematic analysis guided the development of three themes and twelve codes and subcodes for the evaluation of lesson feasibility within the curriculum. Feasibility was deductively divided into three main areas based on literature from feasibility studies: 1) acceptability; 2) implementation; and 3) integration of the co-design process within the HPE lessons. The themes and codes are listed with example quotes in Table 12. Of the twelve codes, four were determined deductively based on the areas of focus for feasibility studies by *Bowen et al*. [210] and the other nine were determined inductively based on data.

Acceptability

Acceptability was defined as how the intended recipients reacted to the co-design process [210]. All five co-design teams (students and teachers) discussed their satisfaction with *Making a HIIT*. Overall, students enjoyed the opportunity to work in groups and found the nature of the co-design process provided them more freedom and ownership during HPE compared to normal lessons. They also communicated that the lessons enabled an inclusive environment where their opinions were valued. Students expressed that they found the lessons engaging. Similarly, teachers noted a high level of engagement from students, especially when using the heart rate monitors and during group activities where they had more freedom. They also expressed that the lesson content and classroom organisation was appropriate for the students and noted that students were almost always on-task and responsive to the tasks that they needed to complete.

Table 12. *Themes and codes on the feasibility of co-designing high-intensity interval training workouts in the curriculum.*

Theme Code	Participant Quotes
Acceptability	
Appropriateness	So based on time, it was everything that they could have had, and I think the testament to the whole thing is probably the actual results that we got. (School two, teacher) It all seemed logical and there wasn't there wasn't a point where the kids were confused about what to do. Your instructions are very clear. The scaffolded sheet with the example was really good. They always need that gradual release of responsibility and an example. (School three, teacher)
Satisfaction	
Autonomy and choice	The autonomy that they got from designing their own episodes or sessions made them more engaged because they're not being told what to do. They get to actually have some choice. (School three, teacher) Instead of being assigned, we get to decide what to do. (School three, student)
Inclusive	We all had ideas individually then [we] could discuss and decide on the most effective way, so [we] found this successful. (School one, student) Everyone designed equally, but maybe let every group come up with their own heart rate (HR) threshold then see what they are able to get and then decide on actual threshold. (School two, student)
Enjoyable and engaging	Theory had less writing and was very interactive; I liked it. (School one, student) Yeah, the heart rate monitors were excellent because I said to Steph, because I taught most of them last year, there's quite a few in that class who don't like PE and running. It's so good to see them sprinting across the court because they're looking at their heart rate. (School three, teacher)
Working with peers	More group work and collaboration time was fun and encourages you to engage more and exposes you to more ideas than you may think of individually. (School one, student) It was beneficial cause I couldn't have thought about the answer by myself. (School three, student)
Implementation	
Processes	I remember [the researcher] and I had a conversation, and [the researcher asked if I thought] we should put them in groups or let them choose their groups. And I think that was a big difference. I think if we'd placed them in groups, they may not have been receptive because not everyone friends and it may not have been as successful. (School three, teacher)

	Delivery by students was too difficult. Maybe [in future] they demo, but it is led by the teacher. (School one, teacher)
Facilitators of Implementation	The initial barriers and facilitators activity with the sticky notes was just a nice different way of doing the session. You could have just literally got them to write it down and it would have been a lot different but getting up and grouping it was engaging and I think that was kind of a hook to begin with, like this is how it's going to go. If it was you just talking, it would have been very different, so that was good. (School three, teacher) My favourite things about this was the heart rate monitors. (School three, student)
Challenges	Sometimes confusing because most have different ideas and want different things. We had to agree so picked something that we all wanted to do. (School three, student) What was harder for us I guess was we had the one with where we jammed a few things in and the main one of them evaluating each other HIITs, we had like 15 minutes less because of the house choir day. It would have been better if they were able to do a few more of each other's, but I think they did embrace it, definitely. (School two, teacher)
Integration	
Perceived fit in the curriculum	We're across the middle school from Years 7 to 9 so there's obviously so many different descriptors we hit. There's a couple of those that have health benefits. (School two, teacher) I think it was a bit hard this term, like our girls were doing softball and then this, but they've done a health and fitness unit last year for year seven, so it's really complementing that because we've done some different workouts and different things, whether they remember them or not. So, it really complements that, but it's really helpful for them to use in lessons just for fitness because there is a lack of fitness. (School three, teacher)
Perceived sustainability	I would use some or all of [the workouts] because they got my heart rate up and were beneficial. (School one, student) [I would continue to use] the barriers and facilitators, figuring out why young people don't like to exercise or what motivates them to, because if we can get past that, then that's a good starting point. (School three, teacher)
Future suggestions	Maybe not 10 minutes, maybe 5 minutes and they repeat. Students struggled to find that many exercises for a theme and forget that they can repeat. (School one, teacher) Maybe more encouragement and use music during our HIIT workout to hype up students. (School three, student)

Themes and codes generated from semi-structured interviews with teachers, discussion groups with students, and student surveys, related to the co-design of HIIT workouts within the HPE curriculum. This table only includes two illustrative participant quotes per code, thereby providing a summary of the full dataset. School and participant information have been included in round brackets. When necessary, the subject of a sentence has been added in square brackets or tense corrected.

Implementation

Implementation was defined as the extent to which the co-design lessons were implemented as planned [210]. Certain aspects of the lessons were noted by teachers to facilitate the implementation of the co-design process, such as: 1) the sticky notes and active group work that were used to understand students' barriers and facilitators to exercise; 2) the heart rate monitors for encouraging high intensity while performing the workouts; and 3) the booklet of exercises, which allowed students to have a base for creating their workouts. Students unanimously expressed that they enjoyed seeing their heart rate projected in the gymnasium. They communicated that the researcher delivering the lessons was friendly and they liked working with her, which teachers attributed towards the commitment that students demonstrated towards the co-design process. Both the students and teachers noted similar challenges within the lessons stemming from disagreements within the groups and learning to collaborate and discuss differences of opinion. Teachers also expressed challenges related to time constraints. These were due to both external demands that resulted in less time dedicated to the co-design process than expected and due to the amount of material in some lesson, especially with attempting to pilot all the HIIT workouts. The teachers' suggestions regarding how to address perceived challenges are listed below under *Integration*. Finally, teachers discussed the general process of the implementation in their specific class. Pending the class dynamics, teachers either gave the students more freedom and responsibility when choosing their groups and piloting the workouts or provided more guidance. They explained that making some decisions without the entire co-design team (e.g., without student input) enabled smoother implementation due to classroom dynamics and time constraints in the lessons.

Integration

Integration was defined as the extent the co-design process was integrated within the existing curricula and school units [210]. Overall, teachers expressed that the lessons aligned with the Australian HPE curriculum for Years 7 and 8. However, they also noted that the lessons could fit with the curriculum of more senior years where students are tasked with designing fitness programs. All five teachers stated that there were parts of the lessons that they intended to use again, including the sticky notes and heart rate monitors, with one school investigating the use of the Polar GoFit software for other units. Teachers also provided recommendations for the co-design process in future schools, such as shortening the length of the co-designed workout from 10 minutes to 5 minutes and adding additional scaffolding to the first iteration of the HIIT workout design due to time constraints. Some students stated that they intended to continue using the workouts that they created, while others said they preferred team sports or workouts based on repetitions instead of timed intervals and would likely not use the workouts moving forward. Students from schools two and three, who did not have the opportunity to use music for their HIIT workouts, recommended its use to increase motivation.

Impact

Impact was defined as the significance, usefulness, or benefit of the co-design process [211]. Three themes (*Perceived changes to lessons*; *educative outcomes*; and *personal and social capabilities*) and three codes were identified in the data related to impact (Table 13). Students and teachers perceived changes in the lessons compared to normal HPE lessons with additional interaction and active participation involved in the co-design process. The lessons also supported educative outcomes related to the HPE curriculum. Students expressed that they had gained knowledge related to HIIT and the health benefits associated with both HIIT and exercise in general. Further, students expressed that they learned about their barriers and facilitators toward exercise and how to motivate themselves to work harder than they would normally. Lastly, teachers and students both acknowledged that students improved their social and personal capabilities in line with the curriculum through improved confidence, compromise, collaboration, and team management skills.

Table 13. *Themes and codes on the impact of co-designing high-intensity interval training workouts in the curriculum.*

Theme Code	**Participant Quotes**
Educative outcomes	
Health benefits of HIIT	We learned what a HIIT workout was and the health benefits of HIIT. We learned about the factors that influence fitness and the types of fitness. (School one, student) I learnt that exercise is important for your health and don't be afraid to challenge yourself. (School three, student)
HIIT specific knowledge	I learnt how to reach a high intensity in a short amount of time; I learnt what HIIT is and what it is about. (School one, student) I mean before [Steph] did that theory lesson, they had no idea what high intensity was. Where you did that activity - stand here, here or here with the intensity – and that's their curriculum correlation. They've never known that. (School two, teacher)
Student barriers and facilitators to exercise	I learnt that you can push yourself further than you thought. You actually feel good after workout. (School three, student) My favourite part was the sticky notes. Seeing people didn't work out for the same reasons. (School three, student)
Perceived changes to lessons	
	An activity like this or this kind of session allows them to have that autonomy; participation; they can learn from each other. It's just different to what we're typically used. (School three, teacher) [We] created our own instead of mindlessly going with what the teacher says. (School three, student)
Personal and Social Capabilities	
	Expanding my social skills when co-creating HIIT exercises. (School one, student) They learn a lot of like management skills and like how to cooperate with each other and that not every person's opinion is going to be used. (School three, teacher)

Themes and codes generated from semi-structured interviews with teachers, discussion groups with students, and student surveys, related to the co-design of HIIT workouts within the HPE curriculum. This table only includes two illustrative participant quotes per code, thereby providing a summary of the full dataset. School and participant information have been included in round brackets. When necessary, the subject of a sentence has been added in square brackets or tense corrected.

Discussion

The co-design process within *Making a HIIT* was documented in detail in this paper to provide a comprehensive and transparent understanding of how the lessons integrated within the HPE curriculum and its potential to be used within schools in a meaningful manner. The process led to the successful creation of 33 HIIT workouts within the three participating schools, demonstrating that students aged 12 – 14 years are capable of understanding the interaction between intensity and interval duration and applying it to design a HIIT workout targeted at satisfying agreed upon HIIT parameters and evaluation criteria. The co-designed workouts contained a variety of exercises and a range of work-to-rest intervals. They included greater variation than standardised running protocols, which are the most commonly used in this setting [155]. The increased variety and student ownership could have a positive influence on students' engagement with the workouts moving forward [158].

Overall, in this study, co-designing HIIT workouts with students and teachers was perceived to be feasible within the HPE curriculum. Previous literature involving children and varying levels of co-design participation corroborates the feasibility of this type of work. For example, school-aged children have previously been involved in the design of healthy dairy products [212], the design of school buildings [213], new technology [214], and the curriculum [150]. Further, the thematic analysis identified that both students and teachers were largely satisfied with the *Making a HIIT* co-design process. Similarly, a recent study that incorporated HIIT in two schools in New Zealand included teacher input on curriculum connections for HIIT and was well-received by teachers and appeared to enhance the buy-in of the HIIT intervention [215]. In *Making a HIIT*, teachers occasionally determined that certain decisions needed to be made without student input in the interest of time. For example, student groups at school one was able to use equipment (e.g., skipping ropes, balls) and music during their HIIT workouts and students noted that they enjoyed these aspects of the workouts. However, based on teacher feedback from the implementation of the intervention in this school, these options were removed for future schools. Similarly, there were differences between student and teacher opinion on the formation of the small groups that were used in the co-design process. Students almost unanimously preferred to choose their own groups; however, on two occasions teachers determined that due to student dynamics it would be necessary for them to have additional influence on the group creation. The class dynamics and lesson time constraints also influenced how much freedom teachers were willing to provide students for piloting the HIIT workouts. Even though these areas that afforded student autonomy were removed based on teacher discretion and constrained the co-design task to narrower boundaries, students still noted that the co-design process included more active participation, freedom, and choice compared to their standard HPE lessons. Future studies considering similar implementation within lessons need to consider the adaptability of the lessons to meet different teacher preferences and class dynamics. The expertise of the teachers as a member of the co-design team was vital throughout the process due to their relationship with the students and should not be overlooked. Their knowledge of the class dynamics, lesson structure, and school structure assisted in the design of workouts with the potential for successful implementation and sustainability in their specific school.

Students and teachers identified that the lessons provided the intended educative outcomes related to the HPE curriculum, but additionally provided outcomes related to the development of students' personal and social capabilities, which is part of the general capabilities targeted in the curriculum [49]. The personal and social capabilities are characterised by development in both self and social management and include sub-elements such as confidence and adaptability; appreciation of diverse perspectives; working collaboratively; resolving conflict; and developing leadership skills. These additional outcomes, which are afforded by the increased student ownership and autonomy in co-design, expand the potential opportunities for co-design in schools beyond HPE by contributing to broader curriculum aims. Another outcome of the co-design process was that students expressed that they had a greater appreciation of how to create enjoyable and motivational workouts that they would continue to use beyond the scope of the lessons. Further, they shared that they gained an understanding that not all students had the same point of view on what constituted an enjoyable workout. Together, it can be argued that these outcomes contributed to improved physical literacy of the participating students. Physical literacy includes four elements: 1) the affective domain (e.g., motivation and confidence); 2) the physical domain (e.g., fundamental motor skills); 3) the cognitive domain (e.g., knowledge and understanding); and 4) the behavioural domain (e.g., lifelong engagement in physical activities), which were all identifiable in the co-design process [216]. Improving students' physical literacy is noted by Sports Australia in the Australian Physical Literacy Framework to be important for positive lifelong physical activity behaviours, which is an encouraging outcome beyond the successful co-design of HIIT workouts [216].

Strengths and Limitations

This is the first study to embed the design of HIIT workouts within the curriculum in collaboration with teachers and students in an attempt to mitigate some of the typical challenges experienced in school-based research, such as the overburdening of teachers and curricular demands [10]. The co-design process has the potential to increase the sustainability of HIIT workouts through the creation of more engaging workouts for teachers and students [158]. However, due to the heavy involvement of a researcher, wider dissemination of this work would require modifications. This could include developing professional training on HIIT and the process of co-design for teachers, and resources that teachers could use to lead the design of HIIT workouts with students. While integrating *Making a HIIT* within the curriculum afforded important outcomes, several aspects of student ownership could not be completed as initially planned by the research team due to time and space restrictions (e.g., students adding music to workouts, using various pieces of equipment, or choosing the location for the HIIT workouts). These elements could be incorporated in future interventions depending on time availability and the context of the co-design as it is adapted for varying schools. However, even without these elements, students still noted opportunities for active participation, choice, freedom, and sharing of their ideas. Due to the amount of time allotted to the process and the size of participating classes, the feedback captured from the co-design team could not always be as detailed as desired. However, having data from both students and teachers provided a strong overarching evaluation of the process. Further, as the lead author was involved in the co-design process, we must acknowledge that we have subjective biases within the interpretation of these results. However, this involvement with the co-design process and interviews also enabled a more nuanced commentary on the findings. Further, the inclusion of multiple authors in the qualitative data analysis ensured that the views were discussed and agreed upon by all participating authors. While this study was conducted in Queensland, Australia using the relevant HPE curriculum content descriptions, most HPE curricula include similar elements and standards for general fitness units. Therefore, with appropriate modifications, this type of co-design could be integrated in HPE curricula elsewhere in Australia or globally.

Conclusions and Future Directions

Co-designing HIIT workouts with students and teachers resulted in the successful creation of HIIT workouts that were aligned with set HIIT parameters and the developed criteria for engaging workouts. The process was found to be feasible within HPE lessons and contributed positively to students' educative outcomes. It also provided students with additional autonomy and choice compared to normal HPE lessons. Future studies focused on HIIT interventions in schools should consider the use of co-design or a similar process to understand the integration and maintenance of HIIT programming within the school context. As each school is unique, recent recommendations suggest using a context-specific approach when implementing and scaling interventions, where certain intervention components are essential, while others are modifiable [217]. In the context of *Making a HIIT*, an essential component could be providing teachers with the lesson plans that could be integrated either in full or part within the curriculum for HIIT workout design, while affording students additional autonomy and choice in their lessons. The next phase of *Making a HIIT* will examine the effect of co-design on students' motivation, enjoyment, and self-efficacy towards the HIIT workouts when used in an intervention.

Chapter 5: Process Evaluation of *Making a HIIT*

Justification of chapter within the thesis

Chapter One and *Chapter Two* of this thesis identified that literature on school-based high-intensity interval training (HIIT) rarely reports whether interventions were implemented as intended. This is essential for interpreting results and so that future work can continue to enhance interventions with the aims of maintenance and scalability. This chapter evaluates the implementation of the intervention within phase two of *Making a HIIT*. This will be used as a lens to interpret our findings on the impact of HIIT on cardiorespiratory fitness, muscular power, and executive functioning in *Chapter Eight*. Further, as *Making a HIIT* was implemented during HPE lessons and led by HPE teachers, documenting the implementation of the intervention will be useful for future work in this area by providing insight into which components were successfully implemented and which components could be improved.

Was it a HIIT? A process evaluation of *Making a HIIT*: A school-based high-intensity interval training program

Abstract

Background: Research investigating school-based high-intensity interval training (HIIT) interventions is increasing. However, there are limited evaluations of their implementation, which are important for appropriately interpreting outcome findings and augmenting intervention design. This manuscript aims to evaluate the implementation of *Making a HIIT*, a school-based HIIT intervention.

Methods: The *Making a HIIT* intervention spanned 8 weeks and was completed at three schools. Ten classes (intervention group) completed 10-minute teacher-led HIIT workouts at the beginning of health and physical education (HPE) lessons. Five classes (control group) continued with normal HPE lessons. The eight dimensions of the Framework for Effective Implementation by Durlak and DuPre were used for the evaluation.

Results: *Program reach*: Ten schools were contacted to successfully recruit three schools, from which 79% of eligible students (*n* = 308, $\bar{x}$ age: 13.0 ± 0.6 years, 148 girls) provided consent. *Dosage*: The average number of HIIT workouts provided was 10 ± 3 and the average number attended by students was 6 ± 2. *Fidelity*: During HIIT workouts, the percentage of time students spent at ≥ 80% of HRmax was 55% (interquartile range (IQR): 29% - 76%). *Monitoring of the control group*: During lessons, the intervention and control groups spent 32% (IQR: 12% - 54%) and 28% (IQR: 13% - 46%) of their HPE lesson at ≥ 80% of HRmax, respectively. *Responsiveness*: On average, students rated their enjoyment of HIIT workouts as 3.3 ± 1.1 (neutral) on a 5-point scale. *Quality*: Teachers found the HIIT workouts simple to implement but provided insights into the time implications of integrating them into their lessons; elements that helped facilitate their implementation; and their use within the classroom. *Differentiation*: *Making a HIIT* involved students and teachers in the co-design of HIIT workouts. *Adaption*: Modifications were made to the workouts due to location and weather; the complexity of exercises; and time constraints.

Conclusion: The comprehensive mixed methods evaluation of *Making a HIIT* provides important insights into the implementation of school-based HIIT, including positive findings for student enjoyment and fidelity and recommendations for improving dosage that should be considered when developing future interventions.

Introduction

Schools offer a unique opportunity for physical activity interventions due to their ability to reach a large proportion of children and adolescents, their existing infrastructure, and staff who can be trained to help implement such interventions [10, 218]. However, schools also present notable challenges, including time constraints and curriculum requirements, which need to be considered when planning interventions [10, 18]. School-based research commands the literature on adolescent physical activity, although contemporary reviews indicate school-based interventions have had minimal success at increasing physical activity levels [15, 218] and some success at improving cardiorespiratory fitness and cognition, with considerable heterogeneity within relevant findings [219-221].

A major influencing factor for the success of school-based physical activity interventions is implementation [218], which is the process of integrating an intervention within a particular setting [222]. Implementation can be monitored using process evaluations [17], which provide insights into why and how an intervention succeeds (or fails) to accomplish its intended outcomes [223]. A highly used evaluation framework within physical activity literature is Durlak and DuPre's Framework for Effective Implementation, which includes eight dimensions derived from a comprehensive and rigorous review of over 500 health promotion interventions for children and adolescents[161, 224]. A systematic review applying this framework to school-based physical activity interventions noted that most often school and teacher level implementation was assessed solely on dose received by students [17]. Consequently, the authors called for comprehensive intervention evaluations that include other factors crucial for successful implementation, such as intervention quality and fidelity [17]. Currently, real-world implementation of school-based physical activity interventions has been limited, with available results indicating poorer effectiveness of these studies compared to efficacy trials [18]. Comprehensive process evaluations can help understand discrepancies between efficacy and effectiveness trials, contributing to the enhancement of implementation, adoption, and sustainability of school-based physical activity interventions [18].

High intensity interval training (HIIT) is gaining popularity as an intervention technique in school-based physical activity research. This can be attributed to its similarity to children's intermittent patterns of physical activity and research associating higher intensity activities with decreases in cardiometabolic risk [28, 30]. Literature on school-based HIIT interventions has demonstrated positive outcomes for cardiorespiratory fitness, body composition, and blood biomarkers [20, 155, 225]. However, high levels of heterogeneity have been noted in assessed outcomes and there has been a paucity of information related to process outcomes [155]. A recent review on scaling HIIT programs for adolescents highlighted that designing these interventions based on implementation frameworks is critical for their success and called for research investigating their feasibility and acceptability [226].

The *Making a HIIT* study is a real-world school-based HIIT intervention adapted for implementation at three separate schools using HIIT workouts co-designed at each school [207]. Teachers led the intervention within Year 7 and 8 health and physical education (HPE) lessons and adapted the intervention to fit the school and class context [207]. The aim of this paper was to comprehensively evaluate the implementation of the *Making a HIIT* study using the Framework for Effective Implementation [161].

Methods

The *Making a HIIT* study has previously been described in detail in *Chapter Three* [207]. An overview of the study is provided below to contextualise the findings.

Recruitment

Schools in Greater Brisbane were invited to participate in *Making a HIIT* through purposeful sampling, with the aim of recruiting three schools. Years 7 and 8 (students aged 12 – 14 years) were identified as preferred years for the study as they included relevant HPE curriculum content descriptions, including designing fitness plans and modifying systems to increase enjoyment and success [49]. Participating classes were decided collaboratively by the head of HPE department, individual teachers, and researchers. Students in participating classes were excluded if they had any medical condition or injury that prevented them from participating in HIIT or if they were unable to complete the study measures. The first school recruited served as a pilot school and only half the number of classes were recruited in this school.

The study was approved by the University of Queensland's human research ethics committee (Project: 2020/HE002444). Informed consent was collected from school gatekeepers (principals) and teachers. Informed assent and consent were obtained from students and their parents / guardians, respectively.

Intervention

The *Making a HIIT* study consisted of two phases [207]. In phase one, students co-designed HIIT workouts with their class, teacher, and a researcher as part of their HPE curriculum through an iterative process. The process and the results of this phase were discussed in detail in *Chapter Four*.

In phase two, which employed a quasi-experimental design, co-designed HIIT workouts were used in an intervention. Recruited classes were assigned to one of three groups: 1) co-design group, who co-designed the HIIT workouts and subsequently used them in HPE for a term; 2) HIIT only group, who used the HIIT workouts in HPE for a term but were not involved in the co-design process; and 3) control group, who continued with normal HPE lessons. The intervention spanned 8-weeks of the 10-week term. During the 8-weeks, classes in Group 1 and Group 2 completed a teacher-led 10-minute HIIT workout at the start of their HPE lessons before continuing their lesson as normal. Schools one and three completed HIIT workouts in both theory and practical lessons, while school two only used HIIT workouts in practical lessons. Theory lessons were completed in a classroom setting, while practical lessons were completed on courts, in halls, or on fields. Students were encouraged to provide maximal effort during the 'work' periods of HIIT workouts by both the teacher and researcher. Students in Group 3 continued with regular HPE lessons. A researcher was present during the practical lessons for all three groups to administer heart rate monitors.

Theoretical Basis

Making a HIIT was guided by two theories: the theory of expanded, extended, and enhanced opportunities and self-determination theory [57-59]. It aimed to enhance HPE lessons by introducing curriculum content that targeted high-intensity physical activity and implementing co-design to potentially enhance student engagement. Further, it included components to support students' basic psychological needs (autonomy, competence, and relatedness), such as the co-design process, exercise modifications, and partner and group workouts.

Measures Collected

To evaluate the implementation of phase two *Making a HIIT*, we collected data aligned with the eight dimensions from the Framework for Effective Implementation [161] as described below.

Program Reach. Information was recorded about the number of (a) schools contacted until three (one co-educational school, one all-boys school, one all-girls school) were successfully recruited, (b) students who received information about the study, and (c) students who consented to participate.

Dosage. The researcher and participating teachers recorded information about the number of sessions delivered and number of sessions attended by students.

Fidelity. Heart rate data were collected using a heart rate monitor (Polar H10, Polar Electro, Finland) and Polar GoFit software (https://polargofit.com/) during the HIIT workouts in practical lessons for

Groups 1 and 2. Extracted data included students' average and peak heart rates, and time spent in various deciles of maximum heart rate (e.g., 50-59%, 60-69%, 70-79%, 80-89%, and 90% - 100%). Students' maximum heart rate had previously been determined during a 20 m shuttle run test at baseline. Additionally, students completed the omnibus (OMNI) Scale of Perceived Exertion immediately after each HIIT workout (0 [not tired at all], 10 [very, very tired]) in both practical and theory lessons to provide a sessional rating of perceived exertion (RPE) [198]. This measure has been validated against heart rate during continuous, resistance, and ramp exercise, and is frequently used in studies with children and adolescents [198, 227-229]. In our study, the correlation coefficient between the two measurements in practical lessons was 0.39 (*Chapter Six*).

Monitoring of the control group. For Groups 1 and 2, heart rate data during the remainder of the HPE lesson was collected using the same methods detailed above in *fidelity*. For Group 3, heart rate data were recorded for the entire HPE lesson. The researcher recorded the theme of each class's HPE unit for the term, and the activities completed during the practical lessons in a field note diary.

Quality of implementation. A semi-structured interview with each teacher was completed at the end of the intervention to discuss implementation (see Supplement 1 for question guide used). Interviews were led by the researcher involved in the co-design process in conjunction with another researcher. Comprehensive notes were taken during all interviews. Additionally, in school three, interviews were audio recorded and subsequently transcribed. *Quality of workouts.* The heart rate and RPE data described above in the *fidelity* section were used to assess the quality of the workouts. The variation between the HIIT workouts used in practical lessons was examined using both heart rate and RPE data, and the variation between the HIIT workouts used during theory lessons was examined using RPE data.

Responsiveness. To assess enjoyment, students responded to "I enjoyed participating in today's HIIT session" on a 5-point Likert scale ranging from strongly disagree (1) to strongly agree (5) immediately after each workout. A similar question has been used in previous school-based HIIT work to understand student satisfaction [47]. To assess positive and negative affect during HIIT, students in schools two and three completed two scales [196] after the first and last HIIT workouts completed. The positive affect scale included 5 items (proud; satisfied; happy; excited; and relaxed), and the negative affect scale included 4 items (unhappy; nervous; guilty; and angry). Students were asked to rate each item on a 5-point Likert scale from not at all (1) to extremely (5) using the prompt "During this HIIT workout, I felt...". These scales have previously been used to assess positive and negative affect toward sport in children aged 8 – 13 years with reliability coefficients of 0.75 and 0.78, respectively [196]. Finally, responsiveness was also informed by the semi-structured interviews described above in the *quality of implementation* section.

Differentiation. No data were collected during the intervention for the differentiation dimension. The uniqueness of the study was determined during the design of *Making a HIIT* [207] based on a systematic review and meta-analysis on school-based HIIT conducted by the authors [155].

Adaption. The researcher kept a field note diary documenting any modifications made to the HIIT workouts by teachers or to the intended HIIT workout schedule, accompanied by information about the reasons for the modifications.

Data Analysis

Quantitative data were collected for *program reach, dosage, fidelity, quality, responsiveness,* and *monitoring of the control group*. Data were analysed using R (Version 3.6.2; The R Foundation for Statistical Computing, Vienna, Austria) with alpha set to 0.05. Data were assessed for normality using a Shapiro-wilk test and descriptive statistics were reported. Data from all three schools were combined for reporting the results unless a more nuanced presentation was warranted.

Qualitative data were collected for *quality* and *responsiveness*. A thematic analysis was conducted using the transcripts and sets of notes collected during interviews [163, 209]. All recorded interviews were transcribed verbatim within three days of completion by the first author to increase familiarity with the data. The interview notes were digitised within a week of completing the interviews. Any personal or identifiable information was deleted prior to analysis. After familiarisation with the data, a deductive approach, which focused on the semantic (explicit) meaning of the text was used to create codes related to the three relevant dimensions by two authors using NVivo (Version R1) [163]. The first author developed the themes based on the codes and all authors reviewed and refined the themes until consensus was reached.

Results

Three schools from varied backgrounds (co-educational government school; all-girls non-government school; all-boys non-government school) participated in *Making a HIIT* (Table 14). In total, 8 teachers (75% female) and 10 classes (222 students; 46% female) participated in the intervention. The control group included 3 teachers (33% female) and 5 classes (86 students; 52% female). The findings of this study are summarised in Table 15 and extended below according to the eight dimensions of the Framework for Effective Implementation.

Table 14. *School and class characteristics.*

School	School Type	Students	ICSEA percentile*	Background Language Other than English*	Class	Group	Year Level	Average Age (years)	Number of students (% female)
One	State	Co-educational	41%	42%	A	Co-Design	8	13.3 ± 0.3	25 students (44%)
					B	HIIT Only	8	13.3 ± 0.3	12 students (50%)
					C	Control	8	13.2 ± 0.4	12 students (50%)
Two	Independent	Boys Only	87%	24%	D	Co-Design	7	12.6 ± 0.3	25 students (0%)
					E	Co-Design	7	12.5 ± 0.3	24 students (0%)
					F	HIIT Only	8	13.6 ± 0.4	26 students (0%)
					G	HIIT Only	8	13.7 ± 0.3	24 students (0%)
					H	Control	8	13.5 ± 0.2	13 students (0%)
					I	Control	8	13.5 ± 0.4	22 students (0%)
Three	Catholic Education	Girls Only	65%	5%	J	Co-Design	8	13.3 ± 0.3	23 students (100%)
					K	Co-Design	8	13.4 ± 0.3	25 students (100%)
					L	HIIT Only	7	12.4 ± 0.3	20 students (100%)
					M	HIIT Only	7	12.5 ± 0.3	18 students (100%)
					N	Control	7	12.4 ± 0.5	21 students (100%)
					O	Control	7	12.3 ± 0.4	18 students (100%)

*The values presented in the school information columns were acquired from myschool.edu.au and are based on 2021/2022 data. ICSEA = Index of Community Socio-Educational Advantage, which is generated based on family background data that is highly correlated with student performance.

***Table 15**. Summary of eight dimensions included in Durlak and DuPre's Framework for Effective Implementation and their indicators within the Making a HIIT study*

Dimension	Definition	Indicator	Result
Program Reach	The rate of involvement and representativeness of participants	Number of schools contacted to recruit three	10
		Number of consenting students	308 / 388 (79%)
Dosage	The amount of the program that was delivered	Number of sessions provided by teachers (Theory and practical lessons combined)	School one: 14 ± 3; School two: 9 ± 2; School three: 8 ± 1
	The amount of the program that was received	Number of sessions attended by students (Theory and practical lessons combined)	School one: 12 ± 3; School two: 6 ± 2; School three: 6 ± 2
Fidelity	The extent to which the intervention was completed as intended	Average heart rate	161 ± 16 bpm (79% ± 8% of HR_{max})
		Peak heart rate	188 ± 13 bpm (92% ± 6% of HR_{max})
		Percent of Time Above 80% of HR_{max}	55% (IQR: 29% - 76%)
		Percent of Students with average heart rate above 80% of HR_{max}	51% (IQR: 31% - 67%)
		Average RPE	In practical sessions: 6 ± 2 In theory sessions: 4 ± 2
Monitoring of control group	Describing the nature and the amount of high-intensity exercise received by this group	Percent of Time Above 80% of HR_{max}	Intervention group during lessons: 32% (IQR: 12% - 54%) Control group during lessons: 28% (IQR: 13% - 46%)
Quality	How well different program components were conducted	Average heart rate	Intervention group during lessons: 75% ± 8% of HR_{max} Control group during lessons: 73% ± 8% of HR_{max}
		RPE during workouts	In practical sessions: 6 ± 2 In theory sessions: 4 ± 0.5*
		Implementation of workouts	Four themes identified: 1) scheduling and time implications of the workouts; 2) facilitation of the workouts; and 3) use of the HIIT workouts within the classroom
Responsiveness	The degree to which the program stimulates the interest or holds the attention of participants	Student enjoyment	3.3 ± 1.1 out of 5 (Neutral rating)
		Student affect	Positive affect: 3.0 (IQR: 2.2 – 3.6) Negative affect: 1.5 (IQR: 1.0 – 2.0)
		Student engagement	Two themes identified: 1) engagement over time and 2) elements affecting engagement

		Teacher intent to continue using HIIT	Two themes identified: 1) how they might implement HIIT in the future and 2) curriculum integration
Differentiation	Th extent to which a program's theories and practices can be distinguished from other programs	Uniqueness of the study	Involvement of end-users through: 1)co-designed HIIT workouts; and 2) teacher input into dosage of HIIT delivered Educative outcomes achieved by students through the study
Adaption	Changes made in the original program during implementation	Intervention modifications by teachers	Sessions missed due to schedule changes (assemblies, assessments, holidays)
			Changes due to availability and quality of space for workouts
		Workout modifications by teachers	Equipment removed due to time required to set up (skipping ropes, soccer balls) Simplification of workouts (group exercises removed due to time required to form teams; short intervals combined)

A summary table of the eight dimensions and their definitions from the framework by Durlak and DuPre [161]. The indicators and results from the *Making a HIIT* study are presented for each dimension. Further detail for each outcome is provided in text and figures.
Quantitative data was reported as frequencies, mean ± standard deviation, or median (interquartile range) based on normality of the data.
* Provided to one decimal place to indicate the existence of variation within the data
HR = heart rate; HR_{max} = maximum heart rate, IQR = interquartile range; RPE = rating of perceived exertion

Program Reach. During recruitment, seven schools declined to participate, one co-educational school and six all-girls schools. Reasons for not participating included no one to champion the project, reluctance to alter scheduled HPE units, or hesitancy to measure body weight. The overall student consent rate was 79% but differed across schools (65% in school one; 84% in school two; 81% in school three). The consent rates for students in Group 1 (co-design), Group 2 (HIIT only), and Group 3 (control) were 94%, 78%, and 65%, respectively.

Dosage – HIIT workouts provided. The agreed upon dosage varied across schools due to curricular demands and perceived ability to perform HIIT within the classroom (Figure 5). In three of the ten classes, teachers did not provide the agreed upon dosage of HIIT; however, in another three classes the dosage provided was greater than agreed. *Dosage – HIIT workouts attended.* The number of workouts attended by students also varied (Figure 6). The number of students who attended all the HIIT workouts ranged between 11% and 13% across schools. The percentage of students who attended 80% or more of the workouts provided was 83%, 46%, and 36% in schools one, two, and three, respectively. The main reasons for missing HIIT workouts were: 1) policies that required specific uniforms for participation in HPE and 2) policies requiring students to finish assignments prior to partaking in practical HPE lessons.

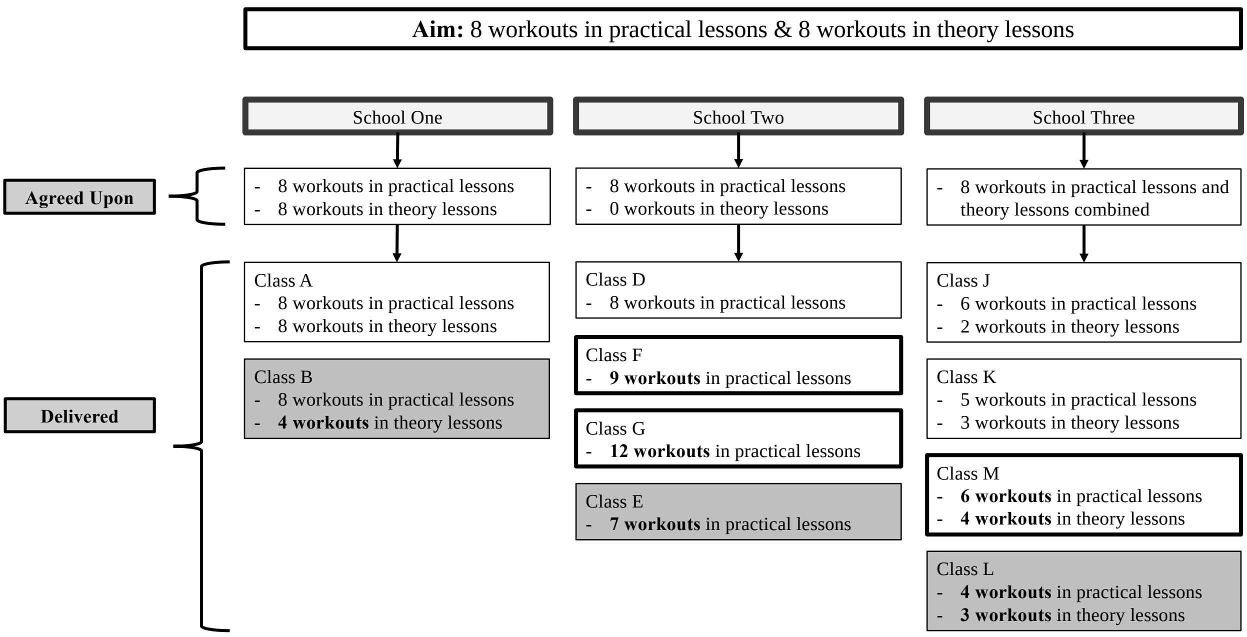


Figure 5. *The dosage of HIIT delivered at each of the schools in Making a HIIT.*

The intended dosage of HIIT for *Making a HIIT*, the dosage of HIIT each school agreed to provide, and the actual dosage provided in each class that participated within the study.

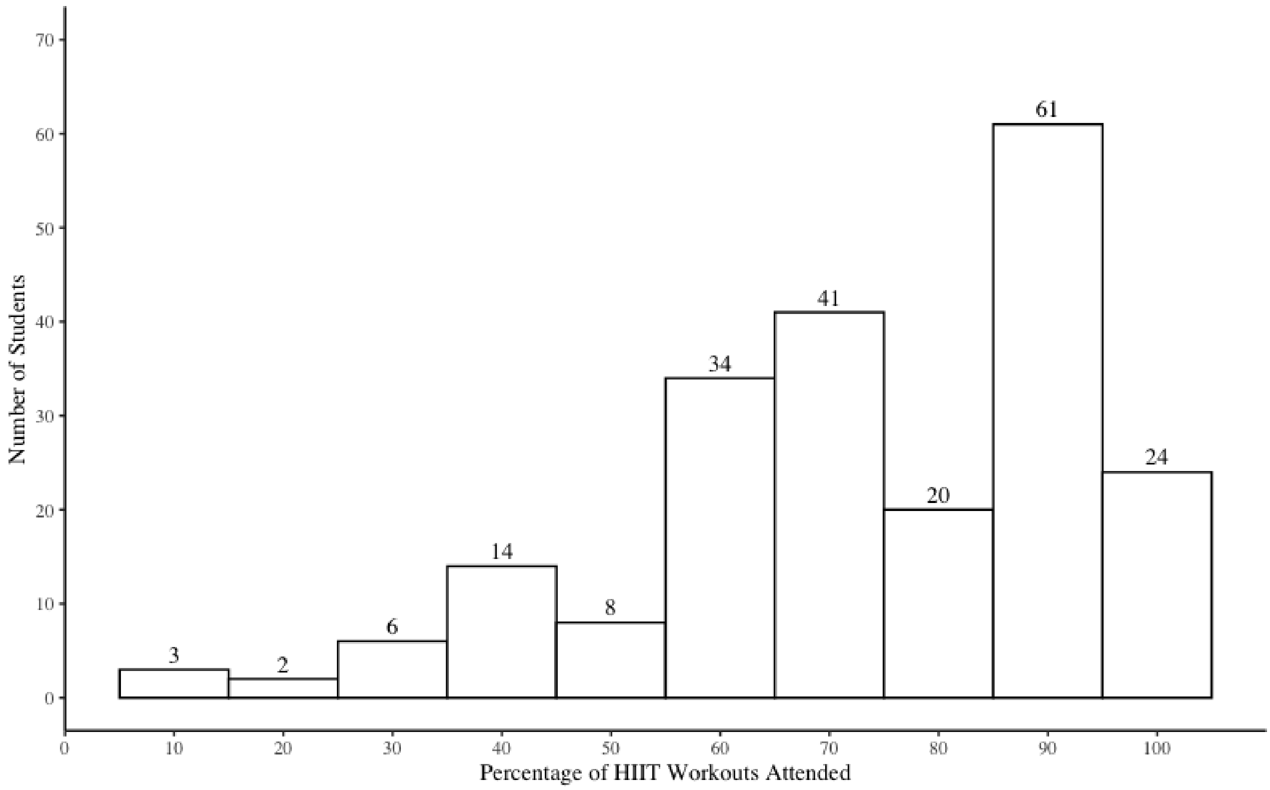


Figure 6. *The number of sessions attended by students.*

A histogram of the number of workouts that each student attended during the *Making a HIIT* intervention. HIIT = high-intensity interval training.

Fidelity. The fidelity of the *Making a HIIT* intervention is discussed in detail in *Chapter Six*. During HIIT workouts in practical lessons, the mean average heart rate was 79% ± 8% and the mean peak heart rate was 92% ± 6% of student's maximum heart rates. On average across the workouts, 51% of students in a class had an average heart rate equal to or greater than 80% of their maximum and spent 55% (IQR: 29% – 76%) of time with an average heart rate equal or above 80% of their maximum heart rate. The average sessional RPE for the HIIT workouts during practical sessions was 6 ± 2, whereas in theory sessions it was 4 ± 2.

Monitoring of the control group. The HPE units completed by participating classes during the intervention varied between schools and year levels. In school one, all three classes of students were completing an "invasion games" unit predominately related to basketball and rugby drills, and small games. In school two, all classes were completing a unit on Australian touch football. In school three, the year seven classes (Group 2 and Group 3) were completing an athletics unit, whilst the year eight classes (Group 1) were completing a unit called "strikes and swings" that included games such as dodgeball, horseshoes, and frisbee golf.

The average HR during lessons for the control group across all three schools was 73% ± 8%, with 28% (IQR: 13% – 46%) of time spent with an average HR equal or above 80% HR_{max}. For the intervention group (Group 1 and 2), the average HR for the remainder of the lesson post HIIT was 75% ± 8%, with 32% (IQR: 12% – 54%) of time spent with an average HR equal or above 80% HR_{max}. These data are contrasted to the intervention group HR data during their HIIT workout in Figure 7. Overall, the intervention group spent 9 minutes (IQR: 5 – 15 minutes) with a HR equal or above 80% HR_{max} compared to 6 minutes (IQR: 3 – 9 minutes) in the control group during practical lessons. The length of lessons in school one, two, and three were 70 minutes, 50 minutes, and 60 minutes, respectively. The minutes with a HR equal or above 80% HR_{max} for the intervention group were 12, 9, and 8 in schools one, two, and three, respectively compared to 8, 6, and 4 minutes in the control groups at the three schools.

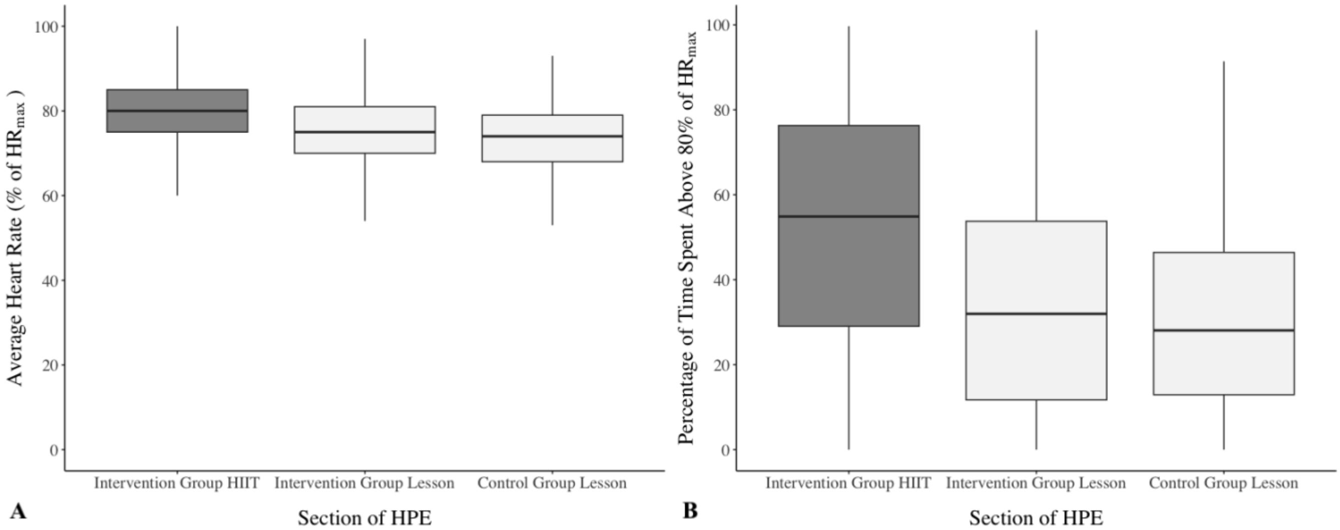


Figure 7. *The heart rate response during the HIIT sessions and health and physical education lessons for both the HIIT and control groups during Making a HIIT.*

A. The average heart rate across all students and sessions during 1) the high-intensity interval training (HIIT) sessions for the HIIT group shown in grey; 2) the HPE lesson for the HIIT group shown in white; and 3) the HPE lesson for the control group shown in white. **B.** The percentage of time students' heart rate was equal to or greater than to 80% of their maximum heart rate across all students and sessions during 1) the high-intensity interval training (HIIT) sessions for the HIIT group shown in grey; 2) the HPE lesson for the HIIT group shown in white; and 3) the HPE lesson for the control group shown in white. HIIT = high-intensity interval training; HPE = health and physical education.

Quality of implementation. Three themes were identified through the thematic analysis in the area of implementation, which related to: 1) the scheduling and time implications of integrating the HIIT workouts into lessons; 2) elements that helped facilitate the implementation of the HIIT workouts; and 3) the use of HIIT during theory lessons within the classroom. Four of eight teachers noted that the workouts took longer than 10 minutes and occasionally cut into the time scheduled for their planned unit of work due to the additional time required for using the heart rate monitors, the transition between the activities, or students needing a water break post the workout. However, the teachers found the workouts easy to lead as most of the included exercises were straightforward and the booklet provided was simple to follow. They found the laminated booklet of workouts useful and noted that the lack of equipment required made the workouts easier to lead. All the teachers stated that they opted to lead the workouts instead of allowing students to lead the workouts due to time constraints and issues related to limited student confidence, maturity, and level of responsibility. Four teachers noted that the time keeping was challenging with the varying interval lengths and that they struggled to focus on students' technique and motivation at the same time. The implementation of HIIT within the classroom received mixed feedback from teachers. Teachers in school one perceived HITT workouts to be a good brain break and beneficial for students, enabling them to settle down. However, teachers in school three struggled with the classroom workouts and identified issues around limited space, lack of suitable uniforms, and calming the students down after the workouts.

Quality of workouts. In practical lessons, 6 different workouts were completed at school one, 10 at school two, and 8 at school three. On average, these HIIT workouts elicited an average heart rate of 78% ± 4% and RPE of 6 ± 2. During theory lessons at schools one and three, 9 different workouts were used. Of the 9, 4 were modified versions of practical lesson workouts and 5 were workouts only used in theory class. The average RPE for these workouts was 4 ± 0.5.

Responsiveness. The average rating for session enjoyment for all students and sessions was 3.3 ± 1.1, with 43% of forms indicating "agree" or "strongly agree" (4 or 5) and 17% of forms stating "disagree" or "strongly disagree" (1 or 2) in response to the item "I enjoyed participating in today's HIIT session" (Figure 8). Mean enjoyment for HIIT workouts was the same in practical and theory lessons (3.3 ± 1.0). Of the 218 students in the intervention group, 49 (22%) reported an average enjoyment of 4 or 5, while 14 (6%) reported an average enjoyment of 2 or 1. The median (interquartile range) scores for the items included in the positive and negative affect scales were 3.0 (2.2 – 3.6) and 1.5 (1.0 – 2.0), respectively, out of 5. The distribution for each of the 9 items in the affect scales is presented in Figure 9. The Cronbach alpha of the positive and negative scale in *Making a HIIT* was 0.85 and 0.71, respectively.

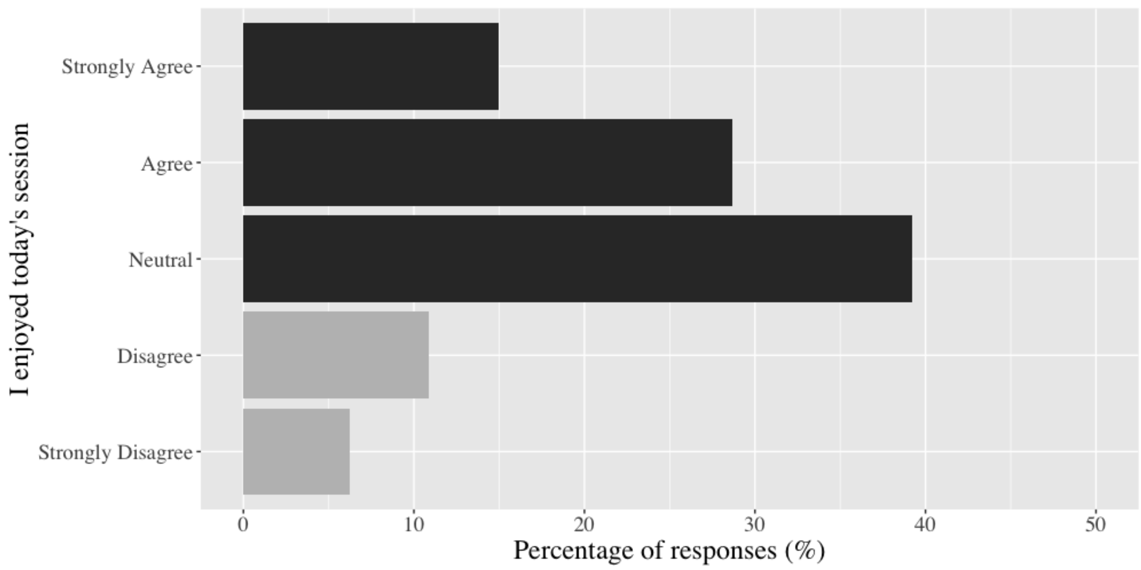


Figure 8. *Student enjoyment of HIIT workouts within Making a HIIT.*

The percentage of responses for each answer to the statement "I enjoyed today's session..." across all students and high-intensity interval training sessions.

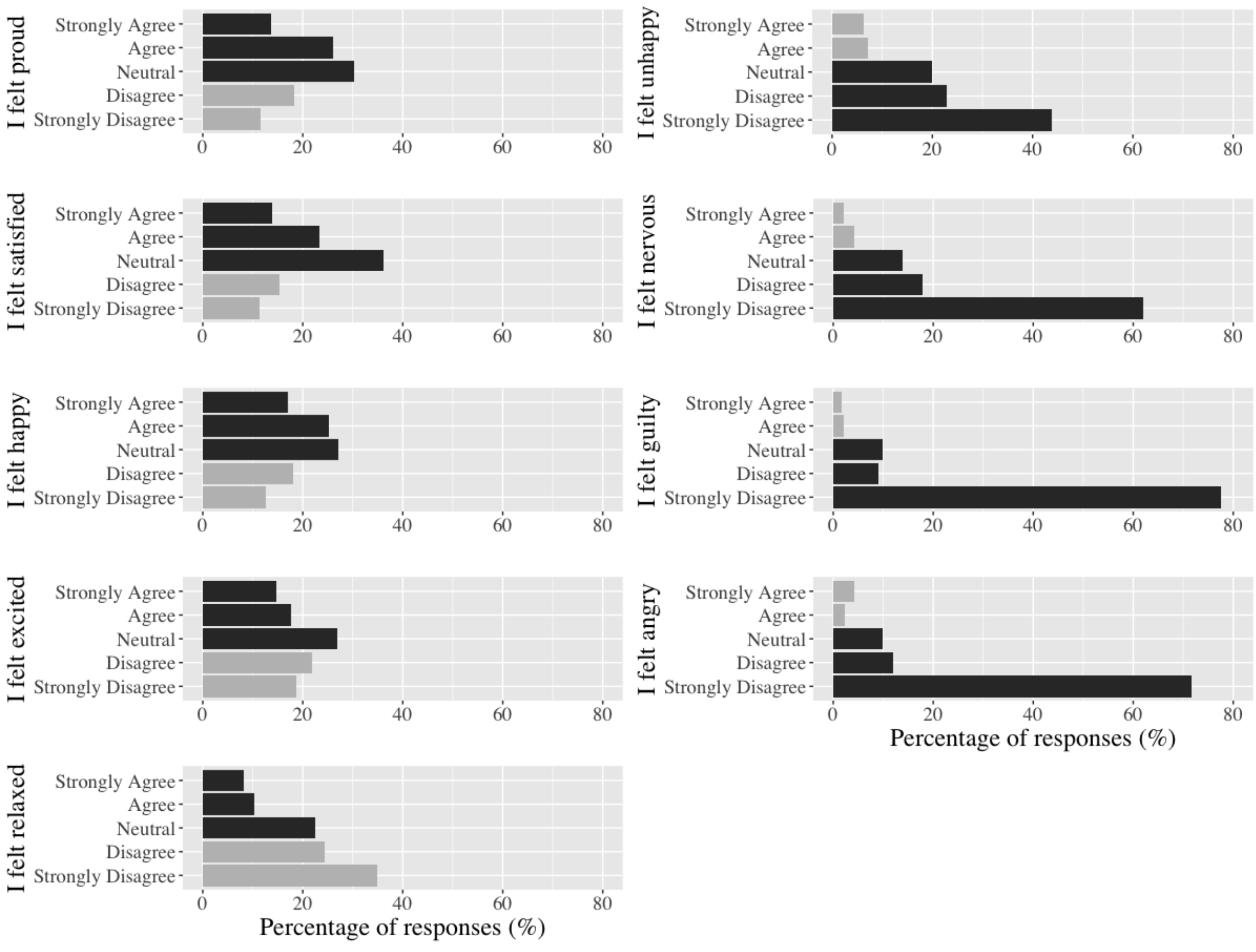


Figure 9. *Student positive and negative affect of the HIIT workouts within Making a HIIT.*

The percentage of responses for each answer across all students and high-intensity interval training sessions.

Two themes relating to responsiveness were identified from the thematic analysis: 1) student engagement and 2) teacher intent to continue using HIIT. Student engagement was discussed by all eight teachers and included two sub-themes: 1) engagement over time and 2) elements affecting engagement. Four teachers perceived that student engagement decreased over the intervention as HIIT became less novel and students became more focused on their friends and less on the workout. However, three teachers felt the engagement stayed similar over the eight weeks, noting that students accepted HIIT as part of their routine and had their friends to continue to motivate them. Overall, teachers identified various elements that affected student engagement. Three of the five teachers involved in the co-design process noted that it had an impact on engagement and that students tended to be biased towards their own workouts or even workouts made by their classmates. Certain exercises within the HIIT workouts were noted to increase engagement, such as exercises that enabled working with friends or that involved competition, while exercises such as burpees, push-ups or exercises requiring use of the floor were noted to decrease engagement. Teachers perceived that the heart rate monitors, and the presence of the researcher also had a positive influence on engagement. Finally, teachers noted that students' general motivation levels within HPE influenced how engaged they appeared in the HIIT workouts, with certain students lacking engagement in both HIIT and HPE.

Two sub-themes were identified within teachers' intent to continue using the HIIT workouts: 1) curriculum integration and 2) how they might implement HIIT in the future. All eight teachers noted either a year level or unit that HIIT could fit in in the future. The units they recommended tended to focus on general fitness, while the year level they recommended for the intervention ranged from 5 to 12, with teachers commenting on ties between the curriculum for both general obligatory HPE and senior elective subjects, such as Sport and Recreation. Six teachers discussed that they would continue to use HIIT in their future lessons as a dynamic warmup in HPE lessons or a classroom break in other subjects. They also indicated that there were aspects within the HIIT workouts that they would continue to use, such as the game-based or fitness-focused exercises, pending on the HPE unit they were completing. One teacher discussed incorporating music in future HIIT workouts to increase student motivation.

Differentiation. A point of differentiation for *Making a HIIT* is that it contained involvement from end-users. Teachers were involved in the decision making for the frequency and timing of the HIIT workouts during the intervention. Further, both the teachers and students were involved in co-designing the HIIT workouts used throughout the intervention, which is novel in school-based HIIT research [155]. Lastly, educative outcomes were considered in the design of the intervention and achieved by the students involved in the co-design process (*Chapter Four*).

Adaption. During the *Making a HIIT* intervention, modifications were occasionally made to workouts. At school one, equipment and relays were removed due to time constraints within the HPE lessons. Consequently, based on this feedback, the co-designed workouts at schools two and three were developed without the use of equipment. To simplify the workouts, teachers sometimes combined two shorter intervals into one longer interval so they could focus more on the students rather than timekeeping. Further, some of the movements (e.g., burpees, push-ups, squat jumps) were occasionally simplified so students could understand them and perform them effectively. Teachers also sometimes modified the workout due to space availability. For example, this included confining the students to a small area of the field for running based activities or changing exercises if the grass or courts were wet.

Modifications were also made to the workouts completed during theory lessons in the classroom. This was done with the researcher and teachers before the intervention began and the updates were included in the final workout booklets provided to the teachers. For school one, this entailed changing running-based intervals to stationary running. In school three, where the uniform included skirts, certain exercises (e.g., floor-based exercises) were modified to enable participation. Further, on two occasions at school three, the 10-minute workout was shortened to 5 minutes due to the length of time teachers needed to calm the students down and continue the lesson.

Modifications to the frequency and duration of the intervention were also made. In school one, class B had four theory lessons in the computer lab and did not complete the HIIT workouts during those lessons. In schools two and three, assessment, assemblies, and public holidays led to fewer HPE lessons completed over the term and therefore, decreased the dosage of HIIT workouts delivered.

Discussion

The process evaluation reported in this paper was guided by Durlak and DuPre's Framework for Effective Implementation and used both quantitative and qualitative data to comprehensively evaluate the *Making a HIIT* intervention [161]. It offers unique insights into the implementation of HIIT workouts within the school setting, which can be used as a lens for examining outcome variables within *Making a HIIT* and to improve future school-based HIIT interventions.

Making a HIIT differs from other school-based HIIT interventions due to the engagement of end-users. It was designed with reference to the Australian HPE curriculum content descriptions and was able to elicit educative outcomes through the co-design process to create the HIIT workouts (*Chapter*

Four). However, the required engagement by end-users also influenced program reach. Seven of the ten schools that were approached declined to participate and the most frequently provided reason was because the HPE department was unsure how to fit the co-designing of HIIT workouts within their pre-existing units or was hesitant to replace a unit with the co-design lessons included in *Making a HIIT*. While systematic reviews on HIIT in schools have called for end-user involvement [20, 155], in practice, the amount of end-user input will need to be adaptable at different schools and within different year levels. Designing future studies to accommodate the varying levels of end-user engagement based on school and teacher needs and preferences will be important to consider for improving program reach. This could include involving students and teachers at a lower level on the participation continuum where instead of co-designing the parameters and exercises of the HIIT workouts, workout frameworks could be provided and modified as needed by the HPE department and individual teachers.

Within *Making a HIIT*, only 26 students (12%) across all three schools attended all the HIIT workouts delivered. This was lower than expected, considering that the HIIT workouts occurred during obligatory lessons. It was also lower than what reported by the two other school-based HIIT interventions with process evaluations [106, 159]. This could be due to the three major barriers to dosage that presented themselves during the *Making a HIIT* study: uniform policies, curricular demands, and conducting HIIT within the classroom. In school one, where the highest attendance was noted, the uniform policy was not an issue as students were permitted to wear their HPE uniform (i.e., shorts and t-shirts) on days that included either practical or theory HPE lessons. In schools two and three (the all-boys and all-girls schools, respectively), students were required to wear formal uniforms throughout the day, including during theory-based HPE lessons. Although the exercises in the HIIT workouts were adapted to account for this, the uniforms still limited the ability of HIIT to be completed in the classroom. Further, if students did not bring the appropriate practical HPE uniform, they were unable to participate in those HPE lessons as well (and therefore, HIIT). Future studies will need to consider varying uniform policies and adapt interventions to meet the needs of individual schools, and if possible, encourage the use of sports uniforms throughout the school day. Available evidence demonstrates that uniform policies that permit students to wear their HPE uniform throughout the day are associated with a significant reduction in sedentary time and non-significant increases to light activity in 8 – 10 year old students [230]. Further, available findings show that most surveyed Australian parents (78%) support policies that enable students to remain in their sports uniforms [231].

In all three schools, curricular demands and related policies led to lower attendance in the HIIT workouts as students needed to prioritise completing schoolwork and assignments that they had missed in theory HPE lessons over partaking in practical HPE lessons. Enabling the delivery of the HIIT workouts at several points in the school day (e.g., lunch, HPE, other lessons) could facilitate enhanced attendance and account for the workouts missed to curricular demands. Previous studies have used HIIT workouts during lunch, before school, and after school [37, 90, 95]. However, these studies included small samples that limit the generalisability of the findings and further, as these are discretionary periods, they can potentially lead to the inclusion of only students who are already motivated to be active. Including HIIT activity breaks in subjects other than HPE should be considered in the future. However, in the *Making a HIIT* study classroom-based HIIT received mixed reviews from teachers, with some noting several barriers to its implementation. In school two, for example, classroom size and uniform policies led to the exclusion of classroom-based HIIT. Classroom management was also identified as an issue in school three, with teachers stating they struggled to calm down the students after the workout. However, teachers in school one stated that they found the workouts to have a calming effect on the students. This discrepancy could be due to different teacher-student dynamics or to differences between the student populations at the two schools. Further, the classroom size in school one was larger than school three, which may have facilitated student participation in HIIT. A previous study has successfully used HIIT workouts within the classroom in primary schools in Canada and noted that they were associated with improved off-task behaviour [146]. A systematic review and meta-analysis on physically active lessons found enhanced educational outcomes; however, 39 of the 42 included studies were completed in primary schools and the authors called for further research into active lessons in high schools [232]. Primary school classrooms tend to be more open with space for play, which could aid in the completion of classroom-based exercise [233]. Future studies on school-based HIIT will need to consider how and when these interventions occur accounting for classroom size, school uniforms, and curricular demands. Enabling flexibility in the delivery of HIIT to account for the variation and unique characteristics within different schools will be important for increasing the dosage delivered and received. Additionally, considering further measures to understand the implementation of these interventions, such as session observations to inform the quality of delivery, should be considered.

While the dosage of HIIT was lower than intended, students had favourable perceptions of the workouts. Students tended to either rate the workouts as enjoyable or neutral, which is similar to other studies that have investigated enjoyment of school-based HIIT in adolescents aged 13 – 18 years [47, 106]. Additionally, very few students reported feeling negative emotions such as unhappiness (12% of students) or nervousness (6% of students) compared to feeling positive emotions such as satisfaction (41% of students) and happiness (42% of students) during HIIT. This corroborates previous findings in adolescents where HIIT did not elicit prominent unpleasant feelings [45] and provides further evidence against previous concerns in the literature that HIIT would evoke feelings of displeasure, which could limit engagement and future adherence [43, 44]. Teachers noted that students particularly enjoyed working with their friends, competing against each other, and quick changing intervals. The insight into student engagement was limited to quantitative data from students and teacher qualitative data and could be enhanced by qualitative data from students in future studies for a more nuanced understanding of how to optimise enjoyment of HIIT. However, even without student qualitative data, the evidence is in favour of HIIT eliciting limited negative responses from students. Some teachers perceived student engagement decreased over time and that students who were unmotivated in general toward HPE tended to be unmotivated towards HIIT. This echoed the decreases in peak and average heart rate throughout the intervention (Discussed in *Chapter Six*), indicating that future studies will need to consider how to encourage continued engagement in the workouts and how to motivate students who do not enjoy HPE in general. However, the heart rate data from *Making a HIIT* indicate that students were for the most part completing high-intensity exercise, which is promising due to the benefits associated with this type of activity, such as improved cardiorespiratory fitness, body composition, and blood biomarkers [27, 28, 155].

In addition to students, teachers also positively evaluated the HIIT intervention. Six of eight teachers stated their intent to continue using the workouts in the future in both HPE lessons and other subjects, which is encouraging for the scalability of HIIT within schools. Although, this must be viewed with the knowledge that the researcher involved with the intervention was conducting the interviews, which could have introduced some bias. They commented that the HIIT workouts were able to be adapted, which was an important aspect due to time constraints, scheduling and location changes, and varying levels of class behaviour. This adds to evidence from two previous studies on school-based HIIT where 80% (n = 22) and 100% (n = 4) of teachers agreed that they intended to use HIIT in their lessons in the future [47, 106].

Conclusion

The comprehensive mixed methods evaluation of *Making a HIIT* provides important insights into the implementation of HIIT within the school setting. The satisfaction of HIIT expressed by students and teachers is promising for future use of HIIT in this setting as is the overall fidelity of the HIIT workouts. Future studies will need to consider the various options for delivering the HIIT workouts throughout the school day to maximise the dosage received by students and optimise potential health benefits. It will also be important for future studies to make use of dosage and fidelity data within their per-protocol analysis of outcomes to gain greater insights into the effectiveness of HIIT. Additionally, the level of end-user engagement within schools to increase satisfaction and without forsaking program reach will need to be further investigated. Consultation with teachers and students will enable future studies to minimise barriers, maximise dosage, and increase the positive perceptions of HIIT within the school setting.

Chapter 6: Quantifying Intensity in School-Based HIIT

The following submitted manuscript has been incorporated as chapter six:

> **Duncombe SL**, Stylianou M, Price L, Walker J, and Barker AR (2023). Making a HIIT: Methods for quantifying intensity in high-intensity interval training in schools and validity of session rating of perceived exertion. Under Review

Author contributions:

	Statement of Contribution			
	Conception & design	**Data Collection**	**Analysis & interpretation**	**Drafting & critical review**
Ms. Stephanie Duncombe	70	100	80	80
A/Prof. Alan Barker	10	0	8	8
Dr. Lisa Price	5	0	2	2
Dr. Jacqueline Walker	5	0	2	2
Dr. Michalis Stylianou	10	0	8	8

Justification of chapter within the thesis

Chapter Two highlighted the scarcity and narrow consideration of intensity data from previous school-based high-intensity interval training (HIIT) interventions, which is an essential component of HIIT. Accordingly, this chapter focuses on the intensity achieved by students during the HIIT workouts in *Making a HIIT* during the intervention in phase two and provides a nuanced discussion on the different quantification methods used to analyse heart rate data. It continues the dialogue that began in *Chapter Five* to enable a comprehensive understanding of the implementation of the intervention within *Making a HIIT* by focusing on fidelity, which was one of the eight components examined within *Chapter Five*'s process evaluation. Further, this chapter investigates the validity of measuring intensity using a sessional rating of perceived exertion (RPE) within the school setting. It does this by examining the correlation between sessional RPE and training load determined with heart rate data. This is of high importance in school-based research, where heart rate measures are not always viable and using a sessional rating of perceived exertion could enable a time efficient and low-cost method to evaluate intensity.

Making a HIIT: Methods for Quantifying Intensity in High-Intensity Interval Training in Schools and Validity of Session Rating of Perceived Exertion

Abstract

This chapter aimed to understand the fidelity of *Making a HIIT*, a school-based high intensity interval training (HIIT) study, by **1)** investigating the variation within and between students showcased through different heart rate quantification methods; and **2)** assessing the criterion validity of session rating of perceived exertion (sRPE) for quantifying the internal training load compared to heart rate. During an 8-week HIIT intervention, 213 students (13.1 (0.6) years; 46% female) completed 10-minute HIIT workouts during physical education lessons. In total, 1057 heart rate and RPE measurements were collected across 68 HIIT workouts. To assess **Aim 1**, descriptive statistics were determined for heart rate quantification methods and variability within and between students was examined using linear mixed models. The average and peak heart rate across all participants and workouts were 79% (8%) and 92% (6%) of HR_{max}, respectively. The average RPE was 6 (2) points on a 10-point scale. However, on average, only 51% of students in a class had an average heart rate ≥ 80% for each workout. Both average and peak heart rate decreased on average by 0.5 percentage points each week ($p < 0.001$). These results demonstrate that it is critical to showcase variability within and between participants, and across the intervention timeline for a more nuanced understanding of fidelity. To assess **Aim 2**, a within-participant correlation was calculated for the internal training load produced using heart rate and RPE data. The correlation was 0.39 ($p < 0.001$), which suggests utility of using sRPE when heart rate is not a viable option.

Introduction

High-intensity interval training (HIIT) is gaining interest as a method for physical activity delivery and health promotion in the school setting [155]. The popularity of HIIT could be attributed to various factors, including research associating time spent in higher intensity physical activity with lower cardiometabolic risk [28], and the similarity to children's intermittent patterns of physical activity [30]. Preliminary evidence suggests that students enjoy school-based HIIT and that a high proportion of teachers intend to continue delivering HIIT beyond the intervention [106]. However, there are limited data on the implementation of school-based HIIT [155], which is integral to understanding the link between interventions and relevant outcomes [17].

Successful implementation of an intervention includes many determinants [17]. One key component that is crucial to the internal validity of a study is fidelity [234]; the extent to which an intervention has been implemented as intended [17]. However, it is one of the least examined determinants in school-based physical activity interventions [17], including HIIT interventions. In exercise interventions, fidelity can encompass the frequency, duration, and intensity of the exercise. Reporting intensity is particularly important for HIIT interventions, as embedded within the prescription of HIIT, is the assumption that participants will be working within a specific intensity range (e.g., above 85% of maximum heart rate), which is necessary to experience benefits [28, 235]. However, the achieved intensity was only reported in 48% of school-based HIIT intervention studies [155].

Heart rate is a valid and reliable method for monitoring intensity [236], and it is the most frequently used method in school-based research [155]. However, there is no standardised procedure for quantifying heart rate data to reflect the intensity of HIIT [155], making it difficult to compare between studies or develop a better understanding of the link between implementation and outcomes [17]. Comparisons among the various methods of quantifying heart rate data are warranted to further understand the implications of using different methods and enable more transparent reporting of the fidelity of HIIT interventions. Two previous studies have examined fidelity in school-based HIIT [106, 147]. However, *Taylor et al.* [147] included only a small subsample of 17 participants, which could be biased towards students who were more actively engaged in the program, and *Kennedy et al.* [106] discussed fidelity as part of a larger process evaluation but did not aim to scrutinise the implications of the various quantification methods that they used.

While heart rate is a valid objective measure of exercise intensity during HIIT, there are some practical limitations to using heart rate monitors regularly in the school environment, including cost, the time required to put on the device, student comfort while wearing the devices, and data loss [227, 237]. An alternative measure of intensity that can be utilised in schools is self-reported rating of perceived exertion (RPE). RPE can be completed with ease in health and physical education (HPE) class as it is low cost, requires minimal class time, and is simple to use in group settings [227].

Both heart rate and RPE can be used to determine the internal training load of a workout, which accounts for the duration and intensity [238]. A 2017 review that examined the criterion validity of sRPE, where an RPE rating is used to reflect the entire exercise session, rather than at a specific moment during exercise [239]. It showcased a wide range of correlations (0.20 to 0.97) between sRPE and internal training load calculated with heart rate for intermittent sport [239]. However, the studies included in this review had sample sizes smaller than 20 participants, were completed with athletic populations, and were not undertaken in the school setting [239]. Currently, there is no evidence on the relationship between sRPE and heart rate for quantifying internal training load within HIIT workouts in the school setting. Investigating the validity of sRPE in a generalisable population during school-based HIIT workouts would help understand the utility of this measure, especially when objective measures of exercise intensity are not feasible.

Therefore, the aim of this paper was to understand the fidelity of *Making a HIIT*, a school-based high intensity interval training study, by **1)** investigating the variation within and between students showcased through different intensity quantification methods using heart rate; and **2)** assessing the criterion validity of sRPE for quantifying the internal training load compared to heart rate.

Methods

The *Making a HIIT* study has been described in detail elsewhere [207]. This paper uses data from the group of classes who participated in the HIIT workouts and focuses only on the HPE lessons where both heart rate and RPE data were collected.

Participants

The *Making a HIIT* study was completed in three secondary schools (one co-educational school, one boys' school, and one girls' school) around Greater Brisbane, Australia. It was completed with grade 7 and 8 students and teachers as part of the HPE curriculum. Within each school, there were three groups: 1) the co-design group, who was involved in the creation of the HIIT workouts and used the HIIT workouts in HPE for a term; 2) the HIIT only group, who used the HIIT workouts in HPE (but was not involved in the co-design of the HIIT workouts); and 3) the control group, who continued with normal HPE lessons. In total, 10 classes completed the HIIT workouts in HPE across participating schools (i.e., groups 1 and 2), and the students from these classes form the sample for this study. *Making a HIIT* was approved by The University of Queensland's human research ethics committee (Project: 2020/HE002444) and relevant governing bodies and gatekeepers. Parents and teachers provided written informed consent for participation in the study, and students provided written informed assent.

Intervention

In brief, classes in group one co-designed HIIT workouts with researchers and teachers in an iterative process across several HPE lessons. In this process, the class created criteria for the workouts based on identified barriers and facilitators to exercise. The class also established the parameters for the workouts, including the target heart rate, and maximum and minimum interval lengths. Then, groups of three to five students each designed a 10-minute HIIT workout. Students trialled the workouts and received peer feedback and heart rate data to modify their workouts in line with the criteria and parameters established in the previous lessons. Due to this process, HIIT workouts varied in terms of theme (e.g., sport-specific, home workouts), percentage of time in work (average = 65%, range: 53 - 75%), and work and rest intervals (range 10 - 60 seconds), although running-based intervals were the most common.

Students in groups one and two used the co-designed HIIT workouts in an 8-week intervention. Teachers received the workouts in a laminated booklet prior to the term and went through them with a researcher. Workouts were delivered across practical and theory HPE lessons but only practical lesson data where heart rate and sRPE were collected are presented in this paper. A researcher was present for all HIIT workouts. Students were encouraged to provide maximal effort during the 'work' periods by both the teacher and researcher throughout the workout. The researcher examined the live heart rate data and provided verbal encouragement to individuals who were not meeting the target.

Intensity measures collected

Heart rate

Students wore heart rate monitors (Polar H10, Polar Electro, Finland) that were fitted by researchers at the start of the intervention to ensure appropriate strap size and placement. Data were recorded using Polar GoFit software (https://polargofit.com/). Participants' maximum heart rate (HR_{max}) was determined using a 20-meter shuttle run test conducted in a HPE lesson one week prior to the intervention [171]. For students who were absent during this lesson (*n* = 38), did not complete the test (*n* = 14), or for whom heart rate was not collected (1 class, *n* = 23), HR_{max} was calculated using the formula 208 – (0.7)*age [240]. For each HIIT workout, the following heart rate data were extracted from Polar GoFit for each student: peak heart rate, peak as a percentage of HR_{max}, average heart rate, average as a percentage of HR_{max}, and time spent with a heart rate between 1) 50 and 59%; 2) 60 and 69%; 3) 70% and 79%; 4) 80% and 89%; and 5) 90% and 100% of HR_{max}. The percentage of time spent in each of the above heart rate zones was calculated by dividing the time spent in each zone by the total length of the workout.

Session rating of perceived exertion

Students reported their sRPE using the Children's OMNI Scale of Perceived Exertion immediately after the completion of each HIIT workout [228]. The OMNI RPE has been validated against heart rate during ramp and continuous exercise, as well as resistance exercise [198, 228, 229]. Students were asked to circle one number between 0 and 10 on the pictorial scale that corresponded to their effort during the entire HIIT workout using the prompt "During this HIIT workout, I felt...". Researchers explained to the students that a ten would equate to an effort that was as hard as they could possibly work and where they felt "very, very tired", while a zero was equivalent to not tired at all.

Data management

Aim one: Quantification of intensity with heart rate

To examine variability within and between students, we used various intensity quantification methods that have previously been used in school-based HIIT studies [85, 86, 90, 93, 94, 97, 99, 106-109, 112-114, 118, 129, 132, 147]. These included: 1) the mean average heart rate (absolute and percentage of HR_{max}) for all students and workouts combined [85, 86, 93, 94, 97, 99, 106-109, 112, 113, 118, 129, 132]; 2) the mean peak heart rate (absolute and percentage of HR_{max}) for all students and workouts combined [85, 90, 94, 106-108, 114, 118]; 3) the percentage of time students spent in various deciles (above 70%, 80%, and 90% of HR_{max}) [109, 118]; 4) the mean percentage of students in a class with an average heart rate above 80% and 90% of HR_{max} [106]; 5) the percentage of students in a class who spent equivalent or more time above 80% and 90% of HR_{max} than the intended time in work for each workout; and 6) the variability within and between students [147].

Aim two: Session-RPE criterion validity

To assess the criterion validity of sRPE, we calculated a training impulse (TRIMP) for heart rate using the Edwards method [241]. This method combines the volume of exercise with total intensity based on five intensity thresholds. The time spent (in seconds) in each heart rate zone as a percentage of HR_{max} was multiplied by a factor (50 – 59% = 1; 60 – 69% = 2, 70 – 79% = 3, 80 – 89% = 4, 90 – 100% = 5) and these were summated to generate a total internal training load (in arbitrary units). To calculate sRPE (in arbitrary units), we multiplied each student's subjective RPE by the total duration (seconds) of the workout equivalent to the duration of the recorded heart rate.

Data analysis

Data analysis was conducted in R (Version 3.6.2; The R Foundation for Statistical Computing, Vienna, Austria). Alpha was set at 0.05.

Aim one: Quantification of intensity with heart rate

Normality was checked using a Shapiro-Wilk test. Means and standard deviations were reported for normally distributed variables and medians and inter-quartile ranges were reported for not normally distributed quantification methods. The variability within and between students was examined using linear mixed models for the outcome variables of peak and average heart rate as percentages of HR_{max}. Sex and intervention week were included as fixed effects. Each student was nested within a school. The assumptions of the model were satisfied, including linearity, homogeneity of variance, and normal distribution of the residuals.

Aim two: Session-RPE criterion validity

To assess the validity of using RPE, the within-participant correlation (*r*) between TRIMP and sRPE was calculated while accounting for repeated measures [242]. This was completed using the RShiny application for repeated measures correlations [243]. The magnitude of the correlations was interpreted as follows: 0.1 to 0.3 = negligible; 0.3 to 0.5 = low; 0.5 to 0.7 = moderate; 0.7 to 0.9 = high; > 0.9 = very high [244].

Results

A total of 68 HIIT workouts included heart rate and RPE data, with 24 unique HIIT workouts completed. Class attendance varied between lessons and the average attendance for each class is reported in Table 16. Occasionally, heart rate data were not recorded for a participant during a workout due to students arriving late (n = 11); leaving the HIIT workout early (n = 3); removing the monitor (n = 5); leaving the Bluetooth range (n = 3); or equipment malfunctions (n = 39). In total, 1057 measurements were collected from 213 students across the 68 HIIT workouts.

Table 16. Classes involved in HIIT intervention.

School	Class	Year	Age Ψ	N (female)*	Number of HIIT workouts with HR data	Number of HIIT Workouts Completed by Students†
One	A	8	13.3 ± 0.3	25 (11)	8	8 (7 to 8)
	B	8	13.2 ± 0.4	12 (6)	8	7 (6 to 7)
Two	C	7	12.6 ± 0.3	24 (0)	6	4 (3 to 5)
	D	7	12.5 ± 0.3	23 (0)	7	5 (5 to 7)
	E	8	13.6 ± 0.4	24 (0)	7	5 (3 to 7)
	F	8	13.7 ± 0.3	24 (0)	11	9 (5 to 10)
Three	G	8	13.4 ± 0.3	21 (21)	6	5 (4 to 5)
	H	8	13.3 ± 0.3	23 (23)	5	3 (3 to 5)
	I	7	12.4 ± 0.3	19 (19)	4	3 (3 to 4)
	J	7	12.5 ± 0.3	18 (18)	6	5 (3 to 5)

Ψ Mean and standard deviation for normally distributed variables
* N = the number of students with valid heart rate data included from each class
† Median and Interquartile range for not normally distributed variables
HIIT = high-intensity interval training; HR = heart rate

Aim One: Quantification of intensity with heart rate

The results showcasing variability between students from the various methods of quantifying intensity data in our study are presented in Table 17. Between student and across time variation is displayed in Figure 10.

Table 17. *Intensity of HIIT workouts using various heart rate quantifications and session rating of perceived exertion.*

Quantification of Intensity	**Full Sample (n = 213)**	**Males (n = 115)**	**Females (n = 98)**
Average HRǂ	161 bpm (16 bpm)	162 bpm (5 bpm)	159 bpm (19 bpm)
Average HR as a percentage of HR maximumǂ	79% (8%)	79% (7%)	79 (9%)
Peak HRǂ	188 bpm (13 bpm)	188 bpm (12 bpm)	186 bpm (16 bpm)
Peak HR as a percentage of HR maximumǂ	92% (6%)	92% (5%)	93% (7%)
Percentage of time between 70 – 79% of HR maximum†	26% (IQR: 14% - 37%)	26% (IQR: 16% - 37%)	25% (IQR: 11% - 37%)
Percentage of time between 80 – 89% of HR maximum†	38% (IQR: 22% - 52%)	38% (IQR: 23% - 52%)	36% (IQR: 20% - 54%)
Percentage of time between 90 – 100% of HR maximum†	6% (IQR: 0% - 23%)	5% (IQR: 0% - 21%)	7% (IQR: 0% - 26%)
Percentage of students with an average HR > 80% Ψ	51% (IQR: 31% - 67%)	50% (IQR: 30% - 67%)	55% (IQR: 40% - 70%)
Percentage of students with an average HR > 90% Ψ	5% (IQR: 0% - 8%)	0% (IQR: 0% - 7%)	0% (IQR: 0% - 13%)
Percentage of students where (Time with HR > 80%) ≥ (Time in work) Ψ	38% (IQR: 20% - 58%)	36% (IQR: 18% - 55%)	47% (IQR: 23% - 60%)
Percentage of students where (Time with HR > 90%) ≥ (Time in work) Ψ	0% (IQR: 0% - 6%)	0% (IQR: 0% - 5%)	0% (IQR: 0% - 7%)
Average rating of perceived exertionǂ*	6 (2)	6 (2)	6 (2)

HR = Heart rate; bpm = beats per minute

ǂ Mean and standard deviation across all students and sessions

† Median and IQR across all students and sessions

Ψ Median and interquartile range within a class

* Using the omnibus children's rating of perceived exertion scale, which ranges from 0 – 10 points.

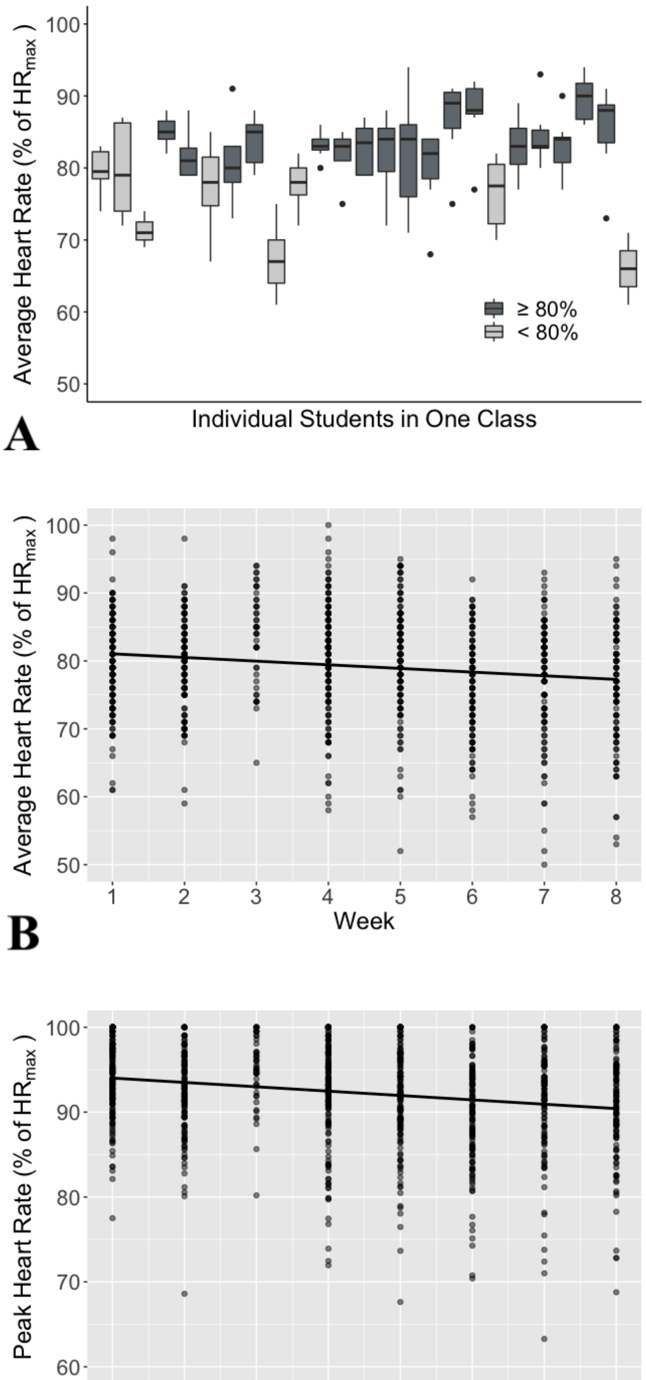


Figure 10. A) *The average heart rate (percentage of heart rate maximum) across the intervention for students in a single class.* ***B)*** *The average heart rate (percentage of heart rate maximum) for each week of the intervention. It decreased on average 0.6% each week.* ***C)*** *The peak heart rate (percentage of heart rate maximum) for each week of the intervention. It decreased on average 0.5% each week.*

The mixed model for peak heart rate had a significant effect for week ($p < 0.001$), with an average decrease of 0.5% (95% CI: -0.6% to -0.4%) per week. The within-person variation was 19 percentage points of HR_{max}. The variation between subjects was 19 percentage points, which explained 51% of the total variance in peak heart rate (Intra-class coefficient (ICC) = 0.51). The mixed model for average heart rate also had a significant effect for week ($p < 0.001$), with a decrease of 0.6% (95% CI: -0.6% to -0.4%) per week. The within-person variation was 31 percentage points of HR_{max}. The variation between subjects was 30 percentage points, which explained 49% of the variance in average heart rate (ICC = 0.49). There was no significant effect for sex in any model.

Aim Two: Criterion validity of session-RPE

The mean sRPE across all students and sessions was 6 (2). The within-person correlation between sRPE and TRIMP was $r = 0.39$ (95% CI: 0.33 – 0.45), $p < 0.001$, indicating a low correlation (Figure 11). When stratified by gender, the correlation was $r = 0.49$ (95% CI: 0.40 – 0.57, $p < 0.001$) for girls and $r = 0.31$ (95% CI: 0.22 – 0.39, $p < 0.001$) for boys. The mixed model for sRPE had a significant temporal effect ($p < 0,001$), with an average decrease of 2.5 arbitrary units (95% CI: -3.0 to -2.0) per week.

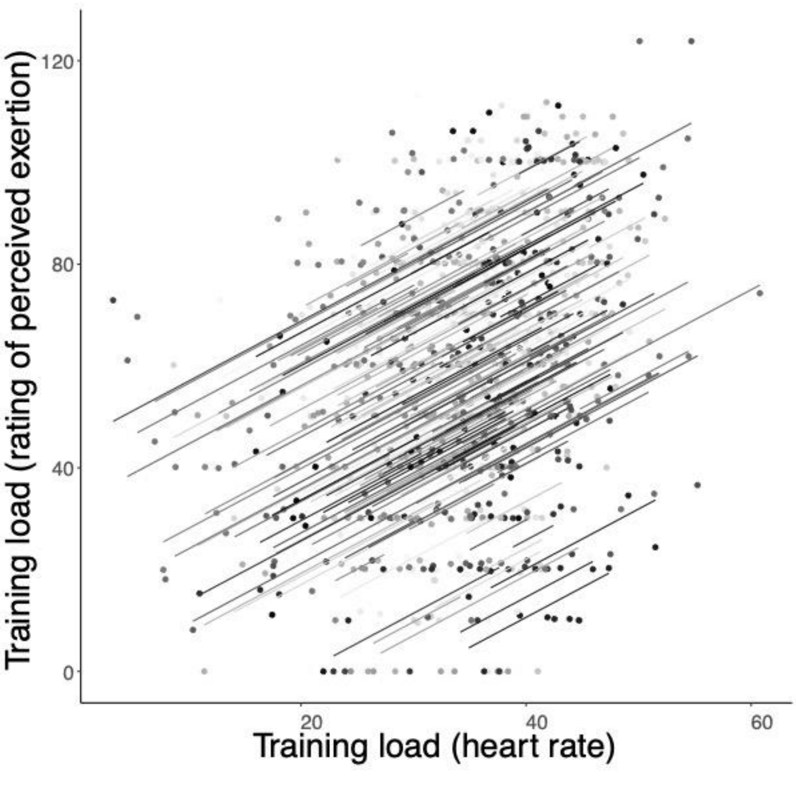


Figure 11. *The within-person correlation between training impulse calculated with Edwards method using heart rate and session rating of perceived exertion.*

Discussion

Making a HIIT is, to our knowledge, the first study to examine different heart rate quantification methods in school-based HIIT. The results demonstrate that the different methods for quantifying heart rate can showcase different levels of variability in the data, including within students, between students, and over time. As HIIT is prescribed on an individual basis, it is important that this variation is acknowledged and considered when evaluating the intervention and its effect on outcome variables. For example, in this study, the average percentage of students in a class with an average heart rate above 80% of HR_{max} was only 51%, indicating that half the students may not have achieved high intensity, which is not evident when only class average or peak heart rate are provided.

Making a HIIT was also the first study to examine the association between sRPE and heart rate during school-based HIIT to understand its validity in this setting and with this type of exercise. The low within-subject correlation of 0.39 will be important to consider moving forward if heart rate or other objective measurements of intensity are not feasible.

Aim One: Intensity and variation within and between students

The most frequently reported methods for quantifying heart rate in the school-based HIIT literature are mean average heart rate and peak heart rate for the entire HIIT workout [85, 90, 93, 94, 97, 99, 106-109, 113, 114, 118, 129], either in beats per minute or as a percentage of HR_{max}, which standardises the measurement based on age and sex. The average and peak heart rate of 161 (17) bpm and 188 (13) bpm, respectively, reported in *Making a HIIT* are within the ranges (143 to 179 and 168 to 207 bpm, respectively) reported in previous school-based HIIT studies (Table 16) [106] [113]. Variation between studies could be partly due to the inclusion of different workout components in the quantification of previous literature as showcased in Table 18. For example, one study included warmup and cooldown in their quantification, while others included the full workout (rest and work intervals) or did not specify what was included. Several previous studies have specified that they only included work intervals for their calculations. As this doesn't include rest, the reported heart rate data tend to be higher, and make it easier for readers to determine if the intended intensity was being achieved. However, this method also has limitations stemming from the heart rate lag at exercise onset, which could limit its ability to capture a portion of heart rate data that is above a threshold if rest is not included [147] with short work bouts further limiting the capture of intensity with this method. Additionally, this type of heart rate capture is not feasible in workouts where students are not working and resting at the same time. Overall, reporting the average or peak heart rate of a workout is a useful first step to quantifying intensity and making comparisons to previous literature. However, transparency on the included workout elements is necessary for these comparisons to be made. Additionally, this quantification method would be enhanced by including other methods that provide further information on the variation within and between students.

Table 18. *Average and peak heart rate as mean (standard deviation) in Making a HIIT compared to previous school-based HIIT studies.*

Study	Data Collection Information	Average Heart Rate		Peak Heart Rate	
		Absolute Value	Percentage of Max	Absolute Value	Percentage of Max
Making a HIIT	Work + Rest Intervals	161 bpm (16)	79% (8)	188 bpm (13)	92% (6)
Kennedy et. al 2020	Work + Rest Intervals	143 bpm (22)	70% (11)	168 bpm (20)	82% (10)
McNarry et. al 2020	Work + Rest Intervals	155 bpm (16)	78% (8)	189 bpm (12)	95% (6)
Lambrick et. al 2016	Work + Rest Intervals	175 bpm (8)	86%	191 bpm (8)	93%
Arariza et al. 2018	Work + Rest Intervals	149 bpm (16)		176 bpm (17)	
Ketelhut et al. 2020	Work + Rest Intervals	161 bpm (31)		207 bpm (11)	
Larsen et al. 2016 [a]	Work + Rest Intervals		74% (4)		
Larsen et al. 2016 [b]	Work + Rest Intervals		74% (5)		
Cvetkovic et al. 2018	Work + Rest Intervals		80% (3)		
Costigan et al. 2016 [c]	Work + Rest + Warmup/Cooldown	148 bpm	74%		
Costigan et al. 2016 [d]	Work + Rest + Warmup/Cooldown	155 bpm	78%		
Baquet et al. 2002 [e]	Only Work Intervals		95% (2)		
Camacho-Cardenosa et al. 2016	Only Work Intervals		90% (4)	192 bpm (9)	
Williams et al. 2016[f]	Only Work Intervals	193 bpm (9)			
Logan et al. 2016 [g]	Only Work Intervals		93% (2)		
Boddy et al. 2010 [h]	Only Work Intervals				94%
Martin-Smith et al. 2019 [h]	Only Work Intervals			185 bpm (12)	92% (1)
Martin et al. 2015	Unspecified Recording	179 bpm (2)	87%		
Buchan et al. 2011 [h]	Unspecified Recording	178 bpm (15)			
Van Biljon et al. 2018	Unspecified Recording	170 bpm (4)			

[a] results are from the interval running HIIT group in the study
[b] results are from the small-sided games HIIT group in the study
[c] results are from the aerobic training HIIT group in the study
[d] results are from the combined aerobic and resistance training HIIT group in the study
[e] results are from the intervals of 130% maximal aerobic speed (MAS), results also presented for 100% MAS in the paper
[f] results are from the 30s intervals, results also presented for 10s intervals in the paper
[g] results are from the group doing 5 sets, results also presented for groups doing 1, 2, 3, and 4 sets in this paper
[h] results are from week 1, results are reported by week in the paper

Providing the percentage of time spent in different heart rate zones (e.g., 70 – 79%, 80 – 89%, 90 – 100%) presents readers with a clearer picture of students' overall effort across the workout and is a valuable method to showcase variability throughout a workout. On average, students in *Making a HIIT* spent more time in the 80% – 89% zone than they did in the 70% – 79% or 90% – 100% zones (Table 2). Only two other studies have looked at percentage of time spent in heart rate zones during school-based HIIT [109, 118]. *Larsen et al.* [109] reported the percentage of time that students (aged 8 to 10 years) spent in the 70% – 79% and 90% – 100% heart rate zones, for two different HIIT protocols (interval running, small-sided games), with similar findings to *Making a HIIT*. *McNarry et al.* [118] reported a higher percentage of time spent above 90% for their HIIT intervention, which included circuits and games-based activities. This could be due to the specific activities performed, the trained professionals leading the workouts, or the participants, which included a group of students with asthma, who could have an altered heart rate response. Although this method implies that there are specific cut-offs that are of significance, it does utilise a greater percentage of collected data and can showcase variability throughout a workout.

The aforementioned heart rate quantification methods group students and workouts to provide an overall average. However, they do not capture the substantial variation that exists between individual students. Examining the number of students that achieved a certain average can enhance understanding of the variation across individuals. In this study, only 51% of students in a class achieved an average heart rate greater or equal to 80% of HR_{max} for a workout. The only other study that used this method in school-based HIIT found that only 17% of participants achieved a heart rate average of 85% across the intervention [106]. Methods that examine data of individual participants enable readers to further understand how many students received the intervention as intended, beyond understanding fidelity at a group level.

Further, using mixed models to understand variability both between and within individuals has only previously been completed in one other school-based HIIT study using peak heart rate [147]. The authors of the *Fun Fast Activity Blast* study reported a within-student variation of 15.1 percentage points, which is similar to the results of this study (18.5 percentage points) and indicates substantial variation within individual students throughout the intervention. The between student variation in this study was larger (18.9 to 7.8 points), which could stem from the larger and more generalisable sample included within the present study [147]. In addition to peak heart rate, average heart rate was examined as an outcome in mixed models in this study, and a greater amount of variation was noted compared to peak heart rate. This is unsurprising as both rest and work time are counted in the second model, which increases within-participant variation. The increased monitoring time is also able to capture greater variability between participants.

Aim Two: Session-RPE criterion validity

The 0.39 within-subject correlation coefficient between sRPE and TRIMP in *Making a HIIT* is within the range of coefficients compiled in a review that assessed the validity of sRPE [239]. It is on the lower end of the range; however, most of the studies included in the review tended to use standard exercise protocols with motivated athletic populations. sRPE decreased throughout the *Making a HIIT* intervention, following a similar temporal trend for intensity to peak and average heart rate. The variance in sRPE that was accounted for by clustering students (ICC = 0.47) was also comparable to peak heart rate (ICC = 0.51) and average heart rate (ICC = 0.49). This, combined with the ease of completing sRPE and the low associated cost [227], suggests that it could be a valuable method for monitoring intensity in large school-based programs.

However, RPE has not been used frequently in school-based HIIT interventions, with only one other study reporting sRPE results. The sRPE reported in this sprint-based HIIT study (3.7 on a 10-point scale) [94] was far lower than the mean RPE in *Making a HIIT* (6 on a 10-point-scale), even though both studies collected sRPE immediately after the workout and had similarly aged participants (11 years old compared to 13 years old in *Making a HIIT*). This discrepancy warrants further exploration into the variation of RPE in this context. Additionally, in *Making a HIIT*, when stratified by gender, girls had a higher correlation coefficient than boys, with non-overlapping 95% confidence intervals. This could be partially attributed to the greater number of measurements (i.e., more practical lessons with heart rate) in the boy's only school compared with the girl's only school. While a previous validation study of the OMNI Pictorial Scale reported no difference between genders [198], there has been speculation that RPE could be effected by gender in addition to fitness level, age, and expertise [239]. However, further research is necessary to corroborate these findings.

Strengths and limitations

Making a HIIT is the first study to comprehensively examine various methods for quantifying intensity using heart rate within a school-based HIIT intervention and to examine the relationship between sRPE and heart rate in this context. *Making a HIIT* was not powered to assess the concurrent validity of RPE as the study was powered for the trial's primary outcome (cardiorespiratory fitness). However, the sample size of this study is greater than other RPE validation studies in youth using the OMNI Scale of Perceived Exertion [198, 228]. This study employed a wide range of HIIT workouts; however, most did not include intervals longer than 30 seconds. Therefore, it will be necessary to examine the relationship between sRPE and heart rate in future work with varying HIIT protocols (e.g., HIIT games). Lastly, the sample in *Making a HIIT* only included a specific age range and originated from a single region under one HPE curricula; therefore, further investigation is warranted to confirm our findings in different age groups and contexts where the HPE curriculum and allotted time differ. However, this age range was selected based on alignment with the Australian HPE curriculum to complement the units being conducted at each school and limit the burden to the teachers and curriculum time.

Conclusions and recommendations

The findings from this study demonstrate the importance of comprehensively investigating and reporting exercise intensity in school-based HIIT research to showcase the variability in heart rate data within and between students. Additionally, the variation over time suggests that future studies need to include intensity measurements across the entire program. It is essential that future studies report which parts of the workout are captured by the heart rate data and document variation to enable readers to have a complete understanding of the extent to which an intervention was implemented as intended. Further, our results suggest the utility of using sRPE when heart rate is not a viable option, but additional studies are necessary to corroborate our findings and to enhance our understanding of using RPE as a prescription tool for high-intensity exercise in this setting.

Chapter 7: The Effect of Co-Design on Motivation and Enjoyment of HIIT

Justification of chapter within the thesis

This chapter focuses on the effect of 1) being involved in the process of co-designing high-intensity interval training (HIIT) workouts and 2) using the co-designed workouts during the HIIT intervention in phase two of *Making a HIIT*, on students' enjoyment, autonomous motivation, confidence, perceived competence, autonomy, and relatedness during HIIT, which are known to be important for intervention adherence. This chapter aims to provide discussion on the impact of involving end-users for future studies to consider.

The effect of co-design on motivation and enjoyment during a school-based HIIT intervention: Findings from *Making a HIIT*

Abstract

Background: The *Making a HIIT* study involved co-designing high-intensity interval training (HIIT) workouts with teachers and students, which were subsequently used in an 8-week intervention. The co-design process, which was guided by self-determination theory, aimed to involve end-users and to move away from traditional running and cycling-based HIIT workouts. The two aims of this chapter were to examine: 1) the effect of participating in the co-design process and 2) the effect of using the co-designed HIIT workouts for 8 weeks on students' enjoyment, autonomous motivation, autonomy, relatedness, perceived competence, and self-efficacy towards HIIT.

Methods: *Making a* HIIT was conducted in health and physical education classes in three schools with students aged 12 – 14 years. Phase one entailed co-designing the HIIT workouts with students and teachers from five classes. In phase two, an 8-week intervention was completed by students who co-designed the workouts (Group 1, n = 122, 48% female) and five additional classes of students (Group 2, n = 100, 44% female). A further five classes continued with normal HPE lessons (Group 3, n = 86, 52% female). Questionnaires (Physical Activity Enjoyment Scale; Perceived Locus of Control; HIIT Self-efficacy; Scales for self-determination theory needs) were completed immediately after the first and last HIIT workout. To assess aim one, Mann Whitney tests were used to compare the responses of students in Group 1 to Group 2 and 3 after the first HIIT workout. For aim two, mixed-effects models were used to compare the responses of the three groups over time.

Results: There was no effect of being involved in the co-design process on any outcome. Enjoyment, autonomous motivation, autonomy, and self-efficacy were rated neutral to positive and remained stable throughout the intervention regardless of group. Girls rated the enjoyment of HIIT workouts higher than boys ($\beta = -0.24$, $p = 0.035$). Perceived competence and relatedness decreased slightly over time ($\beta = -0.36$, $p = 0.036$ and $\beta = -0.47$, $p = 0.031$, respectively) regardless of group.

Discussion: The lack of differences between groups for aim one could be due to the workouts that were designed to be enjoyable and in line with self-determination theory, thereby eliciting neutral to positive ratings for all three groups. Future studies should continue to focus on supporting the self-determination theory needs during school-based interventions by providing students with choice, input in decision making, and the opportunity to collaborate with peers and researchers.

Introduction

Physical activity is crucial for children and adolescents' health, wellbeing, and learning [1, 2]. However, only one quarter of Australian children and adolescents meet the recommended national physical activity guidelines [5, 6]. Schools have been widely used as a setting for physical activity interventions as they can reach a large percentage of children and adolescents with their policies, infrastructure, and trainable personnel [10, 13]. High-intensity interval training (HIIT), which is defined as short bouts of vigorous exercise followed by recovery periods, has recently gained interest as a method for delivering physical activity in schools [29, 155]. This can be attributed to various factors, including research associating time spent in higher intensity physical activity with lower cardiometabolic risk [28], the similarity of HIIT to children's intermittent patterns of physical activity [30], and the time-efficient protocols that enable it to be integrated into the school day at the start of lessons or as an activity break [146, 155].

Despite the intuitive appeal of HIIT, critics state that adherence to HIIT has been exaggerated in the literature [245]. They argue that high-intensity physical activity, defined as activity above the ventilatory threshold, will illicit displeasure, which will cause low levels of adoption and maintenance [42-44]. Although, it is worth nothing that this conclusion is based on predictions from incremental and continuous exercise and may not be appropriate for HIIT, which includes intervals of high-intensity interspersed with recovery periods [42]. Further, these critiques mostly focus on adult literature. Limited studies have documented HIIT adherence and pleasure in child and adolescent populations, but preliminary evidence from studies in laboratory environments and schools showcases positive findings [45, 47, 246]. A recent review on adolescent HIIT has argued that well-designed HIIT programs can improve population health provided they are designed to meet four tenets: 1) they are integrated into existing opportunities; 2) they are delivered in an engaging manner; 3) they are guided by an implementation framework; and 4) they enhance students' motivation, confidence, physical competence, and knowledge [226].

Making a HIIT is a school-based HIIT study that was aligned with all four of the aforementioned tenets [207]. It included an 8-week intervention that was integrated within Health and Physical Education (HPE) lessons to enhance current opportunities for acquiring vigorous physical activity. Prior to the 8-week intervention, *Making a HIIT* involved co-designing HIIT workouts with students, teachers, and researchers. These workouts were developed to meet the following co-designed criteria, which were identified by students as key for increasing engagement: be fun; provide achievable level(s) of challenge; be social; provide feelings of accomplishment; and be beneficial for health or skill development (*Chapter Four)*. The co-design process was guided by the Framework outlined in

Leask et al. and was grounded in self-determination theory [58, 160]. This theory introduces three basic psychological needs: 1) autonomy, which relates to the feeling that one has choices and is acting out of a sense of volition; 2) perceived competence, which relates to a sense or experience of mastery and effectiveness in particular areas; and 3) relatedness, which relates to a sense of belonging and importance to others [59]. Self-determination theory holds that when these three needs are met, an individual's motivation can shift from more controlled, extrinsic motivation to more self-determined, autonomous motivation along a continuum, with the latter more likely to result in sustained participation in physical activity [58, 247].

As discussed in *Chapter Four,* the co-design process aimed to support students' basic psychological needs as it afforded greater autonomy than their standard HPE lessons through creating their own HIIT workouts and choosing their themes and exercises. Relatedness was targeted through the group work and peer feedback structures used within the co-design process. To increase competence, the co-design process included the use of heart rate monitors, discussions around interval length and intensity, and trialling various pre-existing HIIT workouts. Additionally, the HIIT workouts created through the co-design process aimed to strengthen their basic psychological needs through the inclusion of partner or group exercises (relatedness), varying interval lengths (perceived competence), and modifiable exercises (autonomy and perceived competence). While not part of self-determination theory, the HIIT workouts also aimed to increase students' confidence (self-efficacy) during HIIT, which focuses on a students' belief that they can do the HIIT workout instead of the need to master it [248]. Lastly, the HIIT workouts aimed to increase enjoyment towards HIIT through the themes and exercises chosen by the students that moved away from traditional HIIT protocols, which tend to use cycling and running-based protocols [155, 226].

Both the co-design process and the use of the resulting HIIT workouts are novel within the school-based HIIT literature and, therefore, it is necessary to understand the potential effects of this process and the created workouts on student enjoyment and self-determination theory elements throughout the HIIT intervention. To do this, the two aims of this paper were to: 1) examine the effect of participating in the co-design process on students' enjoyment, autonomous motivation, autonomy, relatedness, perceived competence, and self-efficacy towards HIIT; and 2) examine the effect of using the co-designed HIIT workouts for 8 weeks on students' enjoyment, autonomous motivation, autonomy, relatedness, perceived competence, and self-efficacy towards HIIT.

Methods

Study Overview

The *Making a HIIT* study was completed in three secondary schools (one co-educational school, one boys' school, and one girls' school) around Greater Brisbane, Australia. It was completed with grade 7 and 8 students and teachers as part of the HPE curriculum. Within each school, there were three groups: 1) the co-design group, who was involved in the creation of the HIIT workouts and used the HIIT workouts in HPE for a term; 2) the HIIT only group, who used the HIIT workouts in HPE for a term (but were not involved in the co-design process); and 3) the control group, who continued with normal HPE lessons. *Making a HIIT* was approved by The University of Queensland's human research ethics committee (Project: 2020/HE002444) and relevant education governing bodies and gatekeepers. Teachers provided written informed consent. Parents and students provided written informed consent and assent, respectively.

Making a HIIT has previously been described in detail in *Chapter Three*. In brief, as part of phase 1, classes in group one co-designed HIIT workouts with researchers and teachers in an iterative process across several HPE lessons. In this process, each class created criteria for the HIIT workouts based on identified barriers and facilitators to exercise. Each class also established the parameters for the workouts, including the target heart rate, and maximum and minimum lengths for the work and recovery intervals. Then, groups of three to five students each designed a 10-minute HIIT workout. Students trialled the workouts and received peer feedback and heart rate data to modify their workouts in line with the criteria and parameters established previously. Due to this process, the HIIT workouts varied in terms of theme (e.g., sport-specific, workouts that could be done at home), percentage of time in work (average = 65%, range: 53 - 75%), and work and rest intervals (range 10 - 60 seconds), although running-based intervals were the most common and were included in 100% of workouts.

In phase 2, students in the co-design and HIIT only groups used the co-designed HIIT workouts in an 8-week intervention. The frequency of the HIIT workouts ranged from one to three workouts per week. A detailed explanation of the dose provided and received is presented in *Chapter Five*. Teachers received the workouts, including exercise modifications, in a laminated booklet prior to the start of the term. They reviewed the workouts with a researcher and clarified any of the exercises that were unfamiliar to them. Students were encouraged to provide maximal effort during the 'work' periods by both the teacher and researcher throughout the HIIT workout. The control group participated in the first and last HIIT workout to appropriately respond to the questionnaires administered in this study, but otherwise continued with their normal HPE lessons.

Design and Procedures

This phase of *Making a HIIT* used a quasi-experimental design. Questionnaires were completed immediately after the first and last HIIT workout under examination-like conditions. The same HIIT workout was used at both timepoints to avoid introducing additional variation into the responses. Data collection for this study was performed by trained research assistants who were blinded to the group allocation. Research assistants provided standardised instructions to the students based on the study protocol and students could ask clarifying questions prior to starting the completion of questionnaires or throughout the data collection by silently raising their hand. Student responses were entered into a spreadsheet (Microsoft Excel) by the first author and 20% were double-checked to ensure there were no systematic errors in this process. If students missed a question, it was flagged and completed during the following HPE lesson prior to completion of the next HIIT workout or left blank if the student was not in attendance the following lesson.

Measures

Enjoyment of HIIT was measured by the physical activity enjoyment scale (PACES) [192, 193], which has been validated in children and adolescents [192, 194]. For the purposes of this study, the stem of the questionnaire was changed from "When I am active" to "When I am participating in HIIT". The questionnaire includes 16 phrases and students indicated their level of agreement with each phrase using a 5-point Likert scale (1 - Strongly Disagree to 5 - Strongly Agree). Seven of the questions use backward scoring and were reversed for analysis. The 16 questions from the PACES were totalled and divided by the number answered to create an aggregate score between 1 and 5, with higher scores indicating greater levels of enjoyment. Additionally, enjoyment was categorised into agree for total scores ≥ 4, neutral for scores < 4 and > 3, and disagree for scores ≤ 3.

Autonomous motivation towards HIIT was measured by the perceived locus of causality (PLOC) questionnaire that has been used extensively in HPE [182, 184, 249]. For *Making a HIIT*, the stem was changed from "I take part in PE/sport" to "I take part in HIIT workouts…". The PLOC includes five motivation subscales (intrinsic motivation, identified regulation, introjected regulation, external regulation, and amotivation), with four statements each. Support for the factorial structure and reliability of these subscales has previously been established with a Cronbach's alpha of 0.88 – 0.90 for intrinsic motivation (highest on the autonomy continuum) and 0.75 to 0.81 for external regulation (lowest on the autonomy continuum) in Year 7 and 8 children (aged 12 – 14 years) [182, 249]. Students indicated their level of agreement with each statement using a 7-point Likert scale (1 - Strongly Disagree to 7 - Strongly Agree). The subscales were summed separately to create five total scores and divided by the number of questions answered, with higher scores indicating greater levels of each motivation type. Further, intrinsic motivation and identified regulation were combined to create autonomous motivation as previous literature has indicated that these two types of motivation have an additive relationship with enjoyment of exercise [250].

Autonomy, relatedness, and perceived competence were each assessed using five questions with a 7-point Likert scale from 1 (Strongly Disagree) to 7 (Strongly Agree). For the purposes of this study, the stem of the autonomy questions was changed from "In this PE class" to "In this HIIT session"; the stem of the relatedness questions was changed from "With the other students in my PE class I feel" to "With the other students in my HIIT session I feel"; and the subject of the competence questions was changed from PE to HIIT (e.g., "I think I am pretty good at PE" was changed to "I think I am pretty good at HIIT") [187]. All three scales have previously been used reliably in HPE lessons with internal consistencies of $\alpha = 0.81$, $\alpha = 0.91$, and $\alpha = 0.85$ for autonomy, relatedness, and perceived competence, respectively [187-191, 251]. For analysis, the score for the one competence question that was negatively worded was reverse coded. The total score for each psychological need was summed and divided by the number of questions answered. A higher score reflected a higher level of perceived autonomy, competence, and relatedness during the HIIT workouts.

Participants' **confidence towards performing HIIT** was examined using the HIIT self-efficacy questionnaire (HIIT-SQ) [197]. This questionnaire includes six questions on a 10-point Likert scale, with 1 indicating not at all confident, 5 as somewhat confident, and 10 as completely confident. The total score was divided by the number of completed questions for a score between 1 and 10. HIIT-SQ has previously been validated using a population of Australian high-school students, with factor loading coefficients for each question between 0.81 and 0.90 [197]. Further, it has a test-retest intraclass coefficient of 0.99 in a sample of 12 – 14 year old Australian students [197].

Data Analysis

Data analysis was conducted in R (Version 4.2.0; The R Foundation for Statistical Computing, Vienna, Austria). Alpha was set at 0.05. As the first author completed the data analysis, each student's group was known to the author. Descriptive statistics were calculated for each outcome. To assess the reliability of the scales used within *Making a HIIT,* the Cronbach alpha for each scale was calculated using the 'ltm' package in R [252]. To examine **Aim 1 (Effect of Co-Design Process),** the baseline values for those involved in the co-design process were compared with those not involved (the HIIT only and control group) using a Mann-Whitney test as the data was not normally distributed. To examine **Aim 2 (Effect of an Intervention with Co-Designed Workouts),** multi-level models were used to assess changes over time between groups adjusting for sex as a covariate. Sex was included as a covariate as research indicates that sex differences are present for enjoyment, motivation, and perceived competence during general physical activity [151, 253]. The model included fixed effects for group (Co-Design, HIIT only, or Control), time (pre-intervention or post-intervention), group-by-time interaction, and sex. The model included random intercepts to account for the clustering of the data by class and the repeated measure for each student. Only students with complete cases (i.e., responses at both time points) were included in the analysis. The assumptions of the models (normally distributed residuals; linearity; collinearity; homogeneity of variance) were assessed and met.

Results

In total, 308 students (mean age: 13.0 ± 0.6 years, 148 girls) participated in *Making a HIIT*. The co-design process (Group 1) was completed by 122 students (59 girls). Group 2 (HIIT Only) was comprised of 100 students (44 girls) and the control group was formed by 86 students (45 girls). The number of participants at each school and the number of participants who completed the questionnaires at each time point by group is displayed in Figure 12. The completion rate of the questionnaires varied slightly: enjoyment was complete in 92% of cases; autonomous motivation in 97% of cases; autonomy, relatedness, and perceived competence in 95% of cases; and self-efficacy in 91% of cases. The Cronbach's alphas in *Making a HIIT* for enjoyment, intrinsic motivation, external regulation, autonomy, relatedness, perceived competence, and self-efficacy were 0.92, 0.91, 0.85, 0.86, 0.92, 0.85, and 0.91, respectively.

The median and interquartile range (IQR) for each outcome variable is presented in Table 19 and displayed in Figure 13. Findings for **Aim 1** indicated no significant differences between the two groups for any outcome variable at baseline (Table 19). The results from the mixed models for **Aim 2** are displayed in Appendix 7. There was no effect of the HIIT intervention on enjoyment, autonomous motivation, autonomy, or self-efficacy towards HIIT. Relatedness during HIIT decreased over time irrespective of group (β = - 0.47, 95% confidence interval: -0.90 to -0.04, p = 0.031). Perceived competence during HIIT also decreased over time regardless of group (β = - 0.36, 95% confidence interval: -0.71 to -0.02, p = 0.036). Boys rated their level of enjoyment of HIIT lower than girls regardless of group or time point (β = -0.24, 95% confidence interval: -0.26 to -0.02, p = 0.035). When enjoyment was grouped by response categories, the largest shifts in categories were noticed in the co-design group, with 7 fewer students agreeing that they enjoyed HIIT post-intervention but also 6 less students disagreeing that they enjoyed HIIT post-intervention (Figure 14). In total, pre-intervention, 60 students agreed (32.4%), 78 were neutral (42.3%), and 47 disagreed

(25.4%) that they enjoyed HIIT. Post intervention, 45 students agreed (24.3%), 96 were neutral (51.9%), and 44 students disagreed (23.8%) that they enjoyed HIIT.

School 1	School 2	School 3
Consenting Students		
Group 1: 25	Group 1: 49	Group 1: 48
Group 2: 12	Group 2: 50	Group 2: 38
Group 3: 12	Group 3: 35	Group 3: 39

Questionnaires Completed at T1 and T2

	School 1 T1	School 1 T2	School 2 T1	School 2 T2	School 3 T1	School 3 T2
PACES						
1	23	25	31	41	41	34
2	9	9	38	40	28	28
3	12	10	26	24	33	22
PLOC:						
1	23	24	31	41	40	33
2	12	10	38	41	28	27
3	12	10	26	23	33	22
BPN:						
1	23	25	31	37	40	33
2	9	8	38	36	26	28
3	11	10	25	24	32	22
Efficacy:						
1	22	22	28	35	41	34
2	7	10	28	33	25	27
3	10	10	24	23	33	22

Complete Cases

	School 1	School 2	School 3
PACES			
1	23	26	31
2	7	30	20
3	10	20	18
PLOC:			
1	22	26	29
2	10	31	19
3	10	20	18
BPN:			
1	23	23	30
2	6	30	19
3	9	19	17
Efficacy:			
1	19	19	30
2	6	21	17
3	9	19	18

Figure 12. *The number of participants that completed each questionnaire*.

A flow chart outlining the number of students who responded to each questionnaire pre-intervention and post-intervention, and the number of students who completed each questionnaire at both timepoints. T1: Pre-Intervention Measures; T2: Post-intervention measures. PACES: physical activity enjoyment scale; PLOC: perceived locus of control; BPN: basic psychological needs; Efficacy: HIIT self-efficacy questionnaire.

Table 19. *The median and interquartile range for each outcome variable before and after the intervention for each of the three groups.*

	Questionnaire Range	Co-Design Group		HIIT Only Group		Control Group		Baseline Differences†
		Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**P Value**
Enjoyment	1 – 5	3.4 (2.9 – 4.1)	3.2 (3.0 – 3.9)	3.3 (3.0 – 4.1)	3.3 (3.0 – 4.0)	3.6 (2.9 – 4.4)	3.3 (2.8 – 4.0)	0.405
Autonomous motivation	2 – 14	8.3 (6.3 – 11.3)	8.0 (6.0 – 9.5)	8.6 (6.8 – 11.5)	8.0 (6.3 – 10.0)	9.3 (6.4 – 12.0)	8.5 (6.5 – 11.8)	0.095
Competence	1 – 7	5.0 (3.6 – 6.0)	4.6 (3.8 – 5.6)	4.1 (3.4 – 5.5)	4.6 (3.8 – 5.4)	4.8 (3.5 – 6.1)	4.1 (3.2 – 5.2)	0.951
Autonomy	1 – 7	3.4 (2.8 – 4.2)	3.6 (2.4 – 4.0)	3.2 (2.2 – 4.0)	3.4 (2.7 – 4.0)	3.4 (2.4 – 4.6)	2.8 (2.0 – 4.0)	0.478
Relatedness	1 – 7	4.4 (3.6 – 5.5)	4.2 (3.6 – 4.8)	4.4 (3.2 – 5.6)	4.0 (3.4 – 5.9)	4.0 (3.3 – 5.6)	3.8 (2.6 – 5.2)	0.486
Self-efficacy	1 – 10	7.0 (4.7 – 8.2)	6.3 (5.1 – 8.2)	6.8 (4.7 – 8.3)	6.2 (4.8 – 8.2)	6.2 (4.8 – 8.3)	6.3 (4.8 – 8.3)	0.865

The Co-Design group included the students who were involved in co-designing the workouts and completed the intervention; The HIIT Only group included the students who did not partake in the co-design but completed the intervention; The Control group included the students who completed the first and last HIIT workout to appropriately answer the questionnaires but otherwise, continued normal health and physical education lessons. † Baseline values of the Co-Design group were compared to the baseline value of the combined HIIT Only and Control groups to understand the effect of the co-design process (Aim 1) with the *p*-value for this reported in the final column.
Pre – prior to the 8-week high-intensity interval training (HIIT) intervention; Post – after the 8-week HIIT intervention.

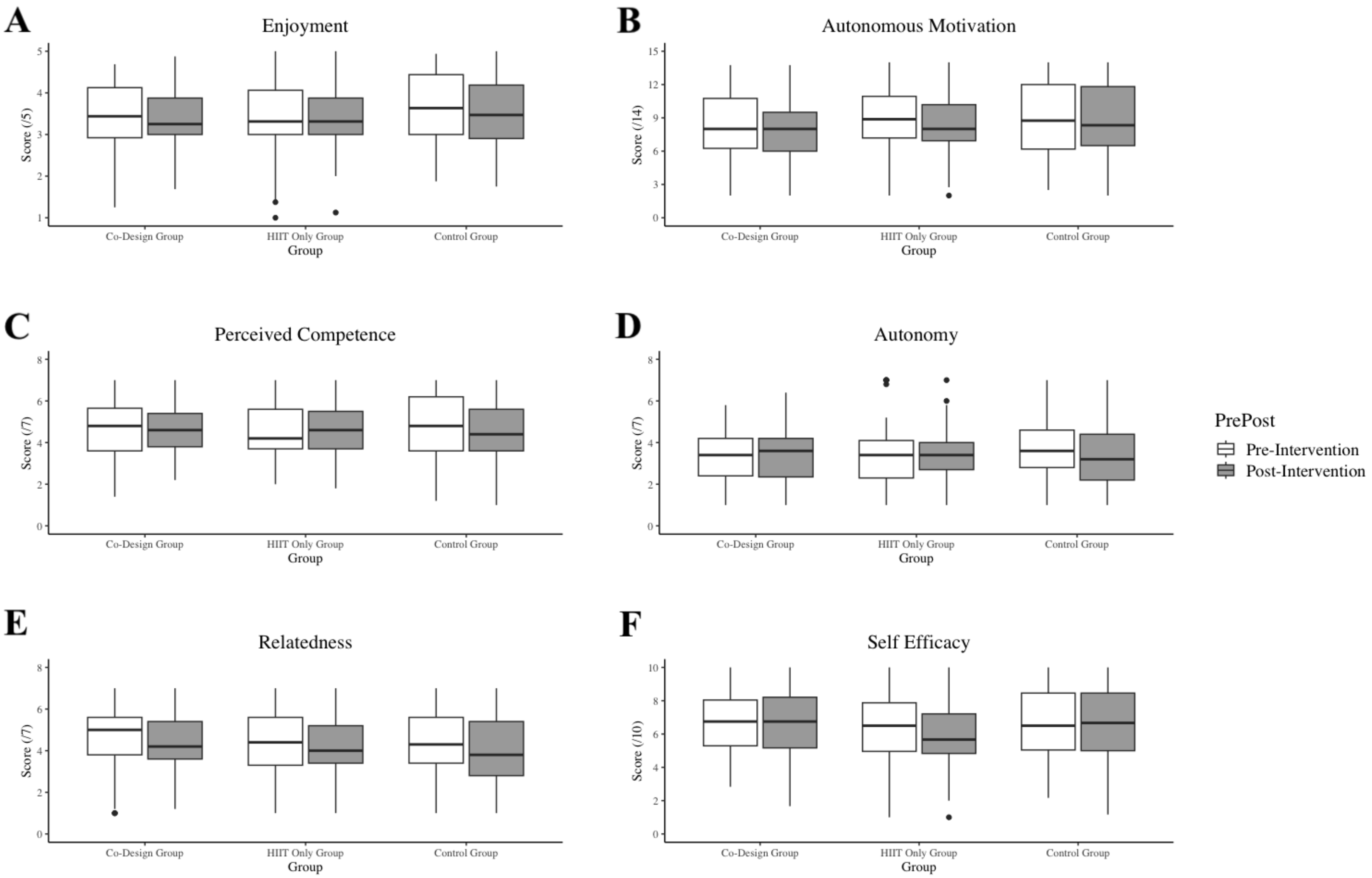


Figure 13. *The score for each questionnaire at both time points for the three groups.*

A. The score on the physical activity enjoyment scale (PACES) for the co-design group, HIIT only group, and control group at the pre-intervention and post-intervention timepoints. A higher score indicates greater enjoyment of HIIT. **B**. The score on the intrinsic motivation and identified motivation scales within the perceived locus of enjoyment (PLOC) questionnaire for the co-design group, HIIT only group, and control group at the pre-intervention and post-intervention timepoints. A higher score indicates greater autonomous motivation towards HIIT. **C**. The score on the perceived competence scale for the co-design group, HIIT only group, and control group at the pre-intervention and post-intervention timepoints. A higher score indicates higher perceived competence towards HIIT. **D**. The score on the autonomy scale for the co-design group, HIIT only group, and control group at the pre-intervention and post-intervention timepoints. A higher score indicates higher autonomy during HIIT. **E**. The score on the relatedness scale for the co-design group, HIIT only group, and control group at the pre-intervention and post-intervention timepoints. A higher score indicates higher relatedness during HIIT. **F**. The score on the self-efficacy questionnaire (HIIT-SQ) for the co-design group, HIIT only group, and control group at the pre-intervention and post-intervention timepoints. A higher score indicates greater self-efficacy towards HIIT. HIIT: high-intensity interval training.

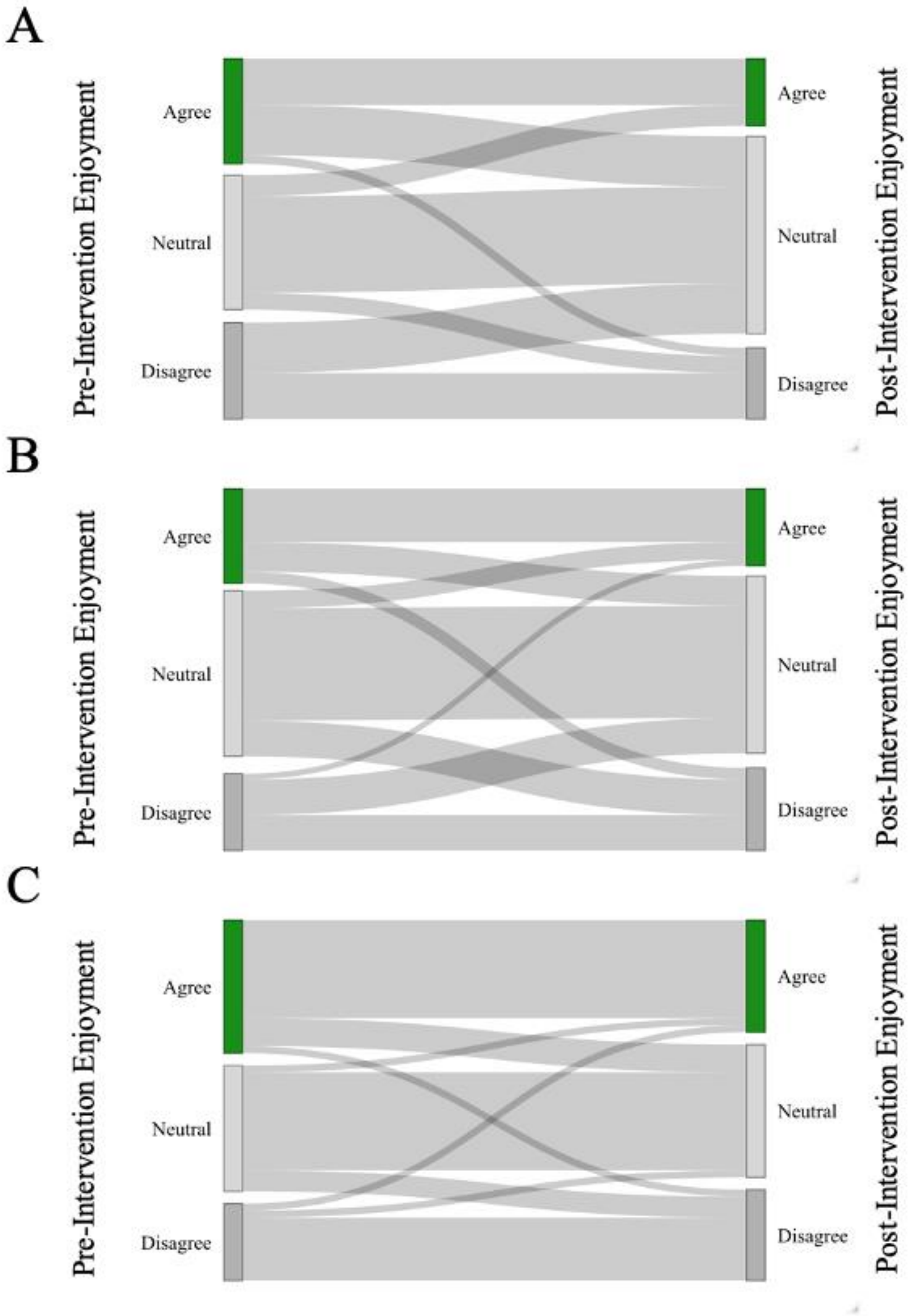


Figure 14. *The ranking of students' enjoyment of HIIT before and after the intervention for each of the three groups*.

A. The proportion of students in the co-design group who responded "Agree" (≥ 4 out of 5), "Neutral" (> 3 and < 4 out of 5) and "Disagree" (≤ 3 out of 5) for their enjoyment of HIIT pre- and post-intervention and the change between the categories over time. **B**. The proportion of students in the HIIT only group who responded "Agree" (≥ 4 out of 5), "Neutral" (> 3 and < 4 out of 5) and "Disagree" (≤ 3 out of 5) for their enjoyment of HIIT pre- and post-intervention and the change between the categories over time. **C**. The proportion of students in the control group who responded "Agree" (≥ 4 out of 5), "Neutral" (> 3 and < 4 out of 5) and "Disagree" (≤ 3 out of 5) for their enjoyment of HIIT pre- and post-intervention and the change between the categories over time.

Discussion

This paper aimed to understand the effect of co-designing HIIT workouts with students and teachers, and the effect of an 8-week intervention using the co-designed workouts on students' enjoyment, autonomous motivation, relatedness, autonomy, perceived competence, and self-efficacy towards HIIT. This responds to recent calls in school-based HIIT for further investigation of the acceptability of and engagement during different types of HIIT, and the exploration of strategies to support students' basic psychological needs and autonomous motivation during HIIT [226].

Enjoyment of HIIT

In *Making a HIIT,* involvement in the co-design process, which aimed to support students' basic psychological needs towards HIIT, did not have an effect on the baseline enjoyment of HIIT, which was completed immediately post the first HIIT workout in the intervention. This differs from a study by *Burford et al*. where students (aged 7 – 11 years) reported significantly higher levels of enjoyment when they were able to choose exercises and lead a HIIT workout compared to when they completed a teacher-led HIIT workout [50]. While the students involved in the co-design process within *Making a HIIT* chose the exercises for the HIIT workouts, similarly to the student-led condition within the *Burford et al*. study, three differences between the studies could explain why the co-design process had no significant effect on enjoyment in *Making a HIIT.* Firstly, all the workouts were teacher-led during the *Making a HIIT* intervention due to time constraints, which would have afforded the students less autonomy. Secondly, students in the co-design group only had the opportunity to do their created workout for one week of the intervention as the teacher rotated through a different workout each lesson to ensure a variety of workouts were used (*Chapter Four).* This meant that only a small number of students completed the workout they created for the baseline measurements. Finally, the study by *Burford et al.* was completed acutely, unlike *Making a HIIT* that involved creating workouts across a term and measuring enjoyment after a HIIT workout the following term. Future work on supporting student autonomy during HIIT interventions and its effect on chronic HIIT enjoyment is necessary.

Within the *Making a HIIT* intervention, the level of enjoyment of HIIT was neutral to positive in all three groups and remained stable across the eight weeks. This supports previous research indicating that HIIT was not disliked by students. A 10-month long school-based HIIT intervention with 8 – 10 year old students that was completed both during school time and in the afternoon had a similar PACES score to *Making a HIIT* and remained stable for the duration of the intervention (Mean ranging between 3.4 – 3.9) [101]. Other school-based HIIT interventions have not evaluated enjoyment over time (*Chapter Two)*. However, one study evaluated post-intervention enjoyment using a different variation of the PACES questionnaire in 26 overweight and obese girls aged 15 – 18 years who completed either HIIT or moderate-intensity interval training [254]. They reported a lower enjoyment score for HIIT (3.3 out of 7) compared with moderate-intensity interval training (4.5 out of 7) [254]. This score is also lower than in *Making a HIIT* but could be attributed to the specific characteristics of the participants that may limit generalisability to the overall school setting. Finally, two school-based interventions (one with Year 11 students and one with Year 9 and 10 students) used a single 5-point Likert question to assess enjoyment of a HIIT intervention as a process outcome, with mean ratings of 3.8 and 4.2 out of 5, respectively, once again indicating neutral to positive ratings [47, 106]. Research from acute HIIT exposure outside the school setting has also indicated that children and adolescents do not dislike HIIT, with studies finding a higher PACES score for HIIT compared to moderate-intensity continuous exercise and to moderate-intensity interval exercise both immediately post-session and 20-minutes post-session [45, 246]. The sustained level of enjoyment during the 8-week intervention in *Making a HIIT* is a promising finding as it indicates the potential for continued use of the co-designed HIIT workouts.

Within *Making a HIIT*, girls expressed significantly greater enjoyment towards HIIT than boys, although the meaningfulness of a 0.2-point difference on a 5-point Likert scale is unknown. However, as boys tend to enjoy Physical Education more than girls [151], this result that indicates that girls enjoyed HIIT similarly to boys is promising. A potential explanation for this could be that the workouts were designed by the girls with their peers in mind, leading to tailored workouts and increased engagement compared to standard HPE lessons [150]. This is corroborated by the study by *Burford et al.*, where there was no difference in enjoyment between sexes during the autonomous HIIT condition, whereas boys expressed significantly greater levels of enjoyment than girls during the non-autonomous HIIT condition [50].

Self-determination elements and self-efficacy during HIIT

There was no significant effect of the co-design process for autonomous motivation, self-efficacy, or any of the basic psychological needs, which could again be due to the HIIT workouts used that may have enabled the neutral to high ratings from all three groups at baseline. During the co-design process, students received peer feedback on the sense of accomplishment, inclusivity, and social interactions afforded during their HIIT workouts as these were deemed important workout qualities by the students in the first part of the co-design process. Subsequently, students had an opportunity to modify their workouts using this feedback to create the final version used in the intervention (*Chapter Four*). Some of the workouts created included partner exercises, which could have increased relatedness during the workouts regardless of group, with research in adults demonstrating that the group dynamics and social aspects of HIIT are an important factor for continued participation [255]. Further, most of the co-designed workouts included exercise modifications (i.e., choice) to account for the varying skill levels of students, which afforded autonomy to students, regardless of their group. The ability to choose their exercise challenge level could also have supports students' confidence and perceived competence towards HIIT regardless of group as previous research has demonstrated that perceived competence is higher during tasks students perceive to be easier [256].

Similar to the enjoyment of HIIT, autonomous motivation towards HIIT remained stable during the *Making a HIIT* intervention. This is in line with two previous school-based HIIT studies where autonomous motivation was sustained for an 8-week and 12-month intervention [47, 133]. No previous school-based HIIT studies could be identified that have examined the basic psychological needs (autonomy, relatedness, or perceived competence) over time. In *Making a HIIT*, autonomy remained stable while relatedness and perceived competence had slight decreases over the HIIT intervention. The decrease in relatedness was less than half a point, so the meaningfulness of this decrease is unclear. However, future studies could consider incorporating more group work through HIIT protocols that include games or providing opportunities for continued student feedback throughout the intervention to support relatedness [257]. Similarly, the decrease in perceived competence was less than half a point, so the meaningfulness of this decrease is also unclear. However, it is worth noting that the HIIT only group trended towards improvement over time (Appendix 7E). Additionally, we did not expect to find a significant decrease in the perceived competence of the control group after only two HIIT sessions. This could be related to the Dunning-Kruger effect, where those unskilled and unknowledgeable in an area tend to overestimate their ability [258]. Self-efficacy towards HIIT remained stable over time in *Making a HIIT*, which was similar to the *Pau te Hau* study that included students of the same year levels and an intervention of the same duration [215]. However, this differed to the Burn2Learn school-based HIIT study, where self-efficacy towards HIIT was improved for the intervention group compared with a control group over the intervention [133], but this study was conducted with older students and spanned a much longer duration (6-months) which could have enabled students with greater confidence in their ability to compete the workouts [133].

Strengths and limitations

The strengths of *Making a HIIT* can be attributed to its methodology. According to recommendations, the co-design process in phase one was guided by a framework on participatory methods and grounded in self-determination theory [58, 160]. The intervention in phase two included measures based on existing valid and reliable instruments that have been used in similar contexts. Further, the study incorporated blinded researchers for data collection to limit bias. However, some limitations should be acknowledged. While the sample of students came from three heterogeneous schools around the Greater Brisbane Area enabling generalisability, the findings might be specific to the age of the participants due to the perceived barriers to physical activity and level of perceived competence and autonomy afforded to students at this age. Further, data regarding basic psychological needs during HIIT was not collected prior to completing the co-design process in phase one, which could have provided a more robust understanding of the effect of the co-design process.

Future Directions

As mentioned in the limitations, future work should investigate the impact of using co-design with different year levels to those within the *Making a HIIT* study. Specific consideration should be given to upper year levels (the final three years of secondary school) where students are afforded greater autonomy in their lessons and may have higher gross motor competence [259]. Additionally, future research should examine the effect of supporting students' basic psychological needs beyond co-designing the workouts. This could include involving students to lead or co-lead the workouts by demonstrating exercises. Further, it could involve students and teachers co-designing various aspects of intervention schedule (e.g., when the workout occurs during HPE, which workout is used during each lesson, whether equipment and music can be used when possible). These aspects will be important to consider in order to improve our ability to create engaging programs that effectively support student's basic psychological needs, but consideration on the time, money, and lesson disruption required by these must also be considered to ensure the intervention remains feasible.

Conclusions

Making a HIIT provides further evidence that HIIT workouts are perceived neutrally to positively in the school setting and that student enjoyment and autonomous motivation in HIIT interventions remain stable over time. Future research focused on school-based HIIT should consider how to further support students' basic psychological needs during interventions. While there was no effect of the co-design process on the outcome variables, it was promising to see that the co-design process could support the creation of HIIT workouts that sustained neutral to positive ratings for enjoyment and autonomous motivation throughout the 8-week intervention.

Chapter 8: The Effect of HIIT on Fitness and Executive Functioning

Justification of chapter within the thesis

Investigating the effect of school-based high-intensity interval training (HIIT) on cardiorespiratory fitness, muscular power, and executive functioning was one of the overarching aims of the *Making a HIIT* study as described in *Chapter Three* and is presented in this final experimental chapter. This chapter utilises the results of *Chapter Five* and *Chapter Six* to investigate if the level of implementation influenced the impact of HIIT by using attendance and heart rate data in sensitivity analyses. It also builds on the work of *Chapter Seven* by assessing whether involvement in the co-design process could have moderated the outcomes within this chapter. This chapter includes only two of the three schools as the first school served only as a pilot for the co-design process.

The effect of a school-based HIIT intervention on student's cardiorespiratory fitness, muscular fitness, and executive function: Findings from *Making a HIIT*

Abstract

Background: Phase two of the *Making a HIIT* study incorporated an 8-week high-intensity interval training (HIIT) intervention within Health and Physical Education (HPE) lessons using HIIT workouts that had been co-designed previously with teachers and students. The primary aim of this study was to examine the effect of the intervention on students' cardiorespiratory fitness (CRF). Secondary aims included examining the effect of the intervention on students' muscular fitness, inhibition, and working memory.

Methods: Students (aged 12 – 14 years) from twelve classes at two schools participated in this portion of *Making a HIIT*. Eight classes (n = 185 students, 86 girls) completed the HIIT intervention, which consisted of a 10-minute co-designed workout at the start of each HPE lesson for 8-weeks. Four classes (n = 73 students, 39 girls) acted as a control group and continued their normal HPE lessons. Before and after the intervention, students completed a 20-metre shuttle run (CRF), standing long jump (muscular fitness), antisaccade task (inhibition), and visual arrays task (working memory). Mixed-effects models were used to assess changes over time and between groups.

Results: There were no significant differences between groups over time. However, both groups had a statistically significant improvement in their CRF (p = 0.004), muscular fitness (p < 0.001), and inhibition (p < 0.001) over time. There were no significant changes to working memory.

Conclusion: An 8-week intervention delivered during HPE using co-designed HIIT workouts had no effect on cardiorespiratory fitness, lower limb muscular fitness, or executive function over time. This could be partially explained by the low dosage of HIIT completed by the intervention group (one 10-minute workout per week) or due to the comparable amount of high-intensity activity completed by the control group during the intervention. It will be important for future studies to consider how to increase the dosage of HIIT received by students, possibly by integrating HIIT into other timepoints in the school day, and to ensure that the control group's activity is monitored to enable a proper between group comparison.

Introduction

Participation in physical activity can improve cardiorespiratory fitness and muscular fitness, in children and adolescents [260, 261]. These components of fitness are associated with health benefits such as decreased adiposity, lower arterial stiffness, and improved bone health [260, 261]. Further, they are associated with a reduced risk of obesity, morbidity, and mortality later in life [260, 262, 263]. Beyond fitness, participation in physical activity can also improve children and adolescents' executive function [264, 265]. Executive function is a set of control processes that enable individuals to manage their thoughts, attention, and actions in goal-driven behaviour, and is strongly associated with academic performance, and social relationships among students [266, 267]. Despite the benefits of participating in physical activity, only one quarter of Australian children and adolescents meet the recommended national physical activity guidelines [5, 6]. Further, both international and Australian data have indicated that children's cardiorespiratory and muscular fitness have declined over the last 30 years [268, 269].

High-intensity interval training (HIIT) is a contemporary strategy for acquiring vigorous physical activity that includes short bouts of high-intensity exercise interspersed with periods of rest or passive recovery. [270]. Literature demonstrates that vigorous physical activity might be driving some of the improvements in fitness and executive function [28, 271]. Within schools, HIIT is growing in popularity, as it is seen to be a time-efficient approach that minimises disruption to curriculum and free time Previous systematic reviews focused specifically on school-based HIIT have demonstrated improvements in both cardiorespiratory, and muscular fitness relative to control groups [73, 155, 225, 270]. Additionally, preliminary evidence indicates that school-based HIIT can contribute to improvements in executive functioning [35].

Currently, the majority of school-based HIIT studies have involved maximal efforts on a bike or running track, which may limit engagement from children and adolescents [155, 226]. Further, most of the completed studies have been completed under controlled conditions within the school setting, where they have been led by a researcher, included a small sample of students, and lacked integration with the school system, which limits scalability [155]. Therefore, there is a need to evaluate the effect of novel HIIT workouts used during real-world interventions that are led by teachers and conducted across multiple classes and schools [226]. The *Making a HIIT* study sought to address these limitations by incorporating co-design to create HIIT workouts with students and teachers as part of the HPE curriculum. This led to the creation of unique HIIT workouts, which aimed to increase student engagement (*Chapter Four)*. Further, the *Making a HIIT* intervention was implemented by teachers and completed across multiple classes and schools within HPE lessons. The primary aim of this chapter was to examine the effect of an 8-week HIIT intervention with co-designed HIIT workouts from the *Making a HIIT* study on students' cardiorespiratory fitness. Additionally, it aimed to understand the effect of the intervention on students' muscular fitness and executive function.

Methods

Study Overview

The *Making a HIIT* study (Trial Registration: ACTRN, ACTRN12622000534785) was completed in three secondary schools (one co-educational school, one all-boys school, and one all-girls school) around Greater Brisbane, Australia. The first school (co-educational) was used as a pilot school and was excluded from this chapter as fitness and cognitive measures were not collected at this school. *Making a HIIT* was completed with grade 7 and 8 students (aged 12 – 14 years) and teachers as part of the health and physical education (HPE) curriculum. Within each school, there were three groups: 1) the co-design group, who was involved in the creation of the HIIT workouts and subsequently used the HIIT workouts in HPE for a term; 2) the HIIT only group, who used the HIIT workouts in HPE (but was not involved in the co-design of the HIIT workouts); and 3) the control group, who continued with normal HPE lessons. *Making a HIIT* was approved by The University of Queensland's human research ethics committee (Project: 2020/HE002444) and relevant governing bodies and gatekeepers. Teachers provided written informed consent. Parents and students provided written informed consent and assent, respectively.

The two phases of *Making a HIIT* have previously been described in detail in *Chapter Three* but pertinent information is restated here. In phase 1, classes in group one co-designed HIIT workouts with researchers and teachers in an iterative process across several HPE lessons. In this process, each class created criteria for the workouts based on identified barriers and facilitators to exercise. Each class also established the parameters for the workouts, including the target heart rate, and maximum and minimum interval lengths. Then, groups of three to five students each designed a 10-minute HIIT workout. Students trialled the workouts and received peer feedback and heart rate data to modify their workouts in line with the criteria and parameters established in the previous lessons. Due to this process, HIIT workouts varied in terms of theme (e.g., sport-specific, home workouts), percentage of time in work (average = 65%, range: 53 - 75%), and work and rest intervals (range 10 - 60 seconds), although running-based intervals were the most common.

This chapter relates to the intervention that occurred in phase 2 of the study. In this phase, the co-design group (Group 1) and HIIT only group (Group 2) were joined to form an intervention group. They used the co-designed HIIT workouts in an 8-week intervention between one and two times a week as outlined in *Chapter Five*. Each workout was 10 minutes in length and completed at the start of the HPE lesson. In the all-boys school, all workouts were completed during practical lessons either in the school gymnasium or on the field. At the all-girls school, the workouts were completed in both theory and practical classes occurring in the classroom, gymnasium, or field. The number of HIIT workouts completed by the classes across the two schools ranged between 7 and 12. Teachers received the workouts in a laminated booklet prior to the start of the term and reviewed them with a researcher in order to ensure they felt prepared to lead them and to address any questions or concerns that they had. Students were encouraged to provide maximal effort during the 'work' periods by both the teacher and researcher throughout the workout.

Design and Procedure

All measures were collected by trained research assistants who were blinded to the group allocation of each class. Data were collected during HPE lessons before and after the HIIT intervention using the same protocol at both time points as shown in Figure 15. The time of day that data collection occurred varied based on the HPE schedule of each class. During a practical lesson, students completed a battery of tests in the following order: 1) cardiorespiratory fitness test; 2) standing long jump; 3) measurement of stature and body mass. Prior to each measure, researchers provided instructions using a standardised script (Appendix 8). On a separate day, students completed a second battery of tests in the following order: 1) executive function tasks; 2) Physical Activity Questionnaire for Older Children (PAQ-C); and 3) Physical Activity Enjoyment Scale (PACES). These tests were completed under examination-like conditions during a theory lesson. Prior to starting the executive function tasks, students received instructions for the entire battery of tests from researchers using a standardised presentation.

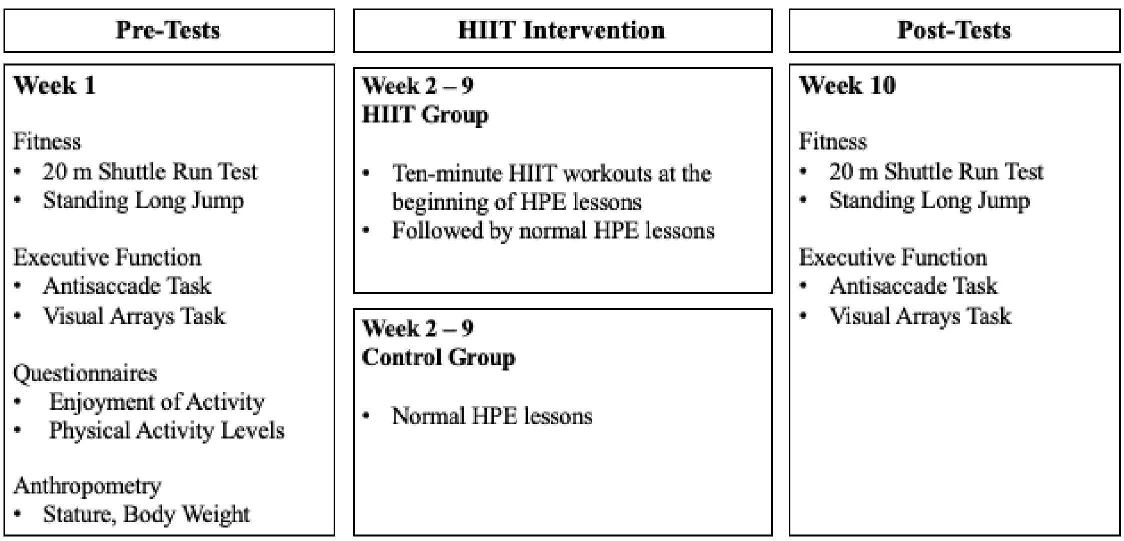


Figure 15. *Intervention Procedure*

Schematic outlining the measures collect before and after the 8-week HIIT intervention. HPE = health and physical education; HIIIT = high-intensity interval training.

Measures

Outcome Variables

Cardiorespiratory fitness was the primary outcome of *Making a HIIT*. It was measured using the 20 meter shuttle run test [171], which is the most commonly used field test for cardiorespiratory fitness [173] and is typically incorporated as part of the HPE curriculum. This test has a moderate to high criterion-related validity against directly determined peak oxygen uptake expressed relative to body mass (r_p = 0.62-0.84) in adolescents [173, 174]. At the beginning of the HPE lesson, each class of participating students was provided with an explanation of the test based on a script, to ensure each class received the same information. This script outlined to students that they would need to run 20 meters, as indicated by cones, between beeps. This would start at 8.5 km/h and increase by 0.5 km/h each level, with participants encouraged to continue in tempo with the beeps and to do their best to see how long they could run. Each student was allowed to miss the line once. The test was terminated the second time they missed the line. Researchers recorded the number of laps each participant successfully completed. The full class participated in the test at the same time. The test was conducted inside the school gymnasium for all but one instance, where an outdoor basketball court was used. Each student wore a numbered sticker on their sleeve and researchers were responsible for recording data for between seven and nine students on a provided score sheet. At the end of the test, students were provided with a water and rest break prior to commencing the standing long jump test.

The **standing long jump** was used to measure lower leg muscular fitness. This test is valid (r = 0.70 with 1 repetition leg extension) and strongly associated with other lower body strength tests (r = 0.83 and r = 0.86 for the countermovement and vertical jumps, respectively) and upper body strength tests (r = 0.69 and r = 0.85 for isometric strength and overhead throws, respectively), making it a suitable general indicator of muscular fitness in youth [175-177]. Further, it is commonly used within the HPE curriculum [47, 87, 89, 110, 121]. Students received both standardised instructions and a demonstration of the jump from the researcher. When participating in this test, they were required to wear their HPE footwear, had to use a two-foot take-off and landing, and were permitted to swing their arms. Similar to the 20-m shuttle run test, this occurred in the school gymnasium for all but one instance, where an outdoor basketball court was used. Students had three attempts; the distance of each jump was recorded in centimetres and their best attempt was used for analysis.

Executive function includes the components of shifting, inhibition, and working memory [1]. The tasks in *Making a HIIT* were used to assess students' inhibitory control of attention and working memory [179]. Inhibitory control of attention refers to one's ability to suppress attention to other stimuli and focus on what is needed, while working memory refers to one's ability to hold information in mind and manipulate it [272]. These two components are strongly related and generally co-occur [272]. Due to this, time constraints, and the ability to compare our data to previously literature [78, 85, 110, 119], the tasks within *Making a HIIT* focused on these two components of executive function. Inhibition was measured using an antisaccade task and working memory was measured using a visual arrays task. The tasks were created with PsychoPy software [178]. Students completed the tasks on their school laptops under examination-like conditions. The tasks were randomised so half the students started with the antisaccade task and half with the visual arrays task. Prior to the tests, a researcher explained both tests to the class using a standardised presentation with examples of each test and was present to answer any questions throughout the tests (Appendix 9). These tests were piloted with a class of Year 8 students who did not participate in this phase of *Making a HIIT*. Modifications based on the pilot test were described in *Chapter Three*.

The antisaccade task predominately measures inhibitory control of attention and has previously been used in an exercise intervention trial with adolescents [180]. This task has good internal consistency (r = 0.92) and test-retest reliability (r = 0.71) in adults aged 18 – 35 years [179]. For this task, students focused on a fixation cross in the centre of their screens. After a visual cue, an asterisk appeared on one side of the screen, followed by a Q or O on the opposite side that was immediately covered by "##". Students needed to determine which letter was presented by typing an O or Q on the keyboard. The number of correctly identified letters was recorded. The visual arrays task measures the capacity of students' working memories and attention control [179]. The visual arrays task has good internal consistency (r = 0.75) and test-retest reliability (r = 0.67) in adults aged 18 – 35 years [179] and has previously been used in children as young as ten years old [181]. Students were shown an array of blue and red rectangles after being instructed to focus on one of the two colours. Subsequently, only the colour they were asked to remember reappeared on screen with one rectangle labelled using a white dot. Students needed to determine if that rectangle changed orientation from the original display by pressing a 5 or 6 on the keyboard. The capacity score *(k)*, which provides a measure of working memory capacity, was determined using the equation $N \times (\text{Hits} + \text{Correction} + \text{Rejections} - 1)$, where N is the set-size for the array [179].

Confounding Variables

Stature was measured using a portable stadiometer (Seca 213 Portable stadiometer). Students were asked to remove their shoes and stand with their feet together and their heels against the back of the stadiometer while keeping their knees straight. Their stature was recorded to the nearest 0.01 m. Body mass was measured using a calibrated scale (Seca 762 Mechanical flat scale). Students were asked to remove shoes and heavy clothing and stand on the scale facing forward with their arms by their side. Body mass was recorded to the nearest 0.1 kg. Body mass index (BMI) was calculated as (body mass (kg) divided by stature (m) squared). Age and sex specific percentile-based BMI cut points based on normative data from the Centre for Disease Control were used to determine weight categories [165]. Students self-reported their sex and birthdate. Maturity status was calculated using an offset score from peak height velocity due to the invasive nature and logistical challenges of other measures [273]. For girls, this equation was $Maturity\ offset = (-8.128741 - 0.2683693) + (0.0070346 * (age * height))$ with a correlation coefficient of 0.90 and a standard error of the estimate of 0.528 [273]. For boys, it was $Maturity\ offset = -7.999994 + (0.0036124 * (age * height))$ with a correlation coefficient of 0.90 and a standard error of the estimate of 0.542 [273]. Pre-peak height velocity was categorised as a maturity offset less than -1; circa-peak height velocity was categorised as a maturity offset between -1 and +1; and post-peak height velocity was categories as a maturity offset greater than +1. Enjoyment of general physical activity was collected using the valid and reliable PACES questionnaire, which includes 16 statements that are ranked on a 5-point Likert scale from 1 (Disagree a lot) to 5 (Agree a lot) [194]. Enjoyment was calculated by averaging students' responses to the 16 phrases for a total score between one and five, with higher scores indicating greater levels of enjoyment. Physical activity levels were determined with the PAQ-C, which is valid and reliable in children [166-168]. Physical activity levels were calculated by averaging students' responses to each of the 9 statements to generate a score between one and five where a higher number indicated greater physical activity levels.

Data Analysis

Data analysis was conducted in R (Version 4.2.0; The R Foundation for Statistical Computing, Vienna, Austria). Alpha was set at 0.05. Descriptive statistics were calculated for all outcomes. Baseline differences between the two groups were assessed with an independent t-test or a Wilcoxon rank sum test depending on the normality of the data. Multi-level regressions were used to assess changes over time between groups adjusted for confounding factors. The unadjusted model included fixed effects for group (HIIT or Control), time (Pre-intervention or post-intervention), and group-by-time interaction. The adjusted models included confounding variables (sex; BMI category; maturity offset; total PAQ-C score; and total PACES score). The adjusted models included confounding variables (sex; BMI category; total PAQ-C score; and total PACES score). Maturity offset was not included as a confounding variable within the models due to its correlation with sex. All the girls included in the model were post peak height velocity compared to only two boys. The models used random intercepts to account for the clustering of the data by class and the repeated measure for each student. These regressions were completed using completed cases formed using list-wise deletion of observations. The assumptions of the model (normally distributed residuals; linearity; collinearity; homogeneity of variance) were assessed and met. In addition, two sensitivity analyses were performed for the primary outcome using student attendance and heart rate data based on the process evaluation in *Chapter Five*: 1) students who participated in ≥ 80% of the delivered HIIT workouts; 2) students who achieved a mean heart rate of ≥ 80% across the HIIT workouts. The authors considered a third sensitivity analysis combining both attendance and heart rate; however, the small sample size would not have enabled meaningful conclusions.

Results

The flow of participants throughout the study is presented in Figure 16. In total, 12 classes and 258 students from two schools completed the intervention within *Making a HIIT* study (48% female, average age 13.0 ± 0.6 years) (Table 20). Table 21 displays the average values for the four outcome variables before and after the intervention for the HIIT and control groups. These are also visually depicted in Figure 17. There were no statistically significant differences between the groups for any of the outcome variables at baseline.

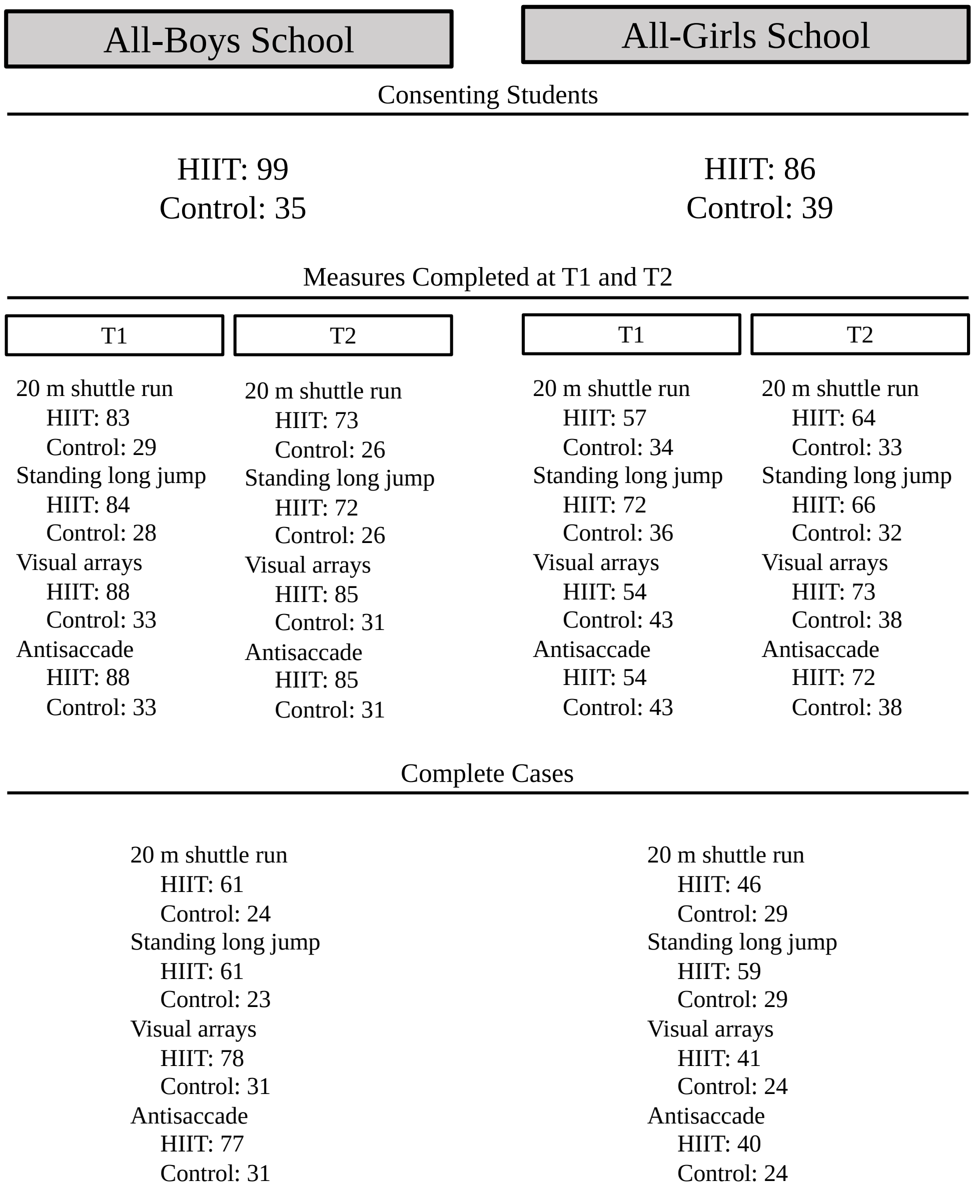


***Figure 16**. The number of participants that completed each questionnaire*.

A flow chart outlining the number of students who participated in each measurement at pre-intervention and post-intervention, and the number of students who completed measurements at both timepoints.

Table 20. *Participant demographics.*

	HIIT	Control
Classes (n)	8	4
Students (n)	185	73
Girls/Boys (n)	86 / 99	39 / 34
Age (years)	13.0 ± 0.6	12.9 ± 0.7
Stature (cm)	160.4 ± 7.9	160.6 ± 8.7
Body mass (kg)	54.0 ± 13.4	54.9 ± 14.7
Pre-PHV/ circa-PHV/ Post-PHV [a] (n)	13/70/76 [b]	1/28/37 [b]
Overweight/Obese [c] (n)	50 / 34	26 / 16
PAQ-C Score [d] (/5)	2.9 ± 0.8	2.9 ± 0.8
PACES Score [e] (/5)	3.7 ± 0.8	3.9 ± 0.7

The participant characteristics of the students involved in the *Making a HIIT* study.
[a] Maturity offset was calculated using students' age and height [273]. Pre-peak height velocity (PHV) indicates scores less than -1; crica PHV indicates scores between -1 and +1, and post-PHV indicates scores greater than +1.
[b] Maturity data was not calculated for 26 students in the HIIT group and 7 students in the control group due to missing height data.
[c] Overweight and Obese classifications were determined using percentile-based body mass index cut points from the Center for Disease Control [165].
[d] PAQ-C = Physical Activity Questionnaire for Older Children, which provides an overall score between 1 and 5 indicating how active a student is, where a higher score indicates more activity.
[e] PACES = Physical Activity Enjoyment Scale, which provides an overall score between 1 and 5 indicating students' enjoyment of general physical activity, where a higher score indicates greater enjoyment.
HIIT = high-intensity interval training.
PHV = peak height velocity.

Table 21. *Descriptive statistics for outcome measures.*

	Full Sample				Girls				Boys			
	HIIT		**Control**		**HIIT**		**Control**		**HIIT**		**Control**	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
20 m shuttle run (Laps completed) ⸸	35 (20-57)	40 (23-52)	29 (20-51)	33 (22-58)	21 (15-32)	24 (16-33)	25 (14-31)	24 (14-33)	46 (35-64)	50 (38-62)	51 (28-68)	56 (37-77)
Standing long jump (cm) Ψ	163 ± 23	168 ± 26	166 ± 32	173 ± 30	153 ± 22	158 ± 25	150 ± 26	160 ± 26	173 ± 23	177 ± 25	186 ± 27	191 ± 26
Antisaccade (Test accuracy percentage) ⸸	63 (51-74)	69 (53-83)	64 (56-77)	75 (55-88)	59 (47-72)	74 (57-84)	59 (51-69)	65 (53-75)	63 (53-76)	67 (51-81)	72 (59-85)	83 (63-92)
Visual arrays (*k*) Ψ	1.2 ± 1.0	1.1 ± 1.0	1.4 ± 1.0	1.3 ± 1.1	1.0 ± 0.8	1.1 ± 0.9	1.1 ± 0.9	1.0 ± 1.0	1.3 ± 1.0	1.0 ± 1.1	1.7 ± 1.0	1.5 ± 1.2

Descriptive statistics for each outcome variable before and after the intervention for the high-intensity interval training (i.e., intervention) and control groups. This is provided as a full sample and stratified by sex.
Pre = prior to the 8-week high-intensity interval training (HIIT) intervention; Post = after the 8-week HIIT intervention.
Ψ mean ± standard deviation
⸸ median (interquartile range)

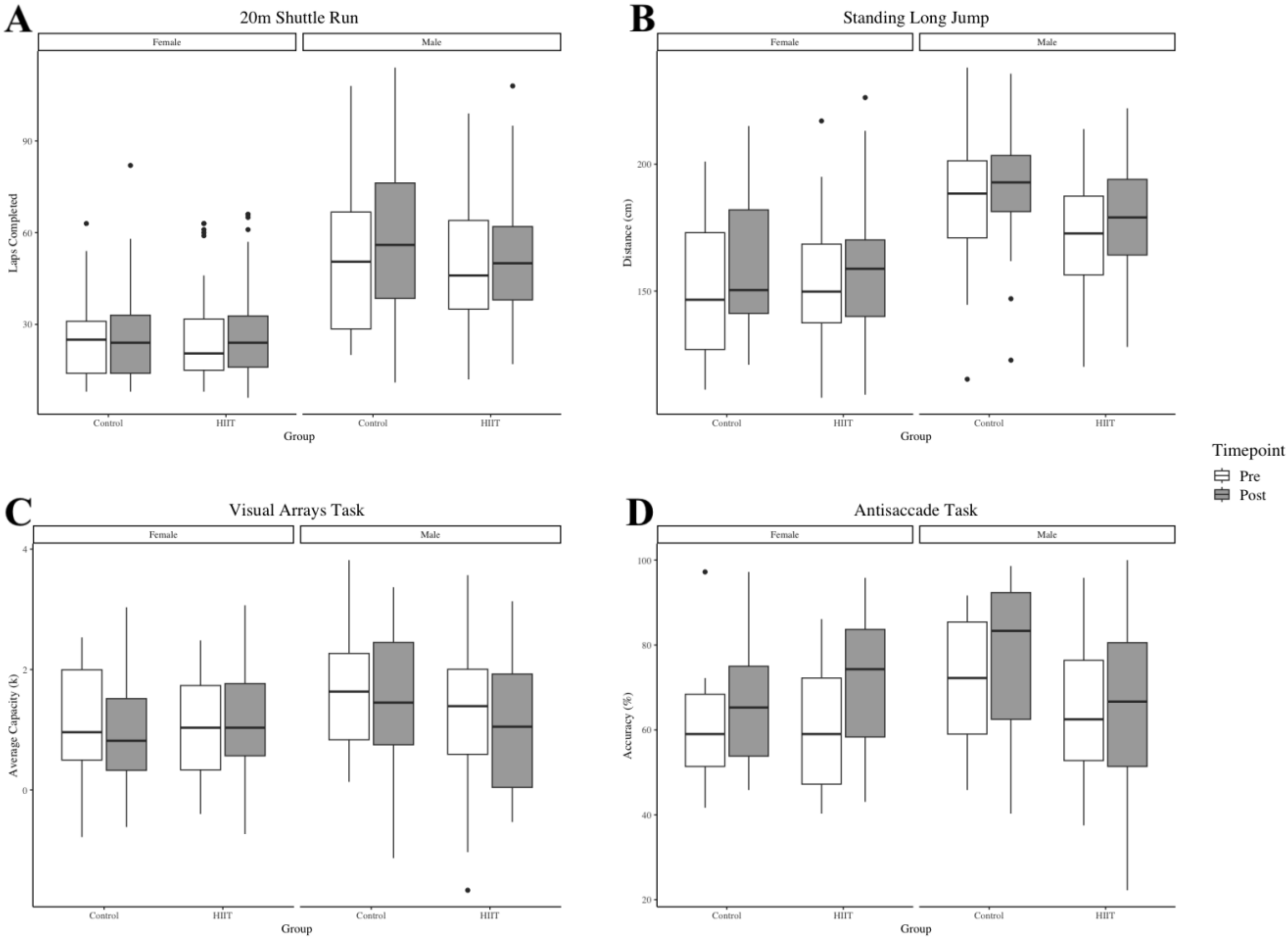


Figure 17*. The result for all four outcomes at both time points for the intervention and control group by sex.*

A. The number of laps completed during the 20-meter shuttle run by the high-intensity interval training (HIIT) group and control group at the pre-intervention and post-intervention timepoints stratified by males and females. **B**. The distance jumped (cm) during the standing long jump by the HIIT group and control group at the pre-intervention and post-intervention timepoints stratified by males and females. **C**. The average capacity (*k)* during the visual arrays task by the HIIT group and control group at the pre-intervention and post-intervention timepoints stratified by males and females. **D**. The accuracy (%) during the antisaccade task by the HIIT group and control group at the pre-intervention and post-intervention timepoints stratified by males and females.

.

The adjusted multi-level models for all four outcomes are presented in Appendix 10. The model for the number of laps completed during the 20-meter shuttle run test (primary outcome) indicated that there was a significant improvement over time ($\beta = 3.06$ laps; $p = 0.004$). However, there was no significant difference in the group-by-time interaction, indicating that both groups improved equally over time. This was the same when only students with > 80% attendance ($n = 73$) were included in the model. When only students with a heart rate average of > 80% of their maximum heart rate ($n = 68$) were used to form the HIIT group, there was a significant value for time ($\beta = 3.00$ laps; $p = 0.006$) and group ($\beta = -9.56$; $p = 0.038$), but not the interaction term. This indicates that both groups improved equally over time, but the HIIT group ran fewer laps at both timepoints.

With regard to secondary outcomes, there was an improvement in the distance jumped post-intervention ($\beta = 5.89$ cm; $p < 0.001$), but there was no significant difference between groups in the model for standing long jump. Similarly, there was an improvement over time in the antisaccade task accuracy ($\beta = 4.23$ percentage points; $p < 0.001$), but no difference between the HIIT and control groups. In the visual arrays task, there were no significant differences between groups or changes over time.

Discussion

Within *Making a HIIT*, there were improvements to students' cardiorespiratory fitness, muscular fitness, and inhibition over time; however, there were no differences between the HIIT and control groups over time. For cardiorespiratory fitness, this differs from most previous school-based HIIT research, as demonstrated by a meta-analysis on school-based HIIT that identified improvements in the HIIT group compared to the control for 18 of 25 studies [155]. However, the majority of these studies occurred under controlled, researcher-led conditions [155]. Muscular fitness has been examined less frequently, but 3 of 5 studies included in a meta-analysis on school-based HIIT determined there was no effect from the intervention [47, 121, 133], which was in line with the findings from *Making a HIIT*. *Making a HIIT* and the other three studies with null findings all included resistance exercises, which was recommended by a systematic review and meta-analysis to improve muscular fitness from HIIT protocols [37]. Interestingly, the two studies with improvements to muscular fitness only included running-based exercises [87, 89]. Four previous school-based HIIT studies have investigated effects on executive function tasks, with heterogeneity in the results [78, 85, 119, 133]. Similar to *Making a HIIT*, three of four studies examining working memory noted no change over time [85, 119, 133]. The one study with improvements to working memory made use of video-based HIIT workouts for 10-year-old students and also noted improved inhibition compared to controls [119]. However, in the two other studies examining inhibition, while there was an improvement in the HIIT group, it was not significantly different from the control group, which matches the findings of *Making a HIIT* [78, 85].

Unlike *Making a HIIT*, the majority of previous literature on school-based HIIT has been researcher-led, conducted on a small-scale, and not designed for integration within the school setting [155]. It is well-established that there is a decrease in effect as interventions transition from efficacy to effectiveness to scale-up trials [19], which could partly explain the differences in the results between *Making a HIIT* and previous studies. When compared to other school-based HIIT studies conducted in 'real-world' context, the findings of *Making a HIIT* are more similar [133, 215]. Pilot evidence from the *Pau te Hau* study that integrated 15-minute HIIT workouts into HPE for 8-weeks with 12-year-old students found no significant difference between the HIIT and control groups for cardiorespiratory fitness or lower limb muscular fitness (number of squats), which echo the findings of *Making a HIIT* [215]. However, they did find a significant improvement to upper limb muscular fitness (number of pull-ups) in the HIIT group [215], which could be an important outcome to investigate when HIIT protocols include resistance exercises targeting these muscles. Another 'real-world' trial that included integration within schools through teacher-led workouts was *Burn2Learn* [133]. However, unlike *Making a HIIT* and *Pau te Hau*, both of which included only two schools, *Burn2Learn* was a large multi-school randomised-control trial of 20 schools [133] and targeted older students (16-year-olds) [133]. Similar to *Making a HIIT*, at the end of the 6-month *Burn2Learn* intervention, there was no improvement to the executive function or lower limb muscular fitness of the HIIT group compared to the control group [133]. Though contrary to *Making a HIIT* and *Pau te Hau* [215], Burn2learn reported that cardiorespiratory fitness significantly improved in the HIIT group compared to the control group [133]. However, unlike in *Making a HIIT,* the control group within *Burn2Learn* had a significant decrease in their cardiorespiratory fitness from baseline, which could partly explain the difference in this outcome [133], and prompts a deeper investigation into the *Making a HIIT* control group.

As the HIIT workouts during *Making a HIIT* were completed during HPE lessons, the control group was still completing physical activity as part of their lessons. As discussed in *Chapter Five*, these lessons occurred during units on touch football and athletics, which both elicit high-intensity aerobic exercise. On average, the control group still spent 5.5 minutes with a heart rate ≥ 80% of their maximum heart rate in their practical HPE lessons (*Chapter Five*), which was only 3.5 minutes less than the HIIT group and had the potential to provide benefits to this group as well. This could explain why improvements occurred in both groups, with no significant difference between the groups over time. Future studies focused on increasing the amount high-intensity physical activity offered to students should consider current opportunities available and aim to supplement units, lessons, or timepoints during the school day where this type of activity does not occur. Similarly, as discussed in *Chapter Five*, monitoring the control group as part of the process evaluation is an important component for understanding the effects of the intervention.

Another ramification of the 'real world' implementation of *Making a HIIT* was the dosage of HIIT completed. While the aim of *Making a HIIT* was to include 2 workouts per week, this was impacted by curricular demands, classroom sizes, and issues with student uniforms (*Chapter Five*) and therefore, *Making a HIIT* only included an average of 1 workout (10 minutes of HIIT) per week for 8 weeks. While observational data indicates that as little as 10 minutes of vigorous physical activity per day is associated with health improvements [28], most of the current school-based HIIT interventions have included a higher total volume of HIIT [155]. Previous school-based HIIT studies that have completed under 100 minutes of HIIT included a before-school dance HIIT for girls aged 10 years [90], a running-based HIIT for students aged 17 years in HPE [114], and a combined resistance and aerobic HIIT during HPE for 15 – 16-year-old students [84]. Among these, only the running-based study showed significant improvements to cardiorespiratory fitness for the HIIT group compared to the control group [114]. Consistent with *Making a HIIT*, the other two studies noted significant improvements in both groups and may indicate that this volume of HIIT is not enough to elicit benefits [84, 90]. Lastly, it is important to note that there is substantial heterogeneity in the current school-based HIIT literature that includes students of varying ages, different school contexts and facilitators for workouts, and a large range of HIIT protocols, which could all influence the outcomes of the intervention [155].

Making a HIIT was the first school-based HIIT study to include workouts designed by students and teachers. As such, there is variation between workouts completed during different weeks and at different schools within the study (*Chapter Three*). However, there were minimal differences in the sustained intensity between the workouts with an average heart rate of 78% ± 4% of maximum heart rate (*Chapter Five*), indicating that contemporary HIIT workouts can elicit an intensity stimulus in line with previous running and cycling variations of HIIT workouts [155]. This finding leads us to assume that the intensity of the workouts was most likely not a possible explanation for the null findings within the *Making a HIIT* study.

Future implications

Future 'real-world' studies will need to consider the volume of HIIT provided as part of the intervention and methods for increasing this to match the frequency of controlled studies, which tend to include 2 – 3 workouts per week [155]. Factors such as curricular demands, classroom sizes and student uniforms vary between schools and require that the implementation is adaptable for different school environments. *Making a HIIT* was designed using the Theory of Expanded, Enhanced, and Extended Opportunities and focused on enhancing current opportunities for physical activity [57]. This was done to both provide students with the opportunity for high-intensity physical activity (phase two of *Making a HIIT*), but also to facilitate curriculum integration and educative outcomes during phase one of *Making a HIIT*. Future studies could consider expanding these opportunities by using different segments of or around the school day to provide opportunities for HIIT, such as theory HPE lessons, recess and lunch breaks, lessons other than HPE, or before and after school. All these segments of the day tend to be low in physical activity but could be effectively used to provide physical activity opportunities [274, 275]. Further, such opportunities could be important to consider when the HPE units being completed already provide students with the opportunity for high-intensity physical activity. Another option for increasing the volume of HIIT would be to increase the duration of the intervention, as a relevant meta-regression demonstrated that intervention duration moderated the effect of HIIT on body fat percentage [155]. Designing studies that are longer in duration will also aid in understanding the sustainability of this type of intervention.

The provision of resources and training for teachers will also be important for future studies. A systematic review on teacher training in school-based physical activity interventions identified that studies that provide: 1) ongoing teacher support; 2) comprehensive subject and pedagogy content to teachers; 3) evaluation of teacher satisfaction with training; and 4) training framed by theories are more effective for improving student physical activity outcomes [276]. Researchers from *Making a HIIT* provided support to teachers through: 1) leading the lessons to co-design the HIIT workouts (*Chapter Three*); 2) meeting with each teacher prior to the intervention to discuss the workouts and provide clarification where necessary; and 3) attending each practical HPE lesson during the intervention to administer heart rate monitors and collect fidelity data. However, this could have been aided by additional training sessions to outline the benefits of providing HIIT and by evaluating teacher satisfaction with the training, both which could promote better buy-in to the program [276]. The *Burn2Learn* study completed a 5-hour professional learning workshop for teachers that was followed by the creation of an agreed upon action plan and session observation and feedback from researchers [277]. Teachers rated these resources as 3.1/4 on average, although similar to *Making a HIIT*, they still noted that the time required for the intervention was too high, especially during periods of the year with high curricular demands [106]. Future studies focused on this area will deepen our understanding of the level of support that teachers require, which can aid in the scale-up and sustainability of these programs [226].

Strengths and limitations

To limit bias within the results, *Making a HIIT* used blinded outcome measurements, accounted for confounding factors, and used sensitivity analyses to investigate deviations from the intended intervention using attendance and heart rate data. However, the data collection for *Making a HIIT* had limitations that must be acknowledged. Due to its 'real-world' implementation, the outcome variables were assessed in HPE lessons during the first and last week of term, which for certain classes occurred at different times of day at the two time points. This had the potential to influence results, especially for aspects of executive function for which research has indicated peak in the morning [278]. Further, while a randomised control trial would have been the preferred method for assessing the effect of HIIT, due to pragmatic reasons randomisation could not occur. Additionally, as both conditions of the intervention occurred at each school, there is the potential for contamination to occur, but this was done to ensure the co-design process resulted in workouts that were specific to the school and students. Lastly, while the 20-meter shuttle run is the most common field test for cardiorespiratory fitness [173], recent evidence has brought the validity of the test into question and has determined that within boys aged 11 – 14 years it is a better reflection of fatness than fitness [279]. However, using this measure did permit comparison with other school-based literature [155].

Conclusions

Overall, the intervention used as part of the *Making a HIIT* study had no effect on improving cardiorespiratory fitness, muscular fitness, or executive function compared to a control group. This could be attributed to the 'real world' implementation of this study, which led to lower dosage of HIIT than intended or possibly due to the amount of high-intensity work completed by the control group in HPE. It will be important for future 'real-world' studies to factor attendance and intensity into investigations on the effect of HIIT. Further, it will be important for researchers to consider how to increase the frequency of the HIIT workouts within the school day without impacting curricular demands or burdening teachers. This could potentially be completed by providing HIIT workouts at various points throughout the school day or enhancing the training that teachers receive.

Chapter 9: General Discussion

This chapter provides a detailed evaluation of the key findings within this thesis and presents future research directions based on this work. It highlights the significant and novel contributions that this thesis made to the literature on school-based high-intensity interval training (HIIT) through two major studies. These contributions include: 1) involving end-users through the co-design of HIIT workouts; 2) conducting an in-depth process evaluation to understand the implementation of the intervention; and 3) evaluating methods used to assess fidelity in school-based HIIT interventions. Combined, these contributions significantly enhance our understanding of school-based HIIT in an ecologically valid manner. Finally, this chapter highlights the strengths and limitations of this thesis work and discusses some practical applications.

Setting the scene: The current evidence-base

The first study (*Chapter Two*) within this thesis was a systematic review and meta-analysis that aimed to synthesise the current research in school-based HIIT. It determined that compared to a control group, the group completing HIIT had significant improvements to waist circumference, body fat percentage, body mass index, cardiorespiratory fitness, resting heart rate, insulin resistance, and low-density lipoprotein. However, there was insufficient evidence to claim that HIIT was superior or inferior to other exercise modalities for health benefits due to a sample of only 13 studies and large heterogeneity between the comparator exercise modalities. Overall, these results suggested that HIIT can provide educators with an additional option for promoting vigorous intensity physical activity in this setting. Further, it indicated that HIIT should be considered by school staff, policy makers, and public health practitioners as a viable strategy for youth to acquire physical activity. However, the quality of the included studies was poor, with 36 of the 42 included studies classified as having a high risk of bias. This was most often due to missing data and deviations from the intended intervention. Further, integral to this thesis, *Chapter Two* also identified that the included studies had limited involvement of end-users, minimal integration within school practice, and poorly documented evaluations of their intervention implementation.

The areas of bias and the limitations identified in *Chapter Two* informed the second study of this thesis, *Making a HIIT*, which was presented across *Chapters Three* to *Eight*. *Making a HIIT* included two phases. The first phase involved co-designing HIIT workouts with Year 7 and 8 students and teachers as part of their Health and Physical Education (HPE) curriculum. This phase was guided by self-determination theory and aimed to increase students' autonomy, relatedness, and perceived competence towards HIIT during their HPE lessons to encourage autonomous motivation. It was also guided by the theory of expanded, extended, and enhanced opportunities and aimed to enhance HPE lessons through the co-design process. The second phase of *Making a HIIT* involved using these workouts in an 8-week intervention within HPE lessons and comparing outcomes among three groups: 1) those completing the intervention who were involved in the co-design process; 2) those only completing the intervention; and 3) a control group who continued normal HPE lessons. The key concepts from *Making a HIIT* are explored in depth below along with recommendations for future research and provision of HIIT in schools.

Involvement of end-users: Positive findings... but can we do better?

Involving students and teachers in design and decision making can strengthen research projects for several reasons. It provides students with a voice, and can enhance their confidence and skill acquisition [205]. Further, it enhances relevant projects through a better understanding of student and teacher needs by involving them as experts [203]. In this thesis, involvement of students and teachers occurred through the process of co-design, which was defined as an active collaboration with end-users to design solutions to pre-specified problems [24]. This enabled the first phase of *Making a HIIT* to be integrated within the curriculum, which, as described in *Chapter Four*, was determined to be feasible. Previous literature corroborates that co-design methods are feasible with school-aged children as they have previously been used to design healthy dairy products [212], school buildings [213], and new technology [214]. Within *Making a HIIT*, both students and teachers expressed satisfaction with the co-design lessons and students noted that they had more freedom and ownership during these lessons compared with their normal HPE lessons. This was consistent with the intentions of the co-design process and in line with self-determination theory, which guided the study. Teachers stated that the lessons aligned with the Australian HPE curriculum for Years 7 and 8 and that there were portions of the lessons they intended to use again. Further, the co-design process within *Making a HIIT* promoted educational outcomes, such as measuring heart rate and designing personal fitness plans. Additionally, the process improved participating students' personal and social capabilities, such as their social skills and management skills through collaboration and teamwork. Altogether, these findings support the continued involvement of teachers and students in designing components of school-based HIIT interventions.

While the original intention of *Making a HIIT* was to enable a higher level of end-user participation, co-design was selected as it provided students with the highest possible level of involvement, while being able to integrate into a single unit and term within the HPE curriculum. *Making a HIIT* intentionally targeted Years 7 and 8 due to the curriculum components aligned with HIIT and because

HPE is still compulsory, enabling a greater reach; however, the teachers involved in the co-design process recommended incorporating it into upper year electives in future. These electives provide more freedom within their curriculum and have fewer time constraints. Further, working with older students who tend to be afforded more autonomy and responsibility could enable increased end-user involvement, such as co-creation, which involves students and teachers in the identification of problems in addition to the creation of solutions [24]. Previously, co-creation has been successfully incorporated into schools during lunch breaks with Year 10 girls [280]. The process led to three different interventions at the three involved schools: 1) sport sessions at lunch breaks using sports that are not usually a part of HPE lessons; 2) the creation of a Facebook page that included resources for at-home workouts and healthy recipes; and 3) excursions to a local park to do a sports activities during lunch breaks [280]. As students are also involved with problem identification, the range of interventions developed is greater than with co-design, where the researcher comes with an identified problem [24]. Therefore, while problem identification was not the intention of *Making a HIIT*, which focused specifically on HIIT, general physical activity interventions could consider this higher level of involvement and future HIIT focused studies could consider providing students with the opportunity to decide when and where to complete HIIT during the school day.

Further along the end-user involvement continuum is participatory action research, which aims to empower students to develop and implement interventions [281]. This has previously been completed during upper year HPE electives (in the final three years of secondary school) over the course of a year, where girls aged 15 – 19 years met for two hours a week and were involved in negotiating their curriculum [150]. It has also been completed after school over the span of two years [282]. This process involved students aged 9 – 12 years meeting weekly or fortnightly to developed interventions focused on their identified issues such as, outdoor play, drinking more water at school, and girls-only activity sessions [282]. Both these studies required a large amount of time due to the nature of participatory action research and therefore, while this method is feasible within schools and the curriculum, it will be important for researchers to consider the trade-off between the level of end-user involvement and the required time for them to appropriately select a method that is both feasible and enables the highest possible level of participation. Additionally, engaging teachers as stakeholders will be critical for ensuring that the method of involvement is appropriate within the school and class context and minimises the burden on teachers and on students' education through relevant integration.

Lessening end-user engagement does not completely negate the intervention's burden on curriculum time, which is known to be a common barrier for most physical activity interventions [10]. Within *Making a HIIT*, teachers occasionally expressed challenges related to time constraints. This led to teachers aiding students to lead their pilot workouts instead of affording them this autonomy during phase one. Additionally, teachers removed the option for students to include equipment or music in their workouts to make the setup more efficient during the second phase of the study. Curriculum integration within phase two of *Making a HIIT* could have been enhanced by designing HIIT workouts that aligned to the unit being completed during the HPE lessons, which could have relieved some of the issues related to time constraints. However, this would need to be weighed against the loss in autonomy provided to students by enabling them to choose a workout theme and exercises based on their interests.

The changes that the teachers made to the co-designed workouts to increase efficiency may have impacted students' enjoyment, autonomous motivation, and basic psychological needs (autonomy, relatedness, and perceived competence) during the intervention as examined in *Chapter Seven*. Aligning phase two more deeply to self-determination theory could have continued to foster students' basic psychological needs by enabling them to: 1) decide when HIIT workouts occur within a lesson instead of stipulating their use as a warmup; 2) decide which HIIT workout to complete during each lesson instead of having a prespecified order; 3) aid in leading or demonstrating the exercises within the HIIT workouts; and 4) use equipment and music during HIIT workouts where appropriate. Very few previous school-based studies have focused on the basic psychological needs of students during HIIT interventions. The *Burn2Learn* study provided the choice of 11 different workouts and, similar to *Making a HIIT*, found autonomous motivation remained stable throughout the intervention [133]. A second study compared a HIIT condition where students could choose the exercises (autonomous) to a condition where the teacher could choose the exercises (non-autonomous) and determined that students had significantly greater enjoyment during the autonomous condition [50]. It will be important for future work to continue the investigation into promoting students' basic psychological needs during HIIT interventions, with this statement echoed by a recent paper on scaling HIIT [226]. However, it was promising to find that the enjoyment and autonomous motivation towards the HIIT workouts during *Making a HIIT* remained stable throughout the intervention and that the co-design process was feasible within the HPE curriculum.

Future Recommendations

Future school-based HIIT interventions should continue to involve students and teachers in their design and implementation, while ensuring that the level of participation is feasible within the allocated time and curriculum constraints. This will hopefully aid in mitigating the burden of the intervention on teachers by providing them with the necessary resources for implementation and by accounting for the varying demands that occur throughout the school term. Further, involving students in multiple components of the intervention design can provide them with a voice and increase the potential that the intervention is engaging and useful for them [158]. Lastly, future work should continue to focus on students' enjoyment, autonomous motivation, and basic psychological needs by considering contemporary HIIT protocols such as HIIT games and providing students with choice during the workouts.

Implementation: Understanding school context to HIIT the spot

Phase two of *Making a HIIT* incorporated an 8-week intervention within HPE lessons. Students who completed the HIIT workouts had improvements to their cardiorespiratory fitness, standing long jump, and antisaccade test. However, these improvements were no different from the control group. The in-depth process evaluation completed in *Making a HIIT* provided possible explanations for these findings. Firstly, it indicated that the dosage of HIIT completed by students was low in comparison to previous school-based HIIT interventions, with only three other studies delivering a total volume of HIIT less than 100 minutes [84, 90, 114]. Like *Making a HIIT*, two of the three studies found no difference between the HIIT and control groups for these measures [90, 114]. Unfortunately, these outcomes were only measured in the two schools in *Making a HIIT* where HIIT was completed on average once a week and therefore, comparisons could not be made to the third school that served as our co-design pilot school and where HIIT was completed on average twice a week (as intended).

The low dosage of HIIT completed in the two schools can be attributed to two main factors: 1) uniform policies and 2) curricular demands. Both schools had a uniform policy that required students to wear a formal uniform throughout the day and only permitted students to change into their HPE uniform during practical HPE lessons. This led to one of the two schools opting to not complete HIIT during theory lessons within the classroom. Additionally, students who forgot their HPE uniform did not partake in practical HPE lessons and therefore, the HIIT workout, which decreased the dosage received by students. Comparatively, the third school that completed HIIT twice a week had a policy that permitted students to wear their HPE uniforms throughout the entire day during any day that included either practical or theory HPE lessons. Uniform policies are not an issue that is specific to HIIT interventions but are a consideration for physical activity interventions in general. Evidence demonstrates that uniform policies that permit students to wear their HPE uniform throughout the day are associated with a significant reduction in sedentary time and non-significant increases to light activity in 8 – 10 year old students [230]. Further, available findings indicate that most surveyed Australian parents (78%) support policies that enable students to remain in their HPE uniforms [231]. It is possible that schools with uniform policies that cater to enabling physical activity do so as part of a wider approach to provide opportunities for activity across the day. Therefore, beyond advocating for HPE uniforms throughout the school day, it will be important for researchers to advocate for general physical activity policies within the school setting and consider different school policies, including those related to uniforms while planning physical activity interventions to ensure that the intervention works within the individual school's context [217].

Curricular demands also contributed to the low dosage of HIIT in one school. Teachers at this school determined that completing a 10-minute workout during both HPE lessons each week would take away too much time from other content and therefore, opted to only complete one HIIT workout a week. As discussed in the previous section, a potential solution to this could have been designing HIIT workouts that related to the HPE unit for the term. Providing further teacher training and support could have also mitigated this issue as a systematic review on teacher training in school-based physical activity interventions identified that studies that were more effective in improving student physical activity outcomes provided: 1) ongoing teacher support; 2) comprehensive subject and pedagogy content to teachers; 3) evaluation of teacher satisfaction with training; and 4) training framed by theories [276]. Lastly, providing the option for teachers to lead HIIT workouts that require less time could also be an option with a previous school-based HIIT study noting that 8-minute HIIT workouts were administered more often than 4 or 12-minute HIIT workouts [106].

Beyond the low dosage of HIIT, the process evaluation demonstrated that the control group was also completing high-intensity exercise during HPE. They spent a median of 28% of their practical lessons, post receiving initial instructions, with a heart rate ≥ 80% of their maximum heart rate, which had the potential to provide benefits to this group as well. Previous research conducted in Year 7 and 8 HPE lessons in six schools in Australia determined that on average 13% to 21% of time was spent being 'very active' based on observational data, which corroborates the finding that HPE lessons do tend to provide this type of physical activity to students [283]. This indicates that HIIT is one of several ways to accumulate vigorous physical activity in HPE and that prior to implementing HIIT in HPE, the unit being completed in HPE should be considered, as it could be equally engaging and effective at promoting vigorous physical activity. Using the theory of expanded, extended, and enhanced opportunities as a guide [57], it could be beneficial for future studies to consider moving outside of HPE lessons to expand the opportunities that students have to complete HIIT. HIIT interventions have previously occurred in other classes, at lunch, and before and after school under controlled conditions [90, 95, 112, 146], but once again, the specific school context will need to be considered when deciding where and when to include HIIT [217].

Future Recommendations

Future HIIT and general physical activity interventions need to adaptable for different school contexts. Recent recommendations from experts in the field of school-based physical activity interventions suggest using a context-specific approach that includes 'essential' and 'peripheral' intervention components to enable local adaption in addition to the core intervention pieces [217]. Examples of this could include specifying a dosage of HIIT, but enabling students and teachers the freedom to decide where the HIIT workouts occur and when during the school day and lessons these occur. Providing teacher training and resources will be critical to prevent the voltage drop that is known to transpire as studies move from efficacy to effectiveness trials [226]. Studies that focus on educating teachers on the benefits of HIIT and provide pedagogy content associated with HIIT should be considered as studies transition from efficacy to effectiveness trials that involve teacher-led HIIT sessions. Finally, *Making a HIIT* occurred over a single school term, which is a common length for school-based HIIT studies as noted in *Chapter Two.* Future studies that incorporate longer interventions will be important to conduct as they can enable a larger dosage of HIIT to be accrued and will also permit the medium and long-term effects of HIIT interventions to be studied.

Finding the HI in HIIT: Measurement of intensity in schools

A specific area of the implementation of HIIT interventions that warrants further consideration is intensity. As literature indicates that physical activity at a higher intensity might be the driving force behind some health benefits provided by physical activity [28], measuring the intensity of HIIT is important for both understanding the effect of HIIT and ensuring that the "HIIT" being completed is in fact high-intensity. The systematic review in *Chapter Two* indicated that a large portion of the current school-based HIIT literature did not report if the intended intensity was achieved during the interventions. Further, when the studies did report intensity data, this was most commonly reported as an average heart rate across all intervention sessions and participants. However, as *Chapter Six* discusses, this does not enable variation between individuals, within individuals, or across the intervention timeline to be assessed. *Chapter Six* outlines additional methods of presenting the heart rate data to capture variation, including 1) time spent in various heart rate zones (e.g., 70 – 79%, 80 – 89%, 90 – 100%) to present readers with a clearer picture of students' overall intensity across the workout; 2) the number of students that achieved an average heart rate above a threshold to understand between student variation; 3) using mixed models to understand variability both between and within individuals and across the intervention timeline for both average and peak heart rate. All three of these methods have previously been used in the school-based HIIT literature in conjunction with reporting a mean average heart rate to provide further interpretation of the intensity achieved during the intervention [106, 109, 118, 147]. Understanding variation is crucial to evaluating relevant interventions as HIIT is prescribed on an individual level and should be monitored similarly. In doing this, researchers will be able to assess the effect of HIIT with an accurate per-protocol approach that incorporates both attendance and intensity [147].

Based on *Chapter Two*, most studies that have used heart rate to measure intensity have either included a small number of participants or only measured intensity in a subset of their participants. *Making a HIIT* used Polar H10 monitors to capture heart rate data for all the HIIT workouts completed during practical HPE lessons. However, this was costly and required substantial resources (both the number of heart rate monitors and researchers' time). Additionally, appropriate positioning the heart rate monitors required additional time during the HPE lesson, which took away from curriculum time, thus heart rate monitors were not used in theory HPE lessons within the classroom. Previous literature has acknowledged that the time and cost associated with heart rate can lead to it not being viable in the school setting [227]. Contemporary HIIT protocols that incorporate games or partner exercises may also complicate capturing heart rate data as not all students are working and resting at the same time. Due to this, it is important to investigate other methods of evaluating intensity.

Making a HIIT also used a sessional rating of perceived exertion (RPE) to assess intensity, which was cost-effective and time efficient. The within-person correlation between the training load from heart rate and sessional RPE was low (0.39). It was within the range of coefficients compiled in a review assessing the validity of sessional RPE, but it was on the lower end; however, most of the included studies in the specific review used standard exercise protocols with motivated athletic populations [239]. Further, the correlation coefficient was similar to correlation coefficients for the association between objective physical activity measures and 'valid' physical activity questionnaires, such as the International Physical Activity Questionnaire and the Physical Activity Questionnaire for Older Children [284, 285], indicating that this type of intensity measurement could be a viable alternative when heart rate is not an option. Previous work examining RPE after each interval in a group of adolescent boys completing 8 x 1 minute work intervals indicated that there was a significant increase in RPE through the intervals and that while the group completing HIIT started with an RPE similar to a group doing moderate intensity intervals, there was a significant group by time interaction throughout the intervals with the HIIT group ending the workout with a significantly higher RPE [45]. This provides promising data on the use of RPE for measuring intensity during HIIT workouts, but more work is needed to understand the relationship between sessional RPE and intensity to appropriately use it as an indicator when it is not feasible to complete RPE after each interval.

Future Recommendations

A key finding from *Chapter Two* was that future studies need to report intensity data to aid in understanding if the intervention was completed as intended. Beyond reporting an average of all sessions and students, it will be important to acknowledge variation between students, within students, and across the intervention timeline. Intensity data should be incorporated into per-protocol analysis and sensitivity analyses in addition to attendance data to understand the true dosage of HIIT completed during the intervention and its effect on the targeted outcomes. To achieve this, researchers should consider what intensity data are available based on their data collection methods. It will also be important for future studies to continue to examine intensity of HIIT within the classroom either using RPE or a less invasive and time-consuming heart rate monitor, such as an arm band.

Further, more research needs to be completed on alternate measures of intensity, especially as school-based HIIT interventions shift from small efficacy trials to larger interventions aimed at maintenance and scale up. Time efficient and cost-effective measures will be important when researchers become less involved to ensure that the burden on teachers and school staff is minimised. Further research on sessional RPE should be considered to properly establish cut-offs for interval training exercise and determine its suitability for measuring intensity compared with heart rate and RPE taken after each work interval.

Strengths and limitations

The main study of this thesis addressed several limitations identified in the school-based HIIT literature. It integrated the creation of HIIT workouts into the curriculum to minimise the burden on curricular demands and involved end-users to co-design HIIT workouts that engaged students and were suitable for the specific school. The co-design process was grounded in theory and guided by a framework to strengthen its implementation. The intervention that made use of these workouts was assessed using a comprehensive process evaluation to provide detailed and nuanced insight into its implementation. *Making a HIIT* was conducted in three schools varying in affluence, school system, and composition of students, enabling a greater understanding of the generalisability and adaptability of the intervention. However, due to the nature of the school setting, several aspects of student ownership could not be completed as originally planned due to time constraints, such as the students leading their HIIT workouts during the trailing of workouts in phase one or the incorporation of equipment into the workouts during phase two. Incorporating a similar program in senior subjects might allow for more student autonomy to negate this limitation. As the outcome measurements were completed during HPE lessons instead of outside school hours, the pre-intervention and post-intervention data collection were completed at different times of day, which is particularly important for the cognitive outcomes and could have affected the findings. Further, the dosage of HIIT delivered to the students was less than intended and future studies should continue to try and address the challenges that are present within the school setting by providing adaptable and context specific interventions that integrate within the school day. The studies in this thesis occurred during the COVID-19 pandemic and the 2022 Brisbane floods, which required alterations to parts of the original study plan that involved data collection in Exeter, England and prevented international investigation of the *Making a HIIT* study. This also prevented earlier contact with schools, which would have enabled greater stakeholder engagement and possibly enabled enough buy-in to run a randomised control trial instead of a quasi-experimental intervention. The lack of differences for outcomes between groups could also be due to the non-randomised study design, which may have introduced bias. Snap lockdowns, required isolations, and the floods could also have caused a decrease in student attendance throughout *Making a HIIT*. Further, these events could have impacted findings due to the known decline in physical activity within this population during the pandemic [286]. However, the willingness of schools to work with researchers to implement physical activity programming during this uncertain time should be viewed positively for future studies targeting schools.

Where to next? Practical applications from *Making a HIIT*

School-based HIIT has the potential to be a viable public health option and provide children and adolescents with opportunities to accumulate vigorous intensity physical activity during the school day. The findings of *Making a HIIT* indicate that: 1) on average, the 10-minute HIIT workouts in HPE lessons provided students with 4.5 minutes of exercise at ≥ 80% of their heart rate maximum; 2) the enjoyment of the workouts was rated as neutral to positive; and 3) the workouts were feasible to complete during HPE lessons. However, the following findings from *Making a HIIT* should be considered to increase the potential that school-based HIIT interventions are implemented as intended and provide benefits to students:

- Integration of HIIT-related concepts and co-design opportunities within the curriculum can provide educative outcomes to students in addition to improving their personal and social capabilities.
- Involvement of teachers and students in HIIT interventions is beneficial, but the amount of involvement should be considered based on the time allotted for the intervention and the age of students to ensure that the involvement is genuine and feasible.
- Decisions around the incorporation of HIIT within the day should be school specific and consider available space, uniform policies, HPE units, and already existing physical activity programming.

- Providing teachers with training on the benefits of HIIT and how to lead HIIT, along with pedagogy content associated with HIIT should be considered to aid in implementation.
- HIIT workouts within the classroom setting will need to consider available space, lesson content, and uniform policies, but could provide a compelling alternative to completing HIIT only in HPE lessons.
- The HIIT workouts and the intervention should be theory-driven and aim to meet students' basic psychological needs (autonomy, competence, and relatedness) to increase students' autonomous motivation towards completing HIIT.
- Monitoring and evaluation of the implementation of HIIT programs should be conducted to ensure that implementation is occurring as intended and to enable modifications when deemed necessary.
- Understanding the dosage of HIIT completed by students by factoring in both attendance and intensity is necessary to fully understand the effect of HIIT interventions.
- HIIT programs that span across a semester, a full school-year or longer are needed to understand the longer-term effects of HIIT.

Conclusion

This thesis made significant and novel contributions to the literature on school-based HIIT through co-designing HIIT workouts, conducting an in-depth process evaluation to understand the implementation of the intervention, and evaluating methods used to assess the intensity of HIIT in this setting. Combined, the findings of this thesis enhance our understanding of school-based HIIT in an ecologically valid manner. The *Making a HIIT* study within this thesis identified challenges associated with the implementation of HIIT in schools that warrant future investigation, but also determined that students are already actively engaging in some high-intensity activity during HPE in these years. Overall, school-based HIIT has the potential to be a viable public health option and integrating HIIT within the curriculum can support various health and educative outcomes for students on their journey to becoming independent, educated, and physically active individuals.

References

1. De Greeff JW, Bosker RJ, Oosterlaan J, Visscher C, Hartman E: **Effects of physical activity on executive functions, attention and academic performance in preadolescent children: a meta-analysis**. *Journal of Science and Medicine in Sport* 2018, **21**(5):501-507.
2. Poitras VJ, Gray CE, Borghese MM, Carson V, Chaput J-P, Janssen I, Katzmarzyk PT, Pate RR, Gorber SC, Kho ME *et al*: **Systematic review of the relationships between objectively measured physical activity and health indicators in school-aged children and youth**. *Applied Physiology, Nutrition, and Metabolism* 2016, **41**(6 (Suppl. 3)):S197-S239.
3. Telama R, Yang X, Viikari J, Välimäki I, Wanne O, Raitakari O: **Physical activity from childhood to adulthood: A 21-year tracking study**. *American Journal of Preventive Medicine* 2005, **28**(3):267-273.
4. Department of Health: **Australian 24-Hour Movement Guidelines for Children (5-12 years) and Young People (13-17 years): An Integration of Physical Activity, Sedentary Behaviour, and Sleep**. In. Canberra, Australia; 2019: https:// www.health.gov.au/health-topics/physical-activity-and-exercise/physical-activity-and-exercise-guidelines-for-all-australians/for-children-and-young-people-5-to-17-years.
5. Hesketh KD, Booth V, Cleland V, Gomersall SR, Olds T, Reece L, Ridgers ND, Straker L, Stylianou M, Tomkinson GR *et al*: **Results from the Australian 2022 Report Card on physical activity for children and young people**. *Journal of exercise science and fitness* 2022, **21**(1):83-87.
6. Active Healthy Kids Australia: **Reboot! Reimagining Physically Active Lives: 2022 Australian Report Card on Physical Activity for Children and Young People.** In. Melbourne, Victoria; 2022.
7. Aubert S, Barnes JD, Demchenko I, Hawthorne M, Abdeta C, Abi Nader P, Adsuar Sala JC, Aguilar-Farias N, Aznar S, Bakalár P *et al*: **Global Matrix 4.0 Physical Activity Report Card Grades for Children and Adolescents: Results and Analyses From 57 Countries**. *Journal of Physical Activity and Health* 2022, **19**(11):700-728.
8. World Health Organization: **Global action plan on physical activity 2018--2030: more active people for a healthier world**. In. Geneva: World Health Organization; 2018.
9. Milton K, Cavill N, Chalkley A, Foster C, Gomersall S, Hagstromer M, Kelly P, Kolbe-Alexander T, Mair J, McLaughlin M *et al*: **Eight Investments That Work for Physical Activity**. *Journal of Physical Activity and Health* 2021, **18**(6):625-630.
10. Booth M, Okely A: **Promoting physical activity among children and adolescents: the strengths and limitations of school-based approaches**. *Health Promotion Journal of Australia* 2005, **16**(1):52-54.
11. Watson A, Timperio A, Brown H, Best K, Hesketh KD: **Effect of classroom-based physical activity interventions on academic and physical activity outcomes: a systematic review and meta-analysis**. *International Journal of Behavioral Nutrition and Physical Activity* 2017, **14**(1).
12. Kriemler S, Meyer U, Martin E, van Sluijs EMF, Andersen LB, Martin BW: **Effect of school-based interventions on physical activity and fitness in children and adolescents: a review of reviews and systematic update**. *British Journal of Sports Medicine* 2011, **45**(11):923-930.
13. Demetriou Y, Höner O: **Physical activity interventions in the school setting: A systematic review**. *Psychology of Sport and Exercise* 2012, **13**(2):186-196.
14. Dobbins M, Husson H, Decorby K, Larocca RL: **School-based physical activity programs for promoting physical activity and fitness in children and adolescents aged 6 to 18**. *Cochrane Database of Systematic Reviews* 2013.

15. Love R, Adams J, Sluijs EMF: **Are school-based physical activity interventions effective and equitable? A meta-analysis of cluster randomized controlled trials with accelerometer-assessed activity**. *Obesity Reviews* 2019, **20**(6):859-870.
16. Harris KC, Kuramoto LK, Schulzer M, Retallack JE: **Effect of school-based physical activity interventions on body mass index in children: a meta-analysis**. *Canadian Medical Association Journal* 2009, **180**(7):719-726.
17. Naylor P-J, Nettlefold L, Race D, Hoy C, Ashe MC, Wharf Higgins J, McKay HA: **Implementation of school based physical activity interventions: A systematic review**. *Preventive Medicine* 2015, **72**:95-115.
18. Cassar S, Salmon J, Timperio A, Naylor P-J, Van Nassau F, Contardo Ayala AM, Koorts H: **Adoption, implementation and sustainability of school-based physical activity and sedentary behaviour interventions in real-world settings: a systematic review**. *International Journal of Behavioral Nutrition and Physical Activity* 2019, **16**(1).
19. McCrabb S, Lane C, Hall A, Milat A, Bauman A, Sutherland R, Yoong S, Wolfenden L: **Scaling-up evidence-based obesity interventions: A systematic review assessing intervention adaptations and effectiveness and quantifying the scale-up penalty**. *Obes Rev* 2019, **20**(7):964-982.
20. Bond B, Weston K, Williams C, Barker A: **Perspectives on high-intensity interval exercise for health promotion in children and adolescents**. *Open Access Journal of Sports Medicine* 2017, **Volume 8**:243-265.
21. Naylor PJ, McKay HA: **Prevention in the first place: schools a setting for action on physical inactivity**. *British Journal of Sports Medicine* 2009, **43**(1):10.
22. Education Services Australia: **Australian Student Wellbeing Framework**. In. Carlton South, VIC: Education Council Secretariat.
23. Sanders EBN, Stappers PJ: **Co-creation and the new landscapes of design**. *CoDesign* 2008, **4**(1):5-18.
24. Vargas C, Whelan J, Brimblecombe J, Allender S: **Co-creation, co-design, co-production for public health – a perspective on definitions and distinctions**. *Public Health Research & Practice* 2022, **32**(2):e322211.
25. World Health Organization: **WHO guidelines on physical activity and sedentary behaviour**. In. Geneva, Switzerland; 2020.
26. Ahmadi MN, Clare PJ, Katzmarzyk PT, del Pozo Cruz B, Lee I-M, Stamatakis E: **Vigorous physical activity, incident heart disease, and cancer: how little is enough?** *European Heart Journal* 2022.
27. Gralla MH, McDonald SM, Breneman C, Beets MW, Moore JB: **Associations of Objectively Measured Vigorous Physical Activity With Body Composition, Cardiorespiratory Fitness, and Cardiometabolic Health in Youth: A Review**. *American Journal of Lifestyle Medicine* 2019, **13**(1):61-97.
28. Tarp J, Child A, White T, Westgate K, Bugge A, Grøntved A, Wedderkopp N, Andersen LB, Cardon G, Davey R *et al*: **Physical activity intensity, bout-duration, and cardiometabolic risk markers in children and adolescents**. *International Journal of Obesity* 2018, **42**(9):1639-1650.
29. Buchheit M, Laursen PB: **High-Intensity Interval Training, Solutions to the Programming Puzzle**. *Sports Medicine* 2013, **43**(10):927-954.
30. Sanders T, Cliff DP, Lonsdale C: **Measuring Adolescent Boys' Physical Activity: Bout Length and the Influence of Accelerometer Epoch Length**. *PLoS ONE* 2014, **9**(3):e92040.
31. Chuensiri N, Tanaka H, Suksom D: **The Acute Effects of Supramaximal High-Intensity Intermittent Exercise on Vascular Function in Lean vs. Obese Prepubescent Boys**. *Pediatric Exercise Science* 2015, **27**(4):503-509.

32. Bond B, Hind S, Williams CA, Barker AR: **The Acute Effect of Exercise Intensity on Vascular Function in Adolescents**. *Medicine & Science in Sports & Exercise* 2015, **47**(12):2628-2635.
33. Harris NK, Dulson DK, Logan GRM, Warbrick IB, Merien FLR, Lubans DR: **Acute Responses to Resistance and High-Intensity Interval Training in Early Adolescents**. *J Strength Cond Res* 2017, **31**(5):1177-1186.
34. Engel F, Härtel S, Strahler J, Wagner MO, Bös K, Sperlich B: **Hormonal, Metabolic, and Cardiorespiratory Responses of Young and Adult Athletes to a Single Session of High-Intensity Cycle Exercise**. *Pediatric Exercise Science* 2014, **26**(4):485-494.
35. Leahy AA, Mavilidi MF, Smith JJ, Hillman CH, Eather N, Barker D, Lubans DR: **Review of High-Intensity Interval Training for Cognitive and Mental Health in Youth**. *Medicine & Science in Sports & Exercise* 2020, **52**:2224 - 2234.
36. Kranen SH, Oliveira RS, Bond B, Williams CA, Barker AR: **The acute effect of high- and moderate-intensity interval exercise on vascular function before and after a glucose challenge in adolescents**. *Experimental Physiology* 2021, **106**(4):913-924.
37. Costigan SA, Eather N, Plotnikoff RC, Taaffe DR, Lubans DR: **High-intensity interval training for improving health-related fitness in adolescents: a systematic review and meta-analysis**. *British Journal of Sports Medicine* 2015, **49**(19):1253-1261.
38. Eddolls WTB, McNarry MA, Stratton G, Winn CON, Mackintosh KA: **High-Intensity Interval Training Interventions in Children and Adolescents: A Systematic Review**. *Sports Medicine* 2017, **47**(11):2363-2374.
39. Logan GRM, Harris N, Duncan S, Schofield G: **A Review of Adolescent High-Intensity Interval Training**. *Sports Medicine* 2014, **44**(8):1071-1085.
40. Barnett EY, Ridker PM, Okechukwu CA, Gortmaker SL: **Integrating children's physical activity enjoyment into public health dialogue (United States)**. *Health Promotion International* 2019, **34**(1):144-153.
41. Wankel LM: **The importance of enjoyment to adherence and psychological benefits from physical activity**. *International Journal of Sport Psychology* 1993, **24**(2):151-169.
42. Ekkekakis P, Hall EE, Petruzzello SJ: **Variation and homogeneity in affective responses to physical activity of varying intensities: An alternative perspective on dose−response based on evolutionary considerations**. *Journal of Sports Sciences* 2005, **23**(5):477-500.
43. Ekkekakis P, Parfitt G, Petruzzello SJ: **The Pleasure and Displeasure People Feel When they Exercise at Different Intensities**. *Sports Medicine* 2011, **41**(8):641-671.
44. Biddle SJH, Batterham AM: **High-intensity interval exercise training for public health: a big HIT or shall we HIT it on the head?** *International Journal of Behavioral Nutrition and Physical Activity* 2015, **12**(1).
45. Malik AA, Williams CA, Weston KL, Barker AR: **Perceptual Responses to High- and Moderate-Intensity Interval Exercise in Adolescents**. *Medicine & Science in Sports & Exercise* 2018, **50**(5):1021-1030.
46. Cockcroft EJ, Williams CA, Tomlinson OW, Vlachopoulos D, Jackman SR, Armstrong N, Barker AR: **High intensity interval exercise is an effective alternative to moderate intensity exercise for improving glucose tolerance and insulin sensitivity in adolescent boys**. *Journal of Science and Medicine in Sport* 2015, **18**(6):720-724.
47. Costigan SA, Eather N, Plotnikoff RC, Taaffe DR, Pollock E, Kennedy SG, Lubans DR: **Preliminary efficacy and feasibility of embedding high intensity interval training into the school day: A pilot randomized controlled trial**. *Preventive Medicine Reports* 2015, **2**:973-979.
48. Ekkekakis P, Hartman ME, Ladwig MA: **A Methodological Checklist for Studies of Pleasure and Enjoyment Responses to High-Intensity Interval Training: Part II. Intensity, Timing of Assessments, Data Modeling, and Interpretation**. *Journal of Sport & Exercise Psychology* 2023, **45**(2):92-109.

49. Australian Curriculum Assessment and Reporting Authority (ACARA)**: The Australian curriculum: Health and Physical Education: Focus areas;** 2018**.** [https://www.australiancurriculum.edu.au/f-10-curriculum/health-and-physical-education/pdfdocuments/]
50. Burford K, Gillespie K, Jowers EM, Bartholomew JB: **Children's Enjoyment, Perceived Competency, and Vigorous Physical Activity during High-Intensity Interval Training in Physical Education**. *Research Quarterly for Exercise and Sport* 2021:1-10.
51. Malik AA, Williams CA, Weston KL, Barker AR: **Influence of personality and self-efficacy on perceptual responses during high-intensity interval exercise in adolescents**. *Journal of Applied Sport Psychology* 2021, **33**(6):590-608.
52. Lederman NG, Lederman JS: **What Is A Theoretical Framework? A Practical Answer**. *Journal of Science Teacher Education* 2015, **26**(7):593-597.
53. Grant C, Osanloo A: **Understanding, Selecting, and Integrating a Theoretical Framework in Dissertation Research: Creating the Blueprint for Your "House"**. *Administrative Issues Journal: Connecting Education, Practice, and Research* 2014, **4**(2):12-26.
54. McLeroy KR, Bibeau D, Steckler A, Glanz K: **An Ecological Perspective on Health Promotion Programs**. *Health Education Quarterly* 1988, **15**(4):351-377.
55. Sallis JF, Owen N: **Ecological Models of Health Behavior**. In: *Health Behavior: Theory, Research, and Practice.* edn. Edited by Glanz K, Rimer BK, Viswanath K: John Wiley & Sons, Incorporated; 2015.
56. Domitrovich CE, Bradshaw CP, Poduska JM, Hoagwood K, Buckley JA, Olin S, Romanelli LH, Leaf PJ, Greenberg MT, Ialongo NS: **Maximizing the Implementation Quality of Evidence-Based Preventive Interventions in Schools: A Conceptual Framework**. *Advances in School Mental Health Promotion* 2008, **1**(3):6-28.
57. Beets MW, Okely A, Weaver RG, Webster C, Lubans D, Brusseau T, Carson R, Cliff DP: **The theory of expanded, extended, and enhanced opportunities for youth physical activity promotion**. *International Journal of Behavioral Nutrition and Physical Activity* 2016, **13**(1).
58. Deci EL, Ryan RM: **Self-determination theory: A macrotheory of human motivation, development, and health**. *Canadian Psychology/Psychologie canadienne* 2008, **49**(3):182-185.
59. Deci EL, Ryan RM: **The" what" and" why" of goal pursuits: Human needs and the self-determination of behavior**. *Psychological Inquiry* 2000.
60. Barker AR, Gracia-Marco L, Ruiz JR, Castillo MJ, Aparicio-Ugarriza R, González-Gross M, Kafatos A, Androutsos O, Polito A, Molnar D *et al*: **Physical activity, sedentary time, TV viewing, physical fitness and cardiovascular disease risk in adolescents: The HELENA study**. *International Journal of Cardiology* 2018, **254**:303-309.
61. Carson V, Rinaldi RL, Torrance B, Maximova K, Ball GDC, Majumdar SR, Plotnikoff RC, Veugelers P, Boulé NG, Wozny P *et al*: **Vigorous physical activity and longitudinal associations with cardiometabolic risk factors in youth**. *International Journal of Obesity* 2014, **38**(1):16-21.
62. 2018 Physical Activity Guidelines Advisory Committee: **2018 Physical Activity Guidelines Advisory Committee Scientific Report**. In., 2nd edn. Washington, DC: US Department of Health and Human Services; 2018.
63. Department of Health & Social Care**: UK Chief Medical Officers' Physical Activity Guidelines** 2019**.** [https://www.gov.uk/government/publications/physical-activity-guidelines-uk-chief-medical-officers-report]
64. Cooper SB, Dring KJ, Nevill ME: **High-Intensity Intermittent Exercise: Effect on Young People's Cardiometabolic Health and Cognition**. *Current Sports Medicine Reports (Lippincott Williams & Wilkins)* 2016, **15**(4):245-251.

65. Martin-Smith R, Cox A, Buchan DS, Baker JS, Grace F, Sculthorpe N: **High Intensity Interval Training (HIIT) Improves Cardiorespiratory Fitness (CRF) in Healthy, Overweight and Obese Adolescents: A Systematic Review and Meta-Analysis of Controlled Studies**. *International Journal of Environmental Research and Public Health* 2020, **17**(8):2955.
66. Thivel D, Masurier J, Baquet G, Timmons BW, Pereira B, Berthoin S, Duclos M, Aucouturier J: **High-intensity interval training in overweight and obese children and adolescents: systematic review and meta-analysis**. *J Sports Med Phys Fitness* 2018, **27**:27.
67. Hsieh S-S, Chueh T-Y, Huang C-J, Kao S-C, Hillman CH, Chang Y-K, Hung T-M: **Systematic review of the acute and chronic effects of high-intensity interval training on executive function across the lifespan**. *Journal of Sports Sciences* 2020:1-13.
68. Cao M, Quan M, Zhuang J: **Effect of High-Intensity Interval Training versus Moderate-Intensity Continuous Training on Cardiorespiratory Fitness in Children and Adolescents: A Meta-Analysis**. *International Journal of Environmental Research and Public Health* 2019, **16**(9):1533.
69. Lonsdale C, Sanders T, Parker P, Noetel M, Hartwig T, Vasconcellos D, Lee J, Antczak D, Kirwan M, Morgan P *et al*: **Effect of a Scalable School-Based Intervention on Cardiorespiratory Fitness in Children: A Cluster Randomized Clinical Trial**. *JAMA Pediatr* 2021, **175**(7):680-688.
70. Kamath CC, Vickers KS, Ehrlich A, McGovern L, Johnson J, Singhal V, Paulo R, Hettinger A, Erwin PJ, Montori VM: **Behavioral Interventions to Prevent Childhood Obesity: A Systematic Review and Metaanalyses of Randomized Trials**. *The Journal of Clinical Endocrinology & Metabolism* 2008, **93**(12):4606-4615.
71. Metcalf B, Henley W, Wilkin T: **Effectiveness of intervention on physical activity of children: systematic review and meta-analysis of controlled trials with objectively measured outcomes**. *BMJ* 2012, **345**(7876):16.
72. Baker L, Rollo I, Stein K, Jeukendrup A: **Acute Effects of Carbohydrate Supplementation on Intermittent Sports Performance**. *Nutrients* 2015, **7**(7):5733-5763.
73. Delgado-Floody P, Latorre-Román P, Jerez-Mayorga D, Caamaño-Navarrete F, García-Pinillos F: **Feasibility of incorporating high-intensity interval training into physical education programs to improve body composition and cardiorespiratory capacity of overweight and obese children: A systematic review**. *Journal of Exercise Science & Fitness* 2019, **17**(2):35-40.
74. Murad MH, Asi N, Alsawas M, Alahdab F: **New evidence pyramid**. *Evidence Based Medicine* 2016, **21**(4):125-127.
75. Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, (editors) WV: **Cochrane Handbook for Systematic Reviews of Interventions**, 2 edn. Chichester (UK): John Wiley & Sons; 2019.
76. Smart NA, Waldron M, Ismail H, Giallauria F, Vigorito C, Cornelissen V, Dieberg G: **Validation of a new tool for the assessment of study quality and reporting in exercise training studies: TESTEX**. *Int J Evid Based Healthc* 2015, **13**(1):9-18.
77. Schünemann H, Brożek J, Guyatt G, Oxman A: **GRADE handbook for grading quality of evidence and strength of recommendations.** : The GRADE Working Group; 2013.
78. Ben-Zeev T, Hirsh T, Weiss I, Gornstein M, Okun E: **The Effects of High-intensity Functional Training (HIFT) on Spatial Learning, Visual Pattern Separation and Attention Span in Adolescents**. *Frontiers in Behavioral Neuroscience* 2020, **14**.
79. Egger M, Smith GD, Schneider M, Minder C: **Bias in meta-analysis detected by a simple, graphical test**. *BMJ* 1997, **315**(7109):629-634.
80. Sterne JAC, Egger M: **Funnel plots for detecting bias in meta-analysis**. *Journal of Clinical Epidemiology* 2001, **54**(10):1046-1055.

81. Higgins JPT, Thompson SG: **Controlling the risk of spurious findings from meta-regression**. *Statistics in Medicine* 2004, **23**(11):1663-1682.
82. Abassi W, Ouerghi N, Ghouili H, Haouami S, Bouassida A: **Greater effects of high-compared with moderate-intensity interval training on thyroid hormones in overweight/obese adolescent girls**. *Horm* 2020, **41**(4):25.
83. Adeniran SA, Toriola AL: **Effects of continuous and interval running programmes on aerobic and anaerobic capacities in schoolgirls aged 13 to 17 years**. *The Journal of Sports Medicine and Physical Fitness* 1988, **28**(3):260 - 266.
84. Alonso-Fernández D, Fernández-Rodríguez R, Taboada-Iglesias Y, Gutiérrez-Sánchez Á: **Impact of a HIIT protocol on body composition and VO2max in adolescents**. *Science & Sports* 2019, **34**(5):341-347.
85. Arariza A: **24 sessions of monitored cooperative high-intensity interval training improves attention-concentration and mathematical calculation in secondary school**. *Journal of Physical Education & Sport* 2018, **18**(3):1572-1582.
86. Baquet G, Berthoin S, Dupont G, Blondel N, Fabre C, van Praagh E: **Effects of high intensity intermittent training on peak VO2 in prepubertal children**. *Int J Sports Med* 2002, **23**(6):439-444.
87. Baquet G, Berthoin S, Gerbeaux M, Van Praagh E: **High-intensity aerobic training during a 10 week one-hour physical education cycle: Effects on physical fitness of adolescents aged 11 to 16**. *Int J Sports Med* 2001, **22**(4):295-300.
88. Baquet G, Gamelin FX, Mucci P, Thevenet D, Van Praagh E, Berthoin S: **Continuous vs. interval aerobic training in 8-to 11-year-old children**. *J Strength Cond Res* 2010, **24**(5):1381-1388.
89. Baquet G, Guinhouya C, Dupont G, Nourry C, Berthoin S: **Effects of a short-term interval training program on physical fitness in prepubertal children**. *J Strength Cond Res* 2004, **18**(4):708-713.
90. Boddy L, Stratton G, Hackett A, George K: **The effectiveness of a 'short, sharp, shock' high intensity exercise intervention in 11- and 12-year-old Liverpool schoolgirls.** *Arch Exerc Health Dis* 2010, **1**(1):19-25.
91. Bogataj S, Trajkovic N, Cadenas-Sanchez C, Sember V: **Effects of school-based exercise and nutrition intervention on body composition and physical fitness in overweight adolescent girls**. *Nutrients* 2021, **13**(1):1-12.
92. Buchan DS, Ollis S, Thomas NE, Buchanan N, Cooper SM, Malina RM, Baker JS: **Physical activity interventions: effects of duration and intensity**. *Scandinavian Journal of Medicine & Science in Sports* 2011, **21**(6):e341-e350.
93. Buchan DS, Ollis S, Young JD, Thomas NE, Cooper SM, Tong TK, Nie JL, Malina RM, Baker JS: **The Effects of Time and Intensity of Exercise on Novel and Established Markers of CVD in Adolescent Youth**. *Am J Hum Biol* 2011, **23**(4):517-526.
94. Camacho-Cardenosa A, Brazo-Sayavera J, Camacho-Cardenosa M, Marcos-Serrano M, Timon R, Olcina G: **Effects of High Intensity Interval Training on Fat Mass Parameters in Adolescents**. *Revista espanola de salud publica* 2016, **90**:e1-e9.
95. Chuensiri N, Suksom D, Tanaka H: **Effects of High-Intensity Intermittent Training on Vascular Function in Obese Preadolescent Boys**. *Childhood Obesity* 2018, **14**(1):41-49.
96. Costigan S, Ridgers N, Eather N, Plotnikoff R, Harris N, Lubans D: **Exploring the impact of high intensity interval training on adolescents' objectively measured physical activity: Findings from a randomized controlled trial**. *Journal of Sports Sciences* 2018, **36**(10):1087-1094.
97. Costigan SA, Eather N, Plotnikoff RC, Hillman CH, Lubans DR: **High-Intensity Interval Training for Cognitive and Mental Health in Adolescents**. *Medicine & Science in Sports & Exercise* 2016, **48**(10):1985-1993.
98. Cvetković N, Stojanović E, Stojiljković N, Nikolić D, Milanović Z: **Effects of a 12 week recreational football and high-intensity interval training on physical fitness in**

overweight children. . *Facta Universitatis: Series Physical Education & Sport* 2018, **16**(2):435-450.
99. Cvetković N, Stojanović E, Stojiljković N, Nikolić D, Scanlan AT, Milanović Z: **Exercise training in overweight and obese children: Recreational football and high-intensity interval training provide similar benefits to physical fitness**. *Scandinavian Journal of Medicine & Science in Sports* 2018, **28**:18-32.
100. Delgado-Floody P, Espinoza-Silva M, García-Pinillos F, Latorre-Román P: **Effects of 28 weeks of high-intensity interval training during physical education classes on cardiometabolic risk factors in Chilean schoolchildren: a pilot trial**. *European Journal of Pediatrics* 2018, **177**(7):1019-1027.
101. Elbe A-M, Wikman JM, Zheng M, Larsen MN, Nielsen G, Krustrup P: **The importance of cohesion and enjoyment for the fitness improvement of 8–10-year-old children participating in a team and individual sport school-based physical activity intervention**. *European Journal of Sport Science* 2017, **17**(3):343-350.
102. Espinoza-Silva M, Latorre-Roman PA, Parraga-Montilla J, Caamano-Navarrete F, Jerez-Mayorga D, Delgado-Floody P: **Response of obese schoolchildren to high-intensity interval training applied in the school context**. *Endocrinologia Diabetes y Nutricion* 2019, **66**(10):611-619.
103. Gamelin F-X, Baquet G, Berthoin S, Thevenet D, Nourry C, Nottin S, Bosquet L, Gamelin F-X, Nottin S: **Effect of high intensity intermittent training on heart rate variability in prepubescent children**. *European Journal of Applied Physiology* 2009, **105**(5):731-738.
104. Granacher U, Goesele A, Roggo K, Wischer T, Fischer S, Zuerny C, Gollhofer A, Kriemler S: **Effects and Mechanisms of Strength Training in Children**. *Int J Sports Med* 2011, **32**(5):357-364.
105. Haghshenas R, Jamshidi Z, Doaei S, Gholamalizadeh M: **The Effect of a High-intensity Interval Training on Plasma Vitamin D Level in Obese Male Adolescents**. *Indian Journal of Endocrinology and Metabolism* 2019, **23**(1):72-75.
106. Kennedy SG, Leahy AA, Smith JJ, Eather N, Hillman CH, Morgan PJ, Plotnikoff RC, Boyer J, Lubans DR: **Process Evaluation of a School-Based High-Intensity Interval Training Program for Older Adolescents: The Burn 2 Learn Cluster Randomised Controlled Trial**. *Children (Basel)* 2020, **7**(12):16.
107. Ketelhut S, Kircher E, Ketelhut SR, Wehlan E, Ketelhut K: **Effectiveness of Multi-activity, High-intensity Interval Training in School-aged Children**. *Int J Sports Med* 2020, **14**:14.
108. Lambrick D, Westrupp N, Kaufmann S, Stoner L, Faulkner J: **The effectiveness of a high-intensity games intervention on improving indices of health in young children**. *Journal of Sports Sciences* 2016, **34**(3):190-198.
109. Larsen MN, Nielsen CM, Orntoft C, Randers MB, Helge EW, Madsen M, Manniche V, Hansen L, Hansen PR, Bangsbo J *et al*: **Fitness Effects of 10-Month Frequent Low-Volume Ball Game Training or Interval Running for 8-10-Year-Old School Children**. *Biomed Res Int* 2017, **2017**:2719752.
110. Leahy AA, Eather N, Smith JJ, Hillman CH, Morgan PJ, Plotnikoff RC, Nilsson M, Costigan SA, Noetel M, Lubans DR: **Feasibility and Preliminary Efficacy of a Teacher-Facilitated High-Intensity Interval Training Intervention for Older Adolescents**. *Pediatric Exercise Science* 2019, **31**(1):107-117.
111. Leahy AA, Michels MFI, Eather N, Hillman CH, Shigeta TT, Lubans DR, Smith JJ: **Feasibility of test administration and preliminary findings for cognitive control in the Burn 2 learn pilot randomised controlled trial**. *Journal of Sports Sciences* 2020, **38**(15):1708-1716.
112. Logan GRM, Harris N, Duncan S, Plank LD, Merien F, Schofield G: **Low-Active Male Adolescents: A Dose Response to High-Intensity Interval Training**. *Medicine & Science in Sports & Exercise* 2016, **48**(3):481-490.

113. Martin R, Buchan DS, Baker JS, Young J, Sculthorpe N, Grace FM: **Sprint interval training (SIT) is an effective method to maintain cardiorespiratory fitness (CRF) and glucose homeostasis in Scottish adolescents**. *Biology of Sport* 2015, **32**(4):307-313.
114. Martin-Smith R, Buchan DS, Baker JS, Macdonald MJ, Sculthorpe NF, Easton C, Knox A, Grace FM: **Sprint Interval Training and the School Curriculum: Benefits Upon Cardiorespiratory Fitness, Physical Activity Profiles, and Cardiometabolic Risk Profiles of Healthy Adolescents**. *Pediatric Exercise Science* 2019, **31**(3):296-305.
115. McManus A, Armstrong N, Williams C: **Effect of training on the aerobic power and anaerobic performance of prepubertal girls**. *Acta Paediatrica* 1997, **86**(5):456-459.
116. McManus AM, Cheng CH, Leung MP, Yung TC, Macfarlane DJ: **Improving Aerobic Power in Primary School Boys: A Comparison of Continuous and Interval Training**. *Int J Sports Med* 2005, **26**(9):781-786.
117. McNarry MA, Lambrick D, Westrupp N, Faulkner J: **The influence of a six-week, high-intensity games intervention on the pulmonary oxygen uptake kinetics in prepubertal obese and normal-weight children**. *Applied Physiology, Nutrition & Metabolism* 2015, **40**(10):1012-1018.
118. McNarry MA, Winn CON, Davies GA, Eddolls WTB, Mackintosh KA: **Effect of High-Intensity Training and Asthma on the V[Combining Dot Above]O2 Kinetics of Adolescents**. *Medicine & Science in Sports & Exercise* 2020, **16**:16.
119. Moreau D, Kirk IJ, Waldie KE: **High-intensity training enhances executive function in children in a randomized, placebo-controlled trial**. *eLife* 2017, **6 (no pagination)**.
120. Mucci P, Baquet G, Nourry C, Deruelle F, Berthoin S, Fabre C: **Exercise Testing in Children: Comparison in Ventilatory Thresholds Changes with Interval-Training**. *Pediatr Pulmonol* 2013, **48**(8):809-816.
121. Muntaner-Mas A, P. P: **EFFECTS OF HIGH INTENSITY INTERVAL TRAINING (HIIT) INTERVENTION AMONGST SCHOOL ADOLESCENTS**. *Journal of Physical Education & Health* 2017, **6**(10):19-25.
122. Nourry C, Deruelle F, Guinhouya C, Baquet G, Fabre C, Bart F, Berthoin S, Mucci P: **High-intensity intermittent running training improves pulmonary function and alters exercise breathing pattern in children**. *European Journal of Applied Physiology* 2005, **94**(4):415-423.
123. Racil G, Ben Ounis O, Hammouda O, Kallel A, Zouhal H, Chamari K, Amri M: **Effects of high vs. moderate exercise intensity during interval training on lipids and adiponectin levels in obese young females**. *European Journal of Applied Physiology* 2013, **113**(10):2531-2540.
124. Racil G, Coquart JB, Elmontassar W, Haddad M, Goebel R, Chaouachi A, Amri M, Chamari K: **Greater effects of high- compared with moderate-intensity interval training on cardio-metabolic variables, blood leptin concentration and ratings of perceived exertion in obese adolescent females**. *Biology of Sport* 2016, **33**(2):145-152.
125. Racil G, Zouhal H, Elmontassar W, Abderrahmane AB, De Sousa MV, Chamari K, Amri M, Coquart JB: **Plyometric exercise combined with high-intensity interval training improves metabolic abnormalities in young obese females more so than interval training alone**. *Applied Physiology, Nutrition & Metabolism* 2016, **41**(1):103-109.
126. Reyes-Amigo T, Molina JS, Martinez Mera G, De Souza Lima J, Ibarra Mora J, Soto-SÁNchez J: **Contribution of high and moderate-intensity physical education classes to the daily physical activity level in children**. *Journal of Physical Education & Sport* 2021, **21**(1):29-35.
127. Ruiz-Ariza A, Suárez-Manzano S, López-Serrano S, Martínez-López EJ: **The effect of cooperative high-intensity interval training on creativity and emotional intelligence in secondary school: A randomised controlled trial**. *European Physical Education Review* 2019, **25**(2):355-373.

128. Segovia Y, GutiÉRrez D: **Effect of a game-based high intensity interval training program on body composition in primary education: comparison of the Sport Education model and traditional methodology**. *Journal of Physical Education & Sport* 2020, **20**(2):791-799.
129. van Biljon A, McKune AJ, DuBose KD, Kolanisi U, Semple SJ: **Do Short-Term Exercise Interventions Improve Cardiometabolic Risk Factors in Children?** *Journal of Pediatrics* 2018, **203**:325-329.
130. Van Biljon A, McKune AJ, Dubose KD, Kolanisi U, Semple SJ: **Short-term high-intensity interval training is superior to moderate-intensity continuous training in improving cardiac autonomic function in children**. *Cardiology (Switzerland)* 2018, **141**(1):1-8.
131. Weston KL, Azevedo LB, Bock S, Weston M, George KP, Batterham AM: **Effect of Novel, School-Based High-Intensity Interval Training (HIT) on Cardiometabolic Health in Adolescents: Project FFAB (Fun Fast Activity Blasts) - An Exploratory Controlled Before-And-After Trial**. *PLoS ONE [Electronic Resource]* 2016, **11**(8):e0159116.
132. Williams CA, Armstrong N, Powell J: **Aerobic responses of prepubertal boys to two modes of training**. *British Journal of Sports Medicine* 2000, **34**(3):168-173.
133. Lubans DR, Smith JJ, Eather N, Leahy AA, Morgan PJ, Lonsdale C, Plotnikoff RC, Nilsson M, Kennedy SG, Holliday EG *et al*: **Time-efficient intervention to improve older adolescents' cardiorespiratory fitness: findings from the 'Burn 2 Learn' cluster randomised controlled trial**. *British Journal of Sports Medicine* 2021, **55**:751-758.
134. Bassali R, Waller JL, Gower B, Allison J, Davis CL: **Utility of waist circumference percentile for risk evaluation in obese children**. *International Journal of Pediatric Obesity* 2010, **5**(1):97-101.
135. Kelishadi R, Mirmoghtadaee P, Najafi H, Keikha M: **Systematic review on the association of abdominal obesity in children and adolescents with cardio-metabolic risk factors**. *J Res Med Sci* 2015, **20**(3):294-307.
136. Xi B, Zong XN, Kelishadi R, Litwin M, Hong YM, Poh BK, Steffen LM, Galcheva SV, Herter-Aeberli I, Nawarycz T *et al*: **International Waist Circumference Percentile Cutoffs for Central Obesity in Children and Adolescents Aged 6 to 18 Years**. *The Journal of Clinical Endocrinology & Metabolism* 2020, **105**(4):e1569-e1583.
137. Reilly JJ, Kelly J: **Long-term impact of overweight and obesity in childhood and adolescence on morbidity and premature mortality in adulthood: systematic review**. *International Journal of Obesity* 2011, **35**(7):891-898.
138. Ayer J, Charakida M, Deanfield JE, Celermajer DS: **Lifetime risk: childhood obesity and cardiovascular risk**. *European Heart Journal* 2015, **36**(22):1371-1376.
139. Dencker M, Thorsson O, Karlsson MK, Lindén C, Wollmer P, Andersen LB: **Daily physical activity related to aerobic fitness and body fat in an urban sample of children**. *Scandinavian Journal of Medicine & Science in Sports* 2008, **18**(6):728-735.
140. Ekelund U, Anderssen SA, Froberg K, Sardinha LB, Andersen LB, Brage S: **Independent associations of physical activity and cardiorespiratory fitness with metabolic risk factors in children: the European youth heart study**. *Diabetologia* 2007, **50**(9):1832-1840.
141. Andersen LB, Hasselstrøm H, Grønfeldt V, Hansen S, Karsten F: **The relationship between physical fitness and clustered risk, and tracking of clustered risk from adolescence to young adulthood: eight years follow-up in the Danish Youth and Sport Study**. *International Journal of Behavioral Nutrition and Physical Activity* 2004, **1**(1):6.
142. Moliner-Urdiales D, Ortega FB, Vicente-Rodriguez G, Rey-Lopez JP, Gracia-Marco L, Widhalm K, Sjöström M, Moreno LA, Castillo MJ, Ruiz JR: **Association of physical activity with muscular strength and fat-free mass in adolescents: the HELENA study**. *European Journal of Applied Physiology* 2010, **109**(6):1119-1127.

143. Martínez-Gómez D, Welk GJ, Puertollano MA, Del-Campo J, Moya JM, Marcos A, Veiga OL: **Associations of physical activity with muscular fitness in adolescents**. *Scandinavian Journal of Medicine & Science in Sports* 2011, **21**(2):310-317.
144. Gutin B, Owens S: **The Influence of Physical Activity on Cardiometabolic Biomarkers in Youths: A Review**. *Pediatric Exercise Science* 2011, **23**(2):169-185.
145. Shen W, Zhang T, Li S, Zhang H, Xi B, Shen H, Fernandez C, Bazzano L, He J, Chen W: **Race and Sex Differences of Long-Term Blood Pressure Profiles From Childhood and Adult Hypertension**. *Hypertension* 2017, **70**(1):66-74.
146. Ma JK, Le Mare L, Gurd BJ: **Classroom-based high-intensity interval activity improves off-task behaviour in primary school students**. *Applied Physiology, Nutrition, & Metabolism = Physiologie Appliquee, Nutrition et Metabolisme* 2014, **39**(12):1332-1337.
147. Taylor KL, Weston M, Batterham AM: **Evaluating Intervention Fidelity: An Example from a High-Intensity Interval Training Study**. *PLOS ONE* 2015, **10**(4):e0125166.
148. Weston K, Barker AR, Bond B, Costigan SA, Ingul C, Williams C: **The BASES Expert Statement on the Role of High-intensity Interval Exercise for Health and Fitness Promotion in Young People**. *The Sport and Exercise Scientist* 2020(64).
149. Oliveira BRR, Santos TM, Kilpatrick M, Pires FO, Deslandes AC: **Affective and enjoyment responses in high intensity interval training and continuous training: A systematic review and meta-analysis**. *PLOS ONE* 2018, **13**(6):e0197124.
150. Enright E, O'Sullivan M: **'Can I do it in my pyjamas?' Negotiating a physical education curriculum with teenage girls**. *European Physical Education Review* 2010, **16**(3):203-222.
151. Cairney J, Kwan MY, Velduizen S, Hay J, Bray SR, Faught BE: **Gender, perceived competence and the enjoyment of physical education in children: a longitudinal examination**. *International Journal of Behavioral Nutrition and Physical Activity* 2012, **9**(1):26.
152. Stylianou M: **Health Benefits of Physical Activity: Cognitive Performance and School Engagement**. *Active and Healthy Journal* 2018, **25**(2/3):32-38.
153. Aubert S, Barnes JD, Abdeta C, Abi Nader P, Adeniyi AF, Aguilar-Farias N, Andrade Tenesaca DS, Bhawra J, Brazo-Sayavera J, Cardon G *et al*: **Global Matrix 3.0 Physical Activity Report Card Grades for Children and Youth: Results and Analysis From 49 Countries**. *Journal of Physical Activity and Health* 2018, **15**(s2):S251-S273.
154. Guthold R, Stevens GA, Riley LM, Bull FC: **Global trends in insufficient physical activity among adolescents: a pooled analysis of 298 population-based surveys with 1·6 million participants**. *The Lancet Child & Adolescent Health* 2020, **4**(1):23-35.
155. Duncombe SL, Barker A, Bond B, Earle R, Varley-Campbell J, Vlachopoulos D, Walker JL, Weston KL, Stylianou M: **School-based high-intensity interval training programs in children and adolescents: A Systematic Review and Meta-Analysis**. *PLOS ONE* 2022, **17**:e0266427.
156. Dudley D, Weaver N, Cairney J: **High-intensity interval training and health optimizing physical education: Achieving health and educative outcomes in secondary physical education-a pilot nonrandomized comparison trial**. *Journal of Teaching in Physical Education* 2021, **40**(2):215-227.
157. International Association for Public Participation**: IAP2 Public Participation Spectrum;** 2004**.** [https://iap2.org.au/resources/spectrum/]
158. Bolster EAM, Gessel Cv, Welten M, Hermsen S, Lugt Rvd, Kotte E, Essen Av, Bloemen MAT: **Using a Co-design Approach to Create Tools to Facilitate Physical Activity in Children With Physical Disabilities**. *Frontiers in Rehabilitation Sciences* 2021, **2**.
159. Weston KL, Innerd A, Azevedo LB, Bock S, Batterham AM: **Process Evaluation of Project FFAB (Fun Fast Activity Blasts): A Multi-Activity School-Based High-Intensity Interval Training Intervention**. *Frontiers in Sports and Active Living* 2021, **3**.
160. Leask CF, Sandlund M, Skelton DA, Altenburg TM, Cardon G, Chinapaw MJM, De Bourdeaudhuij I, Verloigne M, Chastin SFM: **Framework, principles and**

recommendations for utilising participatory methodologies in the co-creation and evaluation of public health interventions. *Research Involvement and Engagement* 2019, **5**(1).
161. Durlak JA, DuPre EP: **Implementation Matters: A Review of Research on the Influence of Implementation on Program Outcomes and the Factors Affecting Implementation**. *American Journal of Community Psychology* 2008, **41**(3-4):327-350.
162. Faul F, Erdfelder E, Buchner A, Lang A-G: **Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses.** *Behavior Research Methods* 2009, **41**:1149-1160.
163. Braun V, Clarke V, Weate P: **Using thematic analysis in sport and exercise research**. London: Routledge; 2016.
164. Wiltshire G, Ronkainen N: **A realist approach to thematic analysis: making sense of qualitative data through experiential, inferential and dispositional themes**. *Journal of Critical Realism* 2021, **20**(2):1-22.
165. Cole TJ, Bellizzi MC, Flegal KM, Dietz WH: **Establishing a standard definition for child overweight and obesity worldwide: international survey**. *BMJ* 2000, **320**(7244):1240-1243.
166. Kowalski KC, Crocker PR, Donen RM: **The physical activity questionnaire for older children (PAQ-C) and adolescents (PAQ-A) manual**. *College of Kinesiology, University of Saskatchewan* 2004, **87**(1):1-38.
167. Benítez-Porres J, López-Fernández I, Raya JF, Álvarez Carnero S, Alvero-Cruz JR, Álvarez Carnero E: **Reliability and Validity of the PAQ-C Questionnaire to Assess Physical Activity in Children**. *Journal of School Health* 2016, **86**(9):677-685.
168. Kowalski KC, Crocker PRE, Faulkner RA: **Validation of the Physical Activity Questionnaire for Older Children**. *Pediatric Exercise Science* 1997, **9**(2):174-186.
169. Biddle SJ, Gorely T, Pearson N, Bull FC: **An assessment of self-reported physical activity instruments in young people for population surveillance: Project ALPHA**. *International Journal of Behavioral Nutrition and Physical Activity* 2011, **8**(1):1.
170. Welk GJ, Wood K: **Physical Activity Assessments in Physical Education: A Practical Review of Instruments and Their Use in the Curriculum**. *Journal of Physical Education, Recreation & Dance* 2000, **71**(1):30-40.
171. The Cooper Institute**: FitnessGram PACER test;** 1982**.** [https://fitnessgram.net/pacertest/]
172. Ruiz JR, Silva G, Oliveira N, Ribeiro JC, Oliveira JF, Mota J: **Criterion-related validity of the 20-m shuttle run test in youths aged 13–19 years**. *Journal of Sports Sciences* 2009, **27**(9):899-906.
173. Castro-Piñero J, Artero EG, España-Romero V, Ortega FB, Sjöström M, Suni J, Ruiz JR: **Criterion-related validity of field-based fitness tests in youth: a systematic review**. *Br J Sports Med* 2010, **44**(13):934-943.
174. Mayorga-Vega D, Aguilar-Soto P, Viciana J: **Criterion-Related Validity of the 20-M Shuttle Run Test for Estimating Cardiorespiratory Fitness: A Meta-Analysis**. *J Sports Sci Med* 2015, **14**(3):536-547.
175. Castro-Piñero J, Ortega FB, Artero EG, Girela-Rejón MJ, Mora J, Sjöström M, Ruiz JR: **Assessing Muscular Strength in Youth: Usefulness of Standing Long Jump as a General Index of Muscular Fitness**. *The Journal of Strength & Conditioning Research* 2010, **24**(7).
176. Fernandez-Santos JR, Ruiz JR, Cohen DD, Gonzalez-Montesinos JL, Castro-Piñero J: **Reliability and Validity of Tests to Assess Lower-Body Muscular Power in Children**. *The Journal of Strength & Conditioning Research* 2015, **29**(8).
177. Ortega FB, Artero EG, Ruiz JR, Vicente-Rodriguez G, Bergman P, Hagströmer M, Ottevaere C, Nagy E, Konsta O, Rey-López JP *et al*: **Reliability of health-related physical fitness tests in European adolescents. The HELENA Study**. *International Journal of Obesity* 2008, **32**(S5):S49-S57.

178. Peirce J, Gray JR, Simpson S, Macaskill M, Höchenberger R, Sogo H, Kastman E, Lindeløv JK: **PsychoPy2: Experiments in behavior made easy**. *Behavior Research Methods* 2019, **51**(1):195-203.
179. Draheim C, Tsukahara JS, Martin JD, Mashburn CA, Engle RW: **A toolbox approach to improving the measurement of attention control**. *Journal of Experimental Psychology: General* 2021, **150**(2):242-275.
180. Krafft CE, Schwarz NF, Chi L, Weinberger AL, Schaeffer DJ, Pierce JE, Rodrigue AL, Yanasak NE, Miller PH, Tomporowski PD *et al*: **An 8-month randomized controlled exercise trial alters brain activation during cognitive tasks in overweight children**. *Obesity* 2014, **22**(1):232-242.
181. Cowan N, Fristoe NM, Elliott EM, Brunner RP, Saults JS: **Scope of attention, control of attention, and intelligence in children and adults**. *Memory & Cognition* 2006, **34**(8):1754-1768.
182. Goudas M, Biddle S, Fox K: **Perceived locus of causality, goal orientations, and perceived competence in school physical education classes**. *British Journal of Educational Psychology* 1994, **64**(3):453-463.
183. Ryan R, Connell J: **Perceived locus of causality and internalization: examining reasons for acting in two domains**. *Journal of personality and social psychology* 1989, **57 5**:749-761.
184. Owen KB, Smith J, Lubans DR, Ng JYY, Lonsdale C: **Self-determined motivation and physical activity in children and adolescents: A systematic review and meta-analysis**. *Preventive Medicine* 2014, **67**:270-279.
185. Michie S, West R, Campbell R, Brown J, Gainforth H: **ABC of Behaviour Change Theories**. Great Britain: Silverback Publishing; 2014.
186. Ryan RM, Deci EL: **Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being**. *American Psychologist* 2000, **55**(1):68-78.
187. Standage M, Duda JL, Ntoumanis N: **A model of contextual motivation in physical education: Using constructs from self-determination and achievement goal theories to predict physical activity intentions**. *Journal of Educational Psychology* 2003, **95**(1):97-110.
188. Richer S, Vallerand RJ: **Construction et validation de l’e´chelle du sentiment d’appartenance sociale [Construction and validation of the perceived relatedness scale]**. *Revue Européene de Psychologie Appliquée* 1998, **48**:129-137.
189. Standage M, Duda JL, Ntoumanis N: **A test of self-determination theory in school physical education**. *British Journal of Educational Psychology* 2005, **75**(3):411-433.
190. McAuley E, Duncan T, Tammen VV: **Psychometric Properties of the Intrinsic Motivation Inventory in a Competitive Sport Setting: A Confirmatory Factor Analysis**. *Research Quarterly for Exercise and Sport* 1989, **60**(1):48-58.
191. Ntoumanis N: **A self-determination approach to the understanding of motivation in physical education**. *British Journal of Educational Psychology* 2001, **71**(2):225-242.
192. Kendzierski D, Decarlo KJ: **Physical Activity Enjoyment Scale: Two Validation Studies**. *Journal of Sport and Exercise Psychology* 1991, **13**(1):50-64.
193. Motl RW, Dishman RK, Saunders R, Dowda M, Felton G, Pate RR: **Measuring enjoyment of physical activity in adolescent girls**. *American Journal of Preventive Medicine* 2001, **21**(2):110-117.
194. Paxton RJ, Nigg C, Motl RW, Yamashita M, Chung R, Battista J, Chang J: **Physical Activity Enjoyment Scale Short Form—Does It Fit for Children?** *Research Quarterly for Exercise and Sport* 2008, **79**(3):423-427.
195. Dishman RK, Motl RW, Saunders R, Felton G, Ward DS, Dowda M, Pate RR: **Enjoyment mediates effects of a school-based physical-activity intervention**. *Med Sci Sports Exerc* 2005, **37**(3):478-487.

196. Ebbeck V, Weiss MR: **Determinanats of Children's Self-Esteem: An Examination of Perceived Competence and Affect in Sport**. *Pediatric Exercise Science* 1998, **10**:285-298.
197. Eather N, Beauchamp MR, Rhodes RE, Diallo TMO, Smith JJ, Jung ME, Plotnikoff RC, Noetel M, Harris N, Graham E *et al*: **Development and Evaluation of the High-Intensity Interval Training Self-Efficacy Questionnaire**. *J Sport Exerc Psychol* 2020:1-9.
198. Robertson RJ, Goss FL, Aaron DJ, Tessmer KA, Gairola A, Ghigiarelli JJ, Kowallis RA, Thekkada S, Liu Y, Randall CR *et al*: **Observation of Perceived Exertion in Children Using the OMNI Pictorial Scale**. *Psychobiology and Behavioral Strategies* 2006, **38**(1):158-166.
199. Gammon C, Pfeiffer KA, Pivarnik JM, Moore RW, Rice KR, Trost SG: **Age-Related Differences in OMNI-RPE Scale Validity in Youth**. *Medicine & Science in Sports & Exercise* 2016, **48**(8):1590-1594.
200. Rachele JN, Cuddihy TF, Washington TL, McPhail SM: **Averting Uncertainty: A Practical Guide to Physical Activity Research in Australian Schools.** *Australian Journal of Teacher Education* 2013, **38**.
201. Schranz N, Glennon V, Evans J, Gomersall S, Hardy L, Hesketh KD, Lubans D, Ridgers ND, Straker L, Stylianou M *et al*: **Results from Australia's 2018 Report Card on Physical Activity for Children and Youth**. *Journal of Physical Activity and Health* 2018, **15**(s2):S315-S317.
202. Janssen I, LeBlanc AG: **Systematic review of the health benefits of physical activity and fitness in school-aged children and youth**. *International journal of behavioral nutrition and physical activity* 2010, **7**(1):1-16.
203. Thabrew H, Fleming T, Hetrick S, Merry S: **Co-design of eHealth Interventions With Children and Young People**. *Frontiers in Psychiatry* 2018, **9**.
204. Larsson I, Staland-Nyman C, Svedberg P, Nygren JM, Carlsson I-M: **Children and young people's participation in developing interventions in health and well-being: a scoping review**. *BMC Health Services Research* 2018, **18**(1).
205. Gaillard S, Malik S, Preston J, Escalera BN, Dicks P, Touil N, Mardirossian S, Claverol-Torres J, Kassaï B: **Involving children and young people in clinical research through the forum of a European Young Persons' Advisory Group: needs and challenges**. *Fundamental & Clinical Pharmacology* 2018, **32**(4):357-362.
206. Preston J, Stones SR, Davies H, Phillips B: **How to involve children and young people in what is, after all, their research**. *Archives of Disease in Childhood* 2019, **104**(5):494-500.
207. Duncombe SL, Barker AR, Price L, Walker JL, Dux PE, Fox A, Matthews N, Stylianou M: **Making a HIIT: study protocol for assessing the feasibility and effects of co-designing high-intensity interval training workouts with students and teachers**. *BMC Pediatrics* 2022, **22**(1).
208. Bergold J, Thomas S: **Participatory Research Methods: A Methodological Approach in Motion [110 paragraphs].** . *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research* 2012, **13**(1):Art. 30.
209. Braun V, Clarke V: **Using thematic analysis in psychology**. *Qualitative Research in Psychology* 2006, **3**(2):77-101.
210. Bowen DJ, Kreuter M, Spring B, Cofta-Woerpel L, Linnan L, Weiner D, Bakken S, Kaplan CP, Squiers L, Fabrizio C *et al*: **How We Design Feasibility Studies**. *American Journal of Preventive Medicine* 2009, **36**(5):452-457.
211. Markiewicz A, Patrick I: **Developing Monitoring and Evaluation Frameworks**. In. Thousand Oaks, California: SAGE Publications, Inc; 2016.
212. Velázquez AL, Galler M, Vidal L, Varela P, Ares G: **Co-creation of a healthy dairy product with and for children**. *Food Quality and Preference* 2022, **96**:104414.
213. Ghaziani R: **Primary school design: co-creation with children**. *Archnet-IJAR: International Journal of Architectural Research* 2021, **15**(2):285-299.

214. Fails JA: **Methods and Techniques for Involving Children in the Design of New Technology for Children**. *Foundations and Trends® in Human–Computer Interaction* 2012, **6**(2):85-166.
215. Harris N, Warbrick I, Atkins D, Vandal A, Plank L, Lubans DR: **Feasibility and Provisional Efficacy of Embedding High-Intensity Interval Training Into Physical Education Lessons: A Pilot Cluster-Randomized Controlled Trial**. *Pediatric Exercise Science* 2021, **33**(4):186-195.
216. Sport Australia: **The Australian Physical Literacy Framework**. 2019:https://www.sportaus.gov.au/__data/assets/pdf_file/0019/710173/735455_Physical-Literacy-Framework_access.pdf.
217. Jago R, Salway R, House D, Beets M, Lubans DR, Woods C, de Vocht F: **Rethinking children's physical activity interventions at school: A new context-specific approach**. *Frontiers in Public Health* 2023, **11**.
218. Van Sluijs EMF, Ekelund U, Crochemore-Silva I, Guthold R, Ha A, Lubans D, Oyeyemi AL, Ding D, Katzmarzyk PT: **Physical activity behaviours in adolescence: current evidence and opportunities for intervention**. *The Lancet* 2021, **398**(10298):429-442.
219. Minatto G, Barbosa Filho VC, Berria J, Petroski EL: **School-Based Interventions to Improve Cardiorespiratory Fitness in Adolescents: Systematic Review with Meta-analysis**. *Sports Medicine* 2016, **46**(9):1273-1292.
220. Pozuelo-Carrascosa DP, García-Hermoso A, Álvarez-Bueno C, Sánchez-López M, Martinez-Vizcaino V: **Effectiveness of school-based physical activity programmes on cardiorespiratory fitness in children: a meta-analysis of randomised controlled trials**. *British Journal of Sports Medicine* 2018, **52**(19):1234-1240.
221. Mura G, Vellante M, Nardi AE, Machado S, Carta MG: **Effects of School-Based Physical Activity Interventions on Cognition and Academic Achievement: A Systematic Review**. *CNS Neurol Disord Drug Targets* 2015, **14**(9):1194-1208.
222. Rabin BA, Brownson RC, Haire-Joshu D, Kreuter MW, Weaver NL: **A glossary for dissemination and implementation research in health**. *J Public Health Manag Pract* 2008, **14**(2):117-123.
223. Humphrey N, Lendrum A, Ashworth E, Frearson K, Buck R, Kerr K: **Implementation and process evaluation (IPE) for interventions in educational settings: A synthesis of the literature**. *London: EEF* 2016.
224. McKay H, Naylor P-J, Lau E, Gray SM, Wolfenden L, Milat A, Bauman A, Race D, Nettlefold L, Sims-Gould J: **Implementation and scale-up of physical activity and behavioural nutrition interventions: an evaluation roadmap**. *International Journal of Behavioral Nutrition and Physical Activity* 2019, **16**(1).
225. Bauer N, Sperlich B, Holmberg H-C, Engel FA: **Effects of High-Intensity Interval Training in School on the Physical Performance and Health of Children and Adolescents: A Systematic Review with Meta-Analysis**. *Sports Medicine - Open* 2022, **8**(1).
226. Lubans DR, Eather N, Smith JJ, Beets MW, Harris NK: **Scaling-Up Adolescent High-Intensity Interval Training Programs for Population Health**. *Exercise and Sport Sciences Reviews* 2022, **50**(3).
227. Lagally KM: **Using Ratings of Perceived Exertion in Physical Education**. *Journal of Physical Education, Recreation & Dance* 2013, **84**(5):35-39.
228. Robertson RJ, Goss FL, Boer NF, Peoples JA, Foreman AJ, Dabayebeh IM, Millich NB, Balasekaran G, Riechman SE, Gallagher JD *et al*: **Children's OMNI Scale of Perceived Exertion: mixed gender and race validation**. *Medicine & Science in Sports & Exercise* 2000, **32**(2):452.
229. Robertson RJ, Goss FL, Rutkowski J, Lenz B, Dixon C, Timmer J, Frazee K, Dube J, Andreacci J: **Concurrent validation of the OMNI perceived exertion scale for resistance exercise**. *Medicine & Science in Sports & Exercise* 2003, **35**(2):333-341.

230. Nathan N, McCarthy N, Hope K, Sutherland R, Lecathelinais C, Hall A, Lane C, Trost S, Yoong SL, Wolfenden L: **The impact of school uniforms on primary school student's physical activity at school: outcomes of a cluster randomized controlled trial**. *International Journal of Behavioral Nutrition and Physical Activity* 2021, **18**(1).
231. McCarthy N, Hope K, Sutherland R, Campbell E, Hodder R, Wolfenden L, Nathan N: **Australian Primary School Principals', Teachers', and Parents' Attitudes and Barriers to Changing School Uniform Policies From Traditional Uniforms to Sports Uniforms**. *Journal of Physical Activity and Health* 2020, **17**(10):1019-1024.
232. Norris E, Van Steen T, Direito A, Stamatakis E: **Physically active lessons in schools and their impact on physical activity, educational, health and cognition outcomes: a systematic review and meta-analysis**. *British Journal of Sports Medicine* 2020, **54**(14):826-838.
233. Brittin J, Sorensen D, Trowbridge M, Lee KK, Breithecker D, Frerichs L, Huang T: **Physical Activity Design Guidelines for School Architecture**. *PLOS ONE* 2015, **10**(7):e0132597.
234. Horner S, Rew L, Torres R: **Enhancing Intervention Fidelity: A Means of Strengthening Study Impact**. *Journal for Specialists in Pediatric Nursing* 2006, **11**(2):80-89.
235. Dencker M, Thorsson O, Karlsson MK, Lindén C, Svensson J, Wollmer P, Andersen LB: **Daily physical activity and its relation to aerobic fitness in children aged 8–11 years**. *European Journal of Applied Physiology* 2006, **96**(5):587-592.
236. Achten J, Jeukendrup AE: **Heart Rate Monitoring**. *Sports Medicine* 2003, **33**(7):517-538.
237. Pasadyn SR, Soudan M, Gillinov M, Houghtaling P, Phelan D, Gillinov N, Bittel B, Desai MY: **Accuracy of commercially available heart rate monitors in athletes: a prospective study**. *Cardiovascular Diagnosis and Therapy* 2019, **9**(4):379-385.
238. Impellizzeri FM, Marcora SM, Coutts AJ: **Internal and External Training Load: 15 Years On**. *International Journal of Sports Physiology and Performance* 2019, **14**(2):270-273.
239. Haddad M, Stylianides G, Djaoui L, Dellal A, Chamari K: **Session-RPE Method for Training Load Monitoring: Validity, Ecological Usefulness, and Influencing Factors**. *Frontiers in Neuroscience* 2017, **11**(612).
240. Mahon AD, Marjerrison AD, Lee JD, Woodruff ME, Hanna LE: **Evaluating the Prediction of Maximal Heart Rate in Children and Adolescents**. *Research Quarterly for Exercise and Sport* 2010, **81**(4):466-471.
241. Edwards S: **High performance training and racing**. Sacramento, CA: Feet Fleet Press; 1993.
242. Bland JM, Altman DG: **Statistics notes: Calculating correlation coefficients with repeated observations: Part 1--correlation within subjects**. *BMJ* 1995, **310**(6977):446-446.
243. Marusich LR, Bakdash JZ: **rmcorrShiny: A web and standalone application for repeated measures correlation**. *F1000Research* 2021, **10**:697.
244. Mukaka MM: **Statistics corner: A guide to appropriate use of correlation coefficient in medical research**. *Malawi Med J* 2012, **24**(3):69-71.
245. Ekkekakis P, Biddle SJH: **Extraordinary claims in the literature on high-intensity interval training (HIIT): IV. Is HIIT associated with higher long-term exercise adherence?** *Psychology of Sport and Exercise* 2023, **64**:102295.
246. Malik AA, Williams CA, Bond B, Weston KL, Barker AR: **Acute cardiorespiratory, perceptual and enjoyment responses to high-intensity interval exercise in adolescents**. *European Journal of Sport Science* 2017, **17**(10):1335-1342.
247. Ng JYY, Ntoumanis N, Thøgersen-Ntoumani C, Deci EL, Ryan RM, Duda JL, Williams GC: **Self-Determination Theory Applied to Health Contexts: A Meta-Analysis**. *Perspectives on Psychological Science* 2012, **7**(4):325-340.

248. Bandura A: **Social foundations of thought and action: A socialcognitive theory.** Englewood Cliffs, NJ: Prentice-Hall; 1986.
249. Ntoumanis N: **A prospective study of participation in optional school physical education using a self-determination theory framework**. *Journal of educational psychology* 2005, **97**(3):444.
250. Vlachopoulos SP, Karageorghis CI: **Interaction of External, Introjected, and Identified Regulation With Intrinsic Motivation in Exercise: Relationships With Exercise Enjoyment**. *Journal of Applied Biobehavioral Research* 2005, **10**(2):113-132.
251. Standage M, Gillison F: **Students' motivational responses toward school physical education and their relationship to general self-esteem and health-related quality of life**. *Psychology of Sport and Exercise* 2007, **8**(5):704-721.
252. Rizopoulos D: **ltm: An R Package for Latent Variable Modeling and Item Response Analysis**. *Journal of Statistical Software* 2006, **17**(5):1 - 25.
253. Martinović D, Ilić J, Višnjić D: **Gender differences in sports involvement and motivation for engagement in physical education in primary school**. *Problems of Education in the 21st Century* 2011, **31**:94.
254. Abassi W, Ouerghi N, Feki M, Jebabli N, Andrade MS, Bouassida A, Sousa CV, Nikolaidis PT, Weiss K, Knechtle B: **Effects of moderate- vs. high-intensity interval training on physical fitness, enjoyment, and affective valence in overweight/obese female adolescents: a pre-/post-test study**. *Eur Rev Med Pharmacol Sci* 2023, **27**(9):3809-3822.
255. Burn N, Niven A: **Why do they do (h)it? Using self-determination theory to understand why people start and continue to do high-intensity interval training group exercise classes**. *International Journal of Sport and Exercise Psychology* 2019, **17**(5):537-551.
256. Law W, Elliot AJ, Murayama K: **Perceived Competence Moderates the Relation Between Performance-Approach and Performance-Avoidance Goals**. *Journal of educational psychology* 2012, **104**(3):806-819.
257. White RL, Bennie A, Vasconcellos D, Cinelli R, Hilland T, Owen KB, Lonsdale C: **Self-determination theory in physical education: A systematic review of qualitative studies**. *Teaching and Teacher Education* 2021, **99**:103247.
258. Kruger J, Dunning D: **Unskilled and unaware of it: How difficulties in recognizing one's own incompetence lead to inflated self-assessments**. In.: American Psychological Association; 1999: 1121-1134.
259. Barnett LM, Lai SK, Veldman SLC, Hardy LL, Cliff DP, Morgan PJ, Zask A, Lubans DR, Shultz SP, Ridgers ND *et al*: **Correlates of Gross Motor Competence in Children and Adolescents: A Systematic Review and Meta-Analysis**. *Sports Medicine* 2016, **46**(11):1663-1688.
260. Raghuveer G, Hartz J, Lubans DR, Takken T, Wiltz JL, Mietus-Snyder M, Perak AM, Baker-Smith C, Pietris N, Edwards NM: **Cardiorespiratory Fitness in Youth: An Important Marker of Health: A Scientific Statement From the American Heart Association**. *Circulation* 2020, **142**(7).
261. Smith JJ, Eather N, Morgan PJ, Plotnikoff RC, Faigenbaum AD, Lubans DR: **The Health Benefits of Muscular Fitness for Children and Adolescents: A Systematic Review and Meta-Analysis**. *Sports Medicine* 2014, **44**(9):1209-1223.
262. García-Hermoso A, Ramírez-Vélez R, García-Alonso Y, Alonso-Martínez AM, Izquierdo M: **Association of Cardiorespiratory Fitness Levels During Youth With Health Risk Later in Life**. *JAMA Pediatrics* 2020, **174**(10):952.
263. García-Hermoso A, Ramírez-Campillo R, Izquierdo M: **Is Muscular Fitness Associated with Future Health Benefits in Children and Adolescents? A Systematic Review and Meta-Analysis of Longitudinal Studies**. *Sports Medicine* 2019, **49**(7):1079-1094.
264. Best JR: **Effects of physical activity on children's executive function: Contributions of experimental research on aerobic exercise**. *Developmental Review* 2010, **30**(4):331-351.

265. Davis CL, Tomporowski PD, Boyle CA, Waller JL, Miller PH, Naglieri JA, Gregoski M: **Effects of aerobic exercise on overweight children's cognitive functioning: a randomized controlled trial**. *Res Q Exerc Sport* 2007, **78**(5):510-519.
266. Samuels WE, Tournaki N, Blackman S, Zilinski C: **Executive functioning predicts academic achievement in middle school: A four-year longitudinal study**. *The Journal of Educational Research* 2016, **109**(5):478-490.
267. Zorza JP, Marino J, Acosta Mesas A: **Executive Functions as Predictors of School Performance and Social Relationships: Primary and Secondary School Students**. *The Spanish Journal of Psychology* 2016, **19**.
268. Tomkinson GR, Lang JJ, Tremblay MS: **Temporal trends in the cardiorespiratory fitness of children and adolescents representing 19 high-income and upper middle-income countries between 1981 and 2014**. *British Journal of Sports Medicine* 2019, **53**(8):478-486.
269. Hardy LL, Merom D, Thomas M, Peralta L: **30-year changes in Australian children's standing broad jump: 1985–2015**. *Journal of Science and Medicine in Sport* 2018, **21**(10):1057-1061.
270. Bento AFPDS, Carrasco Páez L, Raimundo AMDM: **School-Based High-Intensity Interval Training Programs for Promoting Physical Activity and Fitness in Adolescents: A Systematic Review**. *Journal of Teaching in Physical Education* 2022, **41**(2):288-300.
271. Kao S-C, Baumgartner N, Noh K, Wang C-H, Schmitt S: **Acute effects of intense interval versus aerobic exercise on children's behavioral and neuroelectric measures of inhibitory control**. *Journal of Science and Medicine in Sport* 2023, **26**(6):316-321.
272. Diamond A: **Executive Functions**. *Annual Review of Psychology* 2013, **64**(1):135-168.
273. Moore SA, McKay HA, Macdonald H, Nettlefold L, Baxter-Jones ADG, Cameron N, Brasher PMA: **Enhancing a Somatic Maturity Prediction Model**. *Medicine & Science in Sports & Exercise* 2015, **47**(8).
274. Nettlefold L, McKay HA, Warburton DER, McGuire KA, Bredin SSD, Naylor PJ: **The challenge of low physical activity during the school day: at recess, lunch and in physical education**. *British Journal of Sports Medicine* 2011, **45**(10):813-819.
275. Erwin H, Beighle A, Carson RL, Castelli DM: **Comprehensive School-Based Physical Activity Promotion: A Review**. *Quest* 2013, **65**(4):412-428.
276. Lander N, Eather N, Morgan PJ, Salmon J, Barnett LM: **Characteristics of Teacher Training in School-Based Physical Education Interventions to Improve Fundamental Movement Skills and/or Physical Activity: A Systematic Review**. *Sports Medicine* 2017, **47**(1):135-161.
277. Leahy AA, Eather N, Smith JJ, Hillman C, Morgan PJ, Nilsson M, Lonsdale C, Plotnikoff RC, Noetel M, Holliday E *et al*: **School-based physical activity intervention for older adolescents: rationale and study protocol for the Burn 2 Learn cluster randomised controlled trial**. *BMJ Open* 2019, **9**(5):e026029.
278. Xu S, Akioma M, Yuan Z: **Relationship between circadian rhythm and brain cognitive functions**. *Frontiers of Optoelectronics* 2021, **14**(3):278-287.
279. Welsman J, Armstrong N: **The 20 m shuttle run is not a valid test of cardiorespiratory fitness in boys aged 11–14 years**. *BMJ Open Sport & Exercise Medicine* 2019, **5**(1):e000627.
280. Verloigne M, Altenburg T, Chinapaw M, Chastin S, Cardon G, De Bourdeaudhuij I: **Using a Co-Creational Approach to Develop, Implement and Evaluate an Intervention to Promote Physical Activity in Adolescent Girls from Vocational and Technical Schools: A Case Control Study**. *International Journal of Environmental Research and Public Health* 2017, **14**(8):862.

281. Kemmis S, R. M: **Participatory Action Reserach: Communicative Action and the Public Sphere**. In: *The Sage Handbook of Qualitative Resarch.* edn. Edited by NK D, YS L. CA, United States of America: Thousand Oaks; 2007: 271-330.

282. Anselma M, Altenburg TM, Emke H, Van Nassau F, Jurg M, Ruiter RAC, Jurkowski JM, Chinapaw MJM: **Co-designing obesity prevention interventions together with children: intervention mapping meets youth-led participatory action research**. *International Journal of Behavioral Nutrition and Physical Activity* 2019, **16**(1):130-144.

283. Dudley DA, Okely AD, Pearson P, Cotton WG, Caputi P: **Changes in physical activity levels, lesson context, and teacher interaction during physical education in culturally and linguistically diverse Australian schools**. *International Journal of Behavioral Nutrition and Physical Activity* 2012, **9**(1):114.

284. Lee PH, Macfarlane DJ, Lam T, Stewart SM: **Validity of the international physical activity questionnaire short form (IPAQ-SF): A systematic review**. *International Journal of Behavioral Nutrition and Physical Activity* 2011, **8**(1):115.

285. Marasso D, Lupo C, Collura S, Rainoldi A, Brustio PR: **Subjective versus Objective Measure of Physical Activity: A Systematic Review and Meta-Analysis of the Convergent Validity of the Physical Activity Questionnaire for Children (PAQ-C)**. *International Journal of Environmental Research and Public Health* 2021, **18**(7):3413.

286. Reece LJ, Owen K, Foley B, Rose C, Bellew B, Bauman A: **Understanding the impact of COVID-19 on children's physical activity levels in NSW, Australia**. *Health Promot J Austr* 2021, **32**(2):365-366.

Appendices

Appendix 1. Ethical Approval

The original ethics approval and three amendments throughout the course of the study. This ethics covers *Chapter Three – Chapter Eight* in this thesis.

THE UNIVERSITY OF QUEENSLAND

Institutional Human Research Ethics Approval

Project Title:	CREATE: Co-constructing Resources and Exercises to Aid Teachers and Educative Outcomes
Chief Investigator:	Dr Michalis Stylianou
Supervisor:	Dr Michalis Stylianou, Prof Alan Barker, Dr Jaqueline Walker, Dr Lisa Price
Co-Investigator(s):	Ms Stephanie Duncombe
School(s):	School of Human Movement and Nutritional Sciences, The University of Queensland
Approval Number:	2020002444
Granting Agency/Degree:	QUEX Institute scholarship / PhD
Duration:	28 February 2024

Comments/Conditions:

- HREA Form, 13/10/2020
- CREATE_InfoConsent_Gatekeeper, 13/10/2020
- CREATE_InfoConsent_StudentParent_Coconstruct, 20/10/2020
- CREATE_InfoConsent_StudentParent_HIITOnly, 20/10/2020
- CREATE_InfoConsent_Teachers, 20/10/2020
- CREATE_Protocol, 13/10/2020
- CREATE_Stage1_FocusGroup_Discussion Guide, 13/10/2020
- CREATE_Stage1_Process_Interview Guide, 13/10/2020
- CREATE_Stage2_BasicPsychNeeds, 13/10/2020
- CREATE_Stage2_Enjoyment_PACES, 13/10/2020
- CREATE_Stage2_Implementation_Interview Guide, 13/10/2020
- CREATE_Stage2_MotivationQuestions, 13/10/2020
- CREATE_Stage2_RPE_Enjoyment, 13/10/2020

Note: if this approval is for amendments to an already approved protocol for which a UQ Clinical Trials Protection/Insurance Form was originally submitted, then the researchers must directly notify the UQ Insurance Office of any changes to that Form and Participant Information Sheets & Consent Forms as a result of the amendments, before action.

Name of responsible Sub-Committee:
University of Queensland Health and Behavioural Sciences, Low & Negligible Risk Ethics Sub-Committee
This project complies with the provisions contained in the *National Statement on Ethical Conduct in Human Research* and complies with the regulations governing experimentation on humans.

Name of Ethics Sub-Committee representative:
Professor Bill von Hippel
University of Queensland Health and Behavioural Sciences, Low & Negligible Risk Ethics Sub-Committee

Signature ______________ Date **22/10/2020**

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA
CREATE CHANGE
Research Ethics and Integrity

Human Research Ethics Approval

Project Number:	2020/HE002444
Project Title:	CREATE: Co-constructing Resources and Exercises to Aid Teachers and Educative Outcomes
Version:	2.02
Chief Investigator:	Dr Michalis Stylianou Centre for Research on Exercise, Physical Activity and Health
Co-Investigator(s)	Professor Alan Barker Miss Jodie Lauren Koep Dr Jacqueline Louise Walker Mr James David Woodforde Dr Lisa Price Ms Stephanie Duncombe
Funding Body (UQ ref#):	
Approving Committee:	HABS LNR
Approval End Date:	28 Feb 2024
Date of Approval:	Thursday, 18 March 2021

HABS LNR confirms that this project meets the requirements of the National Statement on Ethical Conduct in Human Research (2007, current revision). The University's human research ethics committees are organised and operate in accordance with the National Statement on Ethical Conduct in Human Research (2007, current revision).

Approved Documents

Document Type	File Name	Document Tile	Application Version	Document Version	Last Modified
Application Attachment	CREATE_InfoConsent_StudentParent_Coconstruct_V3.docx	CREATE_InfoConsent_StudentParent_Coconstruct_V3	2.2	2	16/03/2021 12:51:34 PM
Application Attachment	CREATE_InfoConsent_StudentParent_HIITOnly_V3.docx	CREATE_InfoConsent_StudentParent_HIITOnly_V3	2.2	2	16/03/2021 12:51:34 PM
Project Protocol	CREATE_Protocol_20210316.docx	CREATE_Protocol_20210316.docx	2.2	2	16/03/2021 12:51:34 PM

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA
CREATE CHANGE
Research Ethics and Integrity

Human Research Ethics Approval

Project Number: 2020/HE002444

Project Title: CREATE: Co-constructing Resources and Exercises to Aid Teachers and Educative Outcomes

Version: 3.01

Chief Investigator: Dr Michalis Stylianou

Centre for Research on Exercise, Physical Activity and Health

Co-Investigator(s)

Professor Alan Barker
Miss Jodie Lauren Koep
Dr Jacqueline Louise Walker
Mr James David Woodforde
Dr Lisa Price
Dr Natasha Leigh Matthews
Professor Paul Edmund Dux
Ms Stephanie Duncombe

Funding Body (UQ ref#):

Approving Committee: HABS LNR

Approval End Date: 28 Feb 2024

Date of Approval: Friday, 7 May 2021

HABS LNR confirms that this project meets the requirements of the National Statement on Ethical Conduct in Human Research (2007, current revision). The University's human research ethics committees are organised and operate in accordance with the National Statement on Ethical Conduct in Human Research (2007, current revision).

Approved Documents

Document Type	File Name	Document Tile	Application Version	Document Version	Last Modified
Change Tracking	2020_HE002444 v2_02 - v3_01 Changes.pdf	2020/HE002444 v2_02 - v3_01 Changes	3.1	1	6/05/2021 4:53:09 PM
Project Protocol	CREATE_Protocol_20210505.docx	CREATE_Protocol_20210505.docx	3.1	1	6/05/2021 4:53:05 PM
Application Attachment	CREATE_InfoConsent_Gatekeeper_V2.docx	Gatekeeper Consent Form with highlighted changes	3.1	1	6/05/2021 4:53:05 PM

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

CREATE CHANGE
Research Ethics and Integrity

Human Research Ethics Approval

Project Number:	2020/HE002444
Project Title:	CREATE: Co-constructing Resources and Exercises to Aid Teachers and Educative Outcomes
Version:	4.01
Chief Investigator:	Dr Michalis Stylianou Centre for Research on Exercise, Physical Activity and Health
Co-Investigator(s)	Professor Alan Barker Miss Jodie Lauren Koep Dr Jacqueline Louise Walker Mr James David Woodforde Dr Lisa Price Dr Natasha Leigh Matthews Professor Paul Edmund Dux Ms Stephanie Duncombe
Funding Body (UQ ref#):	
Approving Committee:	HABS LNR
Approval End Date:	28 Feb 2024
Date of Approval:	Monday, 26 September 2022

HABS LNR confirms that this project meets the requirements of the National Statement on Ethical Conduct in Human Research (2007, current revision). The University's human research ethics committees are organised and operate in accordance with the National Statement on Ethical Conduct in Human Research (2007, current revision).

Approved Documents

Document Type	File Name	Document Tile	Application Version	Document Version	Last Modified
Change Tracking	2020_HE002444 v3_01 - v4_01 Changes.pdf	2020/HE002444 v3_01 - v4_01 Changes	4.1	1	23/09/2022 11:12:44 PM
Application	Output Form.pdf	Output Form	4.1	4	23/09/2022 11:12:39 PM

Ethics committee representative

Jolanda Jetten
Chair
HABS LNR
The University of Queensland

Appendix 2. Chapter 2 Search Terms

THESAURAUS TERMS

MEDLINE (OVID) MeSH:
Adolescent
Child
Pediatrics
High Intensity Interval Training

EMBASE (OVID) EMTREE:
Adolescent
Child
Pediatrics
High Intensity Interval Training

CINAHL (EBSCOHOST) SH:
Adolescence
Minors
Child
High Intensity Interval Training

SPORTDISCUS (EBSCOHOST) SU:
Adolescent
Child
Pediatrics
High Intensity Interval Training

KEYWORDS

Part I – high intensity interval training

High	Intensity	Interval	Training	Or
"	"	"	Exercise	Or
"	"	"	Activity	Or
"	"	"	Activities	Or
High	Intensity	Training		Or
"	"	Exercise		Or
"	"	Activity		Or
"	"	Activities		Or
"	"	Physical	Activity	Or
"	"	"	Activities	Or
"	"	Aerobic	Training	Or
High	Intensity	Intermittent		Or
Intense	Intermittent	Training		Or
"	"	Exercise		Or
"	"	Activity		Or
"	"	Activities		Or
Intense	Interval	Training		Or
"	"	Exercise		Or
"	"	Activity		Or
"	"	Activities		Or
HIIT				Or
HIIE				Or
Sprint	Interval	Training		

Part II – children and adolescents

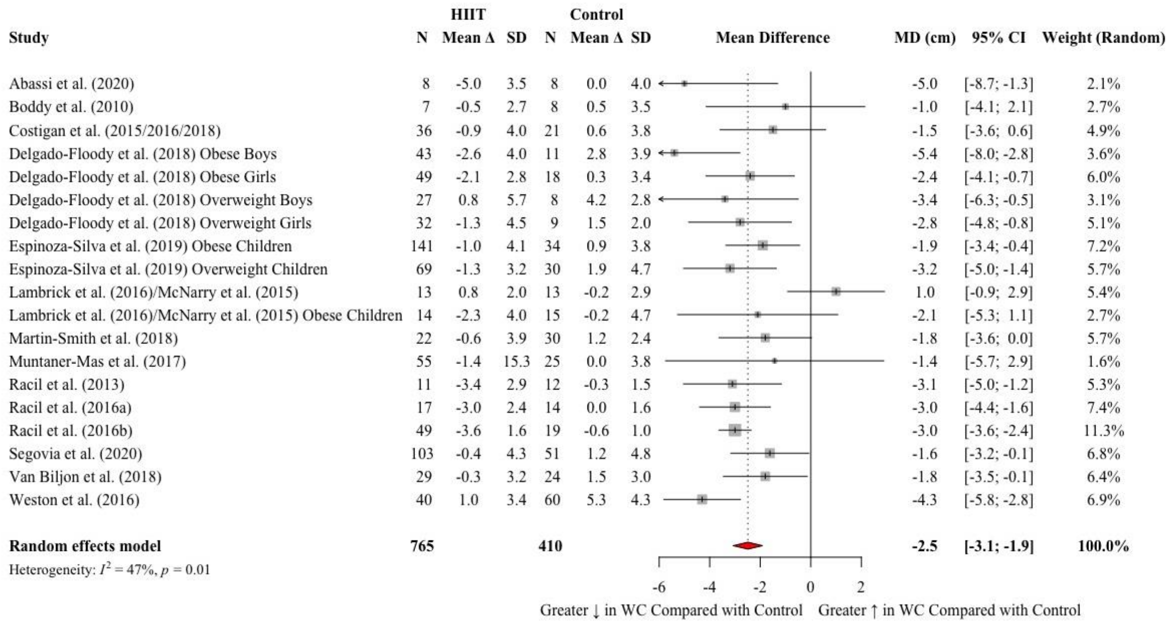
Child	Or
Children	Or
Adolescent*	Or
Adolescence	Or
Pediatric*	Or
Paediatric*	Or
Teen*	Or
Teenager*	Or
Youth*	Or
"Young People"	Or
Juvenile*	Or
Boy*	Or
Girl*	

Part I AND Part II = Final Search

Appendix 3. Chapter 2 Meta-Analysis Forest Plots

Body Composition Forest Plots

1. **Forest plot of high-intensity interval training versus control for waist circumference**

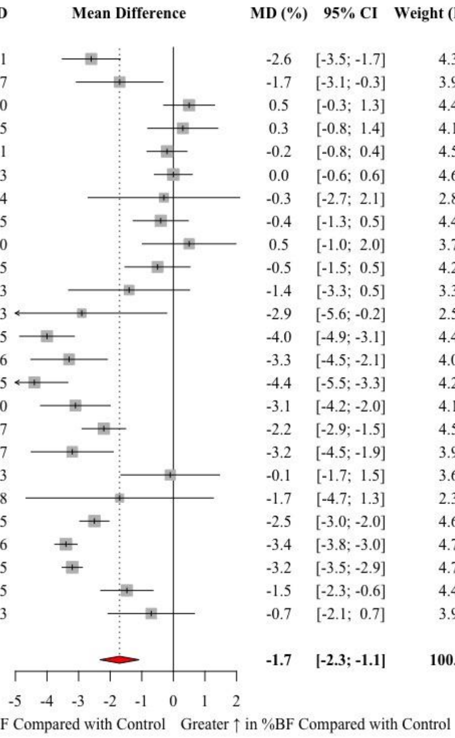


The mean difference between the change scores for high-intensity interval training (HIIT) and the control groups in centimetres
N = number of participants
Mean Δ = change score between pre- and post-tests
SD = standard deviation of the change score
MD = mean difference between the HIIT and control groups
CI = confidence interval
WC = waist circumference
I^2 = variation across studies due to heterogeneity rather than chance

2. Forest plot of high-intensity interval training versus control for body fat percentage

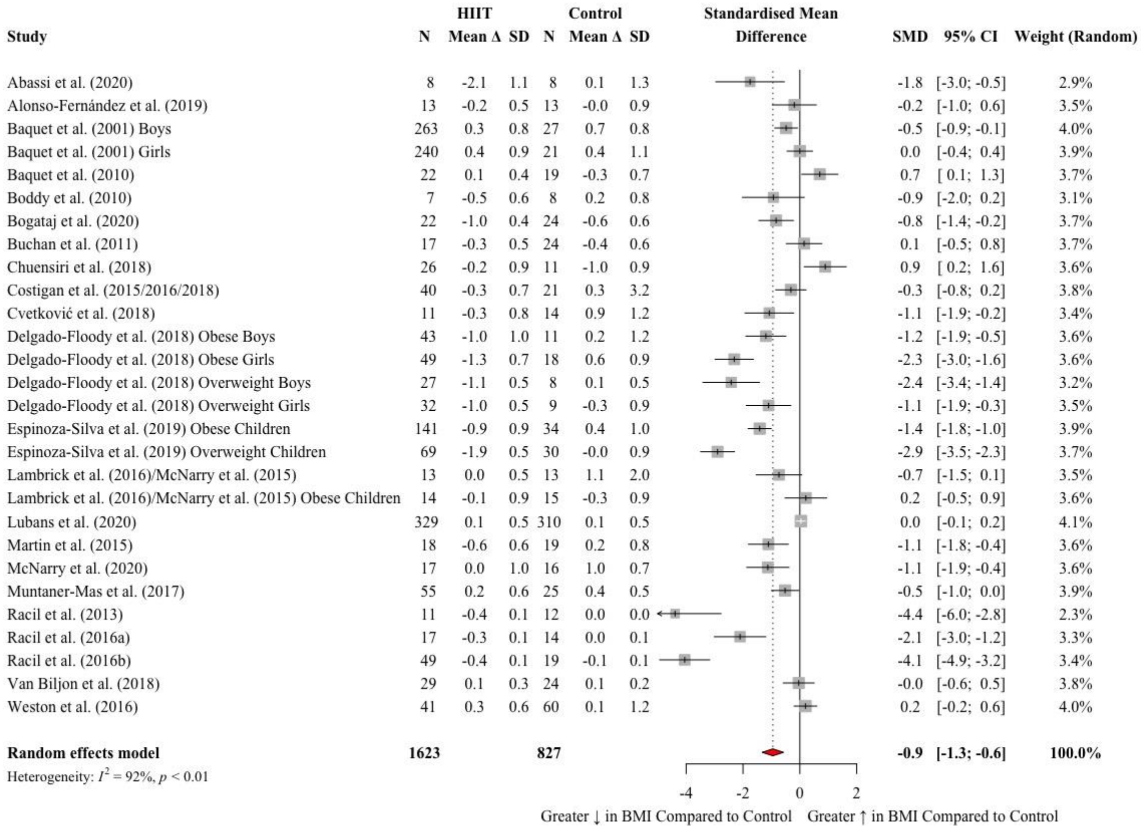
Study	HIIT N	HIIT Mean Δ	HIIT SD	Control N	Control Mean Δ	Control SD	MD (%)	95% CI	Weight (Random)
Abassi et al. (2020)	8	-2.3	0.8	8	0.3	1.1	-2.6	[-3.5; -1.7]	4.3%
Alonso-Fernández et al. (2019)	13	-1.7	1.9	13	0.0	1.7	-1.7	[-3.1; -0.3]	3.9%
Baquet et al. (2001) Boys	263	1.4	2.5	27	0.9	2.0	0.5	[-0.3; 1.3]	4.4%
Baquet et al. (2001) Girls	240	1.8	2.1	21	1.5	2.5	0.3	[-0.8; 1.4]	4.1%
Baquet et al. (2002)	33	-0.9	1.2	20	-0.7	1.1	-0.2	[-0.8; 0.4]	4.5%
Baquet et al. (2004)	47	0.1	1.7	53	0.1	1.3	0.0	[-0.6; 0.6]	4.6%
Boddy et al. (2010)	7	0.2	2.3	8	0.5	2.4	-0.3	[-2.7; 2.1]	2.8%
Bogataj et al. (2020)	22	-0.8	1.5	24	-0.4	1.5	-0.4	[-1.3; 0.5]	4.4%
Buchan et al. (2011)	17	0.5	2.6	24	0.0	2.0	0.5	[-1.0; 2.0]	3.7%
Chuensiri et al. (2018)	26	-1.4	1.5	11	-0.9	1.5	-0.5	[-1.5; 0.5]	4.2%
Cvetković et al. (2018)	11	-1.7	2.5	14	-0.3	2.3	-1.4	[-3.3; 0.5]	3.3%
Delgado-Floody et al. (2018) Obese Boys	43	-5.4	8.6	11	-2.5	1.3	-2.9	[-5.6; -0.2]	2.5%
Delgado-Floody et al. (2018) Obese Girls	49	-2.1	1.9	18	1.9	1.5	-4.0	[-4.9; -3.1]	4.4%
Delgado-Floody et al. (2018) Overweight Boys	27	-2.5	1.3	8	0.8	1.6	-3.3	[-4.5; -2.1]	4.0%
Delgado-Floody et al. (2018) Overweight Girls	32	-2.5	1.1	9	1.9	1.5	-4.4	[-5.5; -3.3]	4.2%
Espinoza-Silva et al. (2019) Obese Children	141	-1.5	5.3	34	1.6	2.0	-3.1	[-4.2; -2.0]	4.1%
Espinoza-Silva et al. (2019) Overweight Children	69	-2.2	1.4	30	0.0	1.7	-2.2	[-2.9; -1.5]	4.5%
Lambrick et al. (2016)/McNarry et al. (2015)	13	-1.0	1.6	13	2.2	1.7	-3.2	[-4.5; -1.9]	3.9%
Lambrick et al. (2016)/McNarry et al. (2015) Obese Children	14	-1.0	1.9	15	-0.9	2.3	-0.1	[-1.7; 1.5]	3.6%
Muntaner-Mas et al. (2017)	55	-1.5	10.9	25	0.2	1.8	-1.7	[-4.7; 1.3]	2.3%
Racil et al. (2013)	11	-2.9	0.6	12	-0.4	0.5	-2.5	[-3.0; -2.0]	4.6%
Racil et al. (2016a)	17	-3.9	0.4	14	-0.5	0.6	-3.4	[-3.8; -3.0]	4.7%
Racil et al. (2016b)	49	-2.9	0.7	19	0.3	0.5	-3.2	[-3.5; -2.9]	4.7%
Segovia et al. (2020)	103	-0.2	2.4	51	1.3	2.5	-1.5	[-2.3; -0.6]	4.4%
Weston et al. (2016)	41	0.7	2.7	60	1.4	4.3	-0.7	[-2.1; 0.7]	3.9%
Random effects model	**1351**			**542**			**-1.7**	**[-2.3; -1.1]**	**100.0%**

Heterogeneity: $I^2 = 93\%$, $p < 0.01$



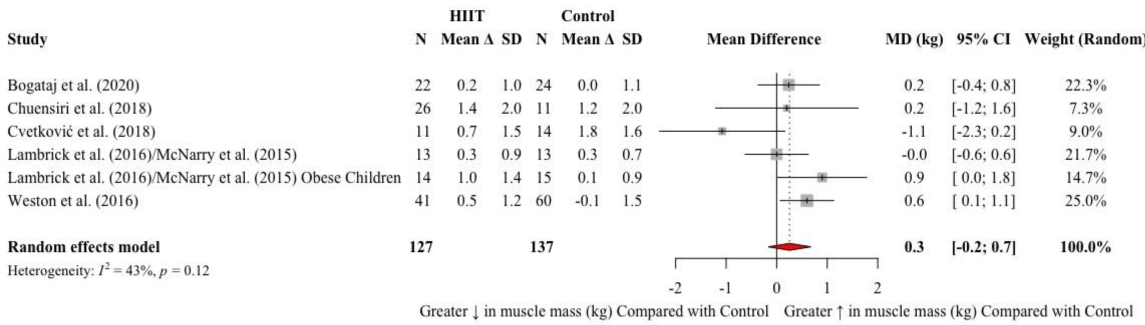
The mean difference between the change scores for high-intensity interval training (HIIT) and the control groups in percentage
N = number of participants
Mean Δ = change score between pre- and post-tests
SD = standard deviation of the change score
MD = mean difference between the HIIT and control groups
CI = confidence interval
%BF = percentage of body fat
I^2 = variation across studies due to heterogeneity rather than chance

3. Forest plot of high-intensity interval training versus control for body mass index



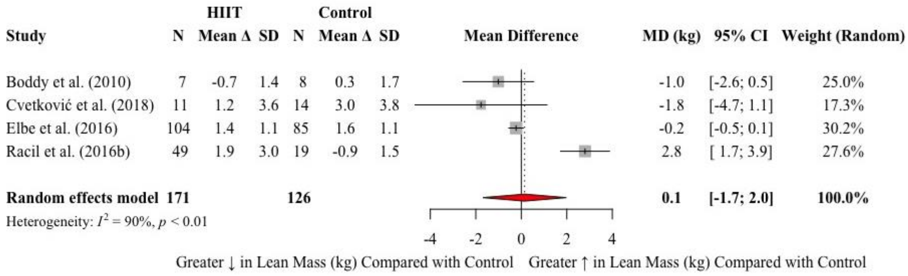
The standardised mean difference (SMD) between the change scores for high-intensity interval training (HIIT) and the control groups. SMD was used to account for numbers expressed as kg/m^2 and as z-scores.
N = number of participants
Mean Δ = change score between pre- and post-tests
SD = standard deviation of the change score
SMD = standardised mean difference between the HIIT and control groups
CI = confidence interval
BMI = body mass index
I^2 = variation across studies due to heterogeneity rather than chance

4. Forest plot of high-intensity interval training versus control for muscle mass



The mean difference between the change scores for high-intensity interval training (HIIT) and the control groups in kilograms
N = number of participants
Mean Δ = change score between pre- and post-tests
SD = standard deviation of the change score
MD = mean difference between the HIIT and control groups
CI = confidence interval
I^2 = variation across studies due to heterogeneity rather than chance

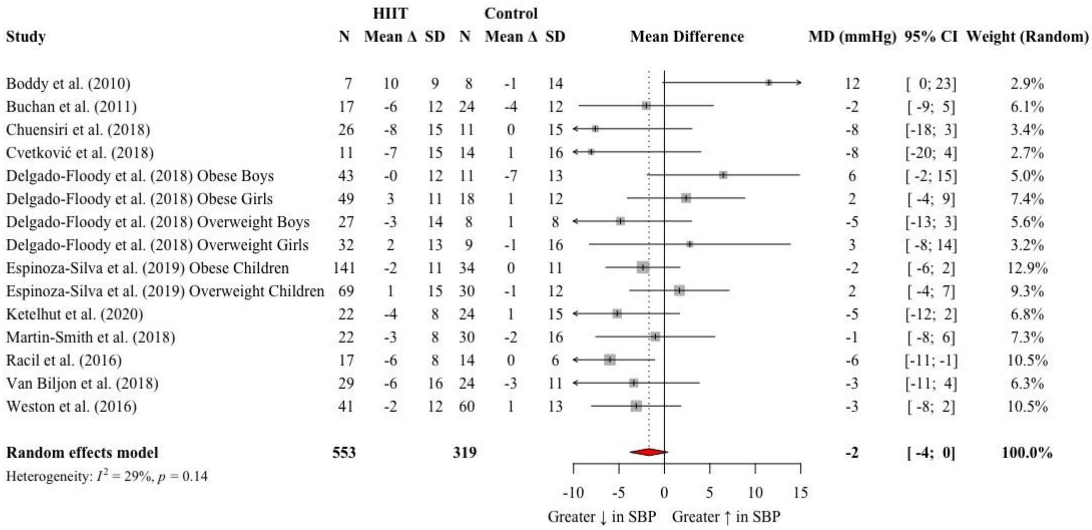
5. **Forest plot of high-intensity interval training versus control for lean mass**



The mean difference between the change scores for high-intensity interval training (HIIT) and the control groups in kilograms
N = number of participants
Mean Δ = change score between pre- and post-tests
SD = standard deviation of the change score
MD = mean difference between the HIIT and control groups
CI = confidence interval
I^2 = variation across studies due to heterogeneity rather than chance

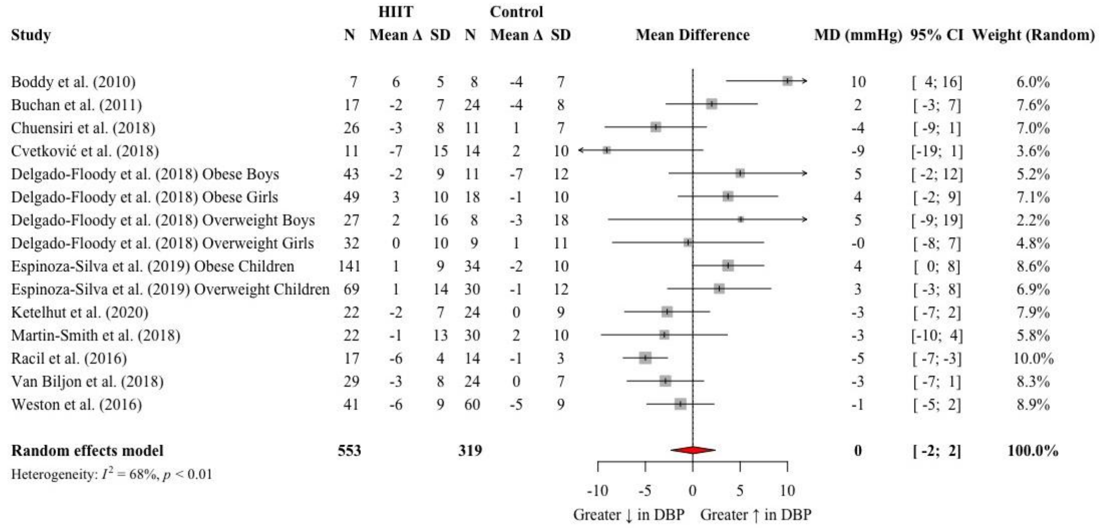
Cardiovascular Health Forest Plots

1. **Forest plot of high-intensity interval training versus control for systolic blood pressure**



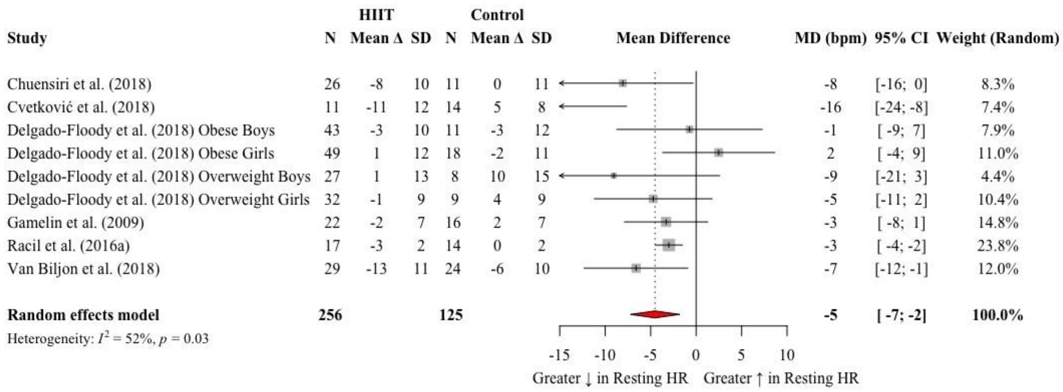
The mean difference between the change scores for high-intensity interval training (HIIT) and the control groups in millimetres of mercury.
N = number of participants
Mean Δ = change score between pre- and post-tests
SD = standard deviation of the change score
MD = mean difference between the HIIT and control groups
CI = confidence interval
SBP = systolic blood pressure
mmHg = millimetres of mercury
I^2 = variation across studies due to heterogeneity rather than chance

2. Forest plot of high-intensity interval training versus control for diastolic blood pressure



The mean difference between the change scores for high-intensity interval training (HIIT) and the control groups in millimetres of mercury.
N = number of participants
Mean Δ = change score between pre- and post-tests
SD = standard deviation of the change score
MD = mean difference between the HIIT and control groups
CI = confidence interval
DBP = diastolic blood pressure
mmHg = millimetres of mercury
I^2 = variation across studies due to heterogeneity rather than chance

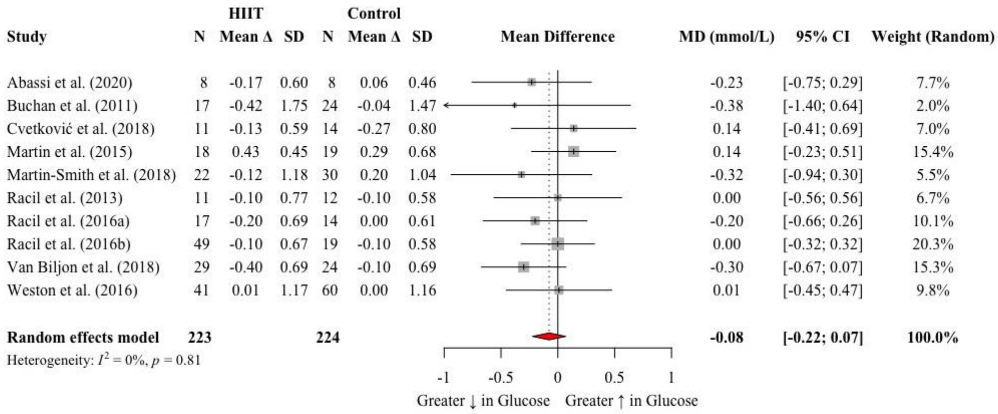
3. Forest plot of high-intensity interval training versus control for resting heart rate



The mean difference between the change scores for high-intensity interval training (HIIT) and the control groups in beats per minute.
N = number of participants
Mean Δ = change score between pre- and post-tests
SD = standard deviation of the change score
MD = mean difference between the HIIT and control groups
CI = confidence interval
HR = systolic blood pressure
Bpm = beats per minute
I^2 = variation across studies due to heterogeneity rather than chance

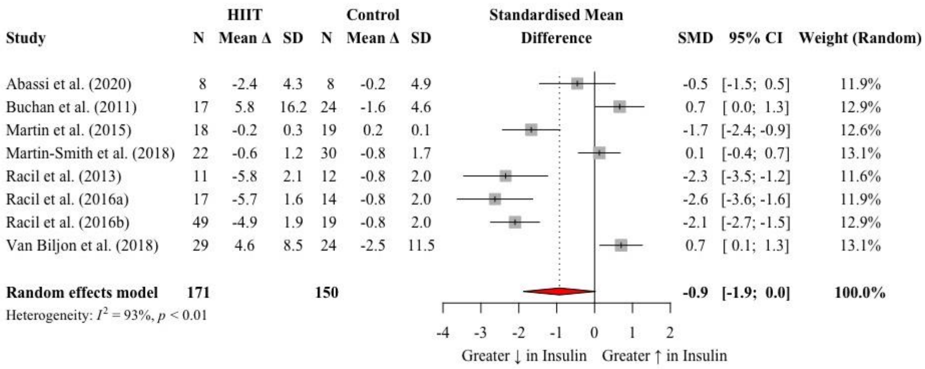
Blood Profile Forest Plots

1. Forest plot of high-intensity interval training versus control for fasting glucose



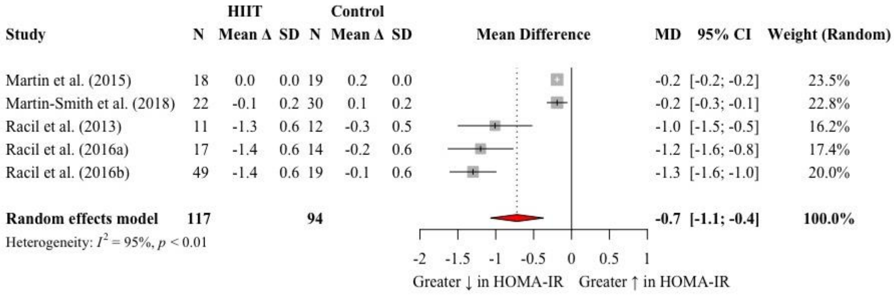
The mean difference between the change scores for high-intensity interval training (HIIT) and the control groups in millimoles per litre.
N = number of participants
Mean Δ = change score between pre- and post-tests
SD = standard deviation of the change score
MD = mean difference between the HIIT and control groups
CI = confidence interval
Mmol/L = millimoles per litre
I^2 = variation across studies due to heterogeneity rather than chance

2. Forest plot of high-intensity interval training versus control for fasting insulin



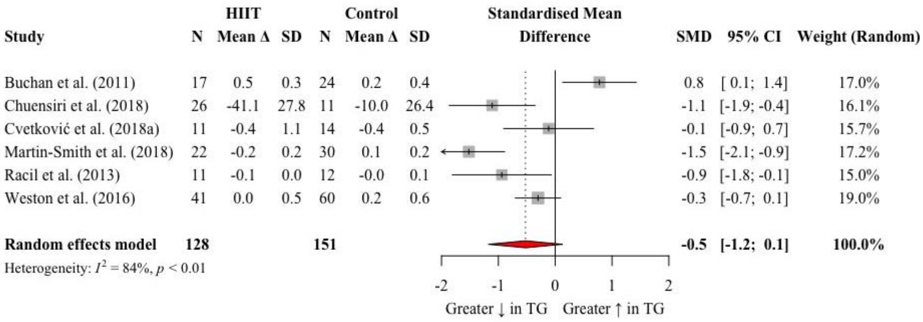
The standardised mean difference (SMD) between the change scores for high-intensity interval training (HIIT) and the control groups. SMD was used to account for different units of measurement presented.
N = number of participants
Mean Δ = change score between pre- and post-tests
SD = standard deviation of the change score
SMD = standardised mean difference between the HIIT and control groups
CI = confidence interval
I^2 = variation across studies due to heterogeneity rather than chance

3. **Forest plot of high-intensity interval training versus control for homeostatic model assessment – insulin resistance (HOMA-IR)**



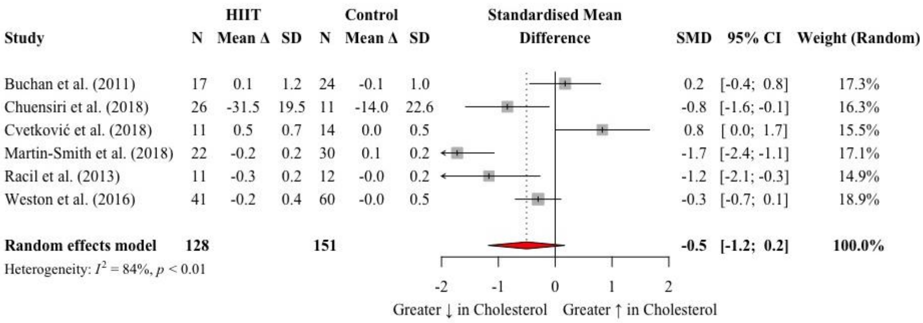
The mean difference between the change scores for high-intensity interval training (HIIT) and the control groups.
N = number of participants
Mean Δ = change score between pre- and post-tests
SD = standard deviation of the change score
MD = mean difference between the HIIT and control groups
CI = confidence interval
HOMA-IR = homeostatic model assessment – insulin resistance
I^2 = variation across studies due to heterogeneity rather than chance

4. **Forest plot of high-intensity interval training versus control for triglycerides**



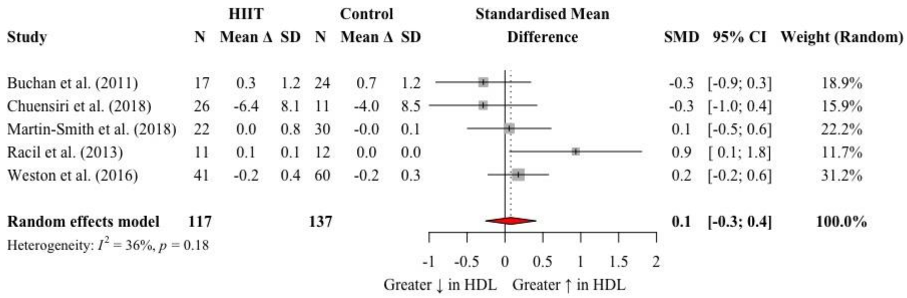
The standardised mean difference (SMD) between the change scores for high-intensity interval training (HIIT) and the control groups. SMD was used to account for different units of measurement presented.
N = number of participants
Mean Δ = change score between pre- and post-tests
SD = standard deviation of the change score
SMD = standardised mean difference between the HIIT and control groups
TG = triglycerides
CI = confidence interval
I^2 = variation across studies due to heterogeneity rather than chance

5. **Forest plot of high-intensity interval training versus control for total cholesterol**



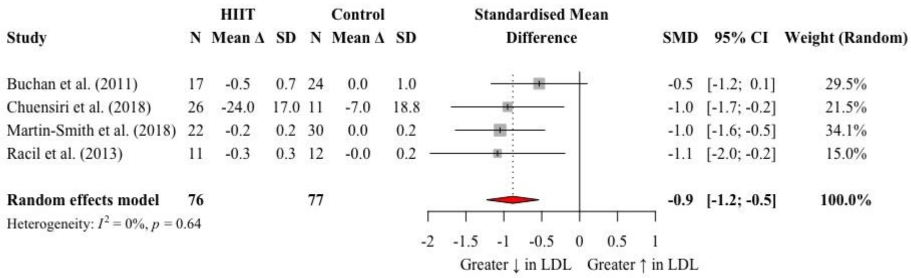
The standardised mean difference (SMD) between the change scores for high-intensity interval training (HIIT) and the control groups. SMD was used to account for different units of measurement presented.
N = number of participants
Mean Δ = change score between pre- and post-tests
SD = standard deviation of the change score
SMD = standardised mean difference between the HIIT and control groups
CI = confidence interval
I^2 = variation across studies due to heterogeneity rather than chance

6. Forest plot of high-intensity interval training versus control for total high-density lipoprotein



The standardised mean difference (SMD) between the change scores for high-intensity interval training (HIIT) and the control groups. SMD was used to account for different units of measurement presented.
N = number of participants
Mean Δ = change score between pre- and post-tests
SD = standard deviation of the change score
SMD = standardised mean difference between the HIIT and control groups
HDL = high-density lipoprotein
CI = confidence interval
I^2 = variation across studies due to heterogeneity rather than chance

7. Forest plot of high-intensity interval training versus control for total low-density lipoprotein



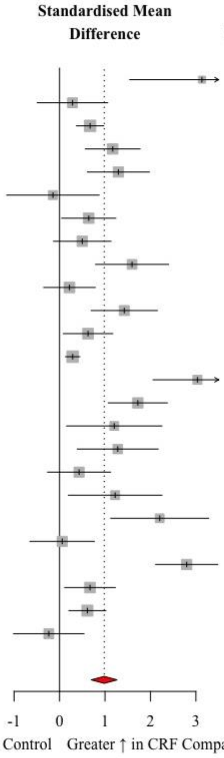
The standardised mean difference (SMD) between the change scores for high-intensity interval training (HIIT) and the control groups. SMD was used to account for different units of measurement presented.
N = number of participants
Mean Δ = change score between pre- and post-tests
SD = standard deviation of the change score
SMD = standardised mean difference between the HIIT and control groups
LDL = low-density lipoprotein
CI = confidence interval
I^2 = variation across studies due to heterogeneity rather than chance

Aerobic and Muscular Fitness Forest Plots

1. **Forest plot of high-intensity interval training versus control for all measurements of cardiorespiratory fitness**

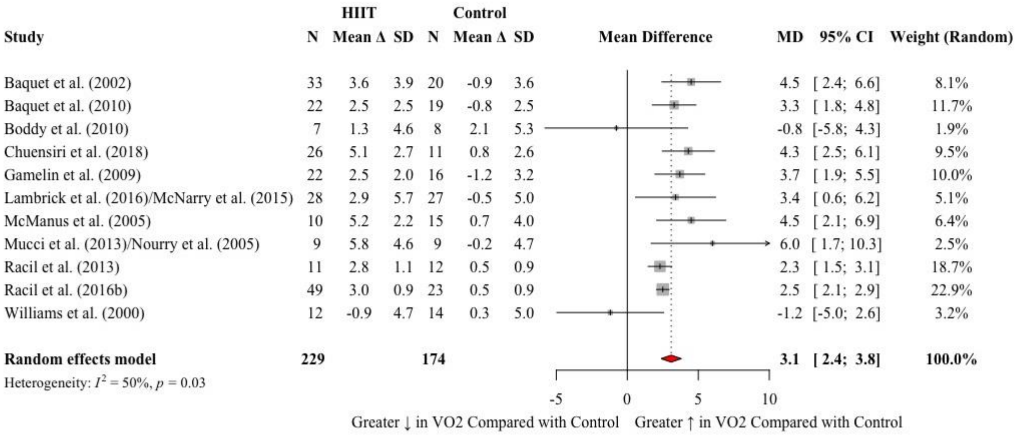
Study	HIIT N	HIIT Mean Δ	HIIT SD	Control N	Control Mean Δ	Control SD	SMD	95% CI	Weight (Random)
Abassi et al. (2020)	8	2.4	0.9	8	-0.3	0.7	3.1	[1.5; 4.7]	2.0%
Alonso-Fernández et al. (2019)	13	4.4	4.6	13	2.9	5.7	0.3	[-0.5; 1.1]	3.9%
Baquet et al. (2001)	503	0.4	0.6	48	0.0	0.6	0.7	[0.4; 1.0]	5.2%
Baquet et al. (2002)	33	3.6	3.9	20	-0.9	3.6	1.2	[0.6; 1.8]	4.4%
Baquet et al. (2010)	22	2.5	2.5	19	-0.8	2.5	1.3	[0.6; 2.0]	4.2%
Boddy et al. (2010)	7	1.3	4.6	8	2.1	5.3	-0.1	[-1.2; 0.9]	3.2%
Bogataj et al. (2020)	22	105.5	92.1	24	50.0	77.6	0.6	[0.0; 1.2]	4.4%
Buchan et al. (2011)	17	6.8	16.1	24	-1.2	15.4	0.5	[-0.1; 1.1]	4.3%
Chuensiri et al. (2018)	26	5.1	2.7	11	0.8	2.6	1.6	[0.8; 2.4]	3.8%
Costigan et al. (2015/2016/2018)	33	3.9	20.0	19	-0.2	15.4	0.2	[-0.3; 0.8]	4.5%
Gamelin et al. (2009)	22	2.5	2.0	16	-1.2	3.2	1.4	[0.7; 2.2]	4.0%
Lambrick et al. (2016)/McNarry et al. (2015)	28	2.9	5.7	27	-0.5	5.0	0.6	[0.1; 1.2]	4.6%
Lubans et al. (2020)	329	0.9	12.7	310	-3.5	17.8	0.3	[0.1; 0.4]	5.4%
Martin et al. (2015)	18	10.0	7.2	19	-13.0	7.7	3.0	[2.1; 4.0]	3.3%
Martin-Smith et al. (2018)	22	3.0	4.1	30	-3.7	3.6	1.7	[1.1; 2.4]	4.3%
McManus et al. (1997)	11	0.1	0.1	7	-0.0	0.1	1.2	[0.2; 2.3]	3.1%
McManus et al. (2005)	10	5.2	2.2	15	0.7	4.0	1.3	[0.4; 2.2]	3.6%
McNarry et al. (2020)	17	0.3	0.3	16	0.1	0.3	0.4	[-0.3; 1.1]	4.1%
Mucci et al. (2013)/Nourry et al. (2005)	9	5.8	4.6	9	-0.2	4.7	1.2	[0.2; 2.3]	3.2%
Racil et al. (2013)	11	2.8	1.1	12	0.5	0.9	2.2	[1.1; 3.3]	3.1%
Racil et al. (2016a)	17	0.1	0.2	14	0.1	0.2	0.1	[-0.6; 0.8]	4.1%
Racil et al. (2016b)	49	3.0	0.9	23	0.5	0.9	2.8	[2.1; 3.5]	4.2%
Van Biljon et al. (2018)	29	6.4	4.5	24	3.3	4.7	0.7	[0.1; 1.2]	4.5%
Weston et al. (2016)	41	6.1	9.8	60	-0.1	10.1	0.6	[0.2; 1.0]	4.9%
Williams et al. (2000)	12	-0.9	4.7	14	0.3	5.0	-0.2	[-1.0; 0.5]	3.9%
Random effects model	**1309**			**790**			**1.0**	**[0.7; 1.3]**	**100.0%**

Heterogeneity: $I^2 = 83\%$, $p < 0.01$



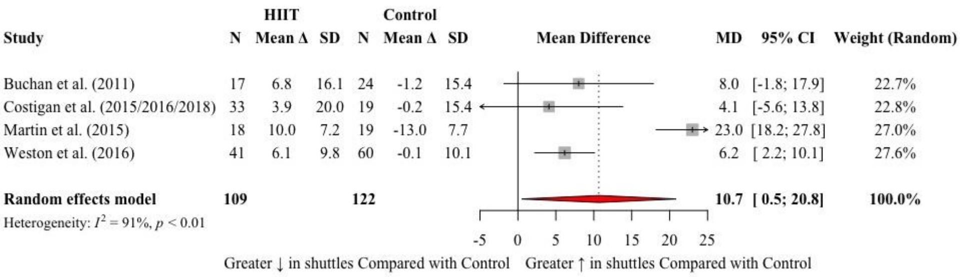
The standardised mean difference (SMD) between the change scores for high-intensity interval training (HIIT) and the control groups. SMD was used to account for different measures used to quantity cardiorespiratory fitness.
N = number of participants
Mean Δ = change score between pre- and post-tests
SD = standard deviation of the change score
SMD = standardised mean difference between the HIIT and control groups
CI = confidence interval
CRF = cardiorespiratory fitness
I^2 = variation across studies due to heterogeneity rather than chance

2. **Forest plot of high-intensity interval training versus control for cardiorespiratory fitness measured using a metabolic cart to measure relative VO_2**



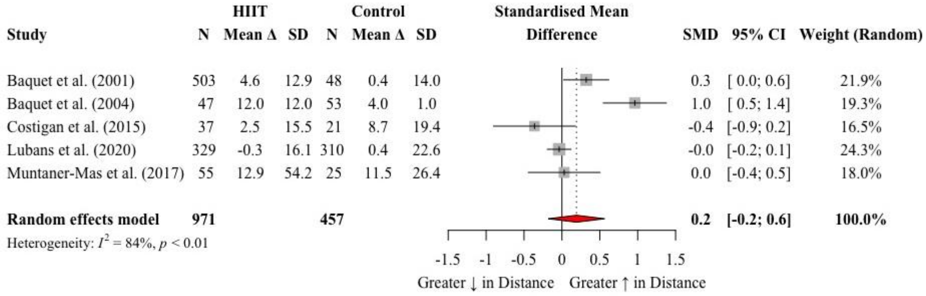
The mean difference between the change scores for high-intensity interval training (HIIT) and the control groups in ml/min/kg.
N = number of participants
Mean Δ = change score between pre- and post-tests
SD = standard deviation of the change score
MD = mean difference between the HIIT and control groups
VO_2 = maximum rate of oxygen consumption
I^2 = variation across studies due to heterogeneity rather than chance

3. **Forest plot of high-intensity interval training versus control for cardiorespiratory fitness measured using number of shuttles completed in the 20 m shuttle run test**



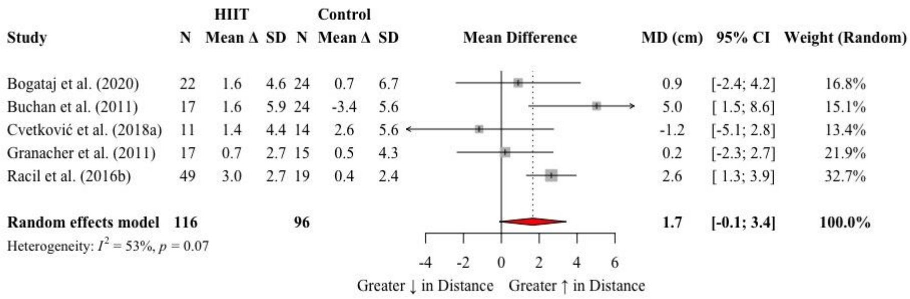
The mean difference between the change scores for high-intensity interval training (HIIT) and the control groups in number of shuttles.
N = number of participants
Mean Δ = change score between pre- and post-tests
SD = standard deviation of the change score
MD = mean difference between the HIIT and control groups
I^2 = variation across studies due to heterogeneity rather than chance

4. Forest plot of high-intensity interval training versus control for standing long jump



The standardised mean difference (SMD) between the change scores for high-intensity interval training (HIIT) and the control groups.
Mean Δ = change score between pre- and post-tests
SD = standard deviation of the change score
SMD = standardised mean difference between the HIIT and control groups
CI = confidence interval
I^2 = variation across studies due to heterogeneity rather than chance

5. Forest plot of high-intensity interval training versus control for countermovement jump



The mean difference between the change scores for high-intensity interval training (HIIT) and the control groups in centimetres
N = number of participants
Mean Δ = change score between pre- and post-tests
SD = standard deviation of the change score
MD = mean difference between the HIIT and control groups
CI = confidence interval
I^2 = variation across studies due to heterogeneity rather than chance

Appendix 4. Discussion and interview guides for evaluating the co-design process.

Teacher Interview Guide

1. Overall, how did you feel that the lessons went?
2. How, if at all, has this process complemented the work you do as part of the curriculum?
3. What aspects of the co-construction process, if any, would you use again? Why?
4. What aspects of the process, if any, do you think were best received by the students? Why?
5. What aspects of the process, if any, do you think could be improved?
6. Is there anything you would add or modify within the lessons?

Student Group Discussion Guide

1. Over the last three weeks we have been working together to design HIIT workouts, have you noticed any differences in the lessons you have done with Stephanie compared to your normal lessons?
2. How did you find working together to co-design the HIIT workouts and why?
   (With researcher, with teacher, with other peers)
3. How/Why did you choose the 1) theme/ 2) exercises/ 3) intervals for your workout?
4. What did you change in your workout after you tried it and why?

Student Individual Written Survey

1. What are two or three things that you learnt throughout the 6 lessons?
2. What was your favourite and least favourite part about the 6 lessons?
3. What, if anything, was beneficial about co-creating HIIT workouts together? And what, if anything, was not beneficial?
4. If we were to do this again, would you change anything or want us to change anything?
5. Which of the workouts that we co-created, if any, would you use again? Why?

Appendix 5. High-intensity interval training criteria for each co-design team (class).

The criteria created by each co-design team based on facilitators and barriers that were identified during the first co-design lesson and the modifications made to the criteria after trialling them on pre-made high-intensity interval training workouts.

School One Class A

1. I found the exercises in this workout fun
2. During this workout, I felt that I had choices to appropriately challenge myself and the workout was inclusive of my skill level
3. I felt like doing this with my friends and classmates made it more enjoyable
4. I had a sense of accomplishment at the end of this workout
5. I felt that I got my heart rate high enough to enable greater health benefits during this HIIT workout
6. I would do this HIIT workout again*

School Two Class B

1. I found the exercises in this workout fun and not too repetitive
2. During this workout, I felt that I had choices to appropriately challenge myself and the workout was not too difficult for me
3. I felt like doing this with my friends and classmates made it more enjoyable
4. I felt like I had a goal to work towards
5. I felt that this HIIT workout could help me improve my fitness and/or my skill levels

School Two Class C

1. I found the exercises in this workout fun, and it was something that I wanted to do
2. During this workout, I felt that I had choices to appropriately challenge myself and the workout was inclusive of my skill level
3. I felt like doing this with my friends and classmates made it more enjoyable
4. I had a sense of accomplishment at the end of this workout
5. I felt that I got my heart rate high enough to enable greater health benefits and improve my fitness during this HIIT workout

School Three Class D

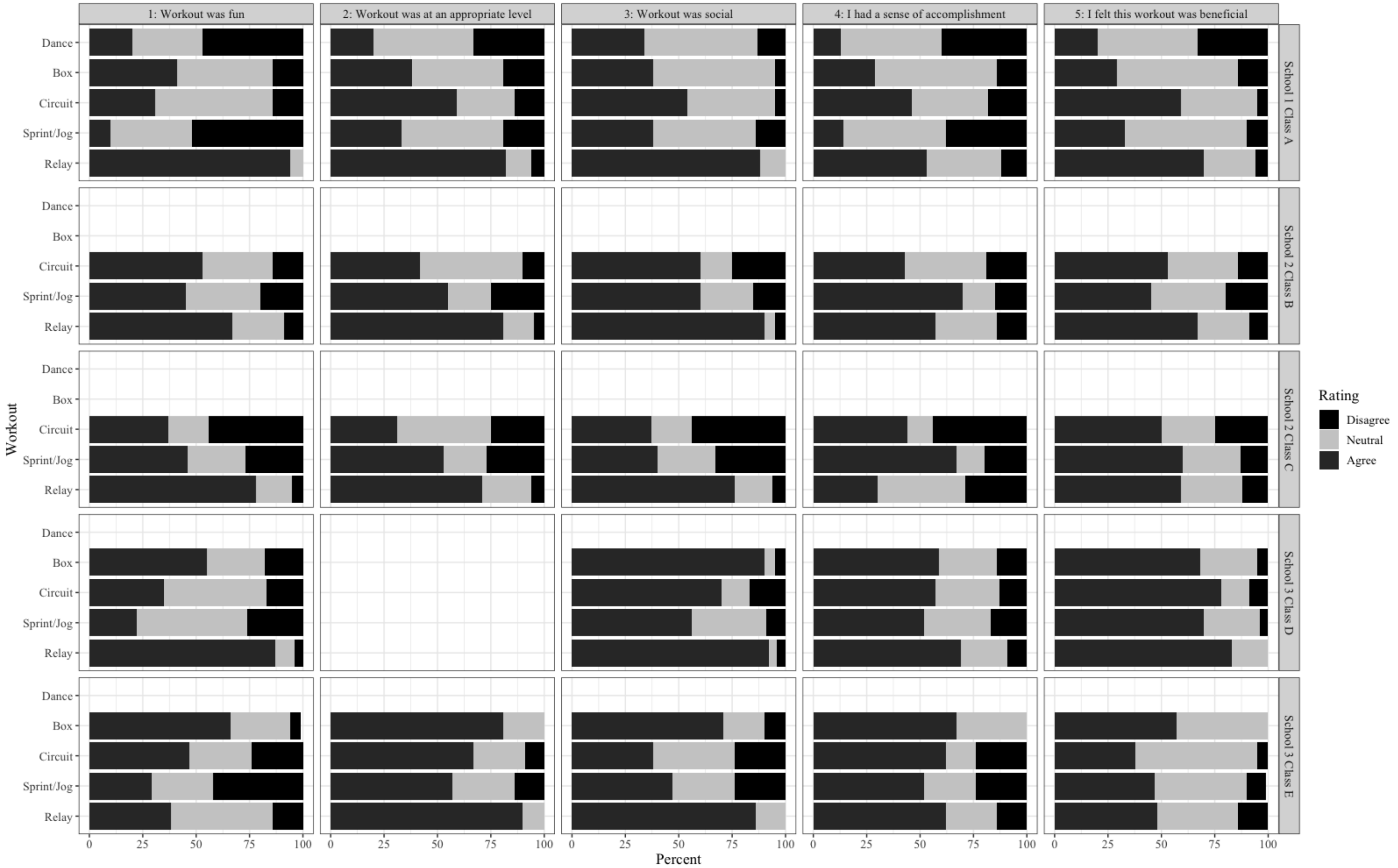
1. I found this workout fun
2. I felt like doing this with my friends and classmates made it more enjoyable
3. I had a sense of accomplishment and success at the end of this workout
4. I felt like this workout was the appropriate level of difficulty for me*
5. I felt that participating in this workout supports my health and my physical activity habits*

School Three Class E

1. I found the exercises in this workout fun
2. I did a good job of completing this workout at an appropriate level
3. I felt like doing this with my friends and classmates made it more enjoyable
4. I had a sense of accomplishment and success at the end of this workout
5. I felt that this HIIT workout helped support my fitness and/or health goals

*Underlined components were not included in iteration one of the criteria.

Appendix 6. Class evaluations of pre-made HIIT workouts.



The evaluations of the pre-made HIIT workouts in each of the five co-design teams. In school two, the dancing and boxing HIIT workouts were not completed and in school three, the dancing HIIT workout was not completed. Class D originally only included four criteria. The graphs indicate how many students agreed, disagreed, or were neutral towards each criterion as a percentage of the class. HIIT = high-intensity interval training.

Appendix 7. Adjusted mixed-effect models for each of the six outcome variables in *Chapter Seven*.

A. Adjusted linear mixed-effect model for students' enjoyment.

Fixed Effects	β	*p*-value
DV: PACES Score		
Intercept	3.74	**< 0.001**
Timepoint (ref: pre-intervention)	-0.08	0.445
Group (ref: control)		
HIIT Only	-0.15	0.367
Co-Design	-0.21	0.176
Group*Time Interaction		
HIIT Only*Time Interaction	0.05	0.747
Co-Design*Time Interaction	0.07	0.576
Sex (ref: female)	-0.24	**0.035**
Random Effects		
$\sigma^{2\ a}$	0.26	
$\tau_{00\ Student:\ Class\ b}$	0.39	
$\tau_{00\ Class\ c}$	0.01	
ICC [d]	0.61	
N_{Class} / $N_{Student}$	15 / 185	
Marginal R^2 / Conditional $R^{2\ e}$	0.029	0.619

The results from the adjusted linear mixed-effect model for the PACES Questionnaire completed in the *Making a HIIT* study. The results demonstrate student enjoyment was not significantly different between groups or over time, but there was a significant difference between boys and girls.
DV = dependent variable.
PACES = Physical Activity Enjoyment Scale, which provides an overall score between 1 and 5 indicating students' enjoyment of high-intensity interval training, where a higher score indicates greater enjoyment.

a = the within-person variance
b = the between-person variance
c = the between-class variance
d = the intra-class coefficient (ICC), which is the ratio of the between-cluster variance to total variance and indicates the proportion of the total variance that is accounted for by the clustering
e = marginal R^2 is the variance explained by the fixed-effects portion of the model; conditional R^2 is the variance explained by both the fixed and random effects

B. Adjusted linear mixed-effect model for students' autonomous motivation.

Fixed Effects	β	*p*-value
DV: Motivation Score		
Intercept	8.93	**< 0.001**
Timepoint (ref: pre-intervention)	-0.26	0.516
Group (ref: control)		
HIIT Only	0.12	0.847
Co-Design	-0.73	0.233
Group*Time Interaction		
HIIT Only*Time Interaction	-0.26	0.625
Co-Design*Time Interaction	-0.06	0.912
Sex (ref: female)	-0.03	0.942
Random Effects		
σ^2 [a]	3.70	
τ_{00} Student: Class [b]	5.24	
τ_{00} Class [c]	0.17	
ICC [d]	0.59	
N_{Class} / $N_{Student}$	15 / 185	
Marginal R^2 / Conditional R^2 [e]	0.019	0.602

The results from the adjusted linear mixed-effect model for the Identified and Intrinsic Motivation scales within the perceived locus of control (PLOC) Questionnaire completed in the *Making a HIIT* study. The results demonstrate students' autonomous motivation was not significantly different between groups or over time.

DV = dependent variable.

Motivation score = combines the identified and intrinsic motivation scales of PLOC questionnaire, which provides an overall score between 1 and 14 indicating students' autonomous motivation towards high-intensity interval training, where a higher score indicates greater autonomous motivation.

.

a = the within-person variance

b = the between-person variance

c = the between-class variance

d = the intra-class coefficient (ICC), which is the ratio of the between-cluster variance to total variance and indicates the proportion of the total variance that is accounted for by the clustering

e = marginal R^2 is the variance explained by the fixed-effects portion of the model; conditional R^2 is the variance explained by both the fixed and random effects

C. Adjusted linear mixed-effect model for students' autonomy.

Fixed Effects	β	*p*-value
DV: Autonomy Score		
Intercept	3.75	**< 0.001**
Timepoint (ref: pre-intervention)	-0.30	0.145
Group (ref: control)		
HIIT Only	-0.23	0.522
Co-Design	-0.32	0.355
Group*Time Interaction		
HIIT Only*Time Interaction	0.20	0.475
Co-Design*Time Interaction	0.24	0.111
Sex (ref: female)	-0.09	0.705
Random Effects		
$\sigma^{2\ a}$	0.98	
$\tau_{00\ \text{Student: Class}\ b}$	0.91	
$\tau_{00\ \text{Class}\ c}$	0.12	
ICC [d]	0.51	
N_{Class} / N_{Student}	15 / 176	
Marginal R^2 / Conditional $R^{2\ e}$	0.006	0.516

The results from the adjusted linear mixed-effect model for the autonomy scale completed in the *Making a HIIT* study. The results demonstrate students' autonomous motivation was not significantly different between groups or over time.
DV = dependent variable.
Autonomy score = Provides an overall score between 1 and 7, which indicates students' autonomy during a high-intensity interval training workout, where a higher score indicates greater autonomy.

a = the within-person variance
b = the between-person variance
c = the between-class variance
d = the intra-class coefficient (ICC), which is the ratio of the between-cluster variance to total variance and indicates the proportion of the total variance that is accounted for by the clustering
e = marginal R^2 is the variance explained by the fixed-effects portion of the model; conditional R^2 is the variance explained by both the fixed and random effects

D. Adjusted linear mixed-effect model for students' relatedness.

Fixed Effects	β	*p*-value
DV: Relatedness Score		
Intercept	4.35	**< 0.001**
Timepoint (ref: pre-intervention)	-0.47	**0.031**
Group (ref: control)		
HIIT Only	0.05	0.874
Co-Design	0.13	0.684
Group*Time Interaction		
HIIT Only*Time Interaction	0.31	0.294
Co-Design*Time Interaction	0.36	0.182
Sex (ref: female)	0.12	0.601
Random Effects		
$\sigma^{2\ a}$	1.04	
$\tau_{00\ \text{Student: Class}\ b}$	1.34	
$\tau_{00\ \text{Class}\ c}$	0.04	
ICC [d]	0.57	
N_{Class} / N_{Student}	15 / 176	
Marginal R^2 / Conditional $R^{2\ e}$	0.015	0.578

The results from the adjusted linear mixed-effect model for the relatedness scale completed in the *Making a HIIT* study. The results demonstrate students' relatedness significantly decreased over time irrespective of their group.
DV = dependent variable.
Relatedness score = Provides an overall score between 1 and 7, which indicates students' relatedness during a high-intensity interval training workout, where a higher score indicates greater relatedness.

a = the within-person variance
b = the between-person variance
c = the between-class variance
d = the intra-class coefficient (ICC), which is the ratio of the between-cluster variance to total variance and indicates the proportion of the total variance that is accounted for by the clustering
e = marginal R^2 is the variance explained by the fixed-effects portion of the model; conditional R^2 is the variance explained by both the fixed and random effects

E. Adjusted linear mixed-effect model for students' perceived competence.

Fixed Effects	β	*p*-value
DV: Perceived Competence Score		
Intercept	4.76	**< 0.001**
Timepoint (ref: pre-intervention)	-0.36	**0.036**
Group (ref: control)		
HIIT Only	-0.25	0.364
Co-Design	-0.14	0.584
Group*Time Interaction		
HIIT Only*Time Interaction	0.40	0.087
Co-Design*Time Interaction	0.35	0.109
Sex (ref: female)	0.04	0.816
Random Effects		
σ^2 [a]	0.68	
$\tau_{00\ Student:\ Class}$ [b]	1.19	
$\tau_{00\ Class}$ [c]	0.00	
ICC [d]	0.64	
N_{Class} / $N_{Student}$	15 / 176	
Marginal R^2 / Conditional R^2 [e]	0.005	0.639

The results from the adjusted linear mixed-effect model for the perceived competence scale completed in the *Making a HIIT* study. The results demonstrate students' perceived competence significantly decreased over time irrespective of their group.
DV = dependent variable.
Perceived competence score = Provides an overall score between 1 and 7, which indicates students' perceived competence during a high-intensity interval training workout, where a higher score indicates greater perceived competence.

a = the within-person variance
b = the between-person variance
c = the between-class variance
d = the intra-class coefficient (ICC), which is the ratio of the between-cluster variance to total variance and indicates the proportion of the total variance that is accounted for by the clustering
e = marginal R^2 is the variance explained by the fixed-effects portion of the model; conditional R^2 is the variance explained by both the fixed and random effects

F. Adjusted linear mixed-effect model for students' self-efficacy.

Fixed Effects	β	*p*-value
DV: HIIT-SQ Score		
Intercept	6.47	**< 0.001**
Timepoint (ref: pre-intervention)	0.02	0.939
Group (ref: control)		
HIIT Only	-0.14	0.760
Co-Design	0.03	0.951
Group*Time Interaction		
HIIT Only*Time Interaction	-0.47	0.446
Co-Design*Time Interaction	0.10	0.276
Sex (ref: female)	0.24	0.801
Random Effects		
$\sigma^{2\ a}$	2.12	
$\tau_{00\ Student:\ Class\ b}$	2.13	
$\tau_{00\ Class\ c}$	0.07	
ICC [d]	0.51	
N_{Class} / $N_{Student}$	15 / 158	
Marginal R^2 / Conditional $R^{2\ e}$	0.015	0.515

The results from the adjusted linear mixed-effect model for the HIIT-SQ Questionnaire completed in the *Making a HIIT* study. The results demonstrate students' autonomous motivation was not significantly different between groups or over time.
DV = dependent variable.
HIIT-SQ = high-intensity interval training self-efficacy questionnaire. It provides an overall score between 1 and 10, which indicates students' self-efficacy during a high-intensity interval training workout, where a higher score indicates greater confidence.

a = the within-person variance
b = the between-person variance
c = the between-class variance
d = the intra-class coefficient (ICC), which is the ratio of the between-cluster variance to total variance and indicates the proportion of the total variance that is accounted for by the clustering
e = marginal R^2 is the variance explained by the fixed-effects portion of the model; conditional R^2 is the variance explained by both the fixed and random effects

Appendix 8. Standard Operating Procedures for *Making a HIIT* intervention data collection.

Practical Measures

1. PACER Test with HR monitor
2. Anthropometry Measurements (Height and Weight)
3. Standing Long Jump .

** class to be split into groups for anthropometry and SLJ based on number of researchers and completed at the same time.

- One researcher on height/weight
- Remaining researchers on long jump

** Steph has already been to each class to hand out HR monitors. There will only be a few students that were absent who need instructions.

Script for start of class:

“Hello everyone,

Today we are going to be completing a beep test, a long jump, and taking your height and weight. It will be very busy so please make sure you are listening so that we do not run out of time to do everything.

We are going to start with the beep test. To do this, I need everyone to put on their heart rate monitors. A reminder that it needs to be touching your skin by your chest here ***point to sternum*.** If you have forgotten your number, it is on the TV screen. Your folders are in a line along the wall. If you still do not have a strap for the monitor, please come see me. I also need you to put the sticker that is on your folder on your left sleeve. This is so we can see when your number when you stop running. When you have your monitor and sticker on, I want you to come back here and sit down. You have 2 minutes. Leave your folder along the wall”

Move onto PACER script.

Post PACER:

“Great work everyone! You really worked hard out there. Now we are going to do the long jump and height and weight. We will be splitting you into groups to do this. Everyone will do their jumps first. Once you have finished your jumps you will go to that corner ****point to where scale is**** to have your weight and height measured. Please stand in a line on one of the taped x marks.

Split class based on number of researchers doing the standing long jump and have them go to the respective jump area with the researcher. One researcher will wait at height/weight area.

Move to Long Jump script.

Progressive Aerobic Cardiovascular Endurance Run (PACER Test)

(BEEP Test)

Equipment:

- Cones
- Measuring tape (Trundle Wheel)
- iPad with MP3 on Apple files (and speaker if needed)
- Score sheets and pencils
- Heart rate monitors

Procedure:

Step 1: Make sure that the 20-meter course is marked with cones and is truly 20-meters with the trundle.

Step 2: Ensure that you have enough copies of the score sheets.

Step 3: Have each student put on a heart rate monitor using the script on page 4.

Step 4: Review the PACER instructions with the students. See script on page 9.

Step 5: Split the class evenly between the researchers so that each researcher only has 6 or 7 students that they are responsible for watching. This will be indicated by the colour sticker on the students' sleeves.

Step 6: Instruct students to stand at the START line.

Step 7: Begin the audio and listen for the **TRIPLE BEEP**, this signifies that the test has begun, and the students should be running. Walking is permitted if the student maintains the "pace."

Step 8: Students will run from the START line to the END line and touch the END line with their foot before the BEEP sounds on the iPad.

Step 9: At the sound of the BEEP the students must turn around and run back to the other end. If students reach the line before the beep sounds, they must wait at the line until they hear the beep and then run back to the other end.

Step 10: When the TRIPLE BEEP sounds students should turn around and run to the other end whether they are at the line or not. The only difference between the BEEP and the TRIPLE BEEP is that the TRIPLE BEEP sounds at the end of each level and alerts students that the pace will increase.

Step 11: Students continue running back and forth from the START line to the END line until they have had two misses. If a student fails to reach the line by the time the BEEP sounds, then that is counted as a miss. If a student has achieved two misses, then they have completed the PACER and should go get a drink and stand to the side. Have students come to you to confirm when they are marked as out.

Step 12: Congratulate the students on finishing the test and have them do some stretches/cooldown

Script

Hello everyone!

Today we are going to do some running. It is not a race, but we want to see how long you can run and how high your heart rate can go. The idea is that you do the best that you can.

I believe that you are familiar with the beep test already, but I will remind you how it works:

At the sound of the beep, you will run from one cone to the other. Make sure when you get to the other end, you stand behind the line. Then when you hear the beep again, I want you to run back to the opposite side and wait behind the other line.

PLAY THE TRACK FOR THE STUDENTS TO LISTEN TO, NOTING THE TWO TYPES OF BEEPS

Did everyone hear the two different types of beeps? That triple beep means the pace will get faster and you will have to run faster to get to the other side before the beep sounds again.

So, what does one beep mean?

What does the triple beep mean?

If you do not reach the line by the time the beep sounds, stop where you are, turn around and run back to the opposite line. This gives you a chance to try to get back on pace. But, if you do not reach the line by the time the beep sounds a second time, you're finished.

When you are finished, please come tell one of us your name or show us the number on your sleeve and then sit over there. You may provide polite and respectful encouragement to those still running.

Scoring

To score with the **group score sheet**:

1. Cross out the lap numbers as they are completed
2. If the student does not reach the line before the beep, write the lap number in the column "first missed lap #"
3. If the student does not reach the line before the beep a second time, write the lap number of the **LAST** crossed out lap (last completed lap) in the column "laps completed"

Level	Laps													
1	~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	~~7~~							
2	~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	~~7~~	8						
3	1	2	3	4	5	6	7	8						

Lane	Student Name	First Miss Lap #	Laps Completed
1	Steph / 124	2.1	2.7

Standing Long Jump

(Broad Jump)

Equipment:

- Tape to mark the line where students start their jump
- Measuring tape
- Stick/ruler/etc. to mark landing of student on measuring tape
- Score sheets and pencils

Procedure:

Step 1: Each researcher should set up a taped line on the floor with a measuring tape going outwards from the line. The 0 cm mark should be on the taped line

Step 2: Divide the class between the researchers to increase speed of the test

Step 3: Have each student stand behind the line marked on the ground with their feet slightly apart

Step 4: Instruct them to have a two-foot take-off and landing – student must land standing and cannot fall backwards. They are encouraged to swing their arms and bend their knees to allow maximum forward drive.

- Researcher to demo once for students
- Each student will have 3 attempts

Step 5: Measurement is from where the back of the foot touches the ground
E.g., the nearest measurement to the starting line)

Step 6: Repeat the jump two more times so each student has three attempts.

Script

Now, we are going to do some jumping. We want to see how far you can jump to understand how powerful your leg muscles are!

I think you are all familiar with the long jump that you do on athletics day. This is very similar.

You will come up to this line and stand with your toes behind it. Bend your knees a bit and swing your arms backward to get yourself in a good start position. When you are ready swing your arms forward and jump as far as you can! You must take off and land on **both your feet**. We will measure from the closest part of you to the line. You will all get three tries to do it.

Any questions?

Once you have done your three attempts, please go stand in the line to get your height and weight measured.

Sample Score Card

Standing Long Jump Score Sheet

Score Keeper: ____________________________ Class: ____________ Date: ________

Student Name / #	Attempt 1	Attempt 2	Attempt 3
Steph	212 cm	232 cm	Fell on bum – 140 cm
Michalis	224 cm	238 cm	241 cm

Anthropometry

Equipment:

- Calibrated scale
- Stadiometer

Protocol

Prior to starting measurements, set up stadiometer/scale in a more private corner of the gym

Step 1: Have students remove shoes and any hat/cap

Step 2: Have student stand at stadiometer with their feet together, heels against the back, and knees straight

Step 3: Have student look straight ahead and not up

Step 4: Have student breathe in and stand tall

Step 5: Read and record height in centimetres using their ID number on the sticker

Step 6: Have student move away from the stadiometer

Step 7: Ensure the scale reads 0.0

Step 8: Ask the student to stand on the scale. They should face forward with their arms by their side and stand still

Step 9: Record the weight in kilograms next to their height on the sheet provided

Step 10: Send students to their teacher for instructions as they will have completed all the measures

Sample Height and Weight Sheet

Score Keeper: ______________________________ Class: _____________ Date: _________

Student Name / #	Height	Weight
122	159 cm	55.3 kg
134	134 cm	47.2 kg

Theory Measures

1. Executive Function Tests
2. Theory Questionnaires

"Hello everyone,

Today we are going to be completing two computer tests that examine your attention and memory and two questionnaires about physical activity. We expect all of these to be done in silence under exam conditions. The computer tests can be a little challenging, but we are going to go over them. For now, please keep your laptops closed on your desks so that we know you are listening."

Move to executive function script.

Executive Function

Equipment:

- Teacher laptop with slides previously sent (teacher laptop used due to projection system at St Laurence)
- Student laptops
- Five HMNS laptops (as backups)

Procedure:

Step 1: Ensure slides and test link have been sent to the teacher (Steph to do)

Step 2: Spend 5 minutes explaining the tests using the provided slides and script on the next page.

Step 3: Have the teacher send the link out to all the students. Ask them to open the link using google chrome and enter their ID number when prompted. Provide their ID number should they forget.

Step 4: Remind the students that this is being done under exam conditions and there should be no talking. When they are done, they can complete the questionnaires next to them.

Step 5: Provide laptops to any students who do not have one.

Step 5: Put out the questionnaires (Theory Questionnaires) when students are settled into the computer tasks.

Step 6: Answer any questions that the students have while they do the tasks.

Script with Slides

Slide 1: Title

Slide 2:

Today we will be doing two computer tests that examine your attention and memory. They each take around 10 minutes to complete. Half of you will start with one task, and the other half of you will start with the other task. You need to be very focused to do well on these, so when we start, no one will be allowed to speak.

Slide 3: Coloured rectangle task

The coloured rectangle task, also known as the visual array task, will take around 8 minutes to do. You will get a slow and fast practice round before the actual test starts.
First, you will be told a colour to remember, either blue or red. It will flash before each set of rectangles. In this example, we must remember only the blue rectangles.

Slide 4:

You will see many rectangles flash on the screen. They will either be horizontal, vertical, or diagonal. You want to remember which way the rectangles are facing, but you only need to remember the colour that you were told.

They will flash very quickly.

Slide 5:

You will then be asked about one rectangle, which will be indicated using a white dot in the centre. You need to decide if the rectangle is facing the same direction that it was before or if it is different.

If it is the **same** direction as before, you press 5 on the keyboard.
If it is a **different** direction, you press 6 on the keyboard.

In this example, would you press 5 or 6?
**Make sure all students understand why they should press 6

You will repeat this task for around 8 minutes. Only the practice session will tell you if you get the answers right or wrong. We care about how **accurate** you are and **not** how fast you are able to finish the task**. Please be as accurate as possible**.

Slide 6: Q or O

The goal of this task is to decide if a Q or an O flashes on the screen.
You will get a slow and fast practice round before the real test. You will also get a break halfway through and you will get feedback on whether you got the answer right the whole way through. This should take you 10 minutes to complete.

Slide 7:

To do this task, watch the cross in the middle of the screen because when it gets bigger, you need to be ready to watch for the O or Q.

Slide 8:

After the cross gets bigger, an asterisk will flash on one side of the screen. You need to look at the other side of the screen to see the O or Q. There will be very little time between the asterisks and the letter.

Slide 9:

The letter will only flash very quickly and then will be hidden by two hashtags. So, you need to look over quickly. After, press the O or Q key depending on what letter you saw. **We care about how accurate you are in this task and not how fast you go.**

Any questions about the two tasks?

***Answer any questions*

If you have questions throughout the tests, please raise your hand quietly and we will come to you.

Slide 10:

Please go to this website. Enter your participant number (the number you have used for your heart rate monitor all term) and 2 as your session number. Remember, please do not click the escape key at any point during the test

Theory Questionnaires

Equipment:

Questionnaire Package for each student

- One: PAQ-C Questionnaire
- Two: PACES Questionnaire

Protocol

Step 1: Hand out the questionnaires to each student while they are completing the computer tests.

This is to be completed by yourself. There are no right or wrong answers; we just want to know your opinion, so please answer honestly. These questionnaires ask you about how much you enjoy general physical activity and how much physical activity you do.

Step 2: Have the students complete the questionnaires when they finish the computer task.

Step 3: Collect the questionnaires and ensure the students have answered all questions/pages.

Step 4: Have the students sit quietly while they wait for the other students to finish.

HIIT Session Questionnaires

Equipment:

Questionnaire Package for each student

- One: RPE, Enjoyment and Affect Questions
- Two: Motivation Questionnaire
- Three: PACES Questionnaire
- Four: Psychological Needs Questionnaire
- Five: Self-efficacy Questionnaire

Protocol

Step 1: Put student folders with questionnaire package and HR monitors in a line.

Step 2: Tell all the students to put on their heart rate monitors and leave folders.

Step 3: Complete HIIT workout that was provided to the teachers and record HR data (**See Page 5)**

Step 4: Have the students go to their folders and sit down.

These are to be completed by yourself so please spread out (if possible). There are no right or wrong answers; we just want to know your opinion, so please answer honestly.

Step 5: complete **questionnaire one.**

*There are a few questions on the first piece of paper about **THIS HIIT WORKOUT**. The top left one asks you about how hard you worked. If 10 was as hard as you possibly could and 0 was not hard at all. Please circle one number. The second question asks about your enjoyment of **THIS HIIT WORKOUT**, please circle a number between 1 and 5. The next few ask you how you felt during **THIS HIIT WORKOUT.***

Step 6: complete **questionnaires two - five.**

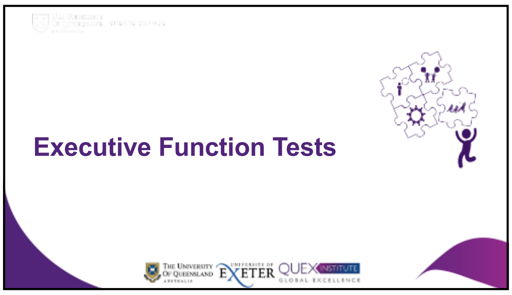
*The next pages ask about your enjoyment of HIIT **IN GENERAL**, not just the workout you completed right now. They also ask about your motivation and confidence to do HIIT. Please read the questions and circle one number for each question. When you are done, please put the questions back in your folder. If you have any questions, please raise your hand.*

Step 7: Collect the questionnaires and ensure the students have answered all questions/pages.

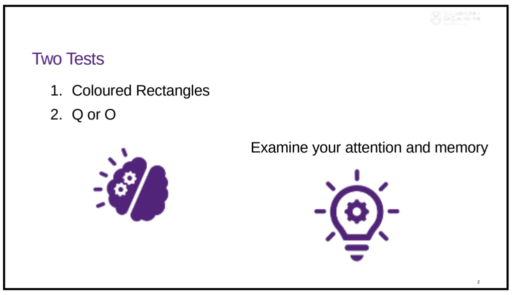
Step 8: Have the students sit quietly while they wait for the other students to finish.

Appendix 9. Executive Function Task Slides

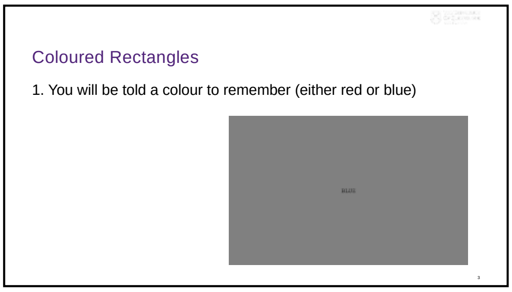
24/6/2023



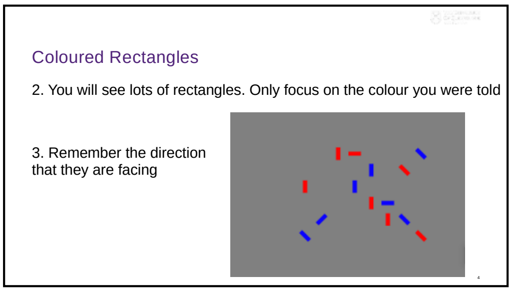
1



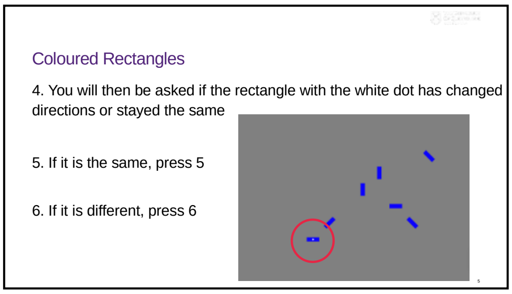
2



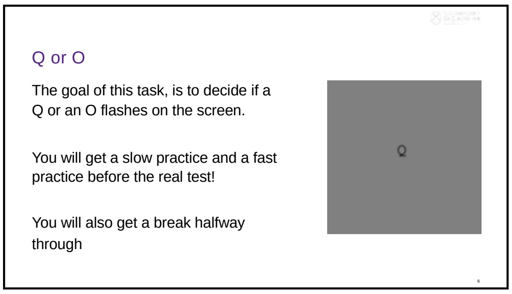
3



4



5



6

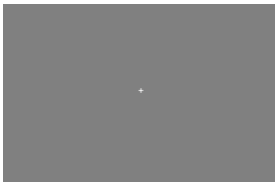
1

Q or O

To do this:

Watch the cross in the middle of the screen

When it gets bigger, be ready to watch for the O or Q

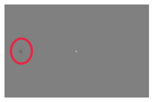


7

Q or O

An asterisk will appear on one side of the screen

The O or Q will appear on the OPPOSITE side of the screen.



8

Q or O

It will then be hidden almost immediately by a “##”

So, look quickly!

Press the O or the Q key depending on what you saw

9

To Do the Tests

1. Open on google chrome:
   https://run.pavlovia.org/sduncombe/attentiontaskscombined/html
2. Type in your participant number and session number (2) and **CLICK** “ok”
3. The instructions for each test will be provided before you start
4. Do these tests quietly and individually
5. Be as ACCURATE as possible

10

When You Are done:

1. Congrats on finishing the tests. Take a second to relax.
2. Please keep quiet and follow any instructions on the whiteboard.

There are no right or wrong answers so please be as honest as possible

11

Appendix 10. Mixed-effects models for the four outcome variables in *Chapter Eight*.

A. Unadjusted and adjusted linear mixed-effects models for the 20-meter shuttle run.

	Unadjusted		Adjusted	
Fixed Effects	β	*p*-value	β	*p*-value
DV: Number of laps completed				
Intercept	41.36	**< 0.001**	-15.90	0.053
Timepoint (ref: pre-intervention)	2.71	**0.015**	3.06	**0.004**
Group (ref: control)	-3.09	0.726	-3.30	0.296
Group*Timepoint Interaction	-1.47	0.278	-1.42	0.325
Sex (ref: female)			20.61	**< 0.001**
Overweight (ref: healthy weight)			-2.56	0.128
Obese (ref: healthy weight)			-0.40	0.843
PAQ-C Score ⸸			7.28	**0.001**
PACES Score Ψ			6.79	**0.001**
Random Effects				
σ^2 [a]	64.39		48.45	
$\tau_{00\ Student:\ Class}$ [b]	321.86		268.02	
$\tau_{00\ Class}$ [c]	179.13		2.72	
ICC [d]	0.89		0.85	
N_{Class} / $N_{Student}$	12 / 152		12 / 152	
Marginal R^2 / Conditional R^2 [e]	0.007	0.887	0.436	0.914
AIC [f]	2658.8		2077.8	

The results from the unadjusted and adjusted linear mixed-effects models for the 20-meter shuttle run completed in the *Making a HIIT* study. The results demonstrate the number of laps completed were significantly explained by the timepoint, the sex of the students, and their score on the PAQ-C and PACES questionnaires.

DV = dependent variable.
⸸ PAQ-C = Physical Activity Questionnaire for Older Children, which provides an overall score between 1 and 5 indicating how active a student is, where a higher score indicates more activity.
Ψ PACES = Physical Activity Enjoyment Scale, which provides an overall score between 1 and 5 indicating students' enjoyment of general physical activity, where a higher score indicates greater enjoyment.
a = the within-person variance
b = the between-person variance
c = the between-class variance
d = the intra-class coefficient (ICC), which is the ratio of the between-cluster variance to total variance and indicates the proportion of the total variance that is accounted for by the clustering
e = marginal R^2 is the variance explained by the fixed-effects portion of the models; conditional R^2 is the variance explained by both the fixed and random effects
f = Akaike Information Criterion, where a lower number indicates a better model fit

B. Unadjusted and adjusted linear mixed-effects models for the standing long jump.

	Unadjusted		Adjusted	
Fixed Effects	β	*p*-value	β	*p*-value
DV: Distance jumped (cm)				
Intercept	170.67	**< 0.001**	117.47	**< 0.001**
Timepoint (ref: pre-intervention)	5.57	**< 0.001**	5.89	**< 0.001**
Group (ref: control)	-5.07	0.560	-5.50	0.161
Group*Timepoint Interaction	-1.81	0.269	-2.48	0.224
Sex (ref: female)			18.40	**< 0.001**
Overweight (ref: healthy weight)			-0.60	0.799
Obese (ref: healthy weight)			-3.71	0.209
PAQ-C Score ǂ			8.10	**0.004**
PACES Score Ψ			5.47	**0.037**
Random Effects				
σ^2 [a]	97.62		110.27	
$\tau_{00\ Student:\ Class}$ [b]	503.83		424.58	
$\tau_{00\ Class}$ [c]	158.88		3.12	
ICC [d]	0.87		0.80	
N_{Class} / $N_{Student}$	12 / 164		12 / 164	
Marginal R^2 / Conditional R^2 [e]	0.019	0.874	0.300	0.856
AIC [f]	2998.9		2437.8	

The results from the unadjusted and adjusted linear mixed-effects models for the standing long jump completed in the *Making a HIIT* study. The results demonstrate the distance jumped (cm) was significantly explained by the timepoint, the sex of the students, and their score on the PAQ-C and PACES questionnaires.

DV = dependent variable.
ǂ PAQ-C = Physical Activity Questionnaire for Older Children, which provides an overall score between 1 and 5 indicating how active a student is, where a higher score indicates more activity.
Ψ PACES = Physical Activity Enjoyment Scale, which provides an overall score between 1 and 5 indicating students' enjoyment of general physical activity, where a higher score indicates greater enjoyment.
a = the within-person variance
b = the between-person variance
c = the between-class variance
d = the intra-class coefficient (ICC), which is the ratio of the between-cluster variance to total variance and indicates the proportion of the total variance that is accounted for by the clustering
e = marginal R^2 is the variance explained by the fixed-effects portion of the models; conditional R^2 is the variance explained by both the fixed and random effects
f = Akaike Information Criterion, where a lower number indicates a better model fit

C. Unadjusted and adjusted linear mixed-effects models for the antisaccade task.

	Unadjusted		Adjusted	
Fixed Effects	β	*p*-value	β	*p*-value
DV: Task accuracy (%)				
Intercept	68.75	**< 0.001**	46.86	**< 0.001**
Timepoint (ref: pre-intervention)	4.23	**0.001**	4.74	**<0.001**
Group (ref: control)	-2.92	0.434	-1.31	0.724
Group*Timepoint Interaction	-0.62	0.685	0.90	0.600
Sex (ref: female)			3.44	0.356
Overweight (ref: healthy weight)			-0.31	0.869
Obese (ref: healthy weight)			3.27	0.135
PAQ-C Score ⸸			1.96	0.256
PACES Score Ψ			3.79	**0.013**
Random Effects				
σ^2 [a]	83.36		73.67	
τ_{00} Student: Class b	165.61		140.87	
τ_{00} Class c	21.47		21.99	
ICC [d]	0.69		0.69	
N_{Class} / $N_{Student}$	12/ 159		12 / 159	
Marginal R^2 / Conditional R^2 [e]	0.033	0.702	0.129	0.729
AIC [f]	2794.4		2125.4	

The results from the unadjusted and adjusted linear mixed-effects models for the antisaccade task completed in the *Making a HIIT* study. The results demonstrate the task accuracy (%) was significantly explained by the timepoint.

DV = dependent variable
⸸ PAQ-C = Physical Activity Questionnaire for Older Children, which provides an overall score between 1 and 5 indicating how active a student is, where a higher score indicates more activity.
Ψ PACES = Physical Activity Enjoyment Scale, which provides an overall score between 1 and 5 indicating students' enjoyment of general physical activity, where a higher score indicates greater enjoyment.
a = the within-person variance
b = the between-person variance
c = the between-class variance
d = the intra-class coefficient (ICC), which is the ratio of the between-cluster variance to total variance and indicates the proportion of the total variance that is accounted for by the clustering
e = marginal R^2 is the variance explained by the fixed-effects portion of the models; conditional R^2 is the variance explained by both the fixed and random effects
f = Akaike Information Criterion, where a lower number indicates a better model fit

D. Unadjusted and adjusted linear mixed-effects models for the visual arrays task.

	Unadjusted		Adjusted	
Fixed Effects	β	*p*-value	β	*p*-value
DV: Average capacity score (*k*)				
Intercept	1.32	**< 0.001**	0.66	**< 0.001**
Timepoint (ref: pre-intervention)	-0.10	0.232	-0.06	0.232
Group (ref: control)	-0.18	0.318	-0.14	0.318
Group*Timepoint Interaction	-0.00	0.980	0.08	0.980
Sex (ref: female)			0.36	0.170
Overweight (ref: healthy weight)			-0.10	0.453
Obese (ref: healthy weight)			0.13	0.403
PAQ-C Score ⸸			-0.09	0.428
PACES Score Ψ			0.21	**0.032**
Random Effects				
σ^2 [a]	0.39		0.44	
τ_{00} Student: Class [b]	0.61		0.51	
τ_{00} Class [c]	0.05		0.02	
ICC [d]	0.63		0.54	
N_{Class} / $N_{Student}$	12 / 159		12 / 159	
Marginal R^2 / Conditional R^2 [e]	0.011	0.632	0.055	0.569
AIC [f]	923.0		716.5	

The results from the unadjusted and adjusted linear mixed-effects models for the visual arrays task completed in the *Making a HIIT* study. The results demonstrate the average capacity score (*k*) did not significantly change based on timepoint or group.

DV = dependent variable
⸸ PAQ-C = Physical Activity Questionnaire for Older Children, which provides an overall score between 1 and 5 indicating how active a student is, where a higher score indicates more activity.
Ψ PACES = Physical Activity Enjoyment Scale, which provides an overall score between 1 and 5 indicating students' enjoyment of general physical activity, where a higher score indicates greater enjoyment.
a = the within-person variance
b = the between-person variance
c = the between-class variance
d = the intra-class coefficient (ICC), which is the ratio of the between-cluster variance to total variance and indicates the proportion of the total variance that is accounted for by the clustering
e = marginal R^2 is the variance explained by the fixed-effects portion of the models; conditional R^2 is the variance explained by both the fixed and random effects
f = Akaike Information Criterion, where a lower number indicates a better model fit