

FEASIBILITY AND EFFICACY OF FITNESS- AND SKILL-BASED HIGH-INTENSITY
INTERVAL EXERCISE PROTOCOLS IN CHILDREN

By

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PUBLIC ABSTRACT

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Despite the breadth of health benefits of engaging in small amounts of vigorous physical activity (VPA), children do not engage in sufficient amounts. This highlights the need to determine enjoyable and effective strategies for youth to attain VPA in order to promote health improvements. The current dissertation first examined the acute physiological and perceptual responses to a body-weight resistance high-intensity interval exercise (HIIE) protocol in young boys and girls. This form of exercise was representative of VPA in individual and group settings and was enjoyed by participants. The second part of this dissertation involved a HIIE intervention delivered to 4th and 5th grade students during physical education (PE). The intervention addressed concerns with previous HIIE studies by aiming to promote the quality (i.e. enjoyment) of student's PE experiences while implementing intense PA. Students participating in the fitness- and skill-based HIIE intervention significantly improved their cardiorespiratory fitness and muscular strength relative to the control group. The physical educator expressed favorable views on the feasibility of the intervention, rating the intervention high in feasibility overall. Students also perceived the intervention favorably with high program satisfaction scores. The program did not change students' perceptions of PE, which remained positive after the intervention. Overall, these results advocate for an increased research attention to the physiological and psychological impacts of delivering HIIE in PE settings and continued use of similar fitness- and skill-based HIIE protocols as a means to promote students' physical health during PE.

ABSTRACT

FEASIBILITY AND EFFICACY OF FITNESS- AND SKILL-BASED HIGH-INTENSITY INTERVAL EXERCISE PROTOCOLS IN CHILDREN

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It is recommended that children engage in at least 60 minutes of moderate-to-vigorous physical activity (MVPA) per day; three occasions should specifically include vigorous physical activity (VPA) to promote cardiorespiratory and muscular fitness and maintain weight status. One evidence-based strategy to promote VPA in children is high-intensity interval exercise (HIIE). The current dissertation presents data from two laboratory-based studies investigating the cardiometabolic and perceptual responses to a body-weight resistance HIIE protocol (CIRC) compared to treadmill-based HIIE (TM) in boys and girls. The first acute study found similar mean heart rate (HR) responses (86 ± 6 %HR_{peak} for CIRC and 85 ± 4 %HR_{peak} for TM, $P > 0.05$) yet a greater mean oxygen consumption (VO₂) response to TM (70 ± 9 %VO_{2peak} for CIRC versus 77 ± 5 %VO_{2peak} for TM, $P = 0.008$) in boys. In contrast, mean HR and VO₂ were similar in girls, but during group CIRC mean HR was higher than in both individual conditions [92 ± 7 %HR_{peak} (Group CIRC); 86 ± 7 %HR_{peak} (CIRC); 85 ± 4 %HR_{peak} (TM)]. Also in girls, VO₂ responses were similar between CIRC and TM (76 ± 11 %VO_{2peak} for CIRC versus 76 ± 10 %VO_{2peak} for TM, $P = 0.60$). In both boys and girls, rating of perceived exertion (RPE), affective valence, and enjoyment responses were similar between CIRC and TM ($P > 0.05$), and only RPE increased during exercise ($P < 0.001$). This dissertation also presents results from a fitness- and skill-based HIIE intervention delivered to 4th and 5th grade students during physical education (PE). The intervention, which focused on promoting physical health outcomes, addressed critical gaps in the HIIE literature by adopting a theoretical approach that focused on the psychosocial

experiences of the delivered intervention. Students participating in the HIIE intervention significantly improved their cardiorespiratory fitness and muscular strength relative to the control group ($F(1,49) = 17.40, P < 0.001, \eta^2 = 0.26$; $F(1,54) = 5.67, P = 0.02, \eta^2 = 0.09$), respectively). A greater amount of time was spent engaging in MVPA in the intervention group compared to the control group, based on both HR and accelerometer data (38.1 ± 7.9 vs. 32.8 ± 8.7 min/hr; $P = 0.025, \eta^2 = 0.08$; 23.4 ± 5.0 vs. 15.7 ± 4.7 min/hr; $P < 0.001, \eta^2 = 0.45$, respectively). However, only the accelerometer data supported that students in the intervention accumulated greater amounts of VPA during PE (4.5 ± 2.6 vs. 2.3 ± 1.3 min/hr; $P < 0.001, \eta^2 = 0.27$). Participants and the physical educator reported favorable program satisfaction and feasibility ratings. Lastly, the program did not change students' perceptions of autonomy, relatedness, and competence during PE, which did not differ from the control group and remained positive after the intervention ($F(3,52) = 1.37, P = 0.26, \eta^2 = 0.07$). These results can be used to advocate for the implementation of fitness- and skill-based HIIE interventions that incorporate both physical fitness and motor competence components delivered in PE settings. The Self Determination Theory may be a suitable theoretical framework to guide future HIIE interventions given that this intervention increased students' physical activity levels without negatively influencing their psychosocial perceptions towards PE, including their enjoyment and their perceptions of autonomy, relatedness, and competence.

This dissertation is dedicated to the children and the physical educator who participated in these research studies. Thank you for making my research experiences enjoyable and fun.

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KEY TO ABBREVIATIONS

ANOVA	Analysis of Variance
BLa	Blood Lactate Concentration
BP	Blood Pressure
HIIE	High-Intensity Interval Exercise
HIIT	High-Intensity Interval Training
HR	Heart Rate
HR _{peak}	Peak Heart Rate
MANOVA	Multivariate Analysis of Variance
MAS	Maximal Aerobic Speed
MVPA	Moderate-to-Vigorous Physical Activity
PA	Physical Activity
PE	Physical Education
SDT	Self Determination Theory
VPA	Vigorous Physical Activity
VO ₂	Aerobic Capacity
VO _{2peak}	Peak Aerobic Capacity

INTRODUCTION

It is recommended that children engage in at least 60 minutes of moderate-to-vigorous physical activity (MVPA) per day; three occasions should specifically include vigorous physical activity (VPA) in order to promote cardiorespiratory and muscular fitness, maintain weight status, and reduce the risk of developing cardiovascular disease risk factors that often track into adulthood.¹ Focusing on activities that promote VPA (e.g., sprinting, jumping) is especially important because engaging in these activities is strongly associated with improved body composition and cardiometabolic health in children, more so than light- or moderate-intensity activities.^{2,3} Given that children 6-12 years old often do not engage in sufficient amounts of VPA during youth sports or active play games,⁴ there is a need to determine enjoyable and efficacious strategies for youth to attain VPA in order to elicit health improvements.

One evidence-based strategy to promote VPA in children that has demonstrated significant improvements in aerobic fitness, body composition, and vascular function is high-intensity interval training (HIIT).⁵⁻⁷ HIIT involves completing brief periods of VPA performed at $\geq 85\%$ of peak heart rate (HR_{peak}) interspersed with passive or active recovery periods performed at a lower intensity.⁵⁻⁷ In pediatric populations HIIT is often performed in a controlled laboratory setting requiring cycle ergometers and treadmills, or in school-based settings utilizing sprint running protocols.⁵ Although running-based HIIT may be a salient mode of VPA to promote cardiometabolic health improvements,⁵ running alone does not provide additional important aspects of physical activity (PA) including the development of motor competence and muscular fitness. These fitness- and skill-based aspects must also be an integral focus when designing exercise programming aimed at promoting VPA in youth since they are pre-requisites for sport participation and recreational PA programs and are linked to habitual PA participation.^{8,9}

Although running and cycling-based HIIT may not be the most developmentally appropriate and attractive mode of VPA for children, the structure of HIIT emulates children's normal activity patterns of performing short bursts of VPA that are interspersed with periods of lower-intensity activity.¹⁰ Therefore, a potential avenue for children to attain VPA is to apply the structure of HIIT to different interval-based exercise protocols that provide brief bouts of VPA but also focus on motor competence and muscular fitness during the work and/or recovery intervals.

Prior to implementing fitness and skill-based interval exercise protocols into school or youth sport settings, it is important to characterize the acute physiological responses to this mode of exercise in children to determine if it provides an appropriate stimulus that may be effective to induce chronic health-related adaptations. Accordingly, recent studies have examined children's acute cardiometabolic responses [i.e. oxygen consumption (VO_2) and heart rate (HR)] to interval exercise protocols that incorporated several important aspects of PA including motor competence and muscular fitness.¹¹⁻¹³ Although these protocols provided a dose of MVPA, the majority of exercises were not representative of VPA. Further, these studies did not include assessment of blood lactate accumulation, which is often used as an indirect marker of exercise intensity, or perceptual responses that influence habitual PA participation including affect and enjoyment.¹⁴ Therefore, these types of protocols may not elicit the long-term adaptations that correspond with regular engagement in VPA. Alternatively, multi-joint body-weight resistance exercises that emphasize foundational movement patterns (i.e., squat, plank, jump) may be a feasible strategy to promote VPA, motor competence, and muscular fitness in children and may be more attractive than running, given the variety of movement patterns and exercises in these protocols. Although previous research has investigated the acute responses to equipment-based resistance exercise and cycling-based interval exercise in active adolescents,¹⁵ it is unknown if body-weight

resistance exercise alone can provide a vigorous physiological stimulus comparable to traditional running-based HIIT protocols in children.

Although initial acute studies are warranted to determine if body-weight resistance exercise is a salient mode of VPA, children will likely need a variety of exercises, including partner-based body-weight exercises, as well as variations in equipment, to maintain engagement and enjoyment during long-term exercise programs. Previous studies support the preliminary efficacy of fitness- and skill-based HIIT interventions utilizing a variety of equipment and exercises specifically in PE settings.¹⁶⁻¹⁹ These preliminary studies have demonstrated improvements in cardiorespiratory and/or muscular fitness in children and report strong fidelity based on participants' peak heart rate during HIIT.^{20, 21} However, further evaluation regarding the acceptability and program satisfaction of these PE-based HIIT protocols are needed to determine if they are a viable strategy for children to attain adequate amounts of VPA during PE. This is an important gap in the literature that must be addressed in future research, especially since incorporating HIIT into the school day has been previously contested.²²

Another limitation of previous fitness- and skill-based HIIT interventions is that the majority did not adopt a theoretical approach and failed to consider aspects of the intervention that influence long-term PA participation, such as the level of enjoyment and self-determined motivation (i.e. participation in PA because it is enjoyable, fun, and challenging) experienced during the intervention. One theoretical perspective that addresses the role of these psychological constructs in promoting self-determined motivation that has been heavily studied in the PE domain is the Self Determination Theory (SDT).²³ The SDT provides a strong theoretical foundation for future fitness and skill-based HIIT interventions focused on promoting VPA and motor competence,²⁴ since this theory postulates that the degree to which the basic psychological

needs of competency (i.e. task mastery), autonomy (i.e. choice), and relatedness (i.e. social interactions) are satisfied determines the extent to which individuals are motivated by self-determined, or intrinsic, properties.²³ In line with relatedness, the social environment as a source of enjoyment in youth PA settings has received little attention in previous, acute, lab-based and fitness- and skill-based PE intervention studies. While the majority of previous studies have focused on individual responses, it is important to assess the attractiveness (i.e. enjoyment) and feasibility of performing this form of exercise in small groups since group settings can positively influence individual behaviors such as PA participation and enjoyment.²⁵ Further, empirical evidence in adults supports that individuals prefer to exercise in groups and that enhanced group cohesion is a source of PA enjoyment.²⁶ Therefore, future studies are warranted to determine children's perceptual responses to performing fitness- and-skill based HIIT in individual versus small group settings with peers.

Given the recent evidence regarding the health benefits of engaging in MVPA and VPA in children, future research must assess if fitness- and-skill based HIIT protocols focused on motor competence and muscular fitness, such as body-weight resistance exercise, are representative of vigorous exercise and if children enjoy engaging in such exercise either individually or in small group settings. Further, following preliminary acute studies it is also important to determine the public health implications of implementing fitness- and skill-based HIIT into PE. This may be accomplished by performing complete process evaluations regarding the acceptability and feasibility of implementing such exercise into PE settings. Accordingly, the purpose of the proposed dissertation is to determine the feasibility of a fitness- and skill-based interval exercise protocol in providing an enjoyable, vigorous-intensity cardiometabolic stimulus in children and to then determine the efficacy and acceptability of such protocols in eliciting

favorable changes in fitness, psychological constructs (i.e. enjoyment and affect), and PA behavior and motivation in a PE setting. In line with the overall purpose of this dissertation, the proposed following specific aims and hypotheses are addressed in three separate studies:

Specific Aims and Hypotheses:

1. To compare the acute cardiometabolic (VO_2 and HR) and perceptual responses (i.e., perceived exertion, affective valence (i.e. feeling state), and enjoyment) to a body-weight resistance exercise circuit (CIRC) versus a treadmill-based HIIT (TM) protocol in 8-11 year-old boys.

Hypotheses:

1a. CIRC would elicit similar changes in VO_2 and HR yet greater blood lactate accumulation compared to TM.

1b. There would be no significant decline in affective valence or exercise enjoyment from baseline to post-exercise for CIRC and TM given the shorter work interval and lower volume compared to previous studies,²⁷ but CIRC would elicit more favorable perceptual responses during exercise compared to TM since the CIRC protocol provides more exercise variety and different movement patterns.

2. To compare girls' acute cardiometabolic and perceptual responses between CIRC and TM protocols performed individually and to CIRC performed in a small group setting.

Hypotheses:

2a. CIRC would elicit similar changes in VO_2 and HR, yet greater blood lactate accumulation, compared to TM.

2b. There would be no significant decline in affective valence or exercise enjoyment during and post-exercise compared to pre-exercise for TM and individual and group-based CIRC.

2c. Group-based CIRC would elicit more positive affective valence and enjoyment at all timepoints during exercise compared to individually performed CIRC and TM protocols since relatedness with peers and group exercise have been linked to higher exercise enjoyment in children and adults.^{28, 29}

3. To evaluate the efficacy and perform a process evaluation of a 6-week fitness and skill-based HIIT intervention delivered during 4th and 5th grade elementary school PE classes compared to a control group engaging in traditional PE activities for promoting MVPA and VPA during PE, selected fitness outcomes, basic psychological needs satisfaction, self-determined motivation, and leisure-time PA. A secondary aim was to evaluate the fidelity of the intervention comparing the time spent engaging in MVPA and VPA between intervention and control groups.

Hypotheses:

3a. Cardiorespiratory fitness, muscular fitness, and motor competence would increase significantly from baseline to post- intervention in the intervention group relative to the control group.

3b. Relative to the control group, participants in the intervention group would significantly improve their physical activity enjoyment and fulfillment of the basic psychological needs (perceived competence, autonomy, and relatedness, proposed by the SDT) at post-intervention compared to baseline.

3c. The intervention would demonstrate strong fidelity, with classes in the intervention group participating in significantly greater amounts of MVPA and VPA during PE compared to control classrooms.

3d. For the process evaluation, we hypothesized that the intervention would demonstrate high feasibility scores by the physical educator and favorable program acceptability from participants and the physical educator.

CHAPTER 1

Review of Literature

The benefits of regular physical activity (PA) participation, especially vigorous-intensity PA (VPA), in children are expansive and include improved physical fitness, maintained weight status, and reduced risk of developing cardiovascular disease risk factors.^{1, 30} However, many children and adolescents do not meet the recommended amount of PA.³¹ Inactive children also present poor motor competence and low PA enjoyment, both of which are related to low motivation to live healthy, active lifestyles during childhood and throughout the lifespan.³² Therefore, a need exists to determine attractive strategies for children to attain VPA while promoting motor competence. This review examines the current literature on the benefits of VPA and the importance of promoting motor competence and muscular fitness in youth. Further, the strengths and limitations of previously implemented strategies to promote VPA in children, including running-based high-intensity interval training (HIIT), as well as more novel HIIT protocols that incorporate motor competence and muscular fitness that may be more developmentally appropriate than running-based protocols, are reviewed. Lastly, important future research directions are highlighted, including the need for the assessment of perceptual responses to individual- and group-based HIIT in children in addition to establishing a theoretical foundation for future school-based HIIT studies.

Benefits of Participating in Vigorous-Intensity Physical Activity

Engaging in VPA, such as sprint running or jumping, may have the greatest impact on indicators of cardiometabolic health in children, more so than light or moderate intensity activities.³⁰ For example, an accumulating body of evidence has demonstrated a stronger inverse relationship between accumulated VPA and adiposity compared to moderate-intensity PA and

moderate-to-vigorous PA (MVPA).^{3, 33, 34} This relationship seems to persist even in children with low cardiovascular fitness and is independent of age, sex, and weight.³⁵ Encouraging participation in VPA is likely to promote improvements in cardiometabolic health in children. Furthermore, VPA is beneficial for cardiorespiratory fitness, with the majority of the literature indicating a positive relationship between levels of VPA and cardiorespiratory fitness, more so than light and moderate-intensity PA.^{2, 36, 37} Given that a sufficient health-improving dose of VPA can range from only 12 to 16 minutes accumulated throughout the day,³⁰ a successful strategy may be to implement small, targeted doses of VPA throughout the school day or at youth sports practices or community PA programs. However, children ages 6-12 years often do not expend enough energy during sports or active play games to be classified as vigorous intensity, or sometimes even moderate intensity.³⁸ Therefore, there is a strong rationale for future research to examine enjoyable and efficacious exercise strategies for youth to attain sufficient levels of VPA to promote cardiometabolic health. Further, engaging in VPA may provide an opportunity to simultaneously promote other important factors of youth development including motor competence and muscular fitness.

The Importance of Developing Motor Competence and Muscular Fitness During Childhood

It is important to move beyond traditional modes of VPA, such as running, and design exercise protocols and PA programs focused on motor competence and muscular fitness because both of these factors are pre-requisites for participation in sport and recreational PA programs and are linked with leisure-time PA behaviors.^{8, 9} Motor competence is defined as the mastery of foundational and fundamental movement skills, that when acquired during childhood, allow for enjoyable participation in PA.³⁹ Motor competence includes the acquisition of fundamental

movement skills that have been previously defined as ‘an organized series of basic movements that involve a combination of movement patterns of two or more body segments’ and include locomotor, stability, and object control tasks.⁴⁰ Becoming proficient in motor competence tasks during childhood also provides a foundation for more complex motor skills required for sport participation during adolescence.³⁹ On the other hand, perceived competence is an individual’s awareness and confidence of their movement capabilities, and is proposed to have a positive relationship with motor competence.⁴¹ Although children acquire motor competency by jumping, sprinting, throwing, catching, and leaping while participating in PA, inactive children with low motor competence are less likely to have the motivation, confidence, and physical capacity to engage in an active lifestyle.⁴² Therefore, the development of motor competence highlights an important mechanism for PA engagement during childhood.⁴³

Several studies have demonstrated positive associations between motor competence and health-related fitness and leisure-time PA participation in children. For example, Hands et al.⁸ demonstrated that over a 5-year period, children with high motor competency out-performed those with low motor competency on cardiovascular fitness, sprint run, throw, jump and balance assessments. An additional study demonstrated that children with high motor competence reported greater sport participation compared to those with low motor competence.⁹ Acquiring proficient motor competence during childhood may also protect against a decline in PA participation often experienced at the onset of adolescence, as several studies have demonstrated that children with the highest motor competence also participate in the greatest amounts of PA.⁴⁴⁻⁴⁶ However, cautious interpretation of these results is warranted since the majority of previous studies assessing the relationship between motor competence and PA participation are cross-sectional. Nonetheless, instead of implementing only running-based programs to promote VPA

that focus exclusively on health-related fitness outcomes such as cardiorespiratory fitness, interventions aimed at promoting VPA should also incorporate exercises focused on motor competence since they may have widespread secondary effects on leisure-time PA participation in addition to health and fitness-related outcomes.

In addition to promoting motor competence, developing muscular fitness is an important aspect of youth development and should be an important consideration when designing programs to promote VPA in children. Muscular fitness has a synergistic relationship with motor competence, as it promotes enhancements in motor control, function, and speed, and both provide a foundation for an active lifestyle during childhood.⁴⁷ In fact, becoming proficient in foundational movements such as the squat, lunge, push, and rotation to further promote motor competence may be of equal importance to skill-based training since children engage in these movement patterns during active play and sports.⁴⁷ The benefits of participating in regular resistance training during childhood are expansive and include improvements in muscular strength,⁴⁸ motor performance and fundamental movement skills,^{49, 50} body composition,⁵¹ skeletal health,⁵² and injury prevention.⁵³ Furthermore, resistance training may be more inclusive for overweight and obese pediatric populations who often experience difficulty engaging in cardiovascular activities such as running. Resistance training programs have been previously implemented in elementary school PE settings with successful outcomes including significant improvements in muscular strength, endurance, and power.^{54, 55} Overall, there is an opportunity for motor competence and muscular fitness components to be incorporated into exercise programs aimed at promoting VPA in children and may be an effective strategy to induce chronic health-related adaptations. However, much of the existing literature has focused on promoting VPA through running or cycling-based protocols such as high-intensity interval

training (HIIT) that emphasize cardiorespiratory fitness but overlook motor competence and muscular fitness aspects^{5, 56}.

Is Traditional High-Intensity Interval Training (HIIT) the Best Strategy to Promote Vigorous-Intensity Physical Activity in Children?

Recent reviews demonstrate that HIIT may be a time-efficient and salient mode of VPA to enhance cardiometabolic health in children and adolescents,^{5, 56} and the Physical Activity Guidelines Advisory Committee Scientific Report highlighted HIIT as an important future research direction in children.¹ HIIT involves completing brief bouts of vigorous-intensity activity performed at $\geq 85\%$ of peak heart rate (HR_{peak}) interspersed with passive or active recovery periods.⁵⁻⁷ There are no universally accepted work:recovery ratios for HIIT, and it is often performed in a controlled laboratory setting with motorized treadmills and cycle ergometers.^{5, 56} One appeal of HIIT is that it is ‘time-efficient’, meaning that adaptations following repeated bouts of HIIT are comparable to repeated sessions of longer duration moderate-intensity continuous exercise. For example, HIIT protocols requiring only 5-15 minutes of total exercise time have demonstrated improved health outcomes such as improved cardiorespiratory fitness and markers of cardiovascular health in children.^{57, 58} Although preliminary evidence supports the efficacy of HIIT in pediatric populations, most studies were performed in a laboratory setting requiring treadmills or cycle ergometers that cannot be translated to ‘real-world’ modalities of HIIT.^{6, 7}

Until recently many of the studies in children that have implemented HIIT in field- or school-based settings have utilized running as the modality to promote VPA.^{5, 56} For example, in a review by Bond et al.⁵, eight of the fifteen school-based HIIT studies opted to use a sprint running protocol performed at 100% maximal aerobic speed. Although the interventions were

designed to promote VPA by having participants perform HIIT at maximal running speeds, the majority of school-based HIIT studies did not assess the fidelity of the HIIT intervention by measuring time spent above 85% HR_{peak} using HR monitors or with accelerometry to determine the percent of time spent engaging in VPA for the entire class period^{57, 59} nor assessed program acceptability, which is an important gap that must be addressed in future research. Nonetheless, Buchan et al.^{60, 61} demonstrated mean HR responses representative of VPA (i.e. greater than 175 beats per minute (bpm)) in two separate studies in adolescents performing 4 sets of 30s:30s running-based HIIT in a PE setting. Further, Martin et al.⁶² demonstrated HR responses representative of HIIT (87% HR_{peak}) during 4-6 sets of 30s:30s sprint interval running in adolescents during PE.

In addition to providing an appropriate stimulus representative of VPA, previous running-based HIIT interventions in youth have demonstrated preliminary efficacy in promoting several health and fitness outcomes. For example, studies that assessed cardiorespiratory fitness using a 20-meter multistage fitness test demonstrated significant improvements in cardiorespiratory fitness following the HIIT intervention.^{16, 59-64} However, the effectiveness of running-based HIIT on other cardiometabolic health markers, such as body composition, is less clear with the majority of school-based HIIT interventions reporting null changes in body composition.^{59, 61, 63, 64} These findings are likely explained by the variety of work:rest ratios used and the amount of energy expended by participants during the HIIT intervention. For example, Baquet et al.^{59, 63, 64} utilized running protocols of 10-20 s work: 10-20 s rest for 1-4 sets, with 3 minutes in between sets during PE, which is perhaps too short of work interval duration to warrant changes in body composition and cardiometabolic health markers. Overall, findings from running-based HIIT interventions in elementary school settings are less conclusive than lab-based investigations,

likely due to differences in participant compliance with the recommended work intensity and/or the use of indirect assessments for cardiometabolic health and fitness.

Although running-based HIIT is an inexpensive and viable strategy to promote VPA in youth, these programs do not focus on additional important aspects of youth development including motor competence and muscular fitness, and most studies did not assess perceptual responses to this mode of HIIT.⁶⁵ However, HIIT emulates children's normal activity patterns of performing short bursts of VPA that are interspersed with periods of lower-intensity activity.¹⁰ Therefore, perhaps a more developmentally appropriate strategy to promote VPA is to apply the structure of HIIT to fitness- and skill-based interval exercise protocols that provide brief bouts of VPA but also focus on motor competence and muscular fitness during the work and/or recovery intervals. Further, incorporating more exercise variety into fitness- and skill-based HIIT protocols may promote positive perceptual responses and greater PA behavior compared to running-based HIIT that offers low variety of exercise choices.⁶⁶

Acute Responses to Fitness-and Skill-based Interval Exercise Protocols in Children

Prior to implementing fitness and skill-based interval exercise interventions that focus on motor competence and muscular fitness into school or youth sport settings as a strategy for children to attain VPA, it is important to assess children's acute responses to this mode of exercise to determine if these protocols do in fact provide a vigorous-intensity cardiometabolic stimulus. Accordingly, recent studies have examined children's acute oxygen consumption (VO_2) and HR responses to fitness- and skill-based interval exercise protocols.¹¹⁻¹³ For example, Faigenbaum et al. observed changes in VO_2 and HR that provided a stimulus representative of MVPA (peak VO_2 values equal to 64-65% $\text{VO}_{2\text{peak}}$) in response to a 10-minute fitness rope and a 10-minute medicine ball protocol in active, fit children.^{12, 13} Similarly, a multi-modal fitness- and

skill-based interval exercise protocol requiring specialized equipment provided a moderate-to-vigorous cardiometabolic stimulus in active children, with no difference in mean VO_2 or HR between the multi-modal protocol and a treadmill walking protocol.¹³ Overall, these protocols did not provide a vigorous-intensity cardiometabolic stimulus and may need to be modified in order to promote long-term health adaptations attendant with regular engagement in VPA. Therefore, future research must assess the acute responses to different fitness- and skill-based interval exercise protocols, such as body-weight resistance exercises, to determine if they are representative of VPA.

In addition to the previous fitness- and skill-based interval exercise protocols not being representative of VPA, these studies had several limitations that must be addressed in future research. For example, no study included a measure of blood lactate accumulation which is often used as an indirect marker of exercise intensity and could further characterize the stimulus provided by these fitness- and skill-based interval exercise protocols. Given that the safety of HIIT has been previously contested,²² future work should also assess blood pressure (BP) responses to characterize the cardiovascular strain provided by fitness- and skill-based HIIT in children. Overall, future research must attempt to further characterize the cardiometabolic responses of various fitness- and skill-based HIIT protocols by including additional physiological measures such as blood lactate accumulation and BP. Second, these studies did not assess children's perceptual responses such as enjoyment or affective valence (i.e. feeling state), both of which are important predictors of leisure-time PA participation.¹⁴ Given the importance of understanding children's affective responses to exercise, future acute HIIT studies must also include assessments of perceptual responses to determine if such protocols are an attractive mode of VPA in children that could ultimately be implemented in school or youth sport settings.

Further, all previous acute studies involved individually performed exercise protocols and did not consider the implications of group-based exercise as a source of PA enjoyment.⁶⁷ Although little attention has been provided to group exercise in youth, research in adults indicates that promoting group cohesion in exercise settings may positively influence enjoyment responses and may be preferred over individually performed exercise.^{29, 68} Therefore, performing HIIT in small group settings may provide greater enjoyment than individually performed protocols, but research is warranted to confirm this hypothesis in children. Overall, findings from this research will determine if interval-based body-weight resistance exercise protocols aimed at promoting motor competence and muscular fitness performed in individual and small group settings can provide an enjoyable yet adequate stimulus representative of VPA.

Psychological Constructs that Contribute to Exercise Enjoyment

If fitness- and skill-based HIIT is to be a viable strategy for children to attain VPA on an impactful public health level, future research must determine if such exercise protocols have a positive influence on the psychological constructs and PA motivational outcomes required to promote long-term PA behaviors. Psychological constructs such as enjoyment and positive affect towards PA are important mediators for self-determined motivation and leisure-time PA behaviors.^{69, 70} Therefore, though engaging in VPA elicits greater health benefits than moderate-intensity PA, the perceptual responses to such exercise, including affective valence and enjoyment, must be considered. The Dual Mode Theory states that exercise above the ventilatory threshold, which would include interval-based exercise protocols designed to promote VPA, elicits adverse psychological responses (i.e., negative affective valence and low exercise enjoyment) and may reduce exercise adherence.⁷¹ The Dual Mode Theory is based on completion of continuous vigorous exercise or, alternatively, graded exercise, which eventually

exceeds the ventilatory threshold. However, engaging in interval exercise that involves completing brief but repetitive bouts of VPA may not lead to the adverse perceptual responses experienced during continuous vigorous exercise and may not hinder PA participation given that its structure differs from these protocols as it is not continuous.⁷¹

Minimal data are available regarding perceptual responses towards interval-based exercise in children. Existing studies in adults and adolescents examining the acute perceptual responses to interval exercise have demonstrated HIIT to elicit similar, if not greater, enjoyment responses compared to continuous exercise performed at a moderate intensity.^{72, 73} However, findings are not conclusive. For example, Malik et al.⁷⁴ demonstrated a significant decline exercise enjoyment during a treadmill-based 8 x 1 minute HIIT protocol in adolescent boys. Although exercise enjoyment declined from pre-exercise, it remained positive during and post-exercise, indicating that participants still perceived the exercise favorably. A possible explanation for the decline in exercise enjoyment is the use of 1-minute work intervals as opposed to a shorter 30-second duration, for shorter work intervals are often perceived as more positive and enjoyable compared to longer work intervals.⁷⁵

No existing acute fitness- and skill-based HIIT studies in children have addressed participants' perceptual responses, and very few intervention studies assessed other relevant outcomes such as program satisfaction.^{20, 24, 76} Given that perceptual responses to exercise are strong mediators of leisure-time PA participation,⁶⁶ this is a critical gap in the literature that must be addressed in future studies. First, acute studies are needed to determine children's perceptual responses to fitness- and skill-based HIIT protocols to determine if they are an attractive strategy for youth to attain VPA that may positively influence leisure-time PA behaviors. Once initial perceptual responses are established, future intervention studies delivered in field settings such

as PE can design fitness- and skill-based HIIT protocols grounded on a theoretical approach to address the role of these psychological constructs in promoting self-determined motivation towards leisure-time PA participation in which previous studies have failed to consider.

Preliminary Efficacy of Fitness- and Skill-based Exercise Interventions in Physical Education Settings

Once the cardiometabolic and perceptual responses to feasible fitness- and skill-based HIIT protocols designed to promote VPA are established, a logical progression is to transition from the laboratory to real-world settings by implementing similar protocols in group settings such as during PE. Given that most children in the United States attend school, PE provides important opportunity for children to accumulate doses of VPA on a public health level. However, most of the research indicates that children are insufficiently active during PE. Previous studies demonstrate a wide range of percent of time spent in MVPA in PE for elementary school students, ranging from approximately 11-88% with the average falling below the national recommendation of 50% of time spent in MVPA and a lower percentage meeting VPA recommendations.⁷⁷ For example, classes assessed by Chow et al.⁷⁸ met the national recommendation with 50.7% of PE time spent in MVPA, as measured by the SOFIT direct observation tool, whereas Kramer et al.⁷⁹ assessed students via accelerometry and reported 33.1% of time spent in MVPA. Nonetheless, the majority of evidence suggests that children miss out on an opportunity to improve their cardiometabolic health by not acquiring enough PA at a sufficient intensity during PE.⁷⁷ Although the body of evidence supporting the health benefits participating in VPA is strong, it is unclear how to best promote VPA in children in this setting.

Several recent interventions have implemented fitness- and skill-based HIIT protocols in PE as a strategy for children to attain adequate amounts of VPA, but mixed results were

produced. For example, Costigan et al.¹⁶ implemented an interval exercise protocol relying on only body-weight exercises (e.g. push-ups, shuttle runs, skipping) into a secondary school PE program. Completion of the interval exercise protocol three times a week for 8 weeks with sessions lasting 8-10 minutes resulted in moderate to large effect sizes for improvements in waist circumference, a small intervention effect for cardiorespiratory fitness, and no intervention effect for muscular fitness.¹⁶ Although the initial findings from this study are encouraging, children may need a variety of exercises and variations in exercise intensity, such as partner-based exercises and various resistance exercise equipment, in order to further promote muscular fitness and maintain engagement and enjoyment during a long-term intervention period. For example, Leahy et al.²⁴ demonstrated favorable program satisfaction following a school-based HIIT program in adolescents in which participants were able to select from a variety of HIIT modalities (i.e. dance, sports, circuit training). Similarly, Lambrick et al.⁸⁰ adapted the structure of HIIT to active play games and had participants perform the protocol twice weekly for 6 weeks for 40 minutes each session during school hours. Throughout the intervention, participants had an average of 86% HR_{peak} during sessions and demonstrated significant improvements in cardiorespiratory fitness and waist circumference (obese participants only).⁸⁰ However, the protocol length of 40 minutes was significantly longer than traditional time-efficient HIIT protocols and may not be feasible for physical educators to implement into their pre-established curricula.

Though not specifically designed to promote VPA like the Costigan, Lambrick, and Leahy studies,^{16, 76, 24} other previous intervention studies have incorporated stations of both fitness- and skill-related exercises performed in an interval format to promote motor competence and muscular fitness that provide informative results for future HIIT studies. For example,

Faigenbaum et al.²¹ completed two separate pilot studies in children from second grade in which classrooms in the intervention group completed a 15-minute fitness- and skill-based exercise program at the beginning of PE class two times per week for eight weeks, whereas control classrooms engaged in traditional PE activities. The intervention programs were strategically designed to enhance motor learning and improve physical fitness and motor competence. The protocols included a series of body-weight resistance exercises (e.g. plank, squats), plyometric drills (e.g. lateral hops, cone drills), and object control tasks using a punch balloon (e.g. backwards throw, lunge chest pass) performed in a circuit format.^{21, 81} In the initial study,²¹ there was a significant group by time interaction with significant improvements in muscular strength and endurance, muscular power, and cardiorespiratory fitness in the intervention group compared to the control group who participated in traditional PE activities. In the second investigation,⁸¹ sex-specific adaptations were noted as the intervention group had significant improvements in cardiorespiratory fitness, muscular strength, muscular endurance in girls only, whereas there were significant improvements in muscular power for girls and boys. The null improvements in speed/agility in both studies may be explained by the included exercises, for no sprinting-based games or activities were included, which would likely lead to improvements in this component of skill-related fitness.

Building upon initial investigations in second graders, Faigenbaum et al.²⁰ implemented a fitness- and skill-based intervention in fourth grade classrooms within one elementary school. Similar to the pilot testing performed in second graders, fourth grade participants in the intervention classrooms engaged in the exercise program for the first 15 minutes of PE class two times per week for eight weeks. However, additional equipment was added to this intervention and included fitness ropes, 1-2 kg medicine balls, BOSU trainers, and colored spots, likely

because the participants were older and could perform more advanced exercises. According to the principle of progressive overload, more advanced exercises were incorporated every two weeks and the work:rest ratio increased from 30s:30s to 45s:30s for the second half of the intervention to enhance training improvements. Like previous findings, there was a significant group by time interaction observed in the intervention group for cardiorespiratory fitness, muscular strength, flexibility, and muscular power, with null improvements for muscular endurance and the long-jump. Overall, these initial pilot studies provide a foundation for the rationale of implementing fitness- and skill-based HIIT protocols during PE to enhance cardiorespiratory and muscular fitness.

Building upon Faigenbaum's initial investigations focused on physical health outcomes, Duncan et al.⁸² assessed the efficacy of a 10-week PE fitness- and skill-based HIIT intervention on improving motor competence, PA self-efficacy, and fitness-related variables in 6-7 year old children. In the Duncan study, the intervention was delivered once per week for 30-40 minutes during PE lessons and consisted of 6-10 exercise stations including squats, bear crawls, and speed ladder drills. Following the intervention, participants undergoing the intervention demonstrated significant improvements in motor competence (2 locomotor and 3 object control skills) compared to the control group, with improvements in PA self-efficacy only evident in boys following the intervention.⁸² Overall, initial pilot investigations support the promise of implementing fitness- and skill-based HIIT protocols into PE to promote improvements in motor competence and muscular fitness in young children, especially boys, yet it is unknown how to best adapt these programs to older children (9-11 year-olds) and in girls.

Although previous fitness- and skill-based HIIT interventions have demonstrated preliminary evidence for promoting several cardiometabolic health and fitness-related variables,

there are several limitations to these studies that must be addressed in future studies designed to promote VPA in children within the PE setting. First, all studies relied on passive or active recovery walking intervals which may not have provided an adequate exercise stimulus to induce chronic fitness and/or motor competence adaptations. This highlights a potential application for the structure of that HIIT that has not been studied previously that may yield more conclusive results. A novel approach that could be addressed in future studies is to include a variety of vigorous-intensity exercises (i.e. fitness rope activities, multi-joint body-weight resistance exercises) that can be interspersed with moderate-intensity exercises (i.e. throw/catch, balance, and agility activities). This may be a more attractive and engaging strategy to promote VPA in children while incorporating more skill-based exercises into the recovery intervals compared to previous studies that relied on passive or active recovery walking rest intervals. Another limitation of previous fitness- and skill-based interval exercise interventions is that few studies included a comprehensive process evaluation including fidelity and program satisfaction. Researchers should continue to assess if their HIIT intervention is successful at achieving the national recommendation of children spending at least 50% of class time engaging in MVPA during PE given that the majority of children fail to reach this recommendation.⁷⁷ Lastly, besides the Duncan et al. study, researchers did not assess the efficacy of their intervention in promoting improvements motor competence or perceived competence and PA behavior outside of the school setting, all of which severely limits the interpretation of findings.

Perhaps the greatest limitation of previous fitness- and skill-based interval exercise interventions in children is the lack of a theoretical approach to the intervention and measurements of constructs that influence long-term PA participation. These previous studies are often narrow in scope and focus on the *quantity* of PA achieved during PE and fail to focus on

psychological constructs that contribute to the *quality* of PE experiences.^{83, 84} An important aspect of quality that can be considered when delivering PE interventions is the type of motivation children experience during PE to be physically active. For example, fostering self-determined motivation (i.e. participation in PA because it is enjoyable, fun, and challenging) within the PE context has been linked with positive affective experiences and increased PA behaviors.⁸⁵ Therefore, promoting self-determined motivation during PE may provide an important mechanism for increased leisure-time PA outside of the school setting, in which most existing fitness- and skill-based HIIT interventions failed to measure.^{20, 21} There is a strong rationale to examine the feasibility and efficacy of fitness- and skill-based interval exercise interventions designed to promote physical health outcomes without compromising the quality of instruction in order to simultaneously promote self-determined motivation and leisure-time PA in children.

Applying a Theoretical Framework to Fitness- and Skill-Based Exercise Interventions

A theoretical perspective that has been heavily studied in the PE domain that can provide a strong foundation for future fitness- and skill-based HIIT interventions is the Self Determination Theory (SDT).^{23, 86} The SDT postulates that the degree to which the basic psychological needs of competency (i.e. task mastery), autonomy (i.e. choice), and relatedness (i.e. social interactions) are satisfied determines the extent to which individuals are motivated by self-determined, or intrinsic, properties.²³ Importantly, children possessing self-determined motivation have more positive behavioral outcomes and more positive cognitive and affective experiences such as higher enjoyment towards PA and increased engagement during PE.^{23, 86, 87} For example, studies have demonstrated positive associations between children's fulfilment of the basic psychological needs in PE and positive affect,⁸⁸ high enjoyment,⁸⁴ and improved

concentration.⁸⁹ Therefore, if future acute studies demonstrate positive perceptual responses to fitness- and skill-based HIIT protocols, interventions utilizing similar protocols have the potential to promote positive PA behaviors outside of the school context if children perceive the experience positively and are in environments that promote positive affect and enjoyment.

Based on the aforementioned findings, a particularly salient and effective strategy for promoting VPA as well as leisure-time PA behaviors may be to target the basic psychological needs of competence, autonomy, and relatedness proposed by the SDT when designing future fitness- and skill-based interval exercise interventions. This is because psychological constructs such as self-determined motivation provide a likely mechanism for increased leisure-time PA both during and after the intervention that ultimately promote physical health.⁸³ Therefore, hypothesis testing and targeted interventions promoting fulfillment of the basic psychological needs may mediate intervention effects including improved health outcomes (i.e., weight maintenance, skill acquisition, and physical fitness) by enhancing long-term self-determined motivation for PA behaviors and student engagement during the PE intervention.^{8, 30} However, future work is needed to verify this hypothesis, for the one HIIT study that adopted the SDT as a theoretical approach failed to see significant improvement in basic needs satisfaction following the intervention in adolescents.²⁴

The SDT provides a mechanistic explanation for the aforementioned associations between motor competence and leisure-time PA participation, because high motor competence can increase PA enjoyment which promotes self-determined motivation towards PA.^{90, 91} This is supported by previous research that demonstrated that the primary reason children find PA to be fun and enjoyable is having the competence and relevant skills to complete the activity.⁹² Further, data support that if motor competence tasks are mastered at a young age and children are

confident in their movement abilities (i.e. have high perceived competence), there is a greater likelihood that they will enjoy being physically active and continue to participate in PA outside of school and throughout their lifespan.^{42, 93, 94} For example, Carroll et al.⁴² noted significant positive relationships between perceived competence and enjoyment in PE and between perceived competence and habitual PA participation in primary school children. Therefore, fitness- and skill-based HIIT interventions align with the basic psychological need of competence, as developing motor competence is a primary goal of such exercise programs. However, most previous studies only focused on fitness outcomes and did not assess changes in physical or perceived competence.^{20, 76, 80} Therefore, future research is needed to determine the efficacy of fitness- and skill-based HIIT interventions in improving both physical health outcomes and promoting the basic psychological need of competence in order to promote self-determined motivation and leisure-time PA.

The SDT provides a strong theoretical framework for fitness- and skill-based HIIT interventions because they can be designed in such a way that promotes student autonomy, the second of three basic psychological needs. Although only one previous fitness- and skill-based interval exercise interventions utilized a theoretical framework such as the SDT,²⁴ previous studies have examined the effects of an autonomy supportive environment in promoting self-determined motivation towards PA within the PE context. The physical educator plays a critical role in supporting or thwarting students' basic psychological needs, for physical educators can establish an autonomy supportive classroom environment which includes adopting a 'child centered' approach.⁸⁷ Characteristics of an autonomy supportive motivational style include one that supports student choice relevant to their interests and goals, provides opportunities to develop competencies, allows for participation in decision making, provides rationale for the

activities, and promotes peer interactions and social interactions.^{87, 95, 96} It is important to incorporate certain aspects of choice into future fitness- and skill-based HIIT interventions because it is often a compulsory subject during primary school and children have diverse interests and abilities that do not coincide with the traditional single-modality interventions. One strategy to promote autonomy in PE is to incorporate a variety of exercise choices given perceived variety in exercise has been linked to well-being and fulfillment of basic psychological needs.^{97, 98} Further, when offering choice to young children it is important to provide activities that are meaningful and important, are not too complex, provide optimal challenge to satisfy the need for competence, and involve encouraging and instructional feedback.⁹⁹

Several investigations have focused on autonomy supportive instructional behaviors during PE,⁹⁹ but studies have not yet specifically been applied to fitness- and skill-based interval exercise interventions in young children. The majority of empirical work was specifically designed to allow students to select which activities to participate from a pre-established list.¹⁰⁰ Overall, directly intervening to offer different choices during PE to foster the basic psychological need of autonomy has shown favorable effects on self-determined motivation for PA participation and engagement during PE lessons.^{28, 100} Interventions examining the effects of choice on promoting self-determined motivation for PA often focus on choosing from different walking activities, yet walking-based interventions overall have demonstrated limited impact on promoting health in children and adolescents.¹⁰¹ Therefore, future fitness- and skill-based HIIT interventions could adopt a station approach with different activity options at each station and allow students to choose their partners/team formation during certain activities. These are hypothesized to be effective strategies to promote a sense of autonomy and engagement in PE to ultimately enhance quality self-determined motivation towards leisure-time PA participation.

Future fitness- and skill-based HIIT interventions grounded in the SDT must also consider the third basic psychological need of relatedness, which can be defined as the need to develop meaningful relationships with teachers and peers.²³ Evidence suggests that children's sense of relatedness has been positively associated with intrinsic, or self-determined, motivation¹⁰² which aligns with the framework of the SDT. Further, a structural equation modeling analysis revealed that students with high perceived relatedness experienced greater basic psychological needs satisfaction that in turn predicted adaptive PE outcomes such as concentration and preference for challenging tasks.⁸⁸ One strategy to promote relatedness is to perform PA in an environment that promotes group cohesion, which has been associated with higher levels of exercise enjoyment in adults,²⁶ but much less is known about group exercise dynamics in children. Therefore, prior to implementing PA interventions aimed at promoting relatedness in children, preliminary research is needed to determine if children enjoy performing fitness- and skill-based interval exercise protocols in a small group with peers. Doing so will provide useful evidence regarding the feasibility of implementing similar protocols in a large group setting. According to Estabrooks et al.⁶⁸, strategies to promote group cohesion and relatedness within a group setting such as PE include incorporating partner-based exercises and small group competitions into PA interventions. Within the PE context, relatedness can also be promoted through an autonomy supportive environment that emphasizes peer interactions and establishes positive relationships between students and the physical educator.⁸⁷ Although previous research has addressed the efficacy of autonomy and relatedness supportive environments in promoting self-determined motivation,¹⁰⁰ limited studies have integrated this perspective within interventions designed to promote VPA and physical health outcomes. Accordingly, future research must address the feasibility and efficacy of delivering PE

interventions that simultaneously provide opportunities to promote physical fitness and movement competence without compromising opportunities to promoting basic needs satisfaction amongst students a strategy to promote both cardiometabolic health and quality motivation towards long-term PA engagement.

Despite the potential benefits of designing fitness- and skill-based HIIT interventions that focus on the quality and consequences of promoting self-determined motivation in addition to physical health promotion through increased quantity of PA (i.e. duration and intensity), the majority of school-based PA literature tends to focus on either physical health outcomes or psychosocial outcomes.^{20, 76, 80} This is problematic given that changes in physical fitness are likely not enough to promote long-term PA behaviors, as self-determined motivation is linked with more favorable perceptual and behavioral consequences and provides a mechanism for increased leisure-time PA participation in children. Although the impact of implementing HIIT on student's psychosocial experiences in PE are unclear, it can be postulated that these interventions, especially those that were running-based, did not elicit high enjoyment for all participants, possibly on the basis that they did not address tenets of the SDT, including competency, autonomy, or relatedness. Further, current reviews have highlighted the lack of feasibility and process evaluation in existing PE interventions that must be addressed in future research to better understand the long-term sustainability of implementing interventions into existing PE programs.⁸³ Overall, there is a strong rationale to for fitness- and skill-based HIIT interventions to adopt a holistic approach in order to promote favorable changes in both physical fitness and basic psychological needs satisfaction proposed by the SDT.

Summary

Based on previous literature, fitness- and skill-based interval exercise is a promising and developmentally appropriate alternative to running-based protocols in children. However, given the paucity of studies, the exact physiological stimulus to this form of exercise is not well understood, and research in a laboratory-based setting is needed to characterize the intensity of these protocols. By addressing this literature gap, researchers would understand if fitness- and skill-based interval exercise provides a vigorous stimulus representative of HIIT that may induce chronic adaptations. Further, no previous acute fitness- and skill-based studies characterized perceptual responses, which is a critical gap that must be addressed in future research given that enjoyment and affect are strong predictors of exercise adherence. Overall, assessing the acute physiological and perceptual responses to fitness- and skill-based interval exercise is necessary to determine whether this form of exercise provides a sufficient and enjoyable VPA stimulus that may be effective in improving or maintaining health.

Once these responses are characterized, fitness- and skill-based HIIT interventions can be carefully designed to incorporate small, titrated doses of VPA into PA programs, such as PE. Although existing fitness- and skill-based HIIT interventions have been mostly successful at promoting physical health outcomes, the majority of studies failed to adopt a theoretical framework and did not determine the psychosocial impact of incorporating HIIT into PE programs. It is hypothesized that by grounding HIIT interventions within the SDT framework, incorporating more vigorous exercise into PE would not compromise student's ability to maintain or improve their self-determined motivation towards leisure-time PA participation.

CHAPTER 2

Cardiometabolic and Perceptual Responses to Body-Weight Resistance High-Intensity Interval Exercise in Boys

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ABSTRACT

The majority of studies examining children's responses to high-intensity interval exercise (HIIE) primarily utilized running; however, this modality does not require/include other important aspects of physical activity including muscular fitness. **PURPOSE:** To compare acute responses between a body-weight resistance exercise circuit (CIRC) and treadmill-based (TM) HIIE.

METHOD: Seventeen boys (age=9.7±1.3 years) completed a graded exercise test to determine peak heart rate (HR_{peak}), oxygen uptake (VO_{2peak}) and maximal aerobic speed (MAS). Sessions were randomized and counterbalanced. CIRC required two sets of 30s maximal repetitions of four exercises. TM included eight 30s bouts of running at 100% MAS. Both included 30s active recovery between bouts. Blood lactate concentration (BLa) was measured pre- and post-exercise. Rating of perceived exertion (RPE), affective valence, and enjoyment were recorded pre-exercise, after intervals 3 and 6, and post-exercise. **RESULTS:** Participants attained 88±5 %HR_{peak} and 74±9 % VO_{2peak} for CIRC and 89±4 %HR_{peak} and 81±6 % VO_{2peak} for TM, with a significant difference in % VO_{2peak} ($P=0.003$) between protocols. Post-exercise BLa was higher

following CIRC (5.0 ± 0.7 mM) versus TM (2.0 ± 0.3 mM) ($P < 0.001$). RPE, affective valence and enjoyment responses did not differ between protocols ($P > 0.05$). **CONCLUSION:** HR responses were near-maximal during CIRC, supporting that this body-weight circuit is representative of HIIE.

INTRODUCTION

It is recommended that children engage in at least 60 minutes of moderate-to-vigorous physical activity (MVPA) per day and vigorous PA (VPA) three times per week to promote cardiorespiratory and muscular fitness, maintain weight status, and reduce the risk of developing cardiovascular disease risk factors that often track into adulthood.¹⁰³ Nonetheless, many children and adolescents do not meet these PA recommendations.¹⁰⁴ One strategy to promote MVPA or VPA in children and adolescents is high-intensity interval exercise (HIIE), which consists of brief bouts of vigorous activity at $\geq 85 - 90\%$ peak heart rate (HR_{peak}) separated by bouts of rest or lower-intensity recovery.⁵ Recent reviews demonstrate that HIIE may be a time-efficient form of exercise to enhance cardiometabolic health in children and adolescents.^{5, 56} However, the majority of prior investigations were performed in a laboratory setting requiring treadmills or cycle ergometers which cannot be translated to ‘real-world’ modalities of HIIE.^{6, 7} Further, the majority of these ‘real-world’ or field-based studies utilized HIIE running, as highlighted in a review by Bond et al.⁵ in which 75% of the school-based HIIE studies included in the review utilized running-based protocols. Although running-based HIIE is an inexpensive and viable strategy to promote VPA, it may not foster the development of other important aspects of PA such as motor competence and muscular fitness.⁶⁵ These components provide a foundation for a

healthy and active lifestyle and are strongly related to PA engagement, specifically VPA, and physical fitness during childhood and early adulthood.^{105, 106}

Multi-joint body-weight resistance exercises that emphasize foundational movement patterns (i.e., squat, plank, jump) may provide a vigorous physiological stimulus and therefore warrant investigation as an alternative to running-based HIIE. To date, few studies have investigated this type of HIIE in youth. For example, insertion of interval exercise protocols comprising of only body-weight exercises (e.g. push-ups, shuttle runs, skipping) or active-play games within secondary school PE significantly improved physical and cognitive measures.^{16, 17, 19} However, in previous studies exercise intensity is often only reported as percentage of HR_{peak} ,^{24, 76} and therefore a full picture of children's physiological and perceptual responses to HIIE remains unclear. Prior to implementing this form of HIIE in an intervention setting, research is needed to characterize the intensity of these protocols to determine if they provide a vigorous stimulus representative of HIIE that may induce chronic adaptations. Faigenbaum et al.¹² observed changes in HR and oxygen consumption (VO_2) in response to a medicine ball protocol in active children. However, exercise HR (61-89% HR_{peak}) was below the suggested threshold for HIIE (i.e. $\geq 85\% HR_{peak}$) during the majority of the protocol duration.

An additional research gap that must be addressed in future studies investigating various HIIE protocols in children is the assessment of children's affective (i.e., feeling state) and enjoyment responses given that perceptual responses are correlates of habitual PA and exercise adherence throughout the lifespan.¹⁴ In adults, brief repeated bouts of VPA similar to HIIE do not diminish affective valence and/or enjoyment often experienced during continuous or graded vigorous exercise and may not hinder future exercise adherence.¹⁰⁷ In adolescents, it appears that the intensity at which HIIE is performed influences perceptual responses.^{74, 108} For example,

Malik et al.²⁷ demonstrated more favorable in-task and post-exercise affective valence and enjoyment responses to cycling-based HIIE performed at 85% peak power output (PPO) compared to 100% PPO. Further, in adolescent boys,^{74, 108} results indicate higher post-exercise enjoyment following cycling/running-based HIIE versus moderate-intensity exercise. Nonetheless, there is a paucity of research assessing affective valence and enjoyment responses to alternative modes of HIIE, including body-weight or circuit-based protocols, in young boys or girls. This is an important topic considering that perceptual responses experienced during exercise are predictive of current and future habitual PA participation.¹⁴

Overall, assessing the acute physiological and perceptual responses to body-weight resistance HIIE is necessary to determine whether this exercise prescription provides a sufficient and enjoyable VPA stimulus that may be effective in improving or maintaining health. Therefore, the purpose of this study was to assess the acute cardiometabolic and perceptual responses to a novel body-weight resistance exercise circuit (CIRC) and compare these responses to a standard treadmill-based (TM) HIIE protocol in boys. Cardiometabolic responses were assessed using HR, VO₂ and blood lactate concentration (BLa). We hypothesized that CIRC would elicit similar changes in VO₂ and HR yet greater BLa compared with TM. Second, we hypothesized there would be no significant decline in affective valence or exercise enjoyment from baseline to post-exercise for TM and CIRC given the shorter work interval duration and lower volume compared to previous studies.²⁷

METHODS

Participants and Study Design

Boys ages 8-11 years old were primarily recruited to participate in the study via email correspondence to a university-based parent listserv. Secondary recruitment occurred via flyers

at local fitness centers. Participation in at least one sport or structured PA program within 12 months of study participation was required for recruitment purposes to increase the likelihood of achieving our target sample size and to ensure ability to perform exercise appropriately with limited training. However, the inclusion criteria were broad in order to recruit boys with a wide range of activity levels, since sport participation does not ensure youth meet MVPA and VPA recommendations or maintain high cardiorespiratory fitness.³⁸ Participant characteristics are shown in Table 1. Exclusion criteria included a current orthopedic injury and use of prescribed medications that could influence our measures. Ethical approval was obtained by the Michigan State University Institutional Review Board. Parents provided written permission and children provided written informed assent, and both were informed of the study's risks and potential benefits. Parents reported their child's date of birth and ethnicity. Using VO_2 as the primary outcome variable, an a priori power analysis determined that a sample size of 14 would be sufficient to detect a moderate effect size (0.5) at a power of 80%.¹⁰⁹

Participants completed three laboratory visits over a 1-2 week period at least 48 hours apart. Each visit was completed at least 3 hours post-prandial and was held at approximately the same time of day. During the first visit, participants completed baseline surveys, a graded exercise test and were familiarized to CIRC. Participants subsequently completed CIRC and TM in a randomized and counterbalanced order on the second and third visits.

Procedures

Baseline Assessments and Surveys

Prior to exercise testing, participants completed various surveys consisting of the validated Physical Activity Questionnaire for Children (PAQ-C) to determine PA participation^{110, 111} as well as affect and exercise enjoyment questionnaires (refer to Outcome Measures for

descriptions). The PAQ-C is a summary PA score of a mean of nine items scored 1 to 5, with a higher number representing higher PA. Height was assessed using a wall-mounted, calibrated stadiometer (Shorr Board, Olney, MD). Body mass and percent body fat (%BF) were measured using bioelectrical impedance (Tanita BC-534, Tanita Corporation, Tokyo, Japan). Body mass index was calculated (kg/m^2) and classified using percentiles established by the Centers for Disease Control and Prevention (CDC) for use in children.¹¹²

Exercise Testing

Participants were asked to maintain their regular PA throughout the study and were instructed to refrain from any VPA (i.e. sporting event) 24 hours prior to each session. Participants completed a 5-minute familiarization period on the treadmill (Trackmaster, Newton, KS) and an additional 2-minute warm-up at a self-selected walking pace. $\text{VO}_{2\text{peak}}$ and maximal aerobic speed (MAS) were determined using an incremental test previously used in adolescents¹¹³ with the primary goal of determining each participant's maximal running speed. The protocol started at 5.6 km/h and a 1% grade for 30 seconds, after which speed was increased by 0.5 km/h every 30 seconds until volitional exhaustion.¹¹³ During exercise, gas exchange data were acquired breath-by-breath using a portable metabolic system (OxyCon, Vyaire Medical, Yorba Linda, CA), that was worn across the back like a back pack. The portable system is a valid and reliable method of determining VO_2 and V_E ¹¹⁴ and is a feasible option to use when extensive free movement is required, as in CIRC. Previous research shows that wearing this unit does not affect exercise enjoyment in healthy-weight children.¹¹⁵ $\text{VO}_{2\text{peak}}$ was defined as the highest 10-second average VO_2 attained during the test. Because not all children experience a plateau in oxygen consumption, other criteria were used to verify maximal effort including $\text{HR}_{\text{peak}} > 190$ bpm or a respiratory exchange ratio (RER) > 1.0 .¹¹⁶ HR_{peak} was defined as the highest HR attained during

the test, and MAS was defined as the running speed eliciting the highest VO_2 . Following the graded exercise test and after a 10-minute rest period, participants were familiarized to CIRC by performing one set of the body-weight exercises to practice proper technique and work:rest transitions.

HIIE Protocols

Both protocols started with a 5-minute seated period to collect resting HR, VO_2 , and perceptual measures, followed by a 4-minute warm-up. Participants were familiarized with each perceptual scale prior to each session and at multiple timepoints during the graded exercise test. The CIRC warm-up consisted of dynamic stretches, while the TM warm-up consisted of treadmill walking. Each protocol had a different warm-up due to their dissimilar movement patterns. HIIE protocols had a 1:1 work:rest ratio with 30-second intervals, which is similar to previous HIIE studies in youth as well as body-weight interval exercise studies in adults.^{60, 117}

The CIRC protocol consisted of eight ‘all-out’ 30-second intervals of dynamic, multi-joint exercises separated by 30 seconds of active recovery consisting of stepping in place for a total duration of 8 minutes. Four body-weight exercises were performed twice in this order: mountain climbers, squat jumps, jumping jacks, and burpees. These exercises were chosen to represent HIIE (i.e. $>85\% \text{HR}_{\text{peak}}$) while requiring variations in exercise intensity, and were structured to avoid repeated efforts using the same primary muscle group. Further, the chosen exercises are likely appropriate for the majority of young children on the basis that several studies have supported the use of resistance-based HIIE in obese youth.¹¹⁸ Participants were instructed to complete as many repetitions as possible within each interval and received verbal encouragement throughout, but the intensity was self-selected. Research staff ensured proper technique throughout each exercise and provided feedback when appropriate. The TM protocol

consisted of eight 30-second bouts of running at 100% MAS separated by 30 seconds of walking at 40% MAS for a total duration of 8 minutes. Similar to CIRC, participants received verbal encouragement throughout.

Outcome Measures

Gas exchange data and heart rate: During all sessions, HR was assessed using a heart rate monitor (Polar, Woodbury, NY, USA), and VO_2 and V_E were measured breath-by-breath using the identical portable metabolic system. Beat-by-beat HR and breath-by-breath VO_2 and V_E data were averaged into 10-second samples. Mean HR and VO_2 were the average of all 10-second samples across the 8-minute HIIE protocol, whereas, peak HR and VO_2 are the average of the last 10-second period of each interval. Lastly, recovery HR and VO_2 are calculated as the average of each 30-second recovery (i.e. three 10-second samples). HR and VO_2 responses throughout the entire bout were also quantified using an area under the curve (AUC) approach (GraphPad, La Jolla, CA, USA). To determine the time spent engaging in vigorous exercise, $\text{AUC} > 85\% \text{ HR}_{\text{peak}}$ and $> 70\% \text{ VO}_{2\text{peak}}$ was calculated. A higher total AUC value is representative of a greater workload for the entire session; whereas, a higher AUC value for $> 85\% \text{ HR}_{\text{peak}}$ and $> 70\% \text{ VO}_{2\text{peak}}$ represents a greater amount of time engaging in vigorous exercise.^{5, 56}

Blood lactate concentration (BLa): BLa is often used as an indirect marker of exercise intensity.¹¹⁹ BLa was measured by drawing a small amount of blood (7 μL) from the fingertip using a lancet and a portable analyzer (Lactate Plus, Nova Biomedical, Waltham, MA, USA). BLa was measured in a seated position prior to exercise and 3 minutes post-exercise.

Rating of Perceived Exertion, Affective Valence, and Enjoyment: All perceptual scales were administered by the same researcher for all participants during the three visits. Rating of perceived exertion (RPE) was assessed with the Children's OMNI-walk/run Scale of Perceived

Exertion that includes pictorial and word descriptors to evaluate real-time perceived exertion on a 0 to 10 scale, with a higher value indicating greater fatigue.¹²⁰ The OMNI walk/run scale has been validated during walking and running in children, and significant correlations between the OMNI walk/run RPE response and VO_2 ($r = 0.41\text{-}0.60$) and HR ($r = 0.26\text{-}0.52$)¹²⁰ have been shown. Although participants also completed CIRC, the aerobic exercise OMNI scale was used instead of the Children's OMNI-Resistance Exercise Scale¹²¹ since it was unknown if participants had previous experience with resistance training, and because two of three sessions consisted of aerobic exercise. Affective valence was measured with the Feeling Scale, which was used in previous studies in children and adolescents^{108, 122, 123} and has been validated against other affect scales including the Self Assessment Manikin ($r = 0.51 - 0.88$).¹²² Participants were asked to respond to the statement, 'how do you feel right now?' on an 11-point scale ranging from very bad (-5) to very good (+5) with anchors given at 0 and all odd integers.¹²⁴ Perceived exercise enjoyment was assessed using a single-item 7-point Exercise Enjoyment Scale¹²⁵ with the instruction, 'use the following scale to indicate how much you are enjoying this exercise session'. Anchors were given at each integer, ranging from 'not at all' (1) to 'extremely' (7). During CIRC and TM, RPE, affective valence, and exercise enjoyment were recorded pre-exercise, the last 10 seconds of work intervals 3 and 6 (i.e. at 38% and 75% of protocol completion), and post-exercise. These timepoints were chosen based on previous literature stating that perceptual responses assessed at multiple timepoints during exercise and at the end of work intervals best captures the emotional state experienced during HIIE.¹²⁶

To further assess affective valence and enjoyment responses to each session, participants completed the Positive and Negative Affect Schedule (PANAS) survey¹²⁷ and the modified Physical Activity Enjoyment Scale (PACES).^{128, 129} The PANAS and PACES demonstrate high

internal consistency ($r=0.84-0.85$; $r=0.87$, respectively) and construct validity ($r= 0.24 - 0.66$) in children and adolescents.¹²⁸ The 20-item PANAS survey includes 10 positive and 10 negative words that describe feelings and emotions, with responses on a Likert scale ranging from 1 ('very slightly or not at all') to 5 ('extremely') indicating to what extent participants perceived each feeling or emotion. Positive and negative affect were scored separately with a range of 10-50, with a higher score being preferred for positive affect and a lower score being preferred for negative affect. To measure overall PA enjoyment and compare this to enjoyment experienced in response to each HIIE protocol, participants completed the modified PACES survey¹²⁹ that included 16 questions on a Likert scale ranging from 1 ('disagree a lot') to 5 ('agree a lot'), with seven items reverse scored, and scores ranged from 16-80. The PANAS and PACES surveys were completed prior to the graded exercise test and at 10 minutes post-exercise following CIRC and TM.

Statistical Analysis

All statistical analyses were conducted using SPSS version 24 (IBM Corporation, Armonk, NY, USA), and descriptive statistics are reported as mean \pm SD. Normality for each dependent variable was determined by Q-Q plots, and homogeneity was assessed with Mauchly's test. If homogeneity was violated, the Greenhouse-Geisser correction was used. Differences in outcome measures between CIRC and TM were compared using three separate analyses. First, we compared dependent variables across time (e.g. the work intervals) and protocol (CIRC versus TM) using a series of two-way repeated measures analysis of variance (ANOVA) tests. Physiological variables were compared throughout the exercise session; whereas, the psychological variables were only compared from pre-exercise, work intervals 3 and 6, and post-exercise. When a significant F ratio was observed, a Tukey's post hoc test was used to determine

differences between means. Second, dependent *t*-tests were used to examine differences in mean cardiometabolic and BLa values between CIRC and TM. AUC analyses were compared with paired samples *t*-tests. Cohen's *d* and partial Eta squared were used as measures of effect size, and statistical significance was $P < 0.05$.

RESULTS

The weight status of participants ranged from healthy weight to overweight based on the BMI percentiles for children.¹¹² All 17 boys successfully completed each session with no reported injuries or adverse events. However, four participants (24%) denied one or both blood lactate assessments, and one participant's cardiorespiratory data were not collected during 4 minutes of CIRC due to technical difficulties; these data were removed from the analysis. The final sample included BLa data with $n=13$, cardiometabolic data (HR, VO_2 , V_E) with $n=16$, and perceptual data with $n=17$.

Cardiometabolic Responses

Change in Heart Rate: HR had a main effect for time ($P<0.001$) and a time by protocol interaction ($P<0.001$) (Figure 1A) with higher HR observed during TM at interval 1 (mean difference = 19 ± 13 bpm, mountain climbers) and interval 5 (mean difference = 9 ± 6 bpm, mountain climbers). Mean, peak, and recovery HR were not different between CIRC and TM (Table 2). Total AUC for HR was similar between protocols (CIRC= 3511 ± 582 , TM= 3488 ± 733 a.u., $P=0.95$, $d= 0.04$), while AUC >85% HR_{peak} was significantly higher in CIRC versus TM (616 ± 170 vs. 430 ± 129 a.u., $P=0.008$, $d= 1.27$).

Change in Gas Exchange Variables: VO_2 increased during exercise ($P=0.001$) and a time by protocol interaction was observed ($P<0.001$) (Figure 1B) with higher VO_2 during TM at interval 1 only (mean difference= $7.3 \pm 5.2 \text{ mL} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$, mountain climbers). Mean, peak, and

recovery VO_2 were higher in response to TM versus CIRC ($P=0.008$, $P=0.003$, $P=0.014$; respectively, Table 2). Total AUC for VO_2 was higher in TM (1408 ± 135 a.u.) versus CIRC (1268 ± 125 a.u., $P=0.007$, $d= 1.11$), but the difference in AUC $>70\%$ $\text{VO}_{2\text{peak}}$ was not significantly different between CIRC (203 ± 69) and TM (147 ± 57 , $P=0.05$, $d= 0.93$). There was a significant change in V_E across time ($p<0.001$) but no time by protocol interaction. In response to CIRC and TM, V_E significantly increased at the onset of exercise and remained stable throughout exercise. Session mean V_E responses were similar between protocols ($P=0.40$, Table 2).

Blood Lactate concentration (BLa): Pre-exercise BLa values were similar between CIRC and TM ($P=0.29$, Table 2). There was an increase in BLa from pre- to post-exercise ($P<0.001$) with a significant time by protocol interaction ($P<0.001$). BLa was higher in response to CIRC versus TM ($P<0.001$, Table 2).

Perceptual Responses

Rating of Perceived Exertion: RPE increased during exercise ($P<0.001$) with no time by protocol interaction observed ($P=0.59$) (Figure 2A).

Affective valence: There was no change in affective valence (Feeling Scale) over time during either protocol ($P=0.052$), and no time by protocol interaction was evident ($P=0.91$) (Figure 2B). Notably, affective valence remained positive at all timepoints (Figure 2B). However, two boys reported a value below zero during bout 3 and 6 of CIRC, representing negative affective valence; whereas, a different participant reported a value below zero during bouts 3 and 6 of TM. There was no change in positive or negative PANAS from baseline to post-exercise for CIRC or TM ($P>0.05$). Baseline and post-exercise positive and negative PANAS scores are presented in Table 3.

Enjoyment: There was a main effect of time for exercise enjoyment (Exercise Enjoyment Scale) ($P=0.04$) with no time by protocol interaction ($P=0.19$) (Figure 2C). Exercise enjoyment responses remained positive and relatively stable throughout each protocol (Figure 2C). PACES decreased from baseline to post-exercise for both protocols ($P=0.015$), with post hoc analysis revealing a significant decrease following CIRC (mean difference = -3.9 ± 4.5 , $P=0.01$) but not TM. Baseline and post-exercise PACES scores are presented in Table 3.

DISCUSSION

This study examined acute cardiometabolic and perceptual responses to a body-weight resistance exercise circuit (CIRC) and compared them to a treadmill-based HIIE protocol (TM) in 8-11 year-old boys. Partially consistent with our hypothesis, session mean and peak HR was near-maximal and similar between CIRC and TM, yet session mean and peak VO_2 was higher in response to TM compared to CIRC. In support of our hypothesis, affective valence and exercise enjoyment did not differ between CIRC and TM and remained positive at all timepoints for the majority of participants. Overall, our findings suggest that body-weight resistance exercise provides a vigorous cardiometabolic exercise stimulus in boys, demonstrated by near-maximal HR response representative of HIIE (i.e. peak HR $> 85\%$ HR_{peak}), and was perceived favorably. Our preliminary findings support the utility of our CIRC protocol to provide a vigorous-intensity exercise stimulus representative of HIIE that could be a feasible alternative or addition to existing running- or cycling-based HIIE programs in boys.

Our findings corroborate previous studies that have examined acute cardiometabolic responses to various modes of resistance exercise in boys and girls. In physically active boys and girls, Faigenbaum et al.^{11, 12} characterized acute responses to a 10-minute progressive medicine ball protocol and a 10-minute fitness rope protocol, both requiring 30 s work interspersed with

30 s passive recovery, similar to our study. Both protocols provided a moderate to vigorous cardiometabolic stimulus with peak VO_2 values equal to 64 – 65 % $\text{VO}_{2\text{peak}}$.^{11, 12} In the present study, peak VO_2 during CIRC attained 74% $\text{VO}_{2\text{peak}}$ (range 61-80 % $\text{VO}_{2\text{peak}}$ for individual work intervals). Faigenbaum et al.^{11, 12} utilized protocols starting with lower-intensity exercises (i.e. chest pass) followed by more complex exercises (i.e. medicine ball slams); whereas, we required solely multi-joint and dynamic exercises specifically chosen to represent vigorous-intensity exercise, which in part explains the discrepancy in these findings.

The lower mean oxygen uptake in response to CIRC is likely attributed to the varied cardiometabolic responses attendant with the protocol. For example, during CIRC, participants revealed the lowest HR (77 – 85 % HR_{peak}) and VO_2 (61 – 70 % $\text{VO}_{2\text{peak}}$) during bouts 1 and 5, the mountain climbers exercise. In fact, HR and VO_2 during TM were higher than CIRC only for this particular exercise. These results may be attributed to mountain climbers utilizing smaller muscle mass compared to other CIRC exercises and performance in the prone position that did not elicit cardiorespiratory responses comparable to treadmill running. Also, participants could have performed the exercises less vigorously than intended or held their breath during the mountain climbers exercise. Nonetheless, from a public health perspective, it is important to characterize the intensity of an entire exercise session as opposed to just considering peak values, as overall time spent engaging in VPA is strongly associated with cardiometabolic health.² Therefore, we included an AUC analysis to compare the total exercise intensity between CIRC and TM. Although total AUC for VO_2 was greater for TM, CIRC provided a more potent physiological stimulus since a greater amount of the 8-minute session was spent engaging in vigorous exercise, as indicated by greater AUC above the HR and VO_2 thresholds of vigorous exercise (>85%

HR_{peak} and > 70% VO_{2peak}). A potential explanation for this finding is that the majority of CIRC required greater coordination and muscle mass recruitment compared to running.

Our assessment of blood lactate concentration provided further insight to the relative exercise intensities of each HIIE protocol. Consistent with the present study, a 12-minute 30s:30s resistance-based interval protocol consisting of a weighted squat, push-up, and weighted supine pull exercise elicited significant post-exercise blood lactate accumulation in adolescents (BLa = 7.0 mM).¹⁵ It is plausible that CIRC exhibited a greater BLa compared to TM because the multi-joint exercises performed during CIRC required greater fast-twitch recruitment as well as greater recruitment of all muscle fiber types, resulting in greater blood lactate accumulation compared to treadmill running.¹³⁰

Our CIRC and TM protocols elicited near-maximal HR and significant BLa accumulation, yet a significant decline in affective valence or exercise enjoyment was not observed. Our novel findings that affective valence and exercise enjoyment remained positive during CIRC and TM for the majority of participants are important given that exercise enjoyment is a strong predictor of habitual PA in children.¹⁴ During CIRC, affective valence ranged from +2.3 to +3.4 (in between ‘fairly good’ and ‘good’) and exercise enjoyment ranged from 4 (‘moderate’) to 5 (‘quite a bit’), with no differences between protocols. To our knowledge, there are no data regarding perceptual responses to body-weight resistance exercise in boys, yet previous data in active adults demonstrated a positive affective state during a body-weight exercise protocol, with similar exercise enjoyment compared to moderate-intensity continuous exercise.¹³¹ However, this finding refutes previous studies, as Malik et al.¹⁰⁸ demonstrated a significant decline in affective valence from 4 (in between ‘good’ and ‘very good’) to 1 (‘fairly good’) during treadmill-based HIIE performed at 90% MAS in adolescent boys. In addition, these boys

experienced a decline in exercise enjoyment during the intervals, yet, similar to our study, it remained high post-exercise. A possible explanation for these discrepant findings is the relatively brief duration and lower volume of our exercise protocols, which more closely emulate children's normal activity pattern of short bursts of vigorous activity interspersed with periods of lighter activity.¹⁰ Further, receiving one-on-one verbal encouragement from a research assistant as well as the opportunity to use novel equipment (i.e. treadmill) and try new exercises (i.e. CIRC) may also be factors contributing to the positive affective valence experienced during HIIE.

Post-exercise enjoyment (PACES) declined compared to baseline for CIRC with no differences in post-exercise enjoyment observed between CIRC and TM (Table 3). However, enjoyment only declined 3 units following CIRC, so the clinical significance of this finding is unknown. The high cardiometabolic demand of CIRC, along with participants being potentially unfamiliar with this form of resistance-based exercise, may in part explain the decline in post-exercise enjoyment in our study. Nonetheless, despite the potent nature of CIRC and TM, mean post-exercise PACES scores for CIRC and TM align with those reported by Malik et al.¹⁰⁸ following an 8 x 1 minute cycling-based HIIE protocol in adolescent boys and girls with similar cardiorespiratory fitness levels (i.e. VO_{2peak}) to the boys in the present study. Overall, affective valence remained positive and enjoyment was high during and after CIRC, suggesting that brief intervals of vigorous body-weight resistance exercises interspersed with low-intensity recovery periods may be feasible alternatives to traditional running-based HIIE protocols. However, the majority of studies investigating the perceptual responses to various HIIE protocols have utilized active children or adolescents and therefore additional work is needed to characterize the perceptual responses to such exercise in unfit or obese children.

There are several limitations of our investigation. Our sample consisted of recreationally active boys with weight status ranging from healthy to overweight, who may or may not have been meeting PA recommendations at the study onset given that the inclusion criteria involved participation in one sport/structured PA at any timepoint within the last year. Given that our sample was habitually active, our findings are not generalizable to sedentary or obese children. Further, we did not include girls in the current study due to difficulty in recruiting girls for previous resistance-based studies in our lab, and we acknowledge this as a limitation. Consequently, follow-up studies investigating the acute response to CIRC in girls are warranted. Second, the number of repetitions was not determined during CIRC, as participants were instructed to perform the exercises ‘all out’ with form and technique cues provided by the researcher. Despite these potential limitations, the present study comprehensively characterized the various cardiometabolic and perceptual responses to a practical body-weight resistance exercise circuit and compared these responses with treadmill-based HIIIE in healthy weight and overweight boys. Furthermore, we acquired perceptual responses during exercise at multiple timepoints which follows the recommendation of Backhouse et al.¹²⁶ who stated that in-task affective valence responses are stronger predictors of exercise adherence and are more robust than only pre-and post-exercise assessments. We also included a novel AUC analysis to capture the physiological responses to the entire exercise sessions in addition to traditional analysis approaches. Lastly, our study investigated younger boys (8-11 years old) of various fitness and activity levels as opposed to active adolescents, whose acute and chronic responses to various exercise protocols are widely investigated.⁵

Conclusions

High-intensity interval training may be an effective modality for improving health outcomes in children and adolescents by promoting VPA, yet the majority of data concerning the acute and chronic responses to this form of exercise includes treadmill or cycling-based protocols that are difficult to implement in school or health promotion settings. Our findings support the feasibility of body-weight resistance exercise circuits in providing a cardiometabolic stimulus attendant with HIIE in boys. HR and VO_2 responses to our body-weight circuit were higher than those previously demonstrated for free-weight resistance exercise and comparable to medicine ball interval exercise protocols in children.¹² The practical implications of the current study are noteworthy since the included body-weight resistance exercises are well-tolerated by participants and provide a potent exercise stimulus without the use of specialized equipment. However, when considering implementing similar protocols within a PA program, protocols will likely need to include a variety of body-weight exercises, including those that are partner-based, as well as variations in exercise intensity and equipment to maintain interest and enjoyment and account for a wide distribution in activity and fitness levels among participants. A few studies have investigated the health benefits of circuit-based exercise during physical education,¹³² but they did not address the impact of these programs on influencing the perceptual responses to exercise or PA motivation behaviors. This is an important research direction that must be pursued in order to further understand the long-term implications of feasible resistance-based interval exercise protocols in group-based physical activity settings in children.

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Disclosures

The authors have no conflicts of interest to disclose.

APPENDIX

TABLES

Table 1. Participant Characteristics (N=17)

Variable	Mean \pm SD
Age (years)	9.7 \pm 1.3
Physical Activity (PAQ-C)	3.9 \pm 0.7
Total Annual Sports Teams	2.2 \pm 1.1
% Body Fat	16.6 \pm 3.8
BMI Percentile [^]	48.9 \pm 25.0
Maximal Aerobic Speed (km/h)	10.8 \pm 1.8
VO _{2peak} (mL·kg ⁻¹ ·min ⁻¹)	45.1 \pm 6.0
HR _{peak} (bpm)	192 \pm 12

[^]BMI=body mass index; According to BMI-for-age percentiles from the CDC. Abbreviations: PAQ-C: Physical Activity Questionnaire for Children (range 1-5); VO_{2peak}: peak oxygen uptake; HR_{peak}: peak heart rate.

Table 2. Comparison of Cardiometabolic Responses Between CIRC and TM protocols (N=16)

Outcome Measure	CIRC	TM	<i>d</i>
HR			
Mean (bpm)	164 ± 12	163 ± 12	0.09
Mean (%HR _{peak})	86 ± 6%	85 ± 4%	0.20
Peak HR (bpm)	169 ± 10	172 ± 10	0.31
Peak (%HR _{peak})	88 ± 5%	89 ± 4%	0.23
Recovery (bpm)	162 ± 14	159 ± 13	0.23
Recovery (% HR _{peak})	84 ± 7%	82 ± 4%	0.36
VO ₂			
Mean (mL·kg ⁻¹ ·min ⁻¹)	30.6 ± 2.8	33.5 ± 2.9*	1.05
Mean (% VO _{2peak})	70 ± 9%	77 ± 5%*	1.00
Peak (mL·kg ⁻¹ ·min ⁻¹)	33.7 ± 2.6	36.9 ± 3.5*	1.07
Peak (%VO _{2peak})	74 ± 9%	81 ± 6%*	0.95
Recovery (mL·kg ⁻¹ ·min ⁻¹)	29.5 ± 3.5	32.8 ± 3.8*	0.93
Recovery (%VO _{2peak})	65 ± 9%	72 ± 5%*	0.99
Mean V _E (L·min ⁻¹)	47 ± 10	44 ± 10	0.31
Blood Lactate (mM) [^]			
Pre-exercise	1.2 ± 0.5	1.6 ± 1.1	0.49
Post-exercise	5.0 ± 0.7	2.0 ± 0.3*	5.80

Variables are presented as Mean ± standard deviation and effect size (*d*). Abbreviations: heart rate: HR; %HR_{peak}: percent of peak heart rate; VO₂: oxygen uptake; %VO_{2peak}: percent of peak oxygen consumption; V_E: minute ventilation. *Indicates significant difference between protocols. [^]N=13 (4 participants denied measurement of blood lactate)

Table 3. Comparison of Perceptual Measures Between CIRC and TM protocols (N=17)

Measure	Scale	Baseline	CIRC	TM	ηp^2
Exercise Enjoyment	PACES	66.9 \pm 10.1	63.1 \pm 12.3*	65.9 \pm 9.8	0.23
Positive Affect	PANAS	34.3 \pm 6.3	35.8 \pm 7.9	35.9 \pm 9.2	0.04
Negative Affect	PANAS	17.5 \pm 5.9	15.5 \pm 5.2	17.7 \pm 5.1	0.08

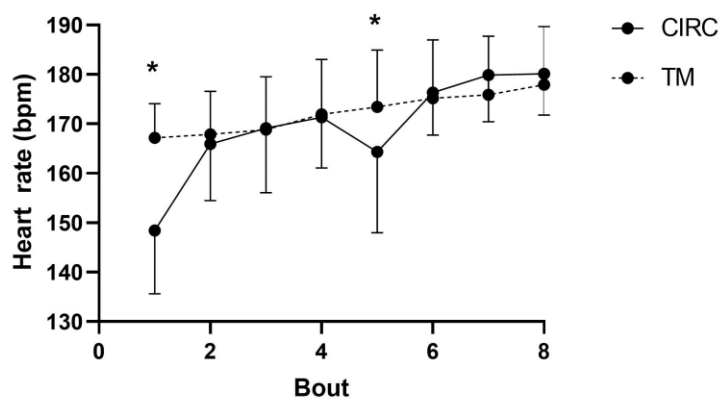
Variables are presented as Mean \pm standard deviation and effect size (partial eta-squared (ηp^2)). Abbreviations: PACES: modified Physical Activity Enjoyment Scale; PANAS: 20-item Positive and Negative Affect Schedule. *Indicates significant difference between baseline and body-weight circuit

FIGURES

Figure 1. Differences in (A) peak heart rate (HR) and (B) peak oxygen consumption (VO_2) in response to body-weight resistance exercise (CIRC) and treadmill-based HIE (TM).

* $P < 0.05$ between CIRC and TM.

1A



1B

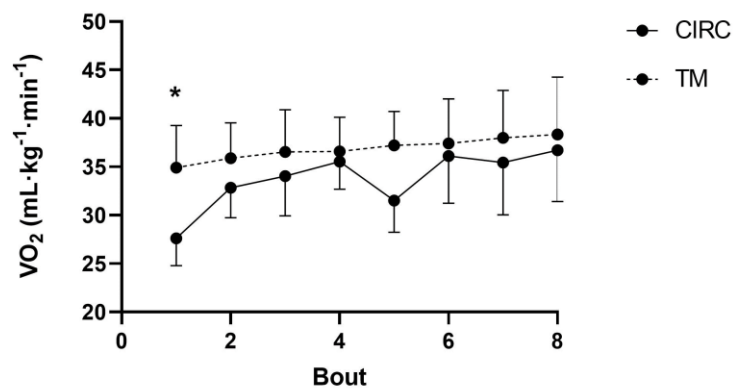
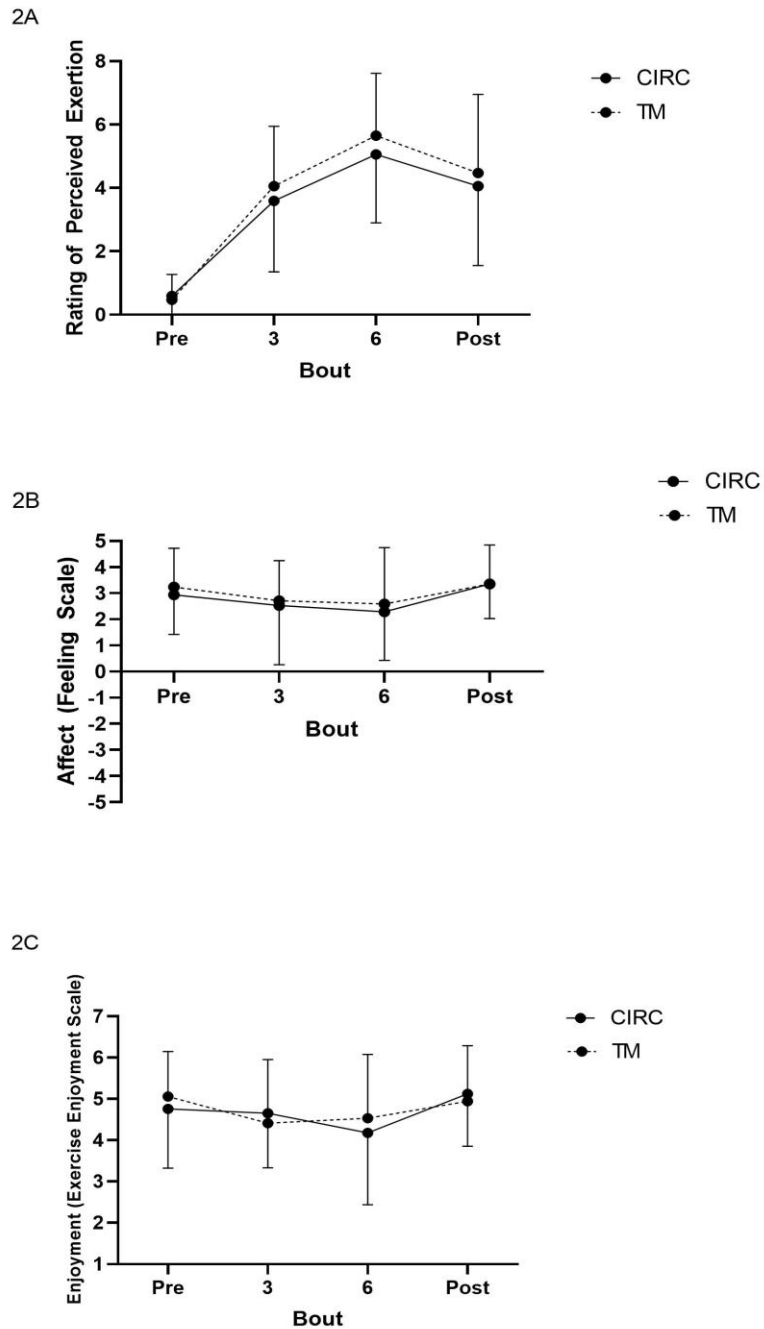


Figure 2. Differences in (A) Rating of perceived exertion (Children's OMNI), (B) Affective valence (Feeling Scale), and (C) Exercise enjoyment (Exercise Enjoyment Scale) in response to body-weight resistance exercise (CIRC) and treadmill-based HIIE (TM).



CHAPTER 3

Acute Cardiometabolic and Perceptual Responses to Individual and Group-Based Body-weight Resistance Exercise in Girls

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ABSTRACT

Girls' acute responses to high-intensity interval exercise (HIIE) in group-based settings are not well characterized. **PURPOSE:** To compare acute responses to treadmill-based HIIE (TM) and body-weight resistance exercise (CIRC), and to CIRC performed in a small group setting (Group CIRC). **METHODS:** Nineteen girls (age= 9.1 ± 1.1 years) completed a graded exercise test to determine peak oxygen uptake ($\text{VO}_{2\text{peak}}$), peak heart rate (HR_{peak}), and maximal aerobic speed (MAS). TM involved eight 30s sprints at 100% MAS. CIRC consisted of 4 exercises of maximal repetitions performed for 30s. Each exercise bout was followed by 30s of active recovery. Blood lactate concentration (BLa) was assessed pre- and post-exercise. Rating of perceived exertion (RPE), affective valence, and exercise enjoyment were recorded at pre-exercise, intervals 3 and 6, and post-exercise. **RESULTS:** Mean HR was higher during Group CIRC (92 ± 7 % HR_{peak}) than CIRC (86 ± 7 % HR_{peak}) and TM (85 ± 4 % HR_{peak}). Mean VO_2 equaled 76 ± 11 % $\text{VO}_{2\text{peak}}$ for CIRC and did not differ from TM ($P=0.60$). CIRC elicited greater post-exercise BLa versus TM (5.8 ± 1.7 vs. 1.4 ± 0.4 , $P<0.001$). Perceptual responses were similar among conditions ($P>0.05$),

and only RPE increased ($P<0.001$). **CONCLUSION:** CIRC represents HIIE and was perceived favorably in a small group-setting and may be a feasible alternative to running-based HIIE.

INTRODUCTION

Evidence suggests that children should engage in vigorous-intensity physical activity (VPA) because it is strongly associated with several indices of cardiometabolic health, including improved cardiorespiratory fitness, body composition, and a reduction in cardiovascular disease risk factors, more so than light or moderate intensity activities.² Given that only approximately 17% of girls meet the national recommendation for moderate-to-vigorous PA (MVPA), significantly less than boys, it is clear that children do not engage in adequate amounts of VPA, especially girls.¹³³ Therefore, it is warranted to investigate effective strategies for girls to obtain VPA. One strategy to promote VPA that has been increasingly studied in youth and adult populations is high-intensity interval exercise (HIIE), more commonly referred to as ‘HIIT’⁵. Although preliminary evidence supports the efficacy of HIIE in promoting cardiometabolic health in youth,^{6, 134} many studies have been performed with treadmills or cycle ergometers in laboratory environments with limited applicability to field-based settings.⁵

Recently, investigators have implemented HIIE protocols that incorporate muscular fitness and motor competence outcomes in children, including body-weight exercises and active-play games.^{16-18, 76} These preliminary results report improvements in physical and/or cognitive measures,^{16-19, 76} but the exact exercise intensity and cardiometabolic demands provided by these protocols remains unclear. Prior to implementing these non-traditional HIIE protocols as an intervention, there is substantial need to conduct empirical studies to examine if they provide a stimulus representative of HIIE and elicit appropriate hemodynamic responses (i.e. blood

pressure [BP]) that are ultimately required to induce chronic health-related adaptations. To date, one study in our laboratory¹³⁵ has characterized the acute cardiometabolic (i.e. oxygen consumption [VO₂] and heart rate [HR]) responses to an 8-minute body-weight resistance circuit in young boys and found it to be representative of HIIE with reported peak HRs attaining > 85% HR_{peak}. However, it is unknown if circuit-based exercise can provide a vigorous cardiometabolic stimulus comparable to running-based HIIE in young girls, especially when applied to group-based settings.

In addition to the cardiometabolic responses attendant with participation in HIIE,⁵ this form of exercise may demonstrate more favorable perceptual responses (i.e., enjoyment and affective valence [mood]) in children compared to moderate-intensity continuous exercise.²⁷ We recently demonstrated high exercise enjoyment and positive affective valence during a body-weight resistance exercise HIIE protocol in young boys.¹³⁵ Others have investigated perceptual responses to treadmill- or cycle-based HIIE protocols, but all been individually performed protocols.^{27, 74, 108, 135} Since children often engage in PA in group settings, such as sport practices or physical education classes, and rarely engage in PA on their own, it is important to assess children's perceptual responses and acceptability towards group-based HIIE. Given that literature in adults suggests that individuals prefer to exercise in group settings,²⁹ promoting group cohesion during HIIE may be associated with higher exercise enjoyment in children.^{26, 67}

Overall, it is imperative to assess children's cardiometabolic and perceptual responses to HIIE performed individually and in group settings to better understand if this form of exercise is an attractive strategy to promote VPA on a broader public health level. It is especially important to investigate this in girls, given they often present lower levels of PA and motor competence compared to boys¹³⁶ and experience steeper declines in PA and cardiorespiratory fitness during

adolescence than boys.¹³³ Therefore, the purpose of this study was to compare girls' acute cardiometabolic and perceptual responses between treadmill-based HIIE (TM) and a body-weight resistance exercise circuit (CIRC) performed individually, and to CIRC performed in a small group setting (group CIRC). We hypothesized that CIRC would elicit similar changes in VO₂, HR, and BP during exercise, yet greater blood lactate concentration (BLa) post-exercise, compared to TM. Second, based on our previous findings in boys, for each condition we hypothesized that there would be no significant decline in affective valence or exercise enjoyment during and post-exercise compared to pre-exercise. Further, we hypothesized that participants would demonstrate more positive perceptual responses at all timepoints during group-based CIRC compared to individually performed protocols since relatedness with peers and group exercise are related to higher exercise enjoyment in children and adults.^{28, 29} Lastly, we hypothesized that > 50% of girls would enjoy performing CIRC in a small group versus on their own and that > 50% of girls would be willing to try group CIRC in their physical education classes.

METHODS

Participants and Study Design

Girls ages 8-11 years old were recruited primarily via email correspondence through a university-based listserv, and secondary recruitment was accomplished with flyers placed at a local fitness studio. Inclusion criteria were broad in order to recruit girls with various sport experience and cardiorespiratory fitness levels. Participation in at least one sport or structured physical activity within the past year of study onset was required to achieve our target sample size and to ensure that participants could perform the exercises appropriately with limited training. Exclusion criteria included an underlying health condition or orthopedic injury,

prescribed medications that could influence exercise responses, and/or a ‘yes’ response to a standard Physical Activity Readiness Questionnaire for Children and Adolescents. Parents’ written permission and children’s written informed assent were obtained, and parents reported the child’s date of birth, ethnicity, and both biological parents’ standing height. Study approval was provided by the Michigan State University’s Institutional Review Board. An a priori power analysis was conducted to determine that a sample size of 15 would be sufficient to detect a moderate effect size (0.5) for the primary outcome variable HR among conditions at a power of 80%.¹⁰⁹ Our sample size is similar to previous studies comparing acute responses between different HIIIE protocols in children and adolescents.^{12, 135}

Participants completed four separate laboratory visits over a 1-2 week period with all sessions held at least 48 hours apart and each visit occurring at least 3 hours post-prandial at approximately the same time of day. Participants were instructed to refrain from any VPA or sport competitions 24 hours before each visit. During the first visit, participants completed baseline surveys, anthropometrics, and a graded exercise test. Subsequently, participants completed TM and CIRC on separate days in a randomized and counterbalanced order, and lastly completed group-based CIRC in a group of 3-4 participants.

Procedures

Baseline Assessments and Surveys

Participants completed baseline questionnaires assessing habitual PA and PA self-efficacy to further characterize the study sample, as well as positive and negative affect and exercise enjoyment surveys, as described below. Participants’ habitual PA was assessed via the Physical Activity Questionnaire for Children (PAQ-C) which provides a summary score using a mean of nine items scored 1 to 5, with a greater number representing higher PA.¹¹¹ The PAQ-C

is a valid measure for assessing PA in children on a population level according to expert review.¹¹⁰ To further characterize our study sample, participants completed the 5-item PA self-efficacy subscale of the Health Behavior Questionnaire at baseline, which is reported as the sum of the 5 items with a possible score of 0-15 (a higher score indicates greater PA self-efficacy).¹³⁷ The self-efficacy subscale of the HBQ has demonstrated adequate internal reliability ($\alpha = 0.67 - 0.69$) and construct validity.¹³⁸ Following completion of all surveys, standing and seated height and weight were assessed using a calibrated stadiometer (Shorr Board, Olney, MD) and weight scale (Tanita BC-534, Tokyo, Japan), respectively. Body mass index (BMI) percentile was calculated according to the BMI-for-age percentiles established by the Centers for Disease Control and Prevention.¹¹² Predicted age at peak height velocity was estimated using anthropometric measures as a valid indicator of girls' maturity status.¹³⁹

Exercise Testing

During the initial visit, participants completed a 5-minute familiarization period of walking on the treadmill (Trackmaster, Newton, KS) without wearing equipment and subsequently completed the surveys. Next, participants remained seated for 5 minutes to collect resting measures prior to completing a 2-minute warm-up at a self-selected walking pace on the treadmill. Participants then completed an incremental test on the treadmill to determine peak oxygen consumption (VO_{2peak}), HR_{peak} , and maximal aerobic speed (MAS).¹¹³ The test started at a speed of 5.0 km/h with grade fixed at 1% throughout the test, and subsequently speed was increased by 0.5 km/h every 30 s until volitional exhaustion.¹¹³ During exercise, HR was assessed continuously with a HR monitor (Polar, Woodbury, NY, USA) worn across the chest, and breath-by-breath gas exchange data were acquired using a portable metabolic analyzer (OxyCon, Vyaire Medical, Yorba Linda, CA). The unit was calibrated according to

manufacturer's instructions prior to exercise, and participants breathed into a Hans Rudolph child-sized facemask that was attached to the unit which was worn like a backpack. The portable system provides valid and reliable measures of VO_2 ¹¹⁴ and was selected as a more appropriate alternative to the standard metabolic cart since extensive free movement was required during CIRC. $\text{VO}_{2\text{peak}}$ and HR_{peak} were defined as the highest 10 s average VO_2 and HR, respectively, during the test, and MAS was defined as the speed on the treadmill eliciting the highest VO_2 during the test. In addition to $\text{VO}_{2\text{peak}}$, maximal effort was verified using established criteria in children including a respiratory exchange ratio > 1.0 and $\text{HR}_{\text{peak}} > 190$ bpm.¹¹⁶ Blood pressure was assessed with an automated motion-tolerant auscultatory monitor (Tango, M2, SunTech Medical, Morrisville, NC). Arm circumference was measured to determine the appropriate cuff size. Prior to exercise, resting BP was recorded 3 times with 2-minute intervals between measures while seated, with resting systolic BP (SBP) and diastolic BP (DBP) calculated as the average of the 3 measures. BP was also recorded once immediately after the graded exercise test. Participants rested for 10 minutes following the exercise test and subsequently completed a familiarization session for the CIRC protocol consisting of one set of each exercise to practice proper technique.

HIIE Protocols

Prior to performing the individual CIRC and TM protocols, participants were seated for 6 minutes to allow measurement of resting VO_2 , HR, BP, and pre-exercise perceptual responses. Then, they completed a 3-minute warm-up on the treadmill at a self-selected walking pace. Participants were familiarized with each perceptual scale prior to each session. Following exercise, participants completed a 2-minute recovery on the treadmill at the same speed as the warm-up. Identical warm-up and cool-down speeds were used for CIRC and TM protocols.

Group CIRC involved completing the CIRC protocol in a small group of 3-4 participants in a private dance studio space. Participants did not know each other prior to the group visit, but a brief ice breaker and introduction session were provided prior to completing this protocol. For group-based CIRC, participants were seated on the floor for 6 minutes to determine resting HR and record pre-exercise perceptual responses, and they subsequently completed a 3-minute warm-up consisting of walking laps around the dance studio. Recovery for group-based CIRC consisted of walking laps for 2 minutes. Each HIIE protocol had a 1:1 work:rest ratio consisting of 30 s intervals, which is similar to previous HIIE studies in children and adults.^{12, 135} A shorter interval duration was cautiously selected since it was unknown how long participants would be able to perform each body-weight exercise at an ‘all out’ intensity while maintaining proper form.

The CIRC protocol was an 8-minute session consisting of two sets of four exercises performed ‘all-out’ for 30 s followed by 30 s of active recovery stepping in place. The exercises performed included mountain climbers, squat jumps, burpees, and jumping jacks that were performed in this order to avoid repeated efforts with the same primary muscle group. These specific exercises are multi-joint movements involving foundational movement patterns, such as the squat, and are vigorous and representative of HIIE in boys.¹³⁵ Further, it is likely that these exercises are appropriate for most children since a previous study documents the use of resistance-based HIIE in obese youth.¹¹⁸ Participants were encouraged to complete as many repetitions as possible during each interval, and the total number of repetitions for each set was recorded. During both individual and group-based CIRC, participants received verbal encouragement to complete the same number of repetitions in the second set as the first set in order to maintain effort during the protocol. In addition, feedback was consistently provided to

maintain appropriate form and technique. Gas exchange data, BP, and BLa were not assessed during group CIRC. The TM protocol was also 8 min long and consisted of eight 30 s sprint efforts at 100% MAS interspersed with 30 s of active recovery at 40% MAS. Participants also received verbal encouragement throughout TM.

Outcome Measures

Oxygen consumption and heart rate: VO_2 was continuously recorded during all sessions (except group-based CIRC) using the portable metabolic unit. In addition, HR was recorded continuously with the portable heart rate monitor. Breath-by-breath and beat-by-beat HR data were averaged and expressed in 10 s intervals. Mean HR and VO_2 were represented as the average of all 10-second samples across the 8-minute HIIE protocols; whereas, the average of the last 10 seconds of each work interval represent peak HR and VO_2 . Recovery HR and VO_2 comprised the average of each 30-second recovery interval (i.e. three 10-second samples). VO_2 (individual protocols only) and HR responses across the 8 minutes were graphed to quantify area under the curve (AUC) (GraphPad, La Jolla, CA, USA). Total AUC was calculated, with a higher value indicating a greater session workload. Time spent engaging in vigorous exercise was determined as $\text{AUC} > 85\% \text{HR}_{\text{peak}}$ and $>70\% \text{VO}_{2\text{peak}}$.^{5,135}

Blood Pressure: To further characterize cardiovascular strain and work effort, BP was measured during the graded exercise test and individually performed HIIE protocols. BP was assessed prior to exercise, during rest interval 7 (i.e. exercise BP), and 5-minutes post-exercise.

Blood lactate concentration (BLa): BLa was measured by using a lancet to draw a small amount of blood (7 μL) from the fingertip, which was then analyzed using a portable blood lactate analyzer (Lactate Plus, Nova Biomedical, Waltham, MA, USA). BLa was assessed pre-exercise

prior to collecting resting measures and at 3-minutes post-exercise following individually performed CIRC and TM protocols.

Rating of Perceived Exertion, Affective Valence, and Enjoyment: Participants were given standardized instructions by the same researcher to record these outcomes. Rating of Perceived Exertion (RPE) was recorded with the validated Children's OMNI-walk/run Scale of Perceived Exertion which includes pictorial and word descriptors on a 0 to 10 scale, with a higher value indicating greater overall fatigue.¹²⁰ The OMNI scale has previously demonstrated strong intraclass reliability ($r=0.95$) and has been validated against objective %VO_{2peak} and %HR_{peak} measures in children ($r=0.86 - 0.89$).¹⁴⁰ The OMNI walk/run scale was used instead of the OMNI resistance exercise scale because 2 of the 4 sessions consisted of treadmill exercise, and the resistance training scale has pictorial images of lifting weights, which was not performed. Aligning with previous research in children and adolescents, affective valence was assessed with the Feeling Scale.^{74, 124, 135} The Feeling Scale is an 11-point valence scale ranging from -5 ('very bad') to +5 ('very good') and has been validated against previous assessments including the valence scale of the Affect Grid ($r=0.41-0.59$).¹⁴¹ To record affective valence, participants were asked to respond to the question, 'how do you feel right now?' with anchors given at 0 and all odd integers. Perceived exercise enjoyment was assessed using a single item from the 4-item physical activity enjoyment visual analog scale, the How(e) Happy Scale, that was previously validated in children.¹⁴² The stem was modified and participants were asked to respond to the question, 'compared to the physical activities you are used to doing, how much are you enjoying this one right now?' on a Likert scale ranging from 1 ('not at all') to 4 ('a lot'). During all protocols, perceptual responses were recorded pre-exercise, during the first 10 s of recovery intervals 3 and 6, and immediately post-exercise. Perceptual responses were assessed during

recovery intervals to avoid biases during group-based CIRC, in which participants indicated their perceptual response by holding the appropriate number of finger(s) behind their backs for researchers to record, which would not be possible during the work intervals. Participants practiced this assessment procedure during the individually performed CIRC protocol.

To further characterize affective valence and enjoyment responses to each protocol, participants completed the 10-item Positive and Negative Affect Schedule (PANAS) survey¹⁴³ and the modified Physical Activity Enjoyment Scale (PACES).¹²⁹ The PANAS and PACES surveys have both demonstrated strong internal consistency ($r=0.84-0.85$; $r=0.87$, respectively) in children.¹⁴³ The 10-item PANAS survey includes 5 positive and 5 negative words that describe different feelings and emotions. Participants were instructed to indicate to what extent they perceived each feeling or emotion on a Likert scale ranging from 1 ('very slightly or not at all') to 5 ('extremely') over the past few weeks. Positive and negative affect were scored separately with a range of 5-25, with a higher score preferred for positive affect and a lower score preferred for negative affect. The modified PACES survey included 16 items regarding enjoyment towards being physically active, with responses ranging from 1 ('disagree a lot') to 5 ('agree a lot').¹²⁹ Seven items were reversed scored with an overall score ranging from 16-80 with a greater score indicative of higher exercise enjoyment. Participants completed these surveys once prior to the graded exercise test to determine overall PA enjoyment and at 15 minutes post-exercise following each of the three protocols to compare overall PA enjoyment to the enjoyment experienced following each HIIE protocol.

Acceptability for CIRC: Following group-based CIRC, participants completed a one-on-one acceptability interview with a trained research assistant regarding preference for performing

CIRC individually versus in a small group, and the likelihood of performing CIRC in the future.

Acceptability data are reported as proportion of sample for selected questions.

Statistical Analysis

Descriptive statistics are reported as mean \pm standard deviation (SD). Normality for each outcome measure was determined with Q-Q plots, and Mauchly's test was used to assess homogeneity. The Greenhouse-Geisser correction was used when homogeneity was violated. For measurements that were only assessed during individual CIRC and TM, we performed the following analyses: 1) Dependent *t*-tests were used to determine differences in mean and peak VO₂, recovery VO₂, VO₂ AUC, mean BLa, and BP values. 2) A series of 2-way repeated measures analysis of variance (ANOVA) tests determined differences and potential interactions among VO₂ and BLa responses across time (each work interval for VO₂; pre- and post-exercise for BLa) and protocol. The dependent variable for VO₂ was the average responses for the last 10 s of each work interval. For measurements that were performed during all 3 conditions (i.e., individual CIRC, group-based CIRC, and TM), we performed the following analyses: 1) Separate, one-way repeated measures ANOVAs determined differences in mean and peak HR, recovery HR, and HR AUC values among the three exercise conditions. 2) Three-way repeated measures ANOVA tests were used to determine differences and potential interactions among HR and perceptual responses across time. The dependent variable for HR was the average responses for the last 10 s of each work interval. The dependent variables for RPE, affective valence, and exercise enjoyment were assessed by time (pre-exercise, intervals 3 and 6, and post-exercise) and protocol. Bonferroni's post-hoc test was used to examine mean differences when a significant *F* ratio was observed. Repetitions performed in each interval between individual CIRC and group-CIRC were compared with dependent samples *t*-tests. Cohen's *d* and partial eta squared (η^2)

were used as measures of effect size, and statistical significance was set at $P < 0.05$.¹⁰⁹ All statistical analyses were conducted using SPSS version 24 (IBM Corporation, Armonk, NY, USA).

RESULTS

All 19 girls completed each session with no adverse events, defined as no injuries or cardiovascular events. Participant characteristics including mean PA self-efficacy results are displayed in Table 4. Participants ranged from healthy (5th to < 85th percentile) to overweight (85th to < 90th percentile) according to the CDC percentiles for children.¹¹² Participants with missing data were excluded from the analysis. Specifically, four participants were removed from the HR analysis for individual protocols and five removed for analyses involving Group CIRC, two were removed from the VO₂ analysis, and five were removed from BP analysis due to technical difficulties experienced during the session. Missing data for perceptual scales were missing for at least one time point for three girls and were excluded from the analysis. Lastly, seven participants denied measurement of BLA.

Cardiometabolic Responses

Mean cardiometabolic responses to each exercise condition with effect sizes are presented in Table 5.

Heart Rate: Mean HR was significantly different among protocols ($F(2,26) = 12.40$, $P < 0.001$, $\eta^2 = 0.49$). Specifically, mean HR was significantly greater in response to Group CIRC versus individual CIRC ($P = 0.001$) and TM protocols ($P = 0.004$). There was no difference among protocols observed for peak HR ($F(2,28) = 1.59$, $P = 0.22$, $\eta^2 = 0.10$). Recovery HR differed among protocols ($F(2,28) = 34.41$, $P < 0.001$, $\eta^2 = 0.71$), with participants exhibiting higher recovery HRs in response to Group CIRC versus individual CIRC ($P < 0.001$) and TM ($P < 0.001$),

and individual CIRC versus TM ($P=0.04$). Total AUC for HR was similar among protocols ($F(2,24)=0.35$, $P=0.71$, $\eta^2=0.03$); whereas, $AUC > 85\%HR_{peak}$ differed among protocols ($F(1.2,14.7)=18.44$, $P<0.001$, $\eta^2=0.61$). $AUC > 85\%HR_{peak}$ was significantly higher in response to Group CIRC versus individual CIRC ($P=0.02$) and TM ($P=0.002$), and individual CIRC versus TM ($P=0.003$). Sample HR AUC data from a participant are presented in Figure 3A. Heart rate increased during exercise ($P<0.001$), and a time by protocol interaction was evident ($F(14, 168)=17.51$, $P<0.001$, $\eta^2=0.59$). Post hoc tests revealed a greater HR response during TM at interval 1 (vs. mountain climbers) compared to CIRC and Group CIRC ($P<0.05$). HR was higher in response to Group CIRC at interval 3 and 4 compared to individual CIRC and TM protocols ($P<0.05$). During intervals 5-8, HR was greater in response to CIRC and Group CIRC compared to TM ($P<0.05$).

Gas Exchange Variables: Mean, peak, and recovery VO_2 were not different between individual CIRC and TM protocols ($t(17)=0.15$, $P=0.88$; $t(17)=-.36$, $P=0.72$; $t(17)=1.28$, $P=0.22$, respectively). Total AUC for VO_2 was similar between protocols ($t(17)=-0.03$, $P=0.97$); whereas, $AUC > 70\% VO_{2peak}$ was significantly higher in response to CIRC versus TM ($t(17)=2.69$, $P=0.02$). Sample VO_2 AUC data from a participant are presented in Figure 3B. VO_2 had a main effect for time ($P<0.001$) and there was a time by protocol interaction ($F(7,112)=5.55$, $P<0.001$, $\eta^2=0.26$). Post hoc analysis revealed that VO_2 was significantly higher during TM at interval 1 (vs. mountain climbers).

Blood Pressure: Mean BP responses immediately following the graded exercise test were 158/56 \pm 25/14 mmHg. SBP increased by 39 \pm 9 mmHg from rest to exercise during TM, which was significantly greater than the 25 \pm 13 mmHg increase in SBP in response to CIRC ($t(11)=-3.19$,

$P=0.01$, $d=1.31$). DBP remained relatively stable from rest to exercise for both protocols, and did not differ between protocols ($t(11)=0.89$, $P=0.40$, $d=0.29$).

Blood Lactate: There was no difference in pre-exercise BLa values prior to CIRC or TM ($t(11)=-0.43$, $P=0.68$). BLa significantly increased from pre- to post-exercise ($P<0.001$) with a time by protocol interaction evident ($F(1,11)=87.41$, $P<0.001$, $\eta^2=0.89$). Results showed that CIRC exhibited a greater BLa compared to TM ($P<0.001$).

Perceptual Responses

Rating of Perceived Exertion: A main time effect for RPE was evident ($F(1.8, 26.5)=53.65$, $P<0.001$, $\eta^2=0.78$) with no time by protocol interaction observed among protocols ($P=0.054$) (Figure 4A). The highest mean RPE value attained was at interval 6 for all protocols (CIRC = 6 ± 2); Group CIRC = 6 ± 3 ; TM = 5 ± 3).

Affective Valence: Affective valence remained positive at all time points and did not change over time during exercise ($F(3,45)=2.15$, $P=0.12$, $\eta^2=0.13$). Furthermore, no time by protocol interaction was observed ($P=0.35$) (Figure 4B). Affective valence remained favorable for most participants during all exercise conditions with one girl reporting a value of -1 (i.e. negative affect) during intervals 3 and 6 for TM and group CIRC protocols. A different girl reported a -1 value during intervals 3 and 6 during individually performed CIRC. There was no change in positive or negative PANAS scores from baseline to post-exercise among protocols ($F(3,54)=0.54$, $P=0.66$, $\eta^2=0.03$) (Table 6).

Enjoyment: There was no time effect for exercise enjoyment (How(e) Happy Scale) ($F(3,45)=0.49$, $P=0.69$, $\eta^2=0.03$) with no difference in enjoyment scores among protocols ($P=0.051$) (Figure 4C). Exercise enjoyment remained high during all exercise conditions for most participants with only one participant reporting a score of 1 ('not at all') during interval 3 of

individual and group-based CIRC protocols. No changes in PACES scores were evident from baseline to post-exercise following the three protocols ($F(3, 51) = 1.21$, $P = 0.31$, $\eta^2 = 0.07$) (Table 6).

Acceptability of CIRC

One-on-one acceptability interviews conducted after Group CIRC revealed that most girls preferred performing CIRC in a group versus individually (Figure 5A). Reasons for preferring group CIRC included that it was ‘more fun and encouraging’ ($n=4$) and ‘more motivating’ ($n=6$) compared to completing CIRC individually. Further, wearing or not wearing the portable metabolic unit did not significantly affect exercise condition preference. Many girls expressed that they would also be willing to try CIRC during their Physical Education classes (Figure 5B). To further characterize potential differences among individual and group-based exercise, the number of repetitions during each interval for individual and group-based CIRC conditions were compared. Girls performed a significantly greater number of repetitions during Group CIRC versus individual CIRC for interval 1 (mountain climbers), interval 3 (burpees), and interval 7 (burpees) (Figure 6).

DISCUSSION

This study characterized active girls’ acute cardiometabolic and perceptual responses to an individual and group-based body-weight resistance exercise circuit (CIRC) compared to a traditional treadmill-based HIIE protocol (TM). Our first hypothesis was partially supported, as mean VO_2 responses were similar between CIRC and TM, yet mean HR was greater in response to group CIRC. Also, CIRC elicited a greater BLA. Consistent with our hypothesis, there was no decline in affective valence or exercise enjoyment during any exercise protocol. However, inconsistent with our hypothesis, girls did not experience greater affective valence or enjoyment

during group-based CIRC compared to individually performed CIRC, although perceptual responses remained positive at all timepoints for all but one participant and the majority of girls preferred Group CIRC. Overall, our findings support that body-weight resistance exercise can be performed at near-maximal intensities (i.e. peak HR >85% HR_{peak}) in individual or small group settings in girls and may be a feasible alternative to running- or cycling-based HIIIE protocols.

Our findings are consistent with previous literature investigating acute cardiometabolic responses to resistance-based HIIIE in children. We previously characterized HR, VO₂, and BLA responses to a similar 8-minute body-weight resistance exercise protocol in recreationally active boys and demonstrated near-maximal intensities with values representing 70% VO_{2peak} and 88% HR_{peak} with an elevated post-exercise BLA of 5.0 ± 0.7 mM.¹³⁵ In the present study, VO₂ and HR attained 76% VO_{2peak} and 85% HR_{peak}, respectively, with post-exercise BLA equal to 5.8 ± 1.7 mM in response to CIRC. In the boys' study, mean VO₂ in response to the body-weight resistance exercise protocol was lower compared to a treadmill-based HIIIE protocol. However, in the present study mean VO₂ responses were similar between individually performed protocols. In the current study, the number of repetitions was counted during each set, and girls were encouraged to achieve at least the same number of repetitions in the second set. These repetition goals were not used in the boys' study, which may explain the comparable VO₂ responses between the body-weight resistance exercise and treadmill-based HIIIE in the present study. The current study also examined responses to group-based CIRC and observed higher HRs than both individual CIRC and TM protocols. Performing CIRC in a group environment may have provided additional motivation and work effort, which may be an explanation for the higher mean HRs experienced during Group CIRC. Secondly, the girls were not wearing the metabolic unit during Group CIRC and were accustomed to the protocol, both of which may also explain

the higher exercise intensity in response to Group CIRC. Previously, Faigenbaum et al.^{12, 13} used a different approach to motivate participants by having them perform various equipment-based HIIE protocols to a desired cadence with the goal of achieving a specific number of pre-determined repetitions. However, participants' cardiometabolic responses were not representative of HIIE (i.e. 28 to 64% $\text{VO}_{2\text{peak}}$). Based on our findings and previous work, practitioners may need to provide additional motivation by encouraging group-based exercise and/or individualized target repetition ranges, as well as longer learning periods, to children performing body-weight resistance exercise HIIE versus treadmill-based protocols in order to achieve vigorous cardiometabolic responses required to promote long-term health benefits attendant with HIIE.¹⁴⁴

Because time spent engaging in VPA is associated with cardiometabolic health in children,² it is important to examine the overall dose of VPA provided by CIRC and TM. We conducted AUC analyses in order to reveal the total exercise intensity attendant with CIRC and TM.¹³⁵ Although total AUC for HR was similar among the three protocols and total AUC for VO_2 was similar between individually performed protocols, $\text{AUC} > 85\% \text{HR}_{\text{peak}}$ was significantly higher for both CIRC conditions compared to TM. Also, $\text{AUC} > 70\% \text{VO}_{2\text{peak}}$ was significantly higher in response to individual CIRC versus TM. This indicates that girls spent a greater amount of time engaging in VPA during circuit-based exercise compared to treadmill running, and accumulated an even greater amount of VPA during group-based CIRC. These findings suggest that body-weight resistance exercise performed in a group environment provided a more potent physiological stimulus compared to individual exercise, likely due to the group environment providing greater motivation and work effort. These findings expand on our previous work that examined AUC responses to individually performed body-weight resistance

exercise in boys.¹³⁵ A potential explanation for our finding is that the majority of the exercises included in CIRC required greater contraction of a greater muscle mass and likely higher force compared to running, resulting in greater amounts of VPA during CIRC. Based on current and previous findings, body-weight resistance exercise appears to elicit VPA in boys and girls, especially when performed in a group setting, and can be easily incorporated into existing PA programming.

To our knowledge, this is the first study to characterize BP responses to body-weight resistance exercise and compare them to a treadmill-based HIIE protocol in young children. The hemodynamic strain imposed by CIRC and TM was lower than that of maximal exercise testing, which provides evidence for the safety of these HIIE protocols. Nonetheless, SBP increased significantly during CIRC and TM compared to pre-exercise with similar responses between protocols, suggesting that body-weight resistance exercise induces a similar hemodynamic response attendant with running. Similar to the current study, Burns et al.¹⁴⁵ demonstrated elevated SBP immediately following two bouts of 30-second sprints on a cycle ergometer interspersed with 4 minutes of recovery in active adolescents, and Tallon et al.¹⁴⁶ reported a significant increase in mean arterial blood pressure immediately following a 6 x 1-minute cycling HIIE protocol in young boys and girls. Overall, our findings in girls corroborate with previous findings and suggest that body-weight resistance exercise provides an appropriate cardiovascular stimulus.⁵

Despite the high-intensity nature of CIRC and TM that elicited an increase in RPE, our finding that individual and group-based HIIE protocols did not induce a decline in affective valence or exercise enjoyment for the majority of girls is important given that they are predictors of PA participation across the lifespan.¹⁴ During individual and group-based CIRC, affective

valence remained relatively stable between 3.1 and 3.4 ('good'), and enjoyment ranged from 3.1 to 3.3 ('a little'), with no difference between conditions. Similarly, our previous data in young boys demonstrated positive in-task affective valence and enjoyment responses during an individually performed body-weight resistance exercise protocol.¹³⁵ Our results differ from those observed in adults, as Roloff et al.¹⁴⁷ demonstrated significant decreases in affective valence with increases in oxygen uptake during cycling-based HIIE. Perceptual responses to treadmill-based HIIE have been previously examined in adolescents, with one study demonstrating a significant decline in affective valence during exercise.⁷⁴ Our findings refute those of Roloff et al.¹⁴⁷ and Malik et al.⁷⁴ potentially due to the lower work volume used in the current study. Roloff et al.¹⁴⁷ used 3 x 3 minute and 5 x 4 minute protocols and Malik et al.⁷⁴ utilized an 8 x 1 minute protocol, containing more volume than our 8 x 30 second protocol. An additional explanation for our findings is that girls in the present study had relatively high PA self-efficacy (Table 4) and may have perceived our HIIE protocols favorably since self-efficacy is a strong predictor of VPA in children.¹⁴⁸

Compared to participants' overall PA enjoyment and affective state (assessed with the PACES and PANAS, respectively), post-exercise enjoyment or affect did not differ from baseline or among protocols. Our mean post-exercise PACES scores for individual and group-based CIRC conditions align with those reported by adolescents following an 8 x 1 minute cycling HIIE protocol,¹⁰⁸ suggesting that body-weight resistance exercise elicits similar favorable enjoyment responses as traditional cycling-based HIIE. Although additional research is needed to characterize the perceptual responses to this form of HIIE in obese or unfit children, our preliminary findings that group-based CIRC was enjoyable for the majority of participants

are encouraging, given that children rarely exercise on their own and need feasible ways for engaging in VPA in group settings.

To expand on findings from previous studies examining acute perceptual responses to HIIE in children, we conducted one-on-one acceptability interviews with all participants at the conclusion of the study. Overall, 79% of participants preferred performing CIRC in a small-group versus an individual setting because it was more ‘fun’ and ‘motivating’. These results were expected, given that relatedness with peers is related to high exercise enjoyment in children²⁶. Interestingly, the notion that most participants found the group setting to be more motivating translated to a greater work effort during group-based CIRC. For example, girls performed a greater number of repetitions for 3 of the 8 sets during group-based CIRC compared to performing CIRC on their own, corresponding with greater HR response experienced during group-based CIRC. Nonetheless, three participants preferred exercising alone because it was ‘easier to focus’ and ‘no one was watching [them]’. This information is insightful and highlights that a best practice may be to have children, especially girls, engage in exercise stations in small groups as opposed to one large group or class. Lastly, 84% of girls reported that they would be willing to perform the exercises included in CIRC during their physical education classes. Although this finding is encouraging, it is likely that the exercises included in the present study may have to be modified or performed with a longer recovery interval to accommodate the wide range of PA and fitness levels of students who participate in physical education.

There are several limitations of our investigation that must be addressed. Our convenience sample consisted of recreationally active girls who may or may not have been physically active at the study onset. Although our sample consisted of normal weight and overweight girls, our findings are not generalizable to obese girls. Further, we did not include boys in

the present study since their acute cardiometabolic and perceptual responses to body-weight resistance exercise were previously examined in our laboratory. However, it would be beneficial for future work to examine group dynamics and perceptual responses to boys and girls performing small group-based HIIE together. Lastly, the present study only investigated acute responses and therefore it is difficult to draw direct conclusions about the long-term effects of performing these HIIE protocols. Despite these limitations, the current study characterized girls' acute cardiometabolic and perceptual responses to group-based HIIE protocols with the addition of blood pressure and acceptability data that have not been reported in previous studies.^{74, 135} Furthermore, in-task RPE, affective valence, and enjoyment were creatively assessed during group-based CIRC to limit potential bias and extend the current body of literature assessing children's perceptual responses to individually performed HIIE. Lastly, our study included young girls of various fitness and activity levels who are often underrepresented in current pediatric HIIE literature.^{74, 135}

Conclusions

High intensity interval exercise is an increasingly popular mode of exercise to promote VPA and cardiometabolic health in children and adolescents.⁵ The current study shows that CIRC provides a more potent exercise stimulus (i.e. $\geq 85\%$ HR_{peak}), when performed individually or in a group setting compared to treadmill-based HIIE in girls.^{12, 15} This particular protocol is practical as it does not require specialized equipment. Our perceptual and acceptability interview data support the appropriateness of body-weight resistance exercise as a mode of HIIE that can be enjoyably performed in a small group setting with peers. As stated earlier, when implementing body-weight resistance exercise protocols within existing PA programs containing children of different fitness levels, it is likely that exercises of varying

intensities and equipment will be necessary to maintain enjoyment.⁶⁶ Nonetheless, there is a paucity of research investigating children's perceptual responses circuit-based HIIIE interventions,^{16, 17} highlighting an important research direction that must be pursued to better understand the long-term effects of implementing group-based HIIIE in youth PA settings.

Acknowledgements

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Disclosures

The authors have no conflicts of interest to disclose.

APPENDIX

TABLES

Table 4. Participant characteristics (N = 19)

Variable	Mean \pm SD
Age (years)	9.1 \pm 1.1
Total Annual Sports Teams	2.2 \pm 0.8
Physical Activity (PAQ-C) (min max: 1-5)	3.0 \pm 0.6
Physical Activity Self-Efficacy (min-max: 0-15)	13.5 \pm 1.3
BMI Percentile [^]	53.1 \pm 29.4
Normal or Healthy Weight (% of sample)	84%
Overweight/Obese (% of sample)	16%
Predicted APHV	11.4 \pm 0.3
Maximal Aerobic Speed (km/h)	9.5 \pm 1.7
VO _{2peak} (mL·kg ⁻¹ ·min ⁻¹)	41.7 \pm 6.4
HR _{peak} (bpm)	188 \pm 13

[^]BMI=body mass index; According to BMI-for-age percentiles from the CDC. Abbreviations: PAQ-C: Physical Activity Questionnaire for Children; APHV: age at peak height velocity; VO_{2peak}: peak oxygen uptake; HR_{peak}: peak heart rate.

Table 5. Comparison of cardiometabolic responses among HIIE protocols

Outcome Measure	TM	CIRC	Group CIRC	ES
HR				ηp^2
Mean (bpm)	$162 \pm 9^*$	$164 \pm 10^*$	175 ± 9	0.67
Mean (%HR _{peak})	$85 \pm 4^*$	$86 \pm 7^*$	92 ± 7	0.66
Peak (bpm)	168 ± 12	171 ± 8	173 ± 9	0.13
Peak (%HR _{peak})	88 ± 3	90 ± 6	91 ± 7	0.14
Recovery (bpm)	$156 \pm 11^{**}$	$164 \pm 11^{**\dagger}$	178 ± 9	0.82
Recovery (% HR _{peak})	$82 \pm 5^{**}$	$87 \pm 8^{**\dagger}$	94 ± 7	0.79
Total Area Under the Curve (AUC) (a.u.)	3817 ± 478	3895 ± 830	3997 ± 788	0.06
AUC > 85% HR _{peak} (a.u.)	$439 \pm 88^*$	$756 \pm 250^{*\dagger}$	961 ± 382	0.63
VO ₂				d
Mean (mL·kg ⁻¹ ·min ⁻¹)	31.6 ± 4.5	31.5 ± 3.8	N/A	0.02
Mean (% VO _{2peak})	76 ± 10	76 ± 11		0.01
Peak (mL·kg ⁻¹ ·min ⁻¹)	32.2 ± 4.7	32.5 ± 3.7		0.07
Peak (%VO _{2peak})	77 ± 11	79 ± 11		0.19
Recovery (mL·kg ⁻¹ ·min ⁻¹)	30.3 ± 3.7	29.1 ± 2.8		0.38
Recovery (%VO _{2peak})	73 ± 9	71 ± 11		0.20
Total AUC (a.u.)	1280 ± 199	1278 ± 155		0.01
AUC > 70% VO _{2peak} (a.u.)	164 ± 96	$223 \pm 81^\dagger$		0.68

Table 5 (cont.)

Blood Pressure			N/A	<i>d</i>
Resting SBP (mmHg)	113 ± 10	115 ± 13		0.18
Resting DBP (mmHg)	55 ± 11	51 ± 6		0.70
Exercise SBP (mmHg)	149 ± 18	142 ± 15		0.43
Exercise DBP (mmHg)	51 ± 9	49 ± 9		0.23
Post-Exercise SBP (mmHg)	124 ± 25	133 ± 25		0.37
Post-Exercise DBP (mmHg)	58 ± 10	58 ± 10		0.01
Blood Lactate concentration (mM) [^]			N/A	<i>d</i>
Pre-exercise	1.4 ± 0.6	1.4 ± 0.4		0.01
Post-exercise	1.4 ± 0.6	5.8 ± 1.7 [†]		3.61

Variables are presented as Mean ± standard deviation and ES (effect size; *d* or η^2).

Abbreviations: heart rate: HR; %HR_{peak}: percent of peak heart rate; VO₂: oxygen consumption; %VO_{2peak}: percent of peak oxygen consumption; SBP: systolic blood pressure; DBP: diastolic blood pressure. VO₂, BP, or BLA were not assessed during Group CIRC.

*Indicates significant difference versus Group CIRC ($P < 0.05$). **Indicates significant difference versus Group CIRC ($P < 0.001$). [†]Indicates significant difference between individual CIRC and TM protocols ($P < 0.05$).

[^]N=12 (7 participants denied measurement of blood lactate concentration).

Table 6. Comparison of perceptual measures among protocols

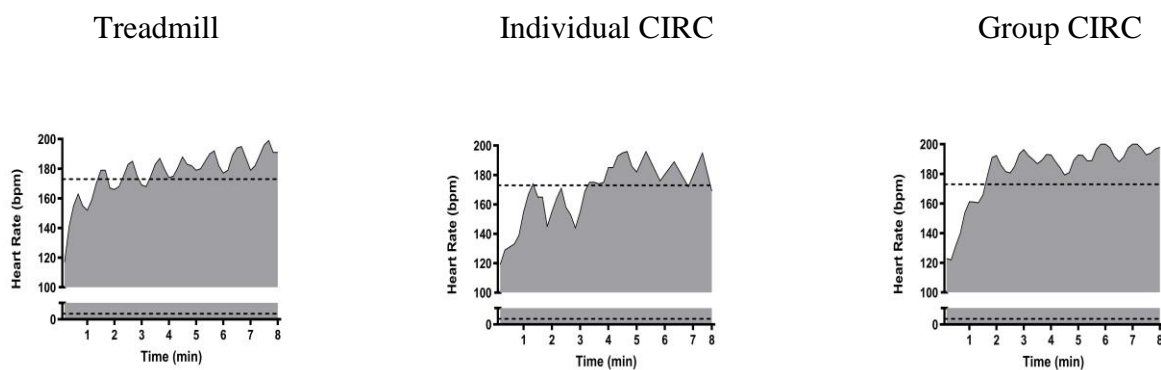
Measure	Scale	Baseline	CIRC	TM	Group CIRC	ηp^2
Exercise Enjoyment	PACES (n=18)	66 \pm 9	68 \pm 10	69 \pm 11	72 \pm 9	0.07
Positive Affect	PANAS (n=19)	20 \pm 3	20 \pm 3	20 \pm 3	21 \pm 4	0.03
Negative Affect	PANAS (n=19)	8 \pm 2	8 \pm 4	8 \pm 3	8 \pm 4	0.03

Variables are presented as Mean \pm standard deviation and effect size (partial eta-squared (ηp^2)). Abbreviations: PACES: modified Physical Activity Enjoyment Scale; PANAS: 10-item Positive and Negative Affect Schedule.

FIGURES

Figure 3. A) Area under the curve (AUC) data from a sample participant comparing AUC >85% HR_{peak} values among protocols and (B) AUC data from a sample participant comparing AUC >70% VO_{2peak} values between protocols

A



B

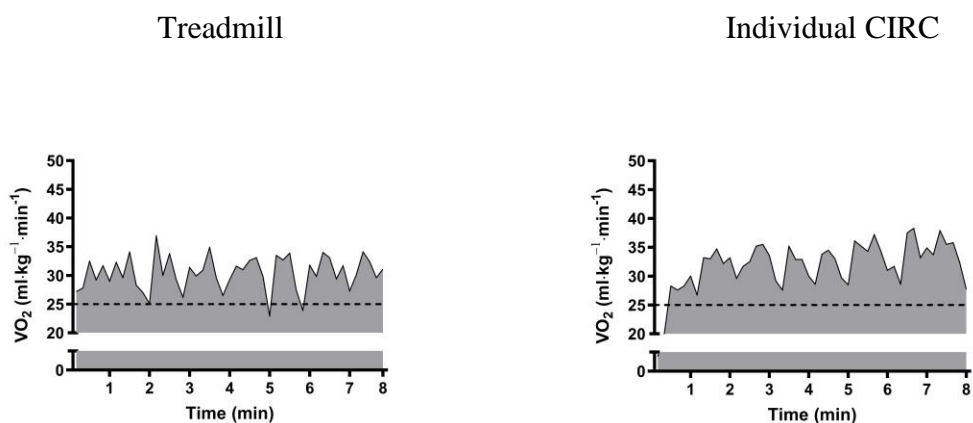


Figure 4. Differences in (A) Rating of perceived exertion (Children's OMNI), (B) Affective valence (Feeling Scale), and (C) Exercise enjoyment (How(e) Happy Scale) in response to body-weight resistance exercise (CIRC), Group CIRC, and treadmill-based HIIE (TM) (n=16)

*A: Indicates a significant difference from pre-exercise ($P < 0.05$)

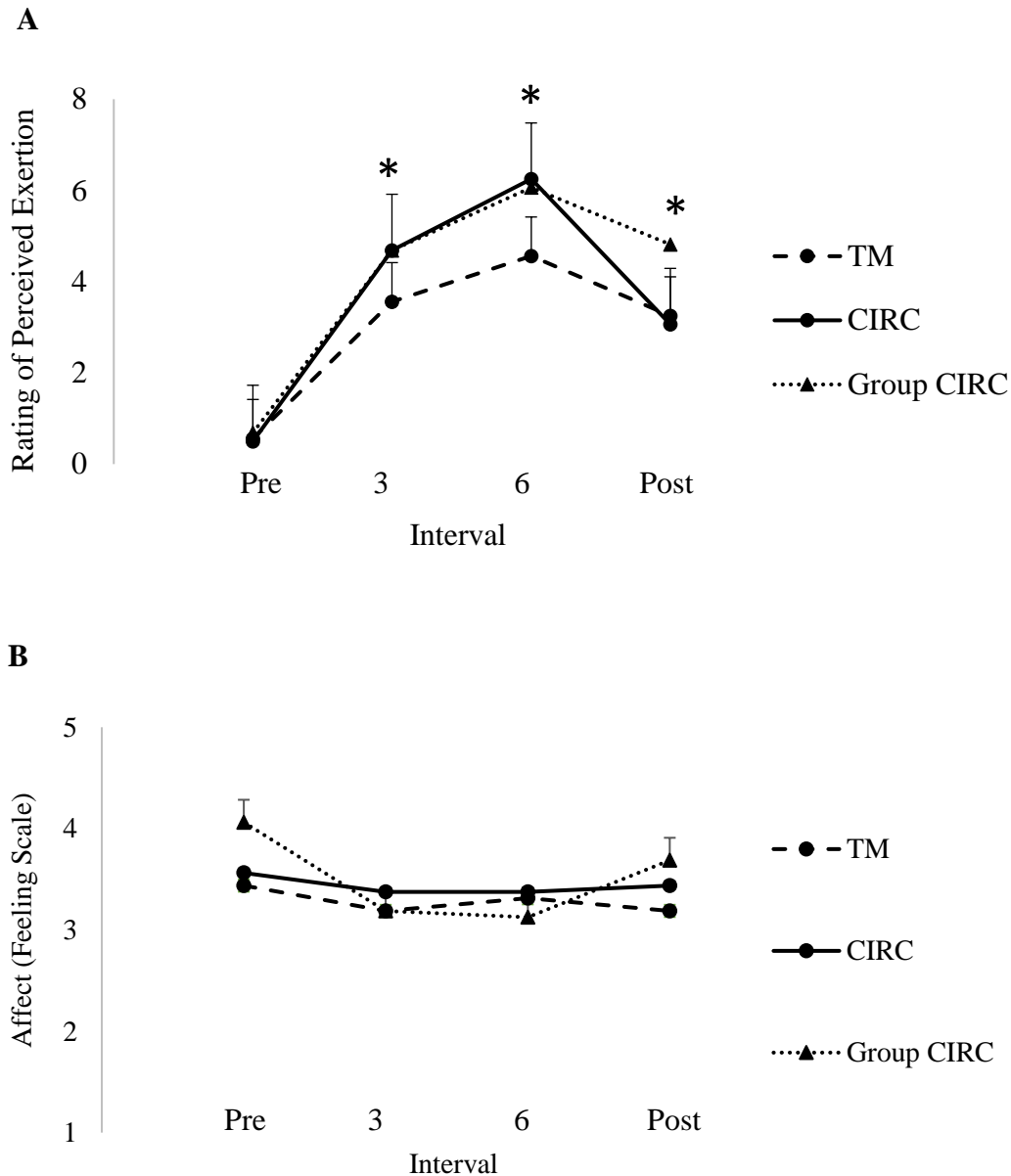


Figure 4 (cont.)

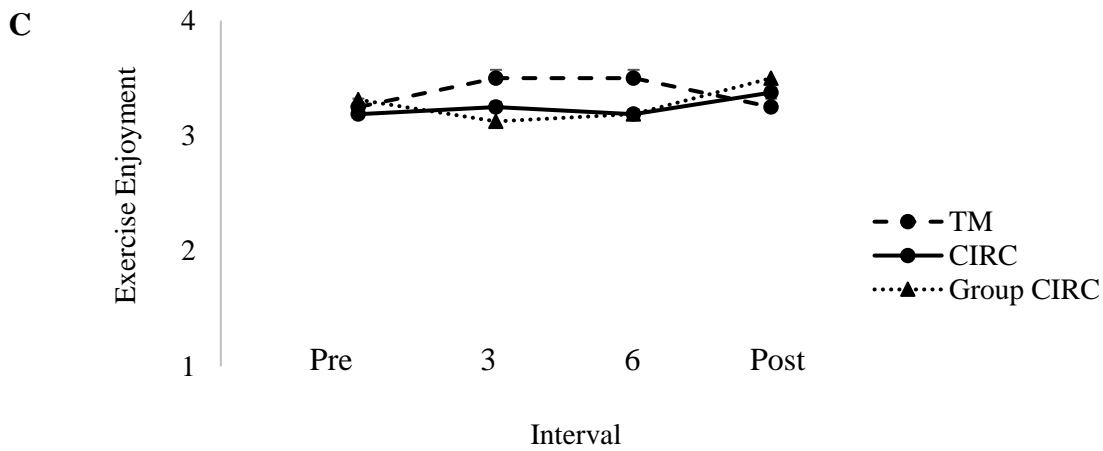


Figure 5. A) Proportion of girls preferring the individually performed body-weight exercise circuit (CIRC) versus group-based CIRC (N=19). B) Proportion of girls willing to try our body-weight exercise circuit in physical education classes (N=19).

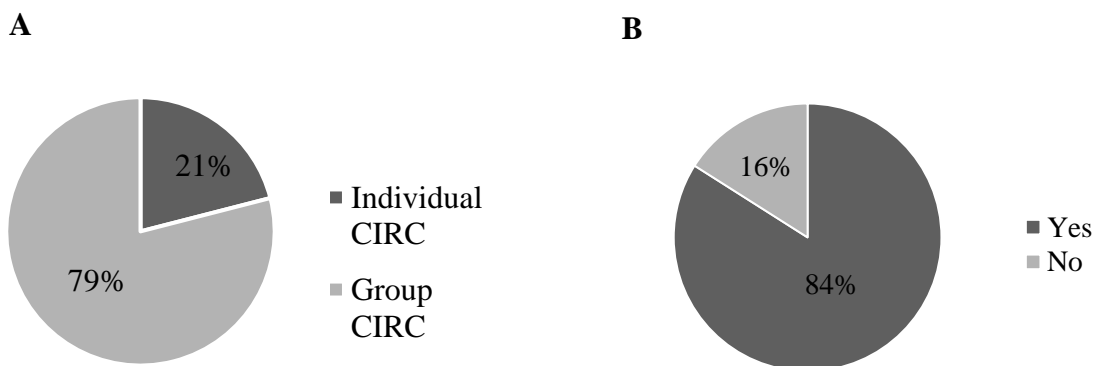
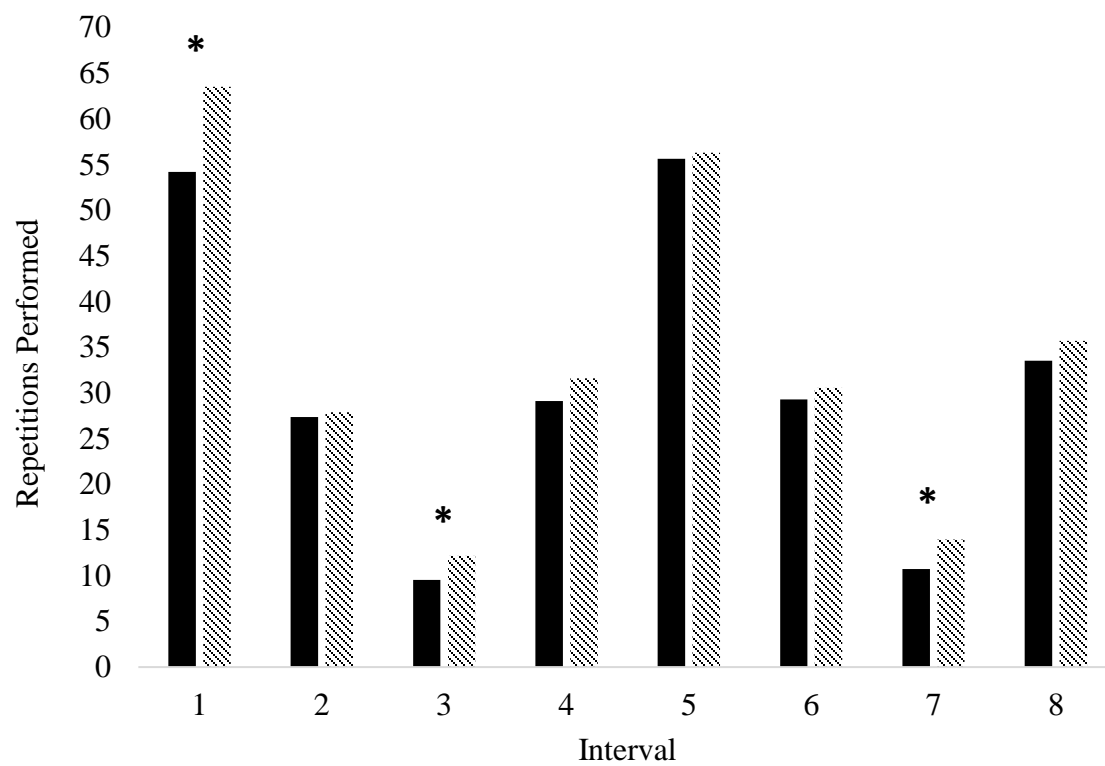


Figure 6. Comparison of repetitions performed during individually performed CIRC (Individual CIRC) and the circuit performed in a small group setting (Group CIRC).

Intervals 1 and 5 = mountain climbers; Intervals 2 and 6 = squat jumps; Intervals 3 and 7 = burpees; Intervals 4 and 8= jumping jacks

**Significantly different between conditions ($P<0.05$)*



CHAPTER 4

Efficacy and Program Evaluation of a Fitness and Skill-Based High-Intensity Interval Training (HIIT) Program in Elementary School Physical Education

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ABSTRACT

Previous school-based high-intensity interval training (HIIT) interventions focused on the quantity of physical activity (PA) achieved during physical education (PE) rather than the quality of students' PE experiences. **PURPOSE:** To evaluate the efficacy of a fitness- and skill based HIIT intervention guided by the Self Determination Theory and perform a program evaluation. **METHODS:** For this pretest-posttest randomized controlled 6-week study, 4-5th grade students (15 boys and 30 girls, age = 10.5±0.9 years) completed a HIIT circuit at the beginning of PE (INT); whereas, 22 students (10 boys and 12 girls, age = 10.5±0.9 years) engaged in regular PE activities (CON). Two-way mixed ANCOVA tests were performed to assess potential intervention effects. **RESULTS:** A time by group interaction ($P<0.001$) was evident for cardiorespiratory fitness, as VO_{2peak} increased in INT from 53.6±6.1 to 56.9±7.3 ml/kg/min. Muscular strength assessed with a handgrip test increased in INT from 35.5±7.3 to 37.2±9.0 kg and decreased in CON ($P=0.02$) from 36.2±12.0 kg to 33.4±9.0 kg. Students in INT exhibited greater amounts of moderate-to-vigorous PA and vigorous PA during PE versus CON, based on accelerometer data (23.4±5.0 vs. 15.7±4.7 min/hr; $P<0.001$, $\eta^2=0.45$; 4.5±2.6 vs. 2.3±1.3 min/hr; $P<0.001$, $\eta^2=0.27$, respectively). Participants and the physical educator reported

favorable program satisfaction (mean 3.6 ± 1.5 out of 5) and feasibility (31/35).

CONCLUSIONS: Similar to previous work, students participating in HIIT were more active during PE and experienced greater training adaptations compared to those engaging in regular PE. Fitness- and skill-based HIIT may be a valuable addition to elementary school PE programs.

INTRODUCTION

From a public health perspective, the school environment can serve as a venue for increasing physical activity (PA) levels in children, especially during physical education (PE).¹⁴⁹ Although PE affords millions of children an opportunity to be physically active, data suggest that children are insufficiently active during PE, with less than 50% of class time spent engaging in moderate-to-vigorous PA (MVPA).⁷⁷ This is troublesome given that the amount of accumulated PA, specifically vigorous-intensity PA (VPA), is strongly linked to cardiometabolic health benefits such as improved weight status and cardiorespiratory and muscular fitness.³⁰ Accordingly, there is a need to determine feasible and attractive strategies to implement small, targeted doses of MVPA and VPA during elementary school PE.

One strategy that has been used to promote higher levels of PA within the PE setting is high-intensity interval training (HIIT), which involves completing brief bouts of intense activity interspersed with periods of lower-intensity activity.⁵⁻⁷ Running-based HIIT interventions delivered to elementary school students have demonstrated significant improvements in indicators of cardiometabolic health,⁵ but they do not enhance additional aspects of PA including motor competence and muscular fitness.⁴⁴ Therefore, applying the structure of traditional running-based HIIT to different interval-based exercise protocols that provide a variety of exercises and modalities may be a more developmentally appropriate and engaging strategy.

Previous studies implementing fitness- and skill-based interval exercise protocols during elementary school PE demonstrated preliminary feasibility and efficacy in promoting cardiorespiratory and muscular fitness and PA self-efficacy.^{16, 20, 21, 82} However, further characterization regarding the effects of HIIT on students' psychosocial experiences during PE are needed, since very few HIIT studies adopted a theoretical approach to their intervention, measured students' enjoyment during HIIT, or conducted a thorough program evaluation.^{16, 24} Accordingly, in addition to focusing on the *quantity* of PA (i.e. intensity, duration) and fitness adaptations achieved, future studies must also consider psychological constructs such as enjoyment and self-determined motivation for PA engagement (i.e. participation stemming from fun, enjoyment, and challenging opportunities) that contribute to the *quality* of the intervention.⁸⁴

Self-Determination Theory (SDT) is one theoretical perspective that has been applied to research in the PE domain to improve the quality of students' PE experiences.^{23, 24, 86} SDT postulates that individuals will demonstrate higher amounts of self-determined (i.e. intrinsic) motivation, and in turn greater PA participation, if the basic psychological needs of competence (i.e. perceptions of task mastery), autonomy (i.e. opportunity for choice and decision making), and relatedness (i.e. social connections among peers and educators) are satisfied.²³ Therefore, an important practical implication of promoting the fulfilment of the basic psychological needs during PE is that it may in turn promote leisure-time PA participation outside of the school setting.⁸⁷ SDT provides a strong theoretical foundation for future fitness- and skill-based interval exercise interventions because these protocols can be systemically designed to promote fulfilment of the basic psychological needs outlined by the SDT. For example, instead of incorporating passive recovery intervals between work stations and only performing HIIT individually as in previous studies,^{20, 21, 56} implementing low-intensity recovery stations requiring

motor skills (throw and catch, balance, etc.) where participants choose from a variety of activities, as well as partner-based exercises, may promote significant improvements in the basic needs of competence, autonomy, and relatedness which may lead to intrinsic motivation, according to SDT.

The purpose of this study was to evaluate the efficacy of a 6-week fitness and skill-based HIIT intervention delivered to 4th and 5th grade students during PE and perform a program evaluation. Changes in cardiorespiratory and muscular fitness, motor competence, basic psychological needs satisfaction, PA enjoyment, intrinsic motivation for PA participation, and leisure-time PA, and the amount of MVPA and VPA during PE, were compared to a traditional PE class. We hypothesized that the HIIT intervention (INT) would elicit significantly greater improvements in fitness outcomes, PA enjoyment, fulfillment of the basic psychological needs (perceived competence, autonomy, and relatedness), intrinsic motivation for PA, and leisure-time PA participation relative to the control group (CON). We also hypothesized that the intervention would demonstrate strong fidelity, with students in the INT group attaining greater amounts of MVPA and VPA compared to CON students. Lastly, we hypothesized that the intervention program would demonstrate high feasibility scores by the physical educator and favorable program acceptability from participants and the physical educator.

METHODS

Study Design and Participants

This study was a pretest-posttest controlled study with randomization occurring at the classroom level. Students from five 4th and 5th grade classrooms at one public elementary school were recruited to participate in this study. See Figure 7 for a study flow diagram of participants throughout the study. Students were eligible to participate if they obtained parental consent (i.e.

permission), provided assent, and had no chronic disease or physical disabilities that would prevent regular PA participation (based on Health History Questionnaire completed by parents during the consent process). The exclusion criterion was severe physical or intellectual disabilities that would result in inability to follow instructions. Demographic data regarding participants' date of birth and sex were self-reported by the parents during the parental consent process. Participant characteristics are displayed in Table 7. Ethical approval was obtained by the elementary school district and Michigan State University's Institutional Review Board.

Theoretical Basis for the Proposed Intervention

In line with SDT, during the intervention period the physical educator and research assistants focused on task mastery, cooperation, and student integration, rather than focusing on outcomes such as the number of repetitions performed at each station.⁹³ The fitness- and skill-based HIIT protocol consisted of alternating high-intensity stations including plyometric drills, fitness rope, and medicine ball exercises, with low-intensity active recovery stations focused on object control tasks (i.e., throwing and catching, circus arts activities), balance, and stability activities. Exercises focused on motor competence were incorporated into low-intensity stations to promote feelings of competence during PE. Table 8 exhibits the exercises performed throughout the intervention. To satisfy the basic psychological need of autonomy and to further promote self-determined motivation towards PA, participants chose the initial work interval station to start each session, chose from previously learned exercises during sessions 7-8, and had a choice of activities at each active recovery station throughout the intervention (e.g. for balance participants chose from Spooner boards, stilts, or body balance activities). Lastly, a relational component was added to the intervention by having participants choose their station

group members as well as a partner with whom to complete partner work and active recovery stations.

Procedures

Baseline Testing

After completion of the consent process, baseline testing occurred during regularly scheduled PE class times. Initially, research staff conducted pencil and paper survey measures with groups of 4-6 participants. Subsequently and in this order, anthropometric, fitness, and motor competence assessments were conducted. Cardiorespiratory and muscular fitness assessments were completed on 2 separate days to avoid fatigue.

Exercise Training

Students participated in 50 minutes of PE on three occasions every two weeks. Participants in INT completed a fitness- and skill-based HIIT circuit at the beginning of each PE class; whereas, participants in CON continued their regularly scheduled activities for 6 weeks. Sample activities performed in CON included active-play team challenges, circus arts activities, and hand-eye coordination games. Following baseline testing, all participants completed two familiarization sessions to practice the preliminary exercises and how to rotate through the stations (INT only), how to use the Plicker magnet system to assess enjoyment, and how to wear the accelerometers and HR monitors. There was a total of 8 INT and 8 CON sessions excluding the practice sessions. The study coordinator was present at all PE classes to record contextual notes and to assist with delivering the HIIT protocol.

Description of HIIT Program

Each training session consisted of a 3-minute warm-up consisting of dynamic stretches (i.e. shuffle, air squats, lunges, etc.) followed by the fitness- and skill-based HIIT protocol (Table 8)

performed in a gymnasium. The protocol used progressive overload¹⁵⁰ by employing more difficult exercises and a greater workload to improve cardiorespiratory fitness, muscular fitness, and motor competence. During sessions 1-4, participants performed 5 high-intensity exercises for 20 s followed by 30 s of lower-intensity exercises for 30 seconds, with a 6-second transition period between each exercise. Participants performed three sets for a total protocol time of 16.5 minutes. During sessions 5-8, exercise duration was increased to 30 s followed by a 30 s active recovery, for a total protocol time of 19 minutes. Participants used 1 or 2 kg medicine balls and a 2 kg fitness rope which have been shown to be safe and appropriate for 8-12 year-olds.^{20, 21} Participants were encouraged to perform each high-intensity exercise at an ‘all out’ effort (i.e. $\geq 80\%$ HR_{peak}), which was displayed as a red color on the heart rate monitor, and each active-recovery exercise at a low-intensity (displayed as a blue color on the heart rate monitor). Following HIIT, the physical educator led the class through activities similar to CON for the remainder of the class period. Lastly, to maintain efficiency and organization, pre-recorded coordinated music was used to note the high and low intensity exercise stations and the transition to the subsequent station.

Outcome Measures

Participant Characteristics: Stature was measured twice with a portable stadiometer (Shorr Productions, Olney, MD), and the two measures were averaged. Body mass was assessed twice with a bioelectrical impedance scale (Tanita BC-534, Tokyo, Japan) with accuracy to the nearest 0.1 kg, and the two measures were averaged. Mass and stature were used to calculate BMI (kg/m^2) and converted to age- and sex-specific percentiles for children.¹⁵¹

Cardiorespiratory and Muscular Fitness: All participants completed the FITNESSGRAM 15-m PACER (Progressive Aerobic Cardiovascular Endurance Run) to assess cardiorespiratory

fitness.¹⁵² The number of laps successfully completed was recorded and converted to peak oxygen consumption ($\text{VO}_{2\text{peak}}$ in ml/kg/min) using a validated equation in children.¹⁵³ The PACER test has a moderate level of criterion validity for estimating cardiorespiratory fitness versus indirect calorimetry ($r= 0.66$)¹⁵⁴ and strong test re-test reliability ($r= 0.89$).¹⁵⁵ Muscular strength and endurance were initially assessed with a standard handgrip test using a Jamar (J.A. Preston Corporation, Clifton, NJ, USA) or a TKK dynamometer (TKK 5101 Grip-D, Takey, Tokyo, Japan). Both dynamometers have strong criterion validity and reliability in youth,¹⁵⁶ and each participant used the same device for pre- and post-testing. The sum of the best trials from the left and right hand were reported.¹⁵⁶ To assess upper body muscular strength and endurance, participants completed the FITNESSGRAM push-up assessment in which the maximum number of repetitions performed with proper technique to a pre-established cadence was recorded.¹⁵⁷ The reliability and validity of these muscular fitness tests have been published elsewhere.^{156, 158}

Motor Competence: Several fundamental movement skills were evaluated using components of the ‘Get Skilled Get Active’ assessment battery.¹⁵⁹ For the current study, two object manipulation skills (catch and throw) and three locomotor skills (static balance, vertical jump, sprint run) were evaluated. For each skill, a score is obtained from 5-6 features that are considered integral to being proficient at the skill.¹⁶⁰ The score for each of the 5 skills was summed to create a composite motor competence score out of 29. The Get Skilled Get Active assessment has been previously validated in children and used in several intervention studies to assess motor competence.^{160, 161}

Leisure-time Physical Activity: PA participation outside of PE was assessed with two different surveys to estimate the amount of MVPA as well as the context of students’ leisure-time PA participation at pre- and post-intervention. Participants completed a single item from the Youth

Risk Behavior Surveillance System to determine the number of days/week they obtained the national recommendation of at least 60 minutes of MPVA per day.¹⁶² Participants also completed the 14-item Evaluation of Activity Survey for Youth (EASY)¹⁶³ in which they indicated their frequency of engagement on an 8-point scale (i.e. 0 – 7 days) for a variety of physical activities in different contexts over a week recall period. The sum of the 14 items is reported (min – max = 0 – 98). This survey is a reliable and valid measure of leisure-time PA versus accelerometry.¹⁶³

Physical Activity Enjoyment: To assess enjoyment of physical activity, participants completed the short form of the modified Physical Activity Enjoyment Scale (PACES) which consisted of 7 negatively worded items that were reversed-scored to ensure that a greater score indicated higher PA enjoyment.¹⁶⁴ The PACES survey has high internal consistency ($r=0.87$) and adequate construct validity ($r= 0.24 – 0.66$) in children and adolescents.^{128, 129}

To assess enjoyment *during* the INT and CON activities, participants responded to a single item using a 4-item visual Likert scale after the second set of HIIT (INT) or 20 minutes into PE class (CON).¹⁴² This enjoyment scale has been previously validated in children.¹⁴² To assess enjoyment during INT, a magnetic whiteboard with the prompt ‘compared to the kinds of physical activity you usually do, how much are you enjoying this one right now?’ along with the 4-item facial scale ranging from 1 ('not at all') to 4 ('a lot') were placed at each exercise station. Each student had their own Plicker magnet and responded to the prompt to indicate their current level of enjoyment. The Plickers have response choices on each side of a square magnet and students turn the magnet so that their answer is on the top and is placed face down so that other students cannot view each other's responses. Responses were then captured using an iPad with the Plicker software. This assessment was conducted during every other class period throughout

the intervention period. Mean enjoyment responses across all assessments during INT and CON are reported.

Basic Psychological Needs Satisfaction in PE: To determine the degree to which participants experienced satisfaction of the three basic psychological needs postulated in the SDT (i.e., perceived competence, autonomy, relatedness) during PE, three previously validated questionnaires were used.⁸⁸ All subscales were adapted and validated within elementary PE in children and demonstrate adequate internal reliability with Cronbach's $\alpha > 0.70$ for each subscale.⁹³ Cronbach's α in the current study were > 0.70 for each subscale. Participants' sense of autonomy was assessed with a 5-item questionnaire⁹³ in which participants responded to items (e.g. 'I have some choice in what I want to do') preceded by the stem 'In PE class'. Perceived competence towards PE was determined with a 5-item questionnaire devised from the 18-item Intrinsic Motivation Inventory.¹⁶⁵ An example item includes, 'I am pretty skilled at PE'. Lastly, relatedness in PE was assessed with the acceptance subscale of the Need for Relatedness Scale^{93, 166} in which participants responded to the stem, 'with the other students in my PE class I feel...' followed by 5 items, including 'close', 'valued', and 'supported'. For all three subscales, responses were on a 7-point Likert scale ranging from 1 ('strongly disagree') to 7 ('strongly agree'). The negatively worded items in the autonomy and competence subscales were reverse scored to ensure that a higher score indicated higher needs satisfaction. The variable 'total need satisfaction' was calculated as the average of the three individual subscales.

Self-Determined Motivation for PA: Self-determined motivation to participate in leisure-time PA was assessed via a modified version of the intrinsic motivation subscale from the Perceived Locus of Causality scale that was previously adapted and validated for elementary school PE (Cronbach's $\alpha = 0.88$).⁸⁸ Cronbach's α for the current study was equal to 0.82. In the present

study, the stem was modified to assess self-determined motivation towards leisure-time PA with the wording ‘I take part in physical activity...’, rather than in PE, since it is hypothesized that promotion of the basic psychological needs within the PE context will promote leisure-time PA outside of school.⁸⁷ Participants responded to four items on a 1 (‘strongly disagree’) to 7 (‘strongly agree’) Likert scale with the average of the four items reported. An example item of the intrinsic motivation subscale includes ‘because PA is fun’.⁸⁸

Process Evaluation

Intervention Reach and Dose: Reach was determined by the study coordinator and physical educator, who monitored and recorded participant attendance at each class period. Dose was recorded as the total number of intervention sessions provided by the study coordinator over the 6-week intervention period.

Program Fidelity: Participants in INT and CON wore either an ActiGraph GT3X-BT (Pensacola, FL; firmware 1.9.2) accelerometer or a wrist-worn heart rate (HR) monitor (Interactive Health Technologies (IHT), Austin, TX, USA) on their non-dominant wrist during an entire PE class period, and participants rotated which device they wore each class period. The accelerometer was initialized using ActiLife software (version 6.13.4) to collect acceleration in three axes (vertical, mediolateral, and anteroposterior) at a sampling rate of 30 Hz, which was reintegrated into activity counts per 5-s.¹⁶⁷ Vector magnitude counts/5-s was calculated as the square root of the sum of the squared counts from each axis. The vector magnitude metric was selected as it uses information from all three axes and is less dependent on monitor orientation. Data from the sessions were extracted using researcher-recorded start and stop times. Chandler et al.¹⁶⁸ cut-points (vector magnitude counts/5-s) were used to classify each 5-s epoch as sedentary behavior, or light, moderate, or vigorous intensity activity. For each participant, minutes per hour

of MVPA and VPA were calculated and reported to correct for small differences in wear time between classes or sessions. HR data were exported and averaged every 5 seconds, and average heart rate for the entire class period and the independent HIIT session are reported. The pre-determined IHT intensity thresholds based on participants' age-predicted peak HR (HR_{peak}) for MVPA ($\geq 50\% HR_{peak}$) and VPA ($\geq 80\% HR_{peak}$) were used to determine minutes per hour of MVPA and VPA.¹⁶⁹

Program Feasibility and Acceptability

Feasibility of administering the intervention within the PE setting was assessed using a 7-item Likert-scale survey provided to the physical educator regarding confidence in ability to deliver a similar program in the future, ease of set-up, and the program's time commitment.²⁴ Three survey items were reverse-coded, and the sum of the 7 items is reported, with a higher score indicating greater program feasibility (min-max = 7 – 35). A separate item asked to what extent the physical educator plans to continue using the intervention components in PE, with responses ranging from 1 ('not at all') to 5 ('to a great extent'). To assess program acceptability, a mixed qualitative and quantitative approach was used to provide summative information regarding program satisfaction. In the week following the intervention a 9-item survey was delivered to participants to evaluate their perceptions of the program components at the beginning of PE class. They rated their agreement with each question on a 5-item Likert scale ranging from 1 ('disagree a lot' to 5 ('agree a lot'), with a higher score indicating greater program acceptability. A semi-structured interview was conducted with the physical educator post-intervention to evaluate acceptability of the program. As a post-hoc follow-up, the physical educator was asked if she perceived the INT and CON classes had similar skill acquisitions for other lesson plan components outside of the intervention.

Statistical Analysis

Descriptive statistics are reported as mean \pm SD unless noted, and data were analyzed using SPSS version 24 with significance set at $P < 0.05$ for all analyses. Participants with missing pre and/or post test data (i.e. absent from testing session) were excluded from the analysis. Differences in participant characteristics and baseline data between groups were assessed with independent samples t-tests. Separate, two-way mixed analysis of covariance (ANCOVA) was performed to assess changes in various outcome measures from baseline to post-intervention (within-subjects factor) between INT and CON (between-subjects factor) while controlling for classroom. Given that autonomy, relatedness, and competence together contribute to self-determined motivation, a multivariate ANOVA was used to assess potential intervention effects on basic needs satisfaction when controlling for classroom. Separate one-way, between-group ANCOVAs were conducted to compare differences in average class HR, minutes/hour of MVPA, and minutes/hour of VPA between INT and CON while controlling for age and sex. A sample size calculation was conducted a priori with an alpha level of 0.05 and a power of 80% and determined that a total sample size of 34 participants was required to detect a within-subject pre- to post-intervention difference of the primary outcome variable (i.e. cardiorespiratory fitness) with a moderate effect size of 0.25. Partial eta squared (η^2) values are reported as a measure of effect size for ANOVA analyses. An independent samples t-test determined mean differences in the single-item enjoyment measure between INT and CON, with effect size reported as Cohen's *d*. The qualitative data acquired from the semi-structured interview with the physical educator at post-intervention was analyzed using a thematic coding analysis with major themes reported. Inter-coder reliability between two assessors was 100% agreement for coding analysis.

RESULTS

There were no significant differences ($P>0.05$) in age or BMI percentile between INT and CON at baseline. In addition, baseline scores for all outcome measures did not differ between groups ($P>0.05$).

Changes in Cardiorespiratory and Muscular Fitness: There was a significant group by time interaction for cardiorespiratory fitness ($F(1,49) = 17.40$, $P<0.001$, $\eta^2 = 0.26$). INT increased participants' VO_{2peak} from pre- to post-intervention from 53.6 ± 6.1 to 56.9 ± 7.3 ml/kg/min, while CON exhibited a decline in VO_{2peak} . Individual VO_{2peak} responses are shown in Figure 8.1A (INT) and 8.1B (CON). The handgrip test showed significant time by group interaction ($F(1,54) = 5.67$, $P = 0.02$, $\eta^2 = 0.09$) as it increased in INT from 35.5 ± 7.3 to 37.2 ± 9.0 kg and decreased in CON from 36.2 ± 12.0 to 33.4 ± 9.0 (Figure 8.2). There was not a significant time by group interaction ($F(1,48) = 0.81$, $P = 0.37$, $\eta^2 = 0.02$) or a main effect of time ($F(1,48) = 0.25$, $P = 0.62$, $\eta^2 = 0.005$) for the number of push-ups performed (Table 9).

Change in Motor Competence: A significant main effect of time and a time by group interaction were observed for total motor competence ($F(1,41) = 5.31$, $P = 0.03$, $\eta^2 = 0.11$; $F(1,41) = 5.79$, $P = 0.02$, $\eta^2 = 0.12$, respectively). Motor competence increased from 23.7 ± 2.9 to 24.7 ± 2.1 in INT, with greater improvements observed in CON (23.1 ± 3.7 to 24.7 ± 2.3) (Figure 8.3).

Leisure-Time Physical Activity: No significant time by group interaction was evident for either the number of days participants accumulated 60 minutes of MVPA per week or for EASY survey scores ($F(1,51) = 0.61$, $P = 0.44$, $\eta^2 = 0.01$; $F(1,56) = 0.13$, $P = 0.72$, $\eta^2 = 0.002$, respectively). While there was a main effect of time for EASY scores in both INT and CON ($F(1, 56) = 4.31$, $P = 0.04$, $\eta^2 = 0.07$), there was no change in the number of days that participants accumulated 60 minutes of MVPA in either INT or CON ($F(1,51) = 1.63$, $P = 0.21$, $\eta^2 = 0.03$) (Table 9).

Enjoyment: A significant time by group interaction occurred in physical activity enjoyment following HIIT ($F(1,55) = 5.76, P = 0.02, \eta^2 = 0.10$). Relative to CON, there was a decrease in mean PACES scores at post-intervention in INT (Table 9). Mean enjoyment scores during PE assessed with the Plicker system were lower ($t(378) = -2.38, P = 0.02, d = 0.23$) in response to INT (2.8 ± 1.1) versus CON (3.1 ± 1.0).

Change in Basic Needs Satisfaction in Physical Education: Change in these variables for INT and CON are shown in Table 9. Basic needs satisfaction experienced in PE did not show an interaction ($F(3,52) = 1.37, P = 0.26, \eta^2 = 0.07$) or effect of time ($F(3,52) = 2.84, P = 0.05, \eta^2 = 0.14$). However, pre-intervention scores were high and did not change post-intervention.

Physical Activity Intrinsic Motivation: There was no significant time by group interaction observed for PA intrinsic motivation scores ($F(1,55) = 3.38, P = 0.07, \eta^2 = 0.06$). Similarly, results showed no significant change in intrinsic motivation over time ($F(1,55) = 1.21, P = 0.28, \eta^2 = 0.02$) (Table 9).

Process Evaluation

Program Reach and Dose: During the intervention, there were no noticeable adverse events or injuries observed or reported. Reach as determined from participant attendance rates was 93% for INT and CON. Dose for the intervention was 100% with all sessions delivered as intended over the 6-week period.

Fidelity of the intervention: The mean HR during HIIT was 121 ± 14 bpm and mean HR for the entire PE class was significantly higher in INT versus CON (116 ± 11 vs 110 ± 9 bpm; $P = 0.04, \eta^2 = 0.07$). Both HR and accelerometer data showed that participants in INT engaged in significantly greater amounts of MVPA during PE compared to CON (38.1 ± 7.9 vs. 32.8 ± 8.7 min/hr; $P = 0.025, \eta^2 = 0.08$; 23.4 ± 5.0 vs. 15.7 ± 4.7 min/hr; $P < 0.001, \eta^2 = 0.45$, respectively).

Further, accelerometer data supported that INT students accumulated greater amounts of VPA compared to CON (4.5 ± 2.6 vs. 2.3 ± 1.3 min/hr; $P < 0.001$, $\eta^2 = 0.27$), but this conclusion was not supported with the HR data that showed no difference between groups ($P = 0.29$, $\eta^2 = 0.02$).

Program Feasibility and Acceptability: The physical educator reported a score of 31 out of 35, demonstrating high program feasibility. Additionally, the physical educator planned to continue delivering the HIIT circuit ‘to a great extent’ (i.e. score of 5 out of 5) in the future. Participants demonstrated favorable program acceptability with a mean score of 3.6 ± 1.5 out of 5. Major themes emerging from the program acceptability interview with the physical educator following the intervention are displayed in Table 10. Lastly, the physical educator thought that both INT and CON classes had similar results in learning skills, such as circus arts, that were part of the lesson plan outside of the HIIT intervention.

DISCUSSION

The purpose of this study was to evaluate efficacy and perform a program evaluation of a fitness- and skill-based HIIT intervention delivered in an elementary school PE setting guided by SDT. The primary finding from this study was that the HIIT intervention improved children’s cardiorespiratory fitness and muscular strength to a greater extent relative to the control group. However, there were no improvements in push-up performance, leisure-time PA, basic psychological needs satisfaction, or PA intrinsic motivation following INT compared to CON. The intervention had strong fidelity, with students in INT engaging in significantly more MVPA and VPA and experiencing higher HRs during HIIT compared to CON. No students experienced injuries or adverse events during the study, supporting that it was well-received by participants. This study extends the work of previous school-based HIIT investigations by reporting multiple elements of program evaluation and demonstrating high feasibility and favorable program

satisfaction from both the students and the physical educator. Overall, our results provide preliminary evidence for the efficacy of fitness- and skill-based HIIT as a developmentally appropriate strategy to promote fitness and MVPA without compromising the psychosocial experience of PE.

A significant finding of the present study is that performing only eight sessions of fitness- and skill-based HIIT for approximately 16 minutes at the beginning of PE class resulted in greater increases in cardiorespiratory fitness and muscular strength versus traditional PE. Given that students in both INT and CON increased their leisure-time PA, the greater improvements in cardiorespiratory and muscular fitness observed in INT are more likely due to the intervention. These findings corroborate data from previous HIIT interventions that improved cardiorespiratory fitness while focusing on motor competence and muscular fitness, which are important developmental aspects of PA in childhood.^{18, 21, 82, 132} For example, Costigan et al.¹⁶ demonstrated significantly greater improvements in cardiorespiratory and muscular fitness in adolescents completing a body-weight resistance exercise HIIT program compared to aerobic-based HIIT or standard PE lessons in adolescents. A likely explanation responsible for the improvements in both cardiorespiratory and muscular fitness following INT is that children may be ‘metabolic nonspecialists’,¹⁷⁰ in that training adaptations are not specific to the metabolic demands of the exercise as seen in adults.²¹ This is supported by Faigenbaum et al.²¹ and Weston et al.⁷⁶ who demonstrated beneficial effects of non-running based HIIT programs on cardiorespiratory fitness in children²¹ and adolescents⁷⁶ when exercising at $\geq 85\%$ HR_{peak}. However, another study showed that a 6-minute, multi-joint, functional HIIT circuit improved muscular fitness but not cardiorespiratory fitness in elementary school children.¹⁷ However, the protocol duration of the HIIT protocol is an important consideration in that training volume equal

to 6-minutes may not provide an adequate stimulus to improve cardiorespiratory fitness.¹⁷

Despite our participants performing HIIT for 16-19 minutes at moderate-vigorous intensity lower than the HIIT threshold of 85% HR_{peak} , the present study produced a large effect for the increase in cardiorespiratory fitness ($d = 1.2$), comparable to the effect size reported in a meta-analysis by Costigan et al.⁵⁶ ($d = 1.05$), supporting that HIIT-structured protocols of approximately 12-30 minutes in work duration are sufficient to induce significant increases in cardiorespiratory fitness. Overall, our HIIT program allowed students to perform developmentally appropriate resistance training exercises, including medicine ball and fitness rope activities, that increased cardiorespiratory fitness and muscular strength while engaging in greater amounts of MVPA and VPA.

A novel attribute of this study was to incorporate exercises focused on developing motor competence during the active recovery periods versus implementing walking or stationary rest periods, as used in previous research.^{16, 18, 21, 82} Circus arts is one effective strategy to improve motor competence in elementary school-aged children¹³⁶ and was therefore incorporated into the active recovery periods during INT. Circus art activities were also an established component of the existing PE program. The use of circus arts during INT and CON may in part explain the improvements in motor competence observed in both groups (Figure 8.3). It is difficult to compare our findings with previous literature, since the majority of previous school-based HIIT studies did not include motor competence as an outcome, nor did they include a skill-based element during recovery. Nonetheless, Duncan et al.⁸² also demonstrated significant improvements in motor competence in 6-7 year-old children completing a 10-week integrative neuromuscular training HIIT program consisting of body-weight and agility exercises delivered during PE. Overall, our findings support that incorporating exercises such as circus arts or agility

training into both the work and rest periods of HIIT protocols may be an effective and engaging strategy to promote motor competence development during PE.

When implementing intense exercise such as HIIT into existing PE programs, it is important to focus on the quality of students' PE experiences. Therefore, we adopted the SDT as a theoretical approach, and the intervention was carefully designed to promote students' perceptions of competence, autonomy, and relatedness (i.e. basic psychological needs) in PE in order to promote leisure-time PA and PA intrinsic motivation. To our knowledge, very few school-based HIIT interventions have incorporated a theoretical approach, nor have they assessed the psychosocial impact of implementing HIIT in PE.^{16, 24} Aligning with our findings, Leahy et al.²⁴ demonstrated no time by group interaction effects for changes in intrinsic motivation or basic needs satisfaction following a fitness- and skill-based HIIT intervention in adolescents compared to usual school activities. A likely explanation for these nonsignificant findings is that at baseline, students exhibited high PA intrinsic motivation and basic psychological needs scores in both INT and CON, leading to a ceiling effect. Additionally, following INT there were no improvements in leisure-time PA relative to the control group, although one of the PA surveys showed improvement over time for both groups. Similar to our findings, Ketelhut et al.¹⁸ did not observe a change in leisure-time PA among students engaging in a 12-week multi-activity HIIT intervention relative to a control group. Nonetheless, this study contributes to the school-based HIIT literature by showing that implementing a fitness- and skill-based HIIT protocol did not negatively impact students' psychological experiences during PE, their motivation to be physically active, or their leisure-time PA. However, future research performed in PE in which students present low baseline levels of basic needs satisfaction are warranted to confirm our findings. Furthermore, our eight sessions may not have been adequate

to induce changes in PA behavior, and a follow-up assessment is warranted to observe if improvements in PA occur at a later date.

In the present study, PA enjoyment and enjoyment during PE were assessed given the role of enjoyment as a mediator of basic psychological needs satisfaction and PA intrinsic motivation.⁸⁷ Our data showed higher enjoyment in CON and a significant decrease in PACES in INT, but scores remained favorable (i.e. 30.4 on a 35-point scale). A likely explanation for this finding is that students in CON engaged in circus arts, which has been identified as an enjoyable form of PA for children, for most class periods.^{136, 171} Nonetheless, enjoyment during HIIT was similar to CON (2.8 ± 1.1 versus 3.1 ± 1.0) (both representing ‘a little’), suggesting that incorporating more intense activity into PE did not severely impact students’ enjoyment. There is a paucity of research evaluating both the effect of performing HIIT on overall PA enjoyment and enjoyment responses *during* school-based HIIT. Costigan et al¹⁶ reported favorable enjoyment scores from 15 year-old students following an 8-week body-weight resistance HIIT intervention performed 3 times per week, but they did not assess enjoyment during exercise. High enjoyment scores during body-weight resistance HIIT in young boys have been documented,¹³⁵ yet comparison with the present study is difficult considering participants performed HIIT individually and in a laboratory setting in the Ricci et al¹³⁵ study. To our knowledge, the current study was the first to use readily available technology (i.e. the Plicker magnets) to assess enjoyment during HIIT in a school-based setting. Further research using similar methodology is needed to better characterize students’ enjoyment during fitness- and skill-based HIIT.

Our data show that INT was delivered with strong fidelity, as students engaging in it resulted in higher HRs during class (116 ± 11 vs 110 ± 9 bpm) and accumulated six additional minutes/hour of MVPA and 2 minutes/hour of VPA during PE compared to CON, based on

accelerometer data. Our findings support previous research showing that incorporating non-traditional HIIT protocols into PE induce significantly higher HR responses compared to standard PE.^{16, 18} However, the mean HR observed during INT (121 ± 14 bpm) was lower than previously reported likely due to the nature of the exercises chosen, which included resistance-based activities. For example, Costigan et al¹⁶ reported mean HR of 148 and 155 bpm during an 8-minute body-weight aerobic (i.e. jumping jacks) and resistance-based HIIT (i.e. push-ups), respectively. Given that intensity and duration exhibit an inverse relationship, we chose both cardiovascular- and resistance-based exercises performed at a moderate-to-vigorous intensity for a longer duration than in previous studies (i.e. 16-19 minutes versus 8 minutes) to accommodate the wide discrepancy of fitness levels among students. Further, although INT students accumulated only 4.5 minutes/hour of VPA on average during PE, this exercise stimulus was sufficient to improve cardiorespiratory and muscular fitness. This supports that implementing small, targeted doses of VPA into existing PE programs may be an appropriate strategy to induce beneficial changes in fitness.

Overall, students displayed favorable program satisfaction towards the intervention. Responses derived from the program satisfaction survey indicated that students enjoyed completing the HIIT exercises with their friends, liked the variety of exercises they were offered, and preferred wearing the HR device as opposed to the accelerometer to monitor their activity levels. Our findings align with previous literature documenting the relationship between exercise variety and enjoyment in children,⁶⁶ suggesting that offering a variety of equipment and exercise choices during HIIT may be more appealing to students compared to traditional running-based HIIT. The physical educator also indicated favorable program satisfaction and plans to implement these exercises in future programming. Our process evaluation findings parallel those

of Leahy et al²⁴ who demonstrated favorable program satisfaction among adolescent participants and program administrators completing a self-selected fitness- and skill-based HIIT program. In addition, Costigan et al¹⁶ reported favorable enjoyment scores from participants and high feasibility scores from the HIIT program administrators who, similar to the present study, intended to incorporate HIIT into PE lessons in the future. The information collected from the interview with the physical educator expands on previous HIIT literature conducting only survey assessments for process evaluations. We gathered important insights from the physical educator interview that may provide guidance for researchers implementing similar HIIT interventions in the future, including preferred exercises and additional implementation strategies to promote student engagement displayed in Table 10. Another encouraging finding was that the physical educator expressed that students performing INT did not have diminished skills for learned components outside of the intervention, despite dedicating a significant portion of class time to fitness- and skill-based HIIT. These findings support that students can perform fitness- and skill-based HIIT to accumulate more PA without compromising their development of other important skills during PE.

Our study has several strengths and limitations that must be acknowledged. First, we adopted a theoretical approach to focus on the quality of the HIIT intervention, which is lacking from previous school-based HIIT research. Second, we assessed both health-related and psychosocial outcomes to evaluate the broader impact of incorporating HIIT into existing PE programs. Additional strengths of the current study include the assessment of enjoyment *during* HIIT, as well as the use of HR measurement that allowed students to monitor their effort during PE and the HIIT circuit. Nevertheless, there are several limitations to this investigation including that the study was conducted within one public elementary school. With only three intervention

and two control classrooms, caution is warranted when interpreting the results for this feasibility study. Furthermore, the physical educator was highly skilled and had a successful PE program prior to the study, which may have impacted students' perceptions of PE and likely improved our ability to deliver the intervention as intended. Although we assessed leisure-time PA at pre- and post-intervention and observed no group interaction, we did not evaluate PA participation outside of the intervention during the 6-weeks that may have contributed to our findings. Lastly, the use of a comprehensive assessment for motor competence beyond the five skills assessed in the present study is warranted for future work. Although we acknowledge that future, larger-scale studies are needed to confirm our findings, our results provide preliminary evidence for the health benefits of a fitness- and skill-based HIIT protocol that was perceived favorably by students and the physical educator.

Conclusions

Compared to traditional PE, implementing a fitness- and skill-based HIIT intervention into an existing PE program resulted in greater improvements in cardiorespiratory and muscular fitness and greater amounts of MVPA and VPA without compromising the quality of the PE program. Our findings extend existing school-based HIIT literature to highlight that incorporating fitness- and skill-based HIIT into PE can promote improvements in fitness without decreasing basic needs satisfaction in PE or intrinsic motivation for being physically active. Furthermore, the high program satisfaction scores and interview findings documented herein are important given that the feasibility of incorporating HIIT into school-based settings has been challenged.²² Overall, our findings exhibit that designing HIIT programs that offer a wide variety of exercise choices and intensity both in the work and recovery periods may be a successful

strategy for promoting fitness and positive psychosocial experiences during 4th and 5th grade elementary-school PE.

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Disclosures

The authors have no conflicts of interest to disclose.

APPENDIX

TABLES

Table 7. Participant characteristics at baseline (mean \pm SD).

INT = intervention classes; CON = control classes

Characteristic	Total (N=67)	INT (n=45)	CON (n=22)
Age (years)	10.5 \pm 0.9	10.5 \pm 0.9	10.5 \pm 0.9
Females/ Males (n)	42/25	30/15	12/10
4 th Grade/5 th grade (n)	32/35	19/26	13/9
Body Mass Index Percentile	51.3 \pm 28.2	51.3 \pm 27.7	51.3 \pm 30

Table 8. Stations and exercise choices for the fitness- and skill-based HIIT protocol

Station/Exercise	Sessions 1 and 2	Sessions 3 and 4	Sessions 5 and 6	Sessions 7 and 8
1. Medicine Balls (MB)	Shoulder press & catch	Single leg shoulder press & catch	Squat to partner pass	‘Choose your move’ from previous exercises
2. Active Recovery #1: 5 th grade: Long-handled circus arts manipulatives (spinning plates, flow wands, etc.) 4 th grade: Sandbag toss into target [†]				
3. Plyometrics	Hurdle run	Hurdle run w/ ball overhead	Hurdle double-leg hop	‘Choose your move’
4. Active Recovery #2: 4 th and 5 th grade: Small circus arts manipulatives (batons, yo-yo, etc.)				
5. Fitness Ropes	Standing side-to-side waves	Standing alternating waves OR double-arm slams	Jumping jacks	‘Choose your move’
6. Active Recovery #3: 5 th grade: Juggling (scarves → balls) 4 th grade: Ball throw target practice [†]				
7. Slam ball	MB squat	Alternating MB Wood chops	Overhead slams	‘Choose your move’
8. Active Recovery #4: 4 th and 5 th grade: Throw and catch activities (partner pass with ball, Ogo sport)				
9. Partner Body-weight Exercises	Push-up high-fives	Mountain climber high-fives	Burpee high-fives	‘Choose your move’
10. Active Recovery #5: 4 th and 5 th grade: Balance exercises (Spooner boards, can stilts, etc.)				

*Work interval stations 1, 3, 5, 7, 9 performed for 20 seconds for sessions 1-4 and increased to 30 seconds for sessions 5-8. Exercises are the same for 4th and 5th graders. Active recovery stations 2, 4, 6, 8, 10 performed for 30 seconds for sessions 1-8. [†]Two of the active recovery stations are different between 5th and 4th grade classes because 4th grade had yet to learn certain circus arts activities. *Note:* Participants completed 3 rounds of the 10 stations per session.

Table 9. Change in select outcome measures for intervention (INT) and control (CON) (mean SD).

Outcome	INT		CON	
	Pre	Post	Pre	Post
Fitness Measures				
Push-ups (reps)	9.3 ± 6.3	8.3 ± 6.1	9.9 ± 4.3	10.3 ± 6.9
Leisure-Time Physical Activity				
# of days (min – max = 0 - 7)	5.1 ± 2.0	4.5 ± 1.7	5.6 ± 1.9	5.9 ± 1.3
EASY survey (min - max= 0 - 98)	27.0 ± 16.6	32.5 ± 18.8*	28.2 ± 15.3	34.7 ± 15.5*
Physical Activity Enjoyment (PACES) (min-max= 0 - 35)	33.3 ± 3.3	30.4 ± 7.1 [†]	31.5 ± 4.2	32.7 ± 3.5
Basic Needs Satisfaction (min – max = 1 – 7)				
Perceptions of Autonomy	5.7 ± 1.0	5.6 ± 1.1	5.4 ± 1.0	4.9 ± 0.8
Perceptions of Competence	6.4 ± 0.7	6.3 ± 1.1	6.1 ± 1.0	6.1 ± 0.9
Perceptions of Relatedness	5.7 ± 1.4	5.6 ± 1.6	5.9 ± 1.0	5.5 ± 1.4
Total Needs Satisfaction	5.9 ± 0.7	5.8 ± 1.1	5.8 ± 0.7	5.5 ± 0.8
Intrinsic Motivation (min – max = 1-7)	6.5 ± 0.7	5.9 ± 1.2	6.3 ± 0.9	6.3 ± 1.0

*Indicates significant change from pre- to post-intervention ($P<0.05$).

[†]Indicates time by group interaction between INT and CON ($P<0.05$).

Table 10. Major themes reported from program satisfaction interview with physical educator

Overall Perceptions of HIIT Intervention	Likes	Dislikes	Future Planning Strategies
<ul style="list-style-type: none"> • Great experience for students to try new equipment • Believed intervention increased students' PA levels • HIIT circuit was not too tiring for students • Students were engaged during the HIIT circuit • 'Absolutely' wants to use the circuit equipment in the future 	<ul style="list-style-type: none"> • Novel equipment (i.e. slam balls and fitness ropes) • Progression of exercises • Equipment-based active recovery intervals 	<ul style="list-style-type: none"> • Hurdle stations (low student effort) • Small medicine balls (sometimes used inappropriately) • Juggling station (need separate lesson to become proficient) • Station preparation was a burden when other classes had different lesson plans 	<ul style="list-style-type: none"> • Continue incorporating HIIT stations for varying durations • Complete 1-2 rotations instead of 3 rotations of circuit • Incorporate levels of difficulty at each high-intensity station • Try HIIT circuit with 2nd and 3rd graders to alleviate preparation burden • Students choose 1 friend to complete stations with instead of all group members

FIGURES

Figure 7. Study flow diagram of participants during the study

**Note: primary outcome of cardiorespiratory fitness*

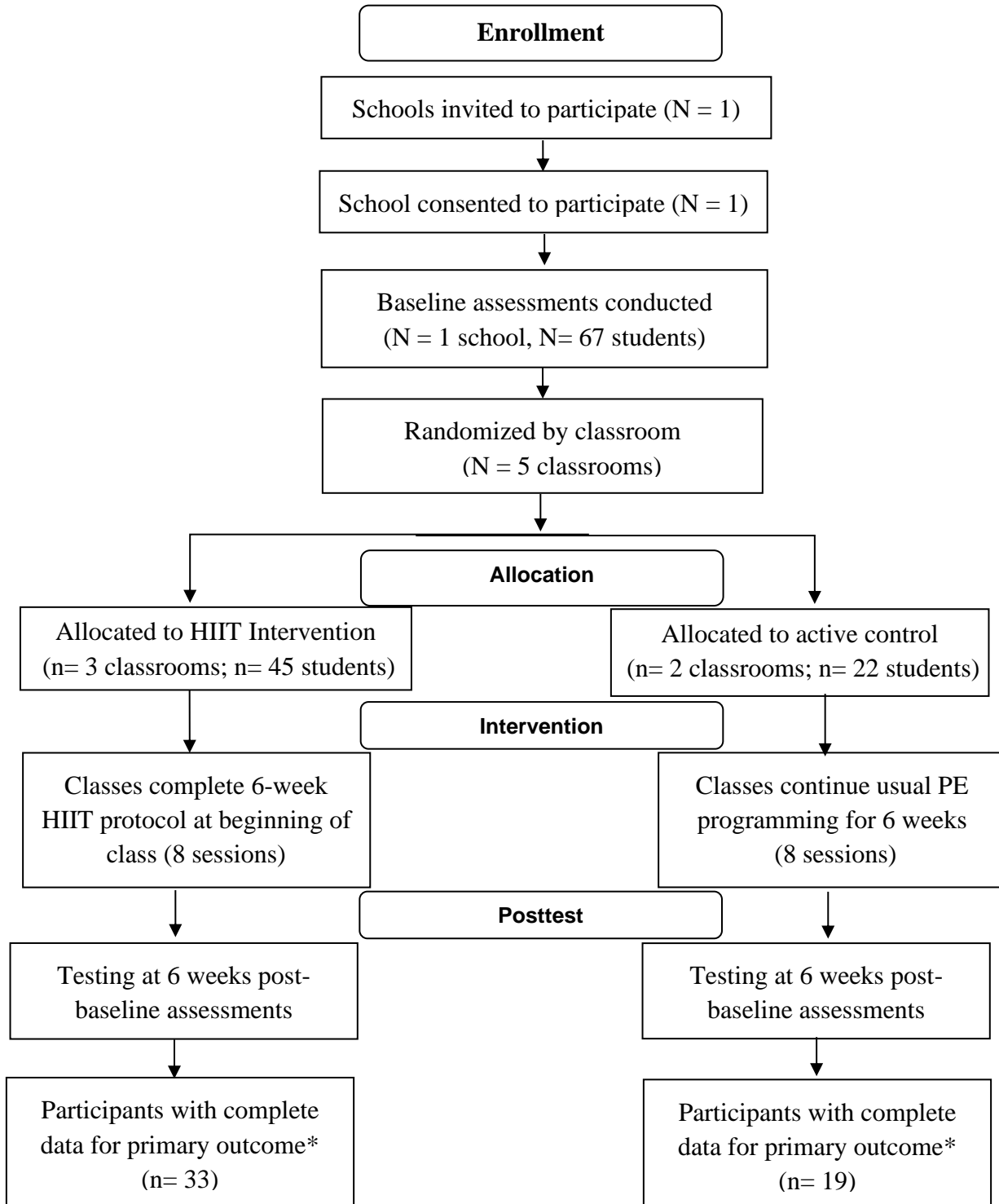


Figure 8.1. Mean \pm SD and individual changes in cardiorespiratory fitness (i.e. estimated $\text{VO}_{2\text{peak}}$) in the intervention group (A) and the control group (B) from pre- to post-intervention.

*Significant difference from pre-intervention ($P < 0.05$)

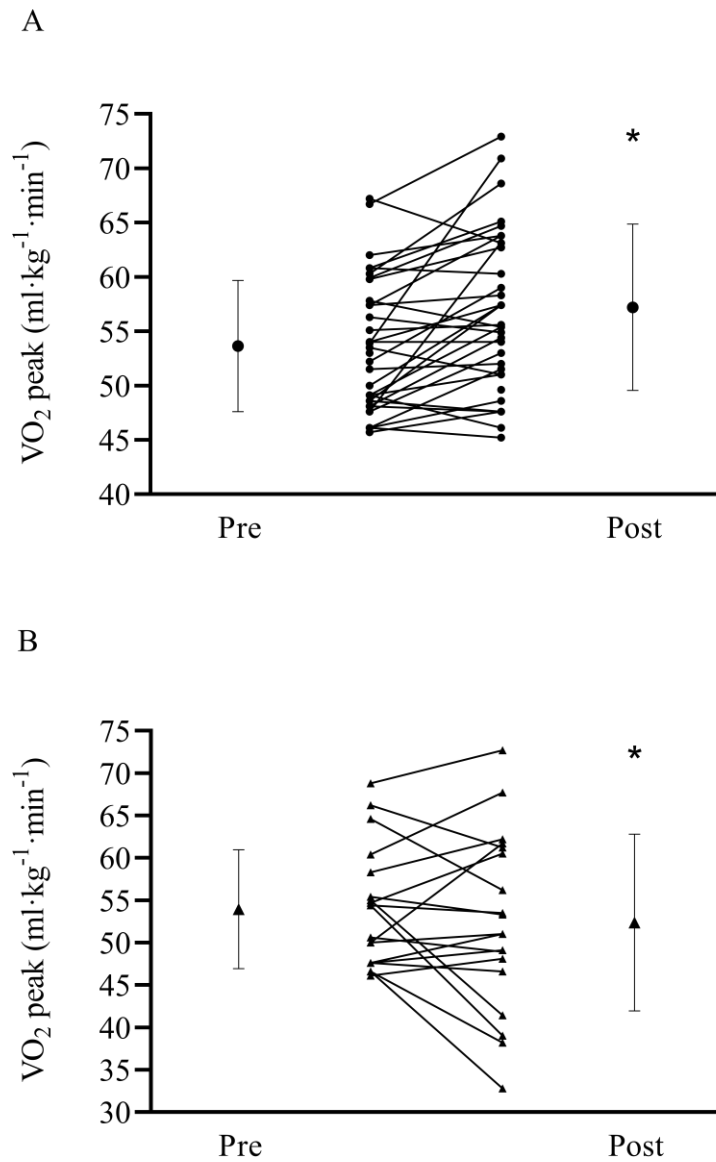


Figure 8.2. Change in handgrip strength in the intervention group and the control group. Values are mean \pm SE.

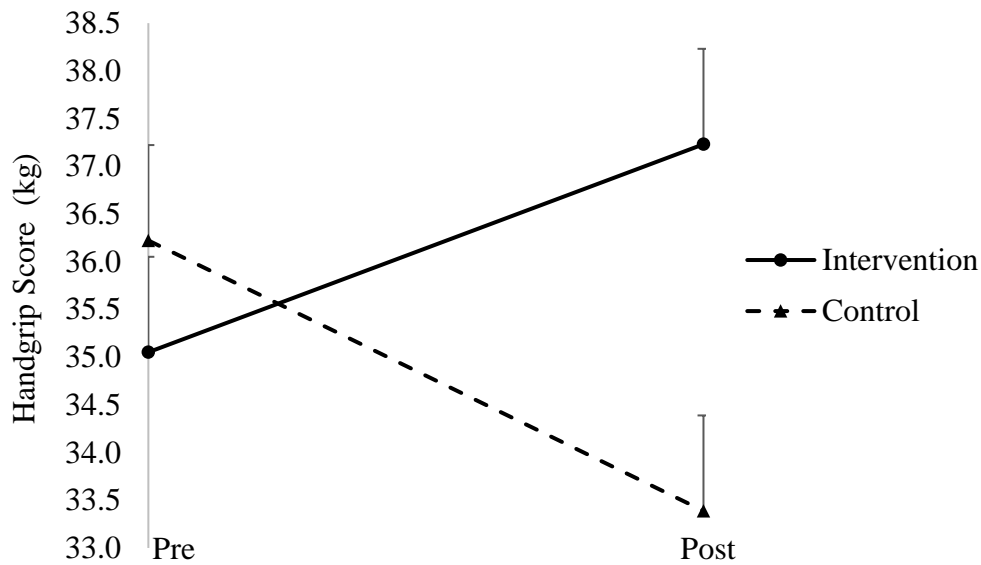
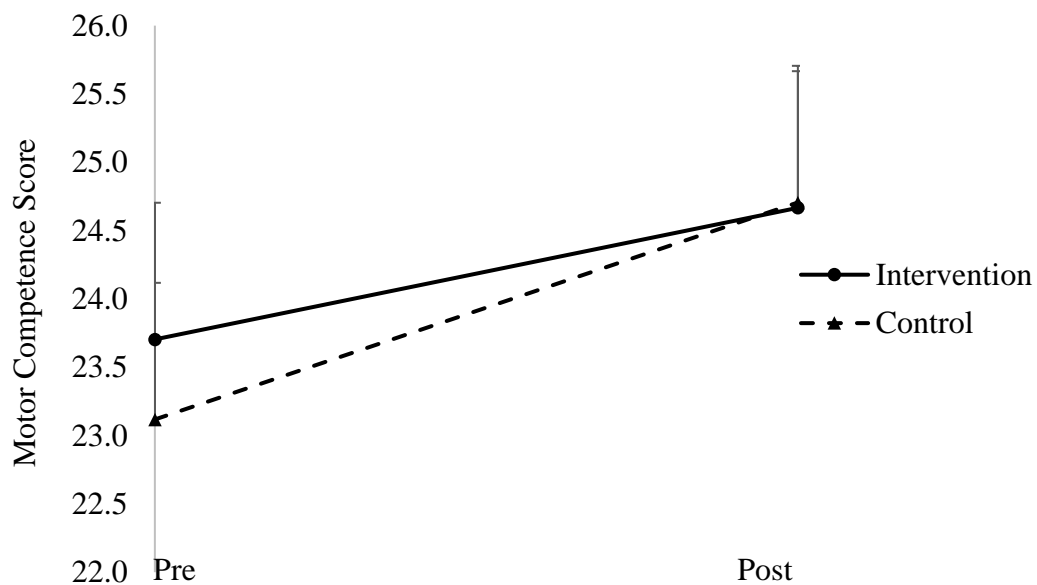


Figure 8.3. Change in motor competence in the intervention group and the control group. Values are mean \pm SE.



CHAPTER 5

Conclusion

Summary

The current dissertation addresses fitness- and skill-based high-intensity interval training (HIIT) in children. This dissertation presents original data from two laboratory-based studies and a comprehensive HIIT intervention delivered in a physical education (PE) setting. The chapters are arranged in an intentional order: the initial, acute, laboratory-based study (chapter 2), followed by a second acute, laboratory-based study (chapter 3) that also investigated group-based activity, and finally the outcomes of the intervention (chapter 4). This approach was chosen to investigate children's acute responses and perceptions to performing high-intensity interval exercise (HIE) in individual and group-based settings prior to implementing this form of exercise in an intervention setting, in that the findings from chapters 2 and 3 helped support the rationale for chapter 4. A summary and brief discussion of each chapter within the context of the dissertation and within existing literature are presented in the following text.

Chapter 2: Cardiometabolic and Perceptual Responses to Body-Weight Resistance High-Intensity Interval Exercise in Boys

The second chapter of this dissertation was a laboratory-based study investigating if body-weight resistance exercise provided a comparable cardiometabolic stimulus to treadmill-based HIE, which has been heavily documented in the literature. The outcome measures assessed during the protocols were VO_2 , HR, blood lactate concentration (BLA) and perceptual responses (i.e. affective valence, enjoyment, and perceived exertion). Results showed that both protocols were representative of HIE ($> 85\% \text{ HR}_{\text{peak}}$). Also, both protocols demonstrated favorable perceptual responses that did not differ between protocols, and affective valence and enjoyment remained positive during and after exercise for the majority of participants. The

results from chapter 2 support that body-weight resistance exercise focused on both cardiorespiratory and muscular fitness is representative of HIIE and may be a feasible alternative to treadmill-based HIIE in boys. Although our findings are encouraging, it is crucial to identify HIIE protocols that are appropriate for children with various fitness levels and PA experience. Therefore, an important future research direction is to characterize the cardiometabolic and perceptual responses to fitness- and skill-based HIIE in unfit or obese children.

High-intensity interval training (HIIT) may be an effective strategy for children to attain VPA and improve health outcomes.⁵ Much of the previous literature investigated acute responses to treadmill- or cycling-based HIIE, which cannot be implemented in school or youth sport settings and does not provide additional important aspects of PA including muscular fitness and motor competence development.^{5,47} Therefore, fitness- and skill-based HIIT, such as sport drills or body-weight exercises, may be a more developmentally appropriate form of exercise to promote VPA in children. With only a few studies investigating the acute responses to this form of exercise, none of which included perceptual assessments,^{11,12,15} the exact cardiometabolic and perceptual responses to fitness- and skill-based HIIE in children remain unclear. Therefore, chapter 2 of this dissertation addressed this gap in the literature by comprehensively characterizing the acute VO₂, HR, and BLa responses to body-weight resistance exercise in boys to determine if this form of exercise provides a vigorous cardiometabolic stimulus that may induce chronic adaptations when performed repeatedly. To our knowledge, this is the first study that measured children's perceptual responses to a fitness- and skill-based HIIE protocol. Assessment of children's enjoyment and affect (i.e. mood state) during acute bouts of HIIE are key because these factors influence future PA participation and adherence. Our results provide

preliminary evidence that body-weight resistance exercise is an enjoyable form of HIIIE that may be implemented in future interventions to promote PA participation.

Chapter 3: Acute Cardiometabolic and Perceptual Responses to Individual and Group-Based Body-weight Resistance Exercise in Girls

The third chapter of this dissertation is a continuation of chapter 2 and presents girls' acute cardiometabolic and perceptual responses to body-weight resistance exercise performed in an individual and group-based setting. The outcome measures were identical to those presented in chapter 2, with the addition of blood pressure (BP) assessments to determine the cardiovascular strain provided by the HIIIE protocols. To build upon the findings presented in chapter 2, following the individual exercise protocols, girls performed the body-weight resistance exercise circuit in a small group setting to determine if HR or perceptual responses differed among conditions. Results were comparable to those presented in chapter 2, yet in girls mean HR was highest in response to group-based HIIIE. Despite the high-intensity nature of our body-weight resistance exercise circuit, similar to the findings in chapter 2, affective valence or exercise enjoyment did not decline during any exercise condition for the majority of girls and did not differ among protocols.

All existing acute laboratory-based HIIIE research has assessed responses to children performing individual exercise,^{11,12,15} yet children rarely exercise on their own. To our knowledge, this was the first study characterize girls' HR and perceptual responses to group-based HIIIE. The results from chapter 3 contribute substantially to our understanding of children's responses to HIIIE given that previous work regarding individually performed exercise may not translate to PA intervention settings. For example, children may be more motivated to exercise in a group setting opposed to on their own,^{26,67} which would likely translate to achieving

a higher exercise intensity and higher levels of enjoyment during group-based HIIE compared to previously reported data for individually performed HIIE. Using a novel assessment technique for perceptual scales and a team-based HR monitoring system, we demonstrated results that support this hypothesis. Specifically, small group-based HIIE provided a greater dose of VPA compared to individually performed HIIE without negatively influencing participant's enjoyment or affect during exercise. However, given that enjoyment or affect responses did not differ between individual or group-based HIIE, it was important to take an additional step to determine which exercise condition participants preferred and their overall perceptions to this form of HIIE. To accomplish this, semi-structured interviews were conducted with each participant following group-based HIIE. Our interview data are the first to provide a qualitative explanation for perceptual scale results that have been documented previously in this dissertation and elsewhere.^{27,74} Although the exercises and the work : recovery ratios included in the present study may need to be modified to accommodate for a wide range of fitness levels among children, results from the interviews provide preliminary evidence for implementing similar HIIE protocols in group settings such as PE.

Overall, findings from chapters 2 and 3 support that body-weight resistance exercise may be a feasible and enjoyable mode of HIIE that can be implemented in PE settings, thus providing the rationale for chapter 4.

Chapter 4: Efficacy and Program Evaluation of a Fitness and Skill-Based High-Intensity Interval Training (HIIT) Program in Elementary School Physical Education

Chapter 4 of this dissertation presents the efficacy, feasibility, and program evaluation of an intervention targeting physical and psychosocial health outcomes through a fitness- and skill-

based HIIT program. This intervention was delivered during PE, with five 4th and 5th grade classrooms at one school randomized to intervention (n= 3 classes) or control (n= 2) groups. Participants in the control group engaged in normal PE activities. Participants in the intervention group completed a 15-18-minute fitness- and skill-based HIIT circuit protocol at the beginning of PE. Over the six-week intervention period, this pretest-posttest randomized controlled study aimed to promote physical fitness, motor competence, PA behavior in PE, leisure-time PA, PA motivation, and basic psychological needs satisfaction during PE through a HIIT intervention that was guided by the Self Determination Theory (SDT).⁸⁸ Results indicate that the intervention group showed significant improvements in cardiorespiratory fitness, muscular strength, and motor competence, and engaged in greater amounts of MVPA during PE relative to the control group. There were no intervention effects for students' perceptions of autonomy, relatedness, and competence during PE or PA intrinsic motivation, all of which were high prior to the intervention and remained favorable after the intervention. Additionally, this intervention demonstrated favorable program satisfaction among students and the physical educator.

This interdisciplinary study contributes to the existing body of HIIT literature that focuses mainly on physical health outcomes and fail to adopt a theoretical approach to their intervention.¹⁷⁻²⁰ Our findings presented in chapter 4 provide support for the implementation of fitness- and skill-based HIIT protocols guided by the SDT as a strategy for students to increase their PA levels and intensity during PE, without compromising their perceptions of PE, PA behavior, or PA motivation. Even if focusing on physical health outcomes, future HIIT interventions should adopt a theoretical approach with the goal of positively influencing PA behavior outside of the intervention. This is especially important in the youth population, who are beginning to establish autonomous behavioral patterns that continue into young adulthood.

Our findings contribute to the HIIT intervention field by demonstrating that adopting a theoretical approach and assessing psychosocial outcomes contributes to a successful intervention and provides context to the broader impact of incorporating HIIT into PE. Our findings providing support for the SDT as a strong theoretical framework that can be adopted in future HIIT interventions as a means to promote both physical and psychosocial health in children.²⁴

This HIIT intervention was the first to assess students' enjoyment during exercise, which may be a stronger predictor of PA participation compared to pre- and post-assessments as done previously.^{16,126} Using novel technology (i.e. the Plicker magnet system) we were able to collect data on children's enjoyment during HIIT in real-time within a large group setting. These results provide a depth to our understanding of how children perceive HIIT and can inform future intervention work in this area. For example, in chapters 2 and 3, we demonstrated high enjoyment scores during body-weight resistance HIIE in active boys and girls. However, student enjoyment scores during our HIIT intervention were lower than in control classrooms, although the program was perceived favorably and had no apparent negative psychosocial consequences. It is likely that although the exercises changed throughout the intervention to provide variety and thus promote enjoyment,⁶⁶ performing the circuit at the beginning of every PE class for six weeks as opposed to less frequently may have led to the lower enjoyment scores in the intervention group. Therefore, an interesting future research direction may be to establish the minimal dose of HIIE required to induce beneficial adaptations in a PE setting, whether it be a shorter protocol duration or the same protocol performed less frequently, while maintaining student engagement.

The majority of previous HIIT interventions conducting a program evaluation report only quantitative results,^{16,24} while this study adds to this body of literature by reporting both survey and qualitative results regarding the students' and the physical educator's acceptability of the intervention. The positive program satisfaction scores from students align with the physical educator's plan to use the included equipment and station format in the future. Although these results are encouraging, our findings need to be replicated in PE programs that are less advanced and have physical educators with lower engagement as the one in the present study, which may make implementation more challenging. Further, the semi-structured interview with the physical educator revealed noteworthy practical implications. For example, the physical educator liked the equipment used (i.e. slam balls, fitness ropes), the progression of exercises, and the implementation of equipment-based active recovery intervals focused on motor competence. This provides support and guidance for researchers and practitioners who may wish to incorporate exercises within active recovery intervals as opposed to walking or stationary rest periods as more commonly done.^{5,17} In conclusion, the findings presented in chapter 4 support the use of fitness- and skill-based HIIT as a strategy to promote PA behavior and physical fitness without compromising the psychosocial experiences students feel during PE.

Implications and Future Directions

Performing preliminary acute laboratory-based studies successfully translated to an effective intervention

We performed acute laboratory-based studies in chapters 2 and 3 to determine the exercise stimulus provided by body-weight resistance exercise, which contributed to our successful HIIT intervention. For example, in these acute studies we gained an

understanding that body-weight resistance exercise provided a greater dose of VPA compared to treadmill running. Thus, there was preliminary evidence for our hypothesis that if delivered in an intervention setting, HIIT would improve cardiorespiratory fitness attendant with participation in VPA. However, given that our body-weight resistance exercise protocols were near-maximal for the entire protocol duration, the HIIT intervention protocol in the PE study included various exercises and equipment in addition to body-weight exercises to accommodate for a wide range of PA experience and fitness levels among students (see Table 7; chapter 4). An additional rationale for this decision was to provide participants with a greater variety, which has been associated to higher levels of exercise enjoyment in children.⁶⁶ Another valuable insight we gained from Chapter 3 that informed our intervention design is that girls worked harder and enjoyed exercising more in a small group setting. Thus, the PE intervention involved students performing HIIT in small groups with their peers as opposed to one large group, which likely contributed to the favorable program satisfaction experienced by the students after the intervention.

It is likely that HIIT research will continue to expand beyond running-based protocols to include a variety of creative exercise modalities. This dissertation highlights the need for future work to perform diligent acute-based studies to characterize children's cardiometabolic and perceptual responses to the exercise prior to implementing it in an intervention setting to better support their hypothesized intervention effects. For example, the acute portion of this dissertation utilized a 30:30s work:recovery ratio and performed two sets of 4 exercises, which may or may not be the most optimal protocol. In the second acute study, we provided girls with a target repetition range for the second set of

exercises based on their performance in the first set, which may have contributed to a higher HR and greater work effort. This is one advantage of utilizing protocols with two sets of the same exercises, as opposed to a protocol with all different exercises. However, future acute testing should examine responses to fitness- and skill-based HIIT of varying work:recovery ratios and protocol length, especially 15:15s for 5-10 minute protocols since this closely emulates children's habitual movement patterns. Once protocol durations are established, further studies are needed to determine an appropriate length for HIIT interventions (i.e. 6 weeks vs. 8 weeks, etc.) that elicit health benefits and sustain participant engagement. Also, resistance training has been advocated as a suitable alternative to running exercise in obese populations, and more work is needed to characterize acute responses to equipment-based HIIT protocols (i.e. medicine balls, fitness ropes) in overweight/unfit children since this has only been done in fit children previously.

Interdisciplinary work is encouraged for fitness- and skill-based HIIT research

Given that students' perceptions during PE influence their PA behaviors outside of the school environment, the type of activities in which students engage during PE have the likelihood to influence leisure-time PA behavior.^{87,88} Therefore, when performing acute- or intervention-based HIIT research, it is essential to perform interdisciplinary work to assess both the physiological and psychosocial consequences of performing such exercise. By adopting this interdisciplinary approach, we were able to design a fitness- and skill-based HIIT intervention that improved students' physical fitness and increased their amount of PA during PE, without inducing negative perceptions towards PE or

decreasing their leisure-time PA participation. If future work also adopts this approach, we may gather a larger body of evidence that refutes the previous claim and preconceived notions that implementing HIIT within the school context is unsafe and infeasible.²²

In addition to the Self-Determination Theory (SDT), future HIIT research should investigate other frameworks

As mentioned previously, our HIIT intervention was grounded in the SDT and was strategically designed to promote students' perceptions of competence, autonomy, and relatedness (i.e. basic needs satisfaction) during PE as well as leisure-time PA behavior. The relational component of the SDT was also addressed in Chapter 3, where performing HIIT with peers was preferred over individual exercise. Although our intervention did not result in significant improvements in students' basic needs satisfaction, it did improve students' leisure-time PA behavior and actual motor competence. A likely explanation for our null findings is that participants demonstrated strong fulfillment of their basic psychological needs during PE and intrinsic PA motivation prior to the start of the intervention, resulting in a ceiling effect. Therefore, an important future research direction is to implement similar HIIT interventions in PE programs where students present unfavorable basic needs satisfaction in PE at study onset. This would permit additional research questions to be addressed, including if fitness- and skill-based HIIT guided by the SDT is more effective and appropriate for improving both physiological and psychosocial outcomes in this population. Aside from further testing of the suitability of the SDT in fitness- and skill-based HIIT research, there may be other theoretical frameworks that may elicit more salient changes. One such theory that has been applied

to promote positive psychosocial experiences in PE is the AGT.^{172,173} This theory focuses on creating a task-oriented mastery climate to promote perceptions of competence.¹⁷² Core to the AGT is promoting a supportive learning environment where effort is important for improvement, which could provide a framework for future HIIT interventions, especially those that are teacher-facilitated. For example, similar to the work in this dissertation, the physical educator could focus on skill development during fitness- and skill-based work and recovery stations and have students participate in small groups, as opposed to running-based HIIT that is often performed in a large group setting during PE. These practices would help mitigate normative comparisons among students, a component of the maladaptive performance climate of the AGT, and in turn may promote students' perceptions of competence and positive motivational outcomes.^{172,173}

Fitness- and skill-based HIIT was well-accepted by children and the physical educator

Although there is a large body of literature on school-based HIIT interventions, little is known regarding children's perceptions of HIIT and how embedding HIIT into existing PE programs may influence learning objective achievement. While in Chapter 3 we demonstrated that girls would be willing to try fitness- and skill-based HIIT during PE, it was important to design the HIIT intervention based on the physical educator's learning objectives. While previous HIIT research reported favorable program satisfaction survey data that align with our findings,^{16,24} we also demonstrated that incorporating HIIT into PE increased students' PA and still showed ability to reach the same learning objectives as the classrooms that did not participate in HIIT. While we came to this conclusion qualitatively following the intervention, it would be important for future research to

quantitatively assess if incorporating fitness- and skill-based HIIT into PE affects students' ability to achieve all learning outcomes/skill development. Overall, designing our fitness- and skill-based HIIT protocol in collaboration with the physical educator likely contributed to favorable program satisfaction among students and the physical educator, and similar processes should be conducted in future work to promote program sustainability.

Dissertation Strengths and Limitations

Despite our encouraging findings from the acute and intervention studies, there are several limitations and strengths to this dissertation. First, the acute studies utilized recreationally active boys and girls that ranged from healthy to overweight. Therefore, future studies examining the acute responses to HIIT in various populations, including sedentary children, obese children, and various age groups, are warranted. Second, the intervention study was conducted in one school that involved a highly skilled physical educator with a successful physical education program. Therefore, caution must be warranted when interpreting the results of these feasibility studies. Despite these limitations, all three of these dissertation studies took an interdisciplinary approach and contributed both acute and chronic perceptual and psychosocial data that was previously lacking from the field of children's HIIT research. Further, we gained a deeper understanding of children's acute responses to fitness- and skill-based HIIT by assessing blood lactate concentration and blood pressure during circuit- and treadmill-based HIIT and heart rate during group-based HIIT, as presented in chapters 2 and 3.

Conclusion

Previous HIIT research tends to focus on the intensity of PA achieved and/or physical health outcomes and not the quality of students' psychosocial experiences. This dissertation suggests that fitness- and skill-based HIIT, including body-weight resistance exercise, is one strategy to promote the amount and intensity of PA without compromising children's exercise enjoyment or perceptions towards PA. As supported by this dissertation, future HIIT interventions may use the SDT as a framework to promote improvements in both physical fitness and maintain positive psychosocial experiences within the PE context.

APPENDICES

Appendix A: IRB Approval Letters

Chapters 2 and 3

MICHIGAN STATE UNIVERSITY

Modification APPROVAL Pre-2018 Common Rule

April 15, 2019

To: Karin Allor Pfeiffer

Re: **MSU Study ID:** STUDY00000486
IRB: Biomedical and Health Institutional Review Board (BIRB)
Principal Investigator: Karin Allor Pfeiffer
Category: Expedited 4, 7
Submission: Modification MOD00001560
Submission Approval Date: 4/15/2019
Effective Date: 4/15/2019
Study Expiration Date: 3/10/2020

Title: Acute Physiological and Perceptual Responses to Different High-Intensity Interval Exercise in Young Girls



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This submission has been approved by the Michigan State University (MSU) BIRB. The submission was reviewed by the Institutional Review Board (IRB) through the Non-Committee Review procedure. The IRB has found that this study protects the rights and welfare of human subjects and meets the requirements of MSU's Federal Wide Assurance (FWA00004556) and the federal regulations for the protection of human subjects in research (e.g., pre-2018 45 CFR 46, 28 CFR 46, 21 CFR 50, 56, other applicable regulations).

This modification included changes to design, assent/consent, new and revised study instruments.

How to Access Final Documents

To access the study's final materials, including those approved by the IRB such as consent forms, recruitment materials, and the approved protocol, if applicable, please log into the Click™ Research Compliance System, open the study's workspace, and view the "Documents" tab. To obtain consent form(s) stamped with the IRB watermark, select the "Final" PDF version of your consent form(s) as applicable in the "Documents" tab. Please note that the consent form(s) stamped with the IRB watermark must typically be used.

Continuing Review: IRB approval is valid until the expiration date listed above. If the research continues to involve human subjects, you must submit a Continuing Review request at least one month before expiration.

Modifications: Any proposed change or modification with certain limited exceptions discussed below must be reviewed and approved by the IRB prior to implementation of the change. Please submit a Modification request to have the

changes reviewed. If changes are made at the time of continuing review, please submit a Modification and Continuing Review request.

New Funding: If new external funding is obtained to support this study, a Modification request must be submitted for IRB review and approval before new funds can be spent on human research activities, as the new funding source may have additional or different requirements.

Immediate Change to Eliminate a Hazard: When an immediate change in a research protocol is necessary to eliminate a hazard to subjects, the proposed change need not be reviewed by the IRB prior to its implementation. In such situations, however, investigators must report the change in protocol to the IRB immediately thereafter.

Reportable Events: Certain events require reporting to the IRB. These include:

- Potential unanticipated problems that may involve risks to subjects or others
- Potential noncompliance
- Subject complaints
- Protocol deviations or violations
- Unapproved change in protocol to eliminate a hazard to subjects
- Premature suspension or termination of research
- Audit or inspection by a federal or state agency
- New potential conflict of interest of a study team member
- Written reports of study monitors
- Emergency use of investigational drugs or devices
- Any activities or circumstances that affect the rights and welfare of research subjects
- Any information that could increase the risk to subjects

Please report new information through the study's workspace and contact the IRB office with any urgent events. Please visit the Human Research Protection Program (HRPP) website to obtain more information, including reporting timelines.

Personnel Changes: Key study personnel must be listed on the MSU IRB application for expedited and full board studies and any changes to key study personnel must be submitted as modifications. Although only key study personnel need to be listed on a non-exempt application, all other individuals engaged in human subject research activities must receive and maintain current human subject training, must disclose conflict of interest, and are subject to MSU HRPP requirements. It is the responsibility of the Principal Investigator (PI) to maintain oversight over all study personnel and to assure and to maintain appropriate tracking that these requirements are met (e.g. documentation of training completion, conflict of interest). When non-MSU personnel are engaged in human research, there are additional requirements. See HRPP Manual Section 4-10, Designation as Key Project Personnel on Non-Exempt IRB Projects for more information.

Prisoner Research: If a human subject involved in ongoing research becomes a prisoner during the course of the study and the relevant research proposal was not reviewed and approved by the IRB in accordance with the requirements for research involving prisoners under subpart C of 45 CFR part 46, the investigator must promptly notify the IRB.

Site Visits: The MSU HRPP Compliance office conducts post approval site visits for certain IRB approved studies. If the study is selected for a site visit, you will be contacted by the HRPP Compliance office to schedule the site visit.

For Studies that Involve Consent, Parental Permission, or Assent Form(s):

Use of IRB Approved Form: Investigators must use the form(s) approved by the IRB and must typically use the form with the IRB watermark.

Copy Provided to Subjects: A copy of the form(s) must be provided to the individual signing the form. In some instances, that individual must be provided with a copy of the signed form (e.g. studies following ICH-GCP E6 requirements). Assent forms should be provided as required by the IRB.

Record Retention: All records relating to the research must be appropriately managed and retained. This includes records under the investigator's control, such as the informed consent document. Investigators must retain copies of signed forms or oral consent records (e.g., logs). Investigators must retain all pages of the form, not just the signature page. Investigators may not attempt to de-identify the form; it must be retained with all original information. The PI must maintain these records for a minimum of three years after the IRB has closed the research and a longer retention period may be required by law, contract, funding agency, university requirement or other requirements for certain studies, such as those that are sponsored or FDA regulated research. See HRPP Manual Section 4-7-A, Recordkeeping for Investigators, for more information.

Closure: If the research activities no longer involve human subjects, please submit a Continuing Review request, through which study closure may be requested. Human subject research activities are complete if there is no further interactions or interventions with human subjects and/or no further analysis of identifiable private information.

For More Information: See the HRPP Manual (available at hrpp.msu.edu).

Contact Information: If we can be of further assistance or if you have questions, please contact us at 517-355-2180 or via email at IRB@msu.edu. Please visit hrpp.msu.edu to access the HRPP Manual, templates, etc.

Expedited Category. Please see the appropriate research category below for the full regulatory text.

Expedited 1. Clinical studies of drugs and medical devices only when condition (a) or (b) is met.

- (a) Research on drugs for which an investigational new drug application (21 CFR Part 312) is not required. (Note: Research on marketed drugs that significantly increases the risks or decreases the acceptability of the risks associated with the use of the product is not eligible for expedited review.)
- (b) Research on medical devices for which (i) an investigational device exemption application (21 CFR Part 812) is not required; or (ii) the medical device is cleared/approved for marketing and the medical device is being used in accordance with its cleared/approved labeling.

Expedited 2. Collection of blood samples by finger stick, heel stick, ear stick, or venipuncture as follows:

- (a) from healthy, nonpregnant adults who weigh at least 110 pounds. For these subjects, the amounts drawn may not exceed 550 ml in an 8 week period and collection may not occur more frequently than 2 times per week; or
- (b) from other adults and children, considering the age, weight, and health of the subjects, the collection procedure, the amount of blood to be collected, and the frequency with which it will be collected. For these subjects, the amount drawn may not exceed the lesser of 50 ml or 3 ml per kg in an 8 week period and collection may not occur more frequently than 2 times per week.

Expedited 3. Prospective collection of biological specimens for research purposes by noninvasive means.

Examples: (a) hair and nail clippings in a nondisfiguring manner; (b) deciduous teeth at time of exfoliation or if routine patient care indicates a need for extraction; (c) permanent teeth if routine patient care indicates a need for extraction; (d) excreta and external secretions (including sweat); (e) uncannulated saliva collected either in an unstimulated fashion or stimulated by chewing gumbase or wax or by applying a dilute citric solution to the tongue; (f) placenta removed at delivery; (g) amniotic fluid obtained at the time of rupture of the membrane prior to or during labor; (h) supra- and subgingival dental plaque and calculus, provided the collection procedure is not more invasive than routine prophylactic scaling of the teeth and the process is accomplished in accordance with accepted prophylactic techniques; (i) mucosal and skin cells collected by buccal scraping or swab, skin swab, or mouth washings; (j) sputum collected after saline mist nebulization.

Expedited 4. Collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing. (Studies intended to evaluate the safety and effectiveness of the medical device are not generally eligible for expedited review, including studies of cleared medical devices for new indications.) Examples: (a) physical sensors that are applied either to the surface of the body or at a distance and do not involve input of significant amounts of energy into the subject or an invasion of the subject's privacy; (b) weighing or testing sensory acuity; (c) magnetic resonance imaging; (d) electrocardiography, electroencephalography, thermography, detection of naturally occurring radioactivity, electroretinography, ultrasound, diagnostic infrared imaging, doppler blood flow, and echocardiography; (e) moderate exercise, muscular strength

testing, body composition assessment, and flexibility testing where appropriate given the age, weight, and health of the individual.

Expedited 5. Research involving materials (data, documents, records, or specimens) that have been collected, or will be collected solely for nonresearch purposes (such as medical treatment or diagnosis). (NOTE: Some research in this category may be exempt from the HHS regulations for the protection of human subjects. 45 CFR 46.101(b)(4). This listing refers only to research that is not exempt.)

Expedited 6. Collection of data from voice, video, digital, or image recordings made for research purposes.

Expedited 7. Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies. (NOTE: Some research in this category may be exempt from the HHS regulations for the protection of human subjects. 45 CFR 46.101(b)(2) and (b)(3). This listing refers only to research that is not exempt.)

Expedited 8. Continuing review of research previously approved by the convened IRB as follows:

- (a) where (i) the research is permanently closed to the enrollment of new subjects; (ii) all subjects have completed all research-related interventions; and (iii) the research remains active only for long-term follow-up of subjects; or
- (b) where no subjects have been enrolled and no additional risks have been identified; or
- (c) where the remaining research activities are limited to data analysis.

Expedited 9. Continuing review of research, not conducted under an investigational new drug application or investigational device exemption where categories two (2) through eight (8) do not apply but the IRB has determined and documented at a convened meeting that the research involves no greater than minimal risk and no additional risks have been identified.

Chapter 4

MICHIGAN STATE UNIVERSITY

EXEMPT DETERMINATION Revised Common Rule

October 4, 2019

To: Karin Allor Pfeiffer

Re: **MSU Study ID:** STUDY00003099
Principal Investigator: Karin Allor Pfeiffer
Category: Exempt 1
Exempt Determination Date: 10/4/2019
Limited IRB Review: Not Required.

Title: Feasibility and Efficacy of an 8-week Fitness and Skill-based Fundamental Integrative Training Program in Elementary School Physical Education

This study has been determined to be exempt under 45 CFR 46.104(d) 1.

Principal Investigator (PI) Responsibilities: The PI assumes the responsibilities for the protection of human subjects in this study as outlined in Human Research Protection Program (HRPP) Manual Section 8-1, Exemptions.

Continuing Review: Exempt studies do not need to be renewed.

Modifications: In general, investigators are not required to submit changes to the Michigan State University (MSU) Institutional Review Board (IRB) once a research study is designated as exempt as long as those changes do not affect the exempt category or criteria for exempt determination (changing from exempt status to expedited or full review, changing exempt category) or that may substantially change the focus of the research study such as a change in hypothesis or study design. See HRPP Manual Section 8-1, Exemptions, for examples. If the study is modified to add additional sites for the research, please note that you may not begin the research at those sites until you receive the appropriate approvals/permissions from the sites.

Please contact the HRPP office if you have any questions about whether a change must be submitted for IRB review and approval.

New Funding: If new external funding is obtained for an active study that had been determined exempt, a new initial IRB submission will be required, with limited exceptions. If you are unsure if a new initial IRB submission is required, contact the HRPP office. IRB review of the new submission must be completed before new funds can be spent on human research activities, as the new funding source may have additional or different requirements.



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MSU is an affirmative-action,
equal-opportunity employer

Reportable Events: If issues should arise during the conduct of the research, such as unanticipated problems that may involve risks to subjects or others, or any problem that may increase the risk to the human subjects and change the category of review, notify the IRB office promptly. Any complaints from participants that may change the level of review from exempt to expedited or full review must be reported to the IRB. Please report new information through the study's workspace and contact the IRB office with any urgent events. Please visit the Human Research Protection Program (HRPP) website to obtain more information, including reporting timelines.

Personnel Changes: After determination of the exempt status, the PI is responsible for maintaining records of personnel changes and appropriate training. The PI is not required to notify the IRB of personnel changes on exempt research. However, he or she may wish to submit personnel changes to the IRB for recordkeeping purposes (e.g. communication with the Graduate School) and may submit such requests by submitting a Modification request. If there is a change in PI, the new PI must confirm acceptance of the PI Assurance form and the previous PI must submit the Supplemental Form to Change the Principal Investigator with the Modification request (available at hrpp.msu.edu).

Closure: Investigators are not required to notify the IRB when the research study can be closed. However, the PI can choose to notify the IRB when the study can be closed and is especially recommended when the PI leaves the university. Closure indicates that research activities with human subjects are no longer ongoing, have stopped, and are complete. Human research activities are complete when investigators are no longer obtaining information or biospecimens about a living person through interaction or intervention with the individual, obtaining identifiable private information or identifiable biospecimens about a living person, and/or using, studying, analyzing, or generating identifiable private information or identifiable biospecimens about a living person.

For More Information: See HRPP Manual, including Section 8-1, Exemptions (available at hrpp.msu.edu).

Contact Information: If we can be of further assistance or if you have questions, please contact us at 517-355-2180 or via email at IRB@msu.edu. Please visit hrpp.msu.edu to access the HRPP Manual, templates, etc.

Exemption Category. The full regulatory text from 45 CFR 46.104(d) for the exempt research categories is included below.¹²³⁴

Exempt 1. Research, conducted in established or commonly accepted educational settings, that specifically involves normal educational practices that are not likely to adversely impact students' opportunity to learn required educational content or the assessment of educators who provide instruction. This includes most research on regular and special education instructional strategies, and research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

Exempt 2. Research that only includes interactions involving educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior (including visual or auditory recording) if at least one of the following criteria is met:

- (i) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained, directly or through identifiers linked to the subjects;
- (ii) Any disclosure of the human subjects' responses outside the research would not reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation; or
- (iii) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects can readily be ascertained, directly or through identifiers linked to the subjects, and an IRB conducts a limited IRB review to make the determination required by 45 CFR 46.111(a)(7).

Exempt 3. (i) Research involving benign behavioral interventions in conjunction with the collection of information from an adult subject through verbal or written responses (including data entry) or audiovisual recording if the subject prospectively agrees to the intervention and information collection and at least one of the following criteria is met:

- (A) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained, directly or through identifiers linked to the subjects;
- (B) Any disclosure of the human subjects' responses outside the research would not reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation; or
- (C) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects can readily be ascertained, directly or through identifiers linked to the subjects, and an IRB conducts a limited IRB review to make the determination required by 45 CFR 46.111(a)(7).

(ii) For the purpose of this provision, benign behavioral interventions are brief in duration, harmless, painless, not physically invasive, not likely to have a significant adverse lasting impact on the subjects, and the investigator has no reason to think the subjects will find the interventions offensive or embarrassing. Provided all such criteria are met, examples of such benign behavioral interventions would include having the subjects play an online game, having them solve puzzles under various noise conditions, or having them decide how

to allocate a nominal amount of received cash between themselves and someone else.

(iii) If the research involves deceiving the subjects regarding the nature or purposes of the research, this exemption is not applicable unless the subject authorizes the deception through a prospective agreement to participate in research in circumstances in which the subject is informed that he or she will be unaware of or misled regarding the nature or purposes of the research.

Exempt 4. Secondary research for which consent is not required: Secondary research uses of identifiable private information or identifiable biospecimens, if at least one of the following criteria is met:

(i) The identifiable private information or identifiable biospecimens are publicly available;

(ii) Information, which may include information about biospecimens, is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained directly or through identifiers linked to the subjects, the investigator does not contact the subjects, and the investigator will not re-identify subjects;

(iii) The research involves only information collection and analysis involving the investigator's use of identifiable health information when that use is regulated under 45 CFR parts 160 and 164, subparts A and E, for the purposes of "health care operations" or "research" as those terms are defined at 45 CFR 164.501 or for "public health activities and purposes" as described under 45 CFR 164.512(b); or

(iv) The research is conducted by, or on behalf of, a Federal department or agency using government-generated or government-collected information obtained for nonresearch activities, if the research generates identifiable private information that is or will be maintained on information technology that is subject to and in compliance with section 208(b) of the E-Government Act of 2002, 44 U.S.C. 3501 note, if all of the identifiable private information collected, used, or generated as part of the activity will be maintained in systems of records subject to the Privacy Act of 1974, 5 U.S.C. 552a, and, if applicable, the information used in the research was collected subject to the Paperwork Reduction Act of 1995, 44 U.S.C. 3501 et seq.

Exempt 5. Research and demonstration projects that are conducted or supported by a Federal department or agency, or otherwise subject to the approval of department or agency heads (or the approval of the heads of bureaus or other subordinate agencies that have been delegated authority to conduct the research and demonstration projects), and that are designed to study, evaluate, improve, or otherwise examine public benefit or service programs, including procedures for obtaining benefits or services under those programs, possible changes in or alternatives to those programs or procedures, or possible changes in methods or levels of payment for benefits or services under those programs. Such projects

include, but are not limited to, internal studies by Federal employees, and studies under contracts or consulting arrangements, cooperative agreements, or grants. Exempt projects also include waivers of otherwise mandatory requirements using authorities such as sections 1115 and 1115A of the Social Security Act, as amended. (i) Each Federal department or agency conducting or supporting the research and demonstration projects must establish, on a publicly accessible Federal Web site or in such other manner as the department or agency head may determine, a list of the research and demonstration projects that the Federal department or agency conducts or supports under this provision. The research or demonstration project must be published on this list prior to commencing the research involving human subjects.

Exempt 6. Taste and food quality evaluation and consumer acceptance studies: (i) If wholesome foods without additives are consumed, or (ii) If a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the Food and Drug Administration or approved by the Environmental Protection Agency or the Food Safety and Inspection Service of the U.S. Department of Agriculture.

Exempt 7. Storage or maintenance for secondary research for which broad consent is required: Storage or maintenance of identifiable private information or identifiable biospecimens for potential secondary research use if an IRB conducts a limited IRB review and makes the determinations required by 45 CFR 46.111(a)(8).

Exempt 8. Secondary research for which broad consent is required: Research involving the use of identifiable private information or identifiable biospecimens for secondary research use, if the following criteria are met:

- (i) Broad consent for the storage, maintenance, and secondary research use of the identifiable private information or identifiable biospecimens was obtained in accordance with 45 CFR 46.116(a)(1) through (4), (a)(6), and (d);
- (ii) Documentation of informed consent or waiver of documentation of consent was obtained in accordance with 45 CFR 46.117;
- (iii) An IRB conducts a limited IRB review and makes the determination required by 45 CFR 46.111(a)(7) and makes the determination that the research to be conducted is within the scope of the broad consent referenced in paragraph (d)(8)(i) of this section; and
- (iv) The investigator does not include returning individual research results to subjects as part of the study plan. This provision does not prevent an investigator from abiding by any legal requirements to return individual research results.

¹Exempt categories (1), (2), (3), (4), (5), (7), and (8) cannot be applied to activities that are FDA-regulated.

² Each of the exemptions at this section may be applied to research subject to subpart B (Additional Protections for Pregnant Women, Human Fetuses and Neonates Involved in Research) if the conditions of the exemption are met.

³ The exemptions at this section do not apply to research subject to subpart C (Additional Protections for Research Involving Prisoners), except for research aimed at involving a broader subject population that only incidentally includes prisoners.

⁴ Exemptions (1), (4), (5), (6), (7), and (8) of this section may be applied to research subject to subpart D (Additional Protections for Children Involved as Subjects in Research) if the conditions of the exemption are met. Exempt (2)(i) and (ii) only may apply to research subject to subpart D involving educational tests or the observation of public behavior when the investigator(s) do not participate in the activities being observed. Exempt (2)(iii) may not be applied to research subject to subpart D.

Appendix B: Dissertation Funding Sources

Dissertation Funding Sources

1. Practicum and Dissertation Funding – 2019/2020

From: Department of Kinesiology, Michigan State University

Funded - \$3,400

Use: These funds were used to compensate data collection staff for dissertation study 3 and to purchase a wrist-worn heart rate system for dissertation study 3.

2. Summer Fellowship Funding – 2019

From: College of Education, Michigan State University

Funded - \$6,500

Use: These funds were used for researcher's stipend for Summer 2019.

3. Midwest American College of Sports Medicine Student Research Grant – 2017, 2018, and 2019

From: Midwest American College of Sports Medicine Chapter

Funded - \$1,500 (\$500 per year)

Use: These funds were used to purchase participant gift cards for dissertation studies 2 and 3 and exercise equipment for dissertation study 3.

Not Funded

1. SHAPE America Student Research Grant – 2019

From: SHAPE America

Unfunded: \$1,500

2. Blue Cross Blue Shield Student Grant - 2019

From: Blue Cross Blue Shield of Michigan

Unfunded - \$2,000

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