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Acute Cardiometabolic Responses to Medicine Ball Interval Training in Children

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ABSTRACT

International Journal of Exercise Science 11(4): 886-899, 2018. Medicine ball interval training (MBIT) has been found to be an effective exercise modality in fitness programs, yet the acute physiological responses to this type of this exercise in youth are unknown. The purpose of this study was to examine the acute cardiometabolic responses to MBIT in children. Fourteen children (mean age 10.1 ± 1.3 yr) were tested for peak oxygen uptake (VO_2peak) on a treadmill and subsequently (> 48 hours later) performed a progressive 10 min MBIT protocol of 5 exercises (EX): standing marches (EX1), alternating lunges (EX2), squat swings (EX3), chest passes (EX4) and double arm slams (EX5). A 2.3 kg medicine ball was used for all trials and each exercise was performed twice for 30 sec with a 30 sec rest interval between sets and exercises. Participants exercised while connected to a metabolic system and heart rate (HR) monitor. During the MBIT protocol, mean HR significantly ($p<0.05$, $\eta^2 = 0.89$) increased from 121.5 ± 12.3 bpm during EX1 to 178.3 ± 9.4 bpm during EX5 and mean VO_2 significantly ($p<0.05$, $\eta^2= 0.88$) increased from 15.5 ± 2.9 ml · kg^{-1} · min^{-1} during EX1 to 34.9 ± 5.1 ml · kg^{-1} · min^{-1}during EX5. Mean HR and VO_2 values during MBIT ranged from 61.1% to 89.6% of HRpeak and from 28.2% to 63.5% of VO_2peak. These descriptive data indicate that MBIT can pose a moderate to vigorous cardiometabolic stimulus in children.

KEY WORDS: Heart rate, circuit training, oxygen consumption, preadolescent, resistance training, youth

INTRODUCTION

Public health guidelines suggest that children should accumulate at least 60 minutes of moderate to vigorous physical activity (MVPA) daily (44), yet a vast majority of youth worldwide fail to achieve this activity threshold (42). While traditional interventions designed to increase physical activity in youth have used moderate intensity continuous exercise (29, 31), there is a need to examine alternative approaches to engaging youth in MVPA. Unlike adults, few children engage in 10-minute or 20-minute bouts of continuous MVPA (37, 43). Differences in the tempo and intensity of physical activity are important considerations because the amount of time youth spend in vigorous physical activity is more strongly associated with positive health outcomes than light or moderate intensity physical activity (8, 32).

Intense intermittent exercise, or interval training, is recognized as a potent, time-efficient exercise modality for adults (21) and there is growing interest in this type of training for youth (5, 20, 36). Recent reviews examining the health outcomes of interval training concluded that the evidence supports the efficacy and feasibility of this type of exercise in children and adolescents (7, 11). However, a majority of the pediatric research has focused on training-induced adaptations from intense intermittent exercise such as short bursts of running and cycling and only limited evidence is available regarding the acute physiological responses to this type of training in youth (4, 12, 25). Moreover, little is known about the acute physiological responses to child-specific modes of interval training using medicine balls.

Conventionally, interval training has been performed with running-based sessions or with sprint intervals on a cycle ergometer, but to fully understand the physiological responses to this type of training it is important to examine other exercise modalities that are used in physical education classes and youth sport programs. For example, medicine balls are weighted vinyl, polyurethane or leather balls that are portable, easy to store, relatively inexpensive and come in a variety of shapes and sizes. Medicine balls provide a unique type of unguided resistance that can be used for an unlimited number of exercises performed at different movement speeds. Training with medicine balls has been found to enhance health- and skill-related components of physical fitness in children (41), adolescents (17) and young female athletes (24).

Recently, researchers examined the acute physiological responses to a 10-minute bout of fitness rope interval exercise in children and found that this type of training can pose a potent cardiometabolic stimulus (15). Others found that the acute responses to a 12-minute session of resistance training or intermittent noncontact boxing in early adolescents could be characterized as "vigorous" and therefore contribute to daily MVPA recommendations (22). To the authors' knowledge, no previous study has examined the acute physiological responses to medicine ball interval training (MBIT) in youth. Due to the growing interest in youth resistance training and the potential for both cardiometabolic and neuromuscular adaptations (6, 27), additional research is needed to fill this research gap. This information will be used to better understand the basic mechanisms underpinning training-induced adaptations and to enhance the design of youth fitness programs.

Therefore, the purpose of this study was to examine the acute cardiometabolic responses to MBIT in children. Our intent was to provide descriptive cardiometabolic data for MBIT and establish preliminary cardiometabolic references values for a child-specific MBIT protocol. Due to reported adaptations from medicine ball training in younger populations (17, 24, 41), we hypothesized that MBIT would elicit a moderate to vigorous cardiometabolic stimulus in children.

METHODS

Participants

Fourteen children (8 boys and 6 girls; mean ± SD age 10.1 ± 1.4 yr; height 141.0 ± 9.4 cm and body mass 36.1 ± 10.9 kg) volunteered to participate in this study. Participants were members of community sports teams (primarily baseball, soccer, and lacrosse). Parents completed a modified physical activity readiness questionnaire (PAR-Q) to evaluate the health status of the participants and assess the safety for performing strenuous exercise. Exclusion criteria included the following: use of medication affecting exercise capacity; cardiopulmonary or metabolic disease; orthopedic limitation; or positive responses from parents to one or more of the PAR-Q questions pertaining to their child's health. No participant was excluded from participation. This study was approved by the Institutional Review Board at The College of New Jersey. All parents signed a parental permission form and all participants signed a child assent form and were informed of the benefits and risks of this investigation. Parental permission was obtained for use of photographs of children.

Protocol
All participants reported to the Human Performance Laboratory at a standardized time of day at least 2 hours postprandial for peak aerobic capacity testing. Participants were asked to refrain from vigorous exercise for at least 24 hours before the testing session. VO_2 peak was assessed using the Fitkids treadmill test protocol (26) and a metabolic system (MedGraphics ULTIMA Metabolic System, MedGraphics Corporation, St Paul, MN, USA). Breath-by-breath VO_2 data were obtained and VO_2 peak was determined by recording the highest measure observed during the test (2). HR was monitored using a soft chest strap with a HR sensor (Model A300; Polar Electro Inc, Woodbury, NY, USA). Peak HR was defined as the highest value achieved during the test. The treadmill test was deemed maximal when at least one of the following objective criteria were met: HR peak > 180 bpm or a respiratory exchange ratio (RER) > 1.0 (3). During the test participants were asked to manually signal without verbalizing their rating of perceived exertion (RPE) on a visually presented scale consisting of verbal expressions along with a numerical response range of 0 to 10 and five pictorial descriptors that represent a child at varying levels of exertion (18).

A standard soft rubber 2.3 kg medicine ball was used for all study procedures. Pilot testing from our center found that a 2.3 kg medicine ball was most appropriate for children. The MBIT protocol consisted of the following five exercises: 1) marching twists (EX1), 2) alternating lunges (EX2), 3) squat swings (EX3), 4) chess passes (EX4), and 5) double-arm slams (EX5) (Table 1). Descriptions of medicine ball exercises are available elsewhere (30). The five exercises were performed in successive order with each exercise set lasting 30 s in duration. Each exercise was performed for two sets with a rest interval of 30 s in between sets and exercises. The total duration of the MBIT protocol was 10 min (including 30 s recovery following the last exercise). Participants were asked to follow a specific cadence using a metronome and verbal cues to complete a target number of repetitions during each set. The MBIT protocol was recorded on video and repetitions for each set were subsequently counted and analyzed. Each exercise was associated with a child-friendly coaching cue that was provided to the participants to assist them in maintaining proper technique. For the five medicine ball exercises, their respective coaching cues were EX1: marching monkey, EX2: giant steps, EX3: elephant swings, EX4: kangaroo punches, and EX5: pancakes.

Table 1. Medicine ball interval training protocol.

Time (min)	Set	Exercise	Repetitions	Rest Interval (sec)
0-0.5	1	Standing march	38.7 ± 2.9	30
1.0-1.5	2		40.5 ± 3.1	30
2.0-2.5	3	Alternating lunge	18.5 ± 1.4	30
3.0-3.5	4		19.1 ± 1.7	30
4.0-4.5	5	Squat swing	15.8 ± 1.5	30
5.0-5.5	6		16.7 ± 1.4	30
6.0-6.5	7	Chest pass	15.0 ± 1.9	30
7.0-7.5	8		15.8 ± 1.9	30
8.0-8.5	9	Double arm slam	15.1 ± 2.5	30
9.0-9.5	10		16.1 ± 2.5	30
9.5-10				30

Participants became familiar with the MBIT protocol and study procedures during a 30-min familiarization session. A Certified Strength and Conditioning Specialist demonstrated proper exercise technique and participants received instructional cues and constructive feedback on the quality of each movement. The familiarization session focused on proper movement patterns and the ability to perform each medicine ball exercise correctly at the desired cadence. To promote exercise adherence, the MBIT protocol was designed to increase in a progressive manner and be feasible for children. Before the familiarization session, height was measured to the nearest 0.1 cm using a wall-mounted stadiometer and body mass was measured to the nearest 0.5 kg using an electronic scale. For both measurements, participants wore light cloths and no shoes.

Participants returned to the Human Performance Laboratory at least two hours postprandial within 2 to 7 days of the peak aerobic capacity test to perform the MBIT test protocol. On arrival, each participant was asked to drink water *ad libitum* to prehydrate and was fitted with a child-size respiratory mask that was placed over the participants face, fastened, and carefully checked for proper sealing. Each participant was fitted with a Polar HR monitor (model A300; Polar Electro Inc, Woodbury, NY, USA) that was used to measure HR before, during and after the MBIT protocol. HR data were downloaded for analysis using a computer software program. HR data analyzed were the mean values collected during each set. Breath-by-breath VO_2 was measured during the MBIT protocol using a metabolic system (MedGraphics ULTIMA Metabolic System, MedGraphics Corporation, St Paul, MN, USA) (Figure 1). Participants were asked to manually indicate their perceived exertion after each set using the same 0 to 10 RPE scale used during peak aerobic capacity testing.

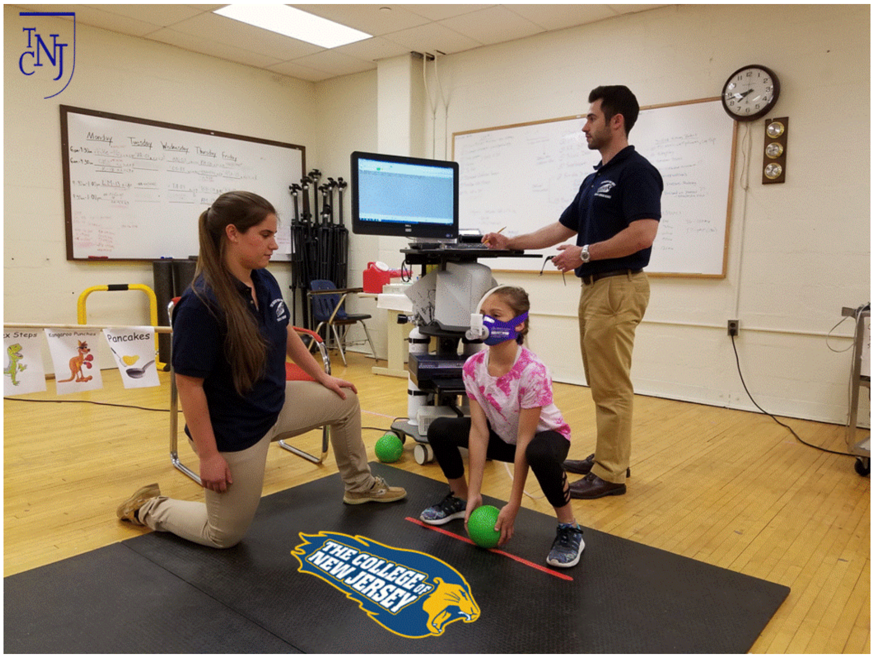

Figure 1. Participant performing squat swing exercise while connected to metabolic cart. Parental permission was obtained to reveal the identity of the child.

Prior to the MBIT trial, each participant sat quietly in a chair for 5 minutes to collect baseline data. Subsequently, each participant performed 2 to 3 minutes of dynamic stretching (e.g., arm circles and knee lifts). Once complete, an approximate one-minute period ensued in which the researcher reviewed session instructions and the participant assumed the starting position for the first exercise. A research assistant monitored the number of repetitions during each time interval. During the MBIT protocol a research assistant periodically checked the facemask for proper fit. Participants were instructed to perform each exercise at a specific cadence with proper exercise technique. During each rest interval a research assistant provided a quick review of the upcoming exercise and reinforced exercise-specific coaching cues to maintain proper technique. Verbal encouragement was used consistently throughout the MBIT trials. All participants performed the same exercises in the same order. The design of the MBIT protocol was based on previous school-based interventions which included short bouts of exercise with 30 s of rest between sets and exercises (13, 14).

Values for HR, absolute VO_2, relative VO_2, minute ventilation (V_E) and respiratory exchange ratio (RER) were recorded during the entire MBIT protocol. Individual breath-by-breath data points for all metabolic variables were averaged for the entire set of each BR exercise. The time corresponding to the initiation of each set and the rest interval length between each set was carefully monitored and labeled during each protocol. The values between these time points were subsequently averaged and analyzed.

Statistical Analysis

Descriptive statistics (mean ± SD) were calculated for all dependent variables. A 1 (group) x 10 (sets) analysis of variance with repeated measures was used to analyze within participant cardiometabolic and RPE data. Subsequent Tukey's post hoc tests were used to determine differences when significant main effects were obtained. For all statistical tests, a probability level of $p \leq 0.05$ denoted statistical significance. To estimate effect size, eta squared (η^2) was computed and reported. An effect size of 0.01 is considered small, 0.06 is considered moderate and 0.13 is considered large (10). Statistical analyses were conducted in SPSS (version 18.0; SPSS, Chicago, IL).

RESULTS

All participants completed study procedures and no injuries or unexpected events occurred. Significant main effects and large effect sizes of MBIT were observed for all variables (table 2). Cardiometabolic and perceptual responses to MBIT are presented in Table 3. Our post hoc comparisons revealed a progressive increase in cardiometabolic demand as VO_2, VE, RER, and HR increased significantly from EX1 (marching twist) to EX5 (double arm slams). The highest peak values for VO_2, V_E, RER, and HR during MBIT were 34.9 ± 5.1 ml · kg^{-1} · min^{-1}, 40.4 ± 8.1 L/min, 0.95 ± 0.05 and 178.3 ± 9.4 bpm, respectively. Relative intensity of each MBIT exercise expressed as a percentage of peak HR and peak VO_2 achieved during the maximal treadmill test ranged from 61.1% to 89.6% and 28.2% to 63.5%, respectively (Table 4).

Table 2. Results of analysis of variance and effect size.

Variable	F-value	*p*-value	Effect size (η^2
HR	110.62	0.001*	0.89
VO_2 ml/kg/min	93.39	0.001*	0.88
VO_2 L/min	83.09	0.001*	0.86
VE	78.84	0.001*	0.86
RER	16.55	0.001*	0.56
RPE	90.63	0.001*	0.87

Note: HR = heart rate; VO_2 = oxygen uptake; VE = minute ventilation; RER= respiratory exchange ratio; RPE = ratings of perceived exertion. * represents statistical significance.

Table 3. Cardiometabolic and perceptual responses to medicine ball interval training.

EX	Set (S)	VO_2 L · min^{-1}	VO_2 ml · kg^{-1} · min^{-1}	V_E L · min^{-1}	RER	HR bpm	RPE
EX1	S1	0.54 ± 0.12[b-j]	15.5 ± 2.9[b-j]	14.5 ± 2.8[b-j]	0.84 ± 0.04[e-h,j]	121.5 ± 12.3[c-j]	1.0 ± 0.96[b-j]
	S2	0.77 ± 0.18[a,c-j]	21.7 ± 2.9[a,d-j]	19.3 ± 3.7[a,d-j]	0.83 ± 0.08[e-j]	128.2 ± 8.9[d-j]	1.3 ± 1.2[d-j]
EX2	S3	0.77 ± 0.20[a,d-j]	21.7± 3.9[a,d-j]	20.3 ± 4.8[a,d-j]	0.86 ± 0.07[e,h,j]	141.4 ± 14.8[d-j]	2.3 ± 1.4[a,e-j]
	S4	1.00 ±0.21[a-c,h-j]	28.4 ± 4.3[a-c,h-j]	27.7 ± 4.6[a-c,e,h-j]	0.92 ± 0.09[e]	153.1 ± 10.5[a-c,h-j]	2.9 ± 1.6[a,b,e-j]
EX3	S5	1.03 ± 0.22[a-c,h-j]	29.3 ± 3.6[a-c,h-j]	31.5 ± 5.8[a-d,j]	1.01 ± 0.07[a-d]	158.6 ± 11.6[a-c,h-j]	3.9 ± 1.7[a-d,i,j]
	S6	0.98 ± 0.21[a-c,g-j]	27.7 ± 3.3[a-c,g-j]	30.5 ± 6.5[a-c,h-j]	0.95 ± 0.06[a,b]	158.8 ± 11.3[a-c,h-j]	4.5 ± 1.3[a-d,i,j]
EX4	S7	1.04 ± 0.26[a-c,f,h-j]	29.5 ± 3.5[a-c,f, h-j]	32.0 ± 6.9[a-c,h,j]	0.94 ± 0.06[a,b]	158.6 ± 12.5[a-c,i,j]	4.9 ± 1.3[a-d,i,j]
	S8	1.23 ± 0.26[a-g]	34.7 ± 5.1[a-g]	37.4 ± 7.2[a-d,f,g]	0.93 ± 0.06[a-c]	170.6 ± 9.5[a-f]	5.3 ± 1.3[a-d,i,j]
EX5	S9	1.22 ± 0.26[a-g]	34.5 ± 5.3[a-g]	36.2 ± 6.8[a-d,f]	0.91 ± 0.06[b]	175.1 ± 9.3[a-g]	6.1 ± 1.2[a-h]
	S10	1.23 ± 0.26[a-g]	34.9 ± 5.1[a-g]	40.4 ± 8.1[a-g]	0.95 ± 0.05[a-c]	178.3 ± 9.4[a-g]	6.7 ± 1.3[a-h]

Note: VO_2 = oxygen uptake; VE = minute ventilation; RER= respiratory exchange ratio; HR = heart rate; RPE = ratings of perceived exertion; EX = exercise, S = set. See methods for description of each exercise.
$p \leq 0.05$, [a]vs S1; [b]vs S2; [c]vs S3; [d]vs S4; [e]vs S5; [f]vs S6; [g]vs S7; [h]vs S8; [i]vs S9; [j]vs S10.

Table 4. Relative intensity of each medicine ball interval training exercise.

EX	Set (S)	% VO_2 peak	%HR peak
EX1	S1	28.2%	61.1%
	S2	39.5%	64.5%
EX2	S3	39.5%	71.1%
	S4	51.7%	76.9%
EX3	S5	53.4%	79.7%
	S6	50.4%	79.8%
EX4	S7	53.7%	79.7%
	S8	63.4%	85.8%
EX5	S9	62.8%	88.8%
	S10	63.6%	89.6%

Note: VO_2 = oxygen uptake; HR = heart rate; EX = exercise, S = set. See methods for exercise descriptions.

Analysis of HR data during each set (S) of the MBIT protocol revealed that values attained during S9 and S10 were significantly higher than S1 through S7; S8 was significantly higher than S1 through S6; and S4, S5, S6 and S7 were significantly higher than S1 through S3. Analysis of oxygen uptake data during each set of the MBIT protocol found that values attained during S8, S9 and S10 were significantly higher than S1 through S7; S7 was significantly higher than S1-S3 and S6; S4, S5 and S6 were significantly higher than S1-S3; and S2 and S3 were significantly higher than S1. Value for V_E, RER and HR tended to increase with each successive exercise and paralleled VO_2 data. Figures 2 and 3 depict the gradual and progressive increase in HR and VO_2, respectively, during the MBIT protocol.

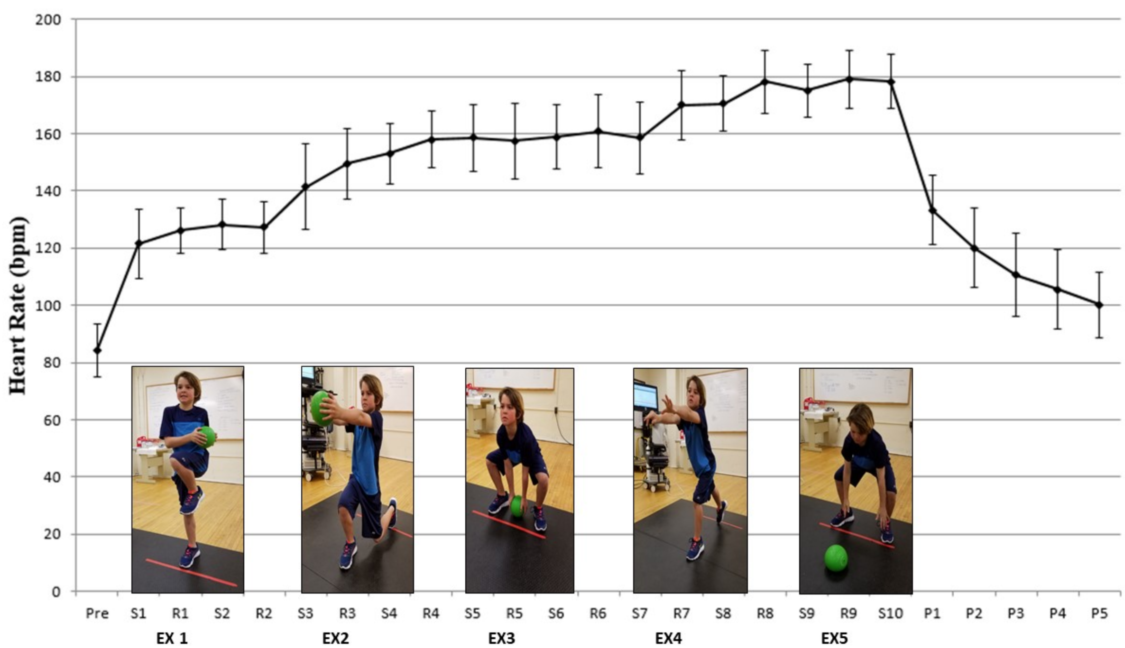

Figure 2. Heart rate (HR) responses (mean ± SD) during the medicine ball interval training protocol. PRE = Baseline. EX = Exercise; S = set; R = rest interval; P = post exercise. See Table 3 for significant differences between sets. Parental permission was obtained to reveal the identity of the child.

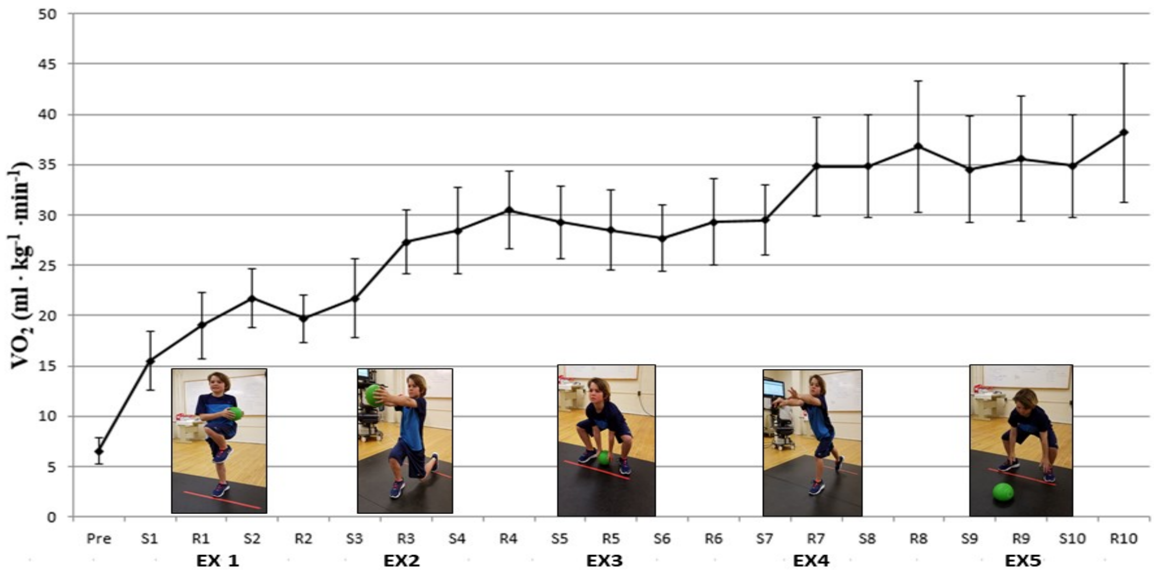

Figure 3. Relative oxygen uptake responses (mean ± SD) during the medicine ball interval training protocol. PRE = Baseline. EX=Exercise; S = set; R = rest interval. See table 3 for significant differences between sets. Parental permission was obtained to reveal the identity of the child.

Significant effects of MBIT were observed for RPE. There was a gradual increase in perceptual responses from EX1 through EX5 (Table 2). Our post hoc comparisons revealed a significant increase in RPE from a rating of 1.0 ± 0.96 during S1 to a rating of 6.7 ± 1.3 (out of 10) during S10. The progressive increase in RPE during MBIT mirrored increases in cardiometabolic responses.

DISCUSSION

The purpose of this study was to describe the acute cardiometabolic responses to MBIT in children. In line with our hypothesis, a progressive protocol of 5 medicine ball exercises comprising 30 s of work with 30 s of passive recovery posed a potent cardiometabolic stimulus as evidenced by significant increases in VO2, V_E, RER and HR. While other pediatric investigations detailed the acute physiological responses to intense intermittent bouts of running or cycling (4, 9, 12, 25), our novel findings describe the acute cardiometabolic demands of child-specific MBIT and highlight the potential benefits of incorporating medicine ball exercises into youth fitness programs. It appears that MBIT has the potential to elicit the same cardiometabolic demand as that achieved during intense intermittent bouts of running and cycling.

Medicine balls provide a unique type of unguided resistance that can be used to train the upper body, lower body and core musculature. For example, when a participant performs the squat swing exercise with a medicine ball the lower body descends and ascends, the shoulders flex and extend, and the core muscles stabilize the torso. Consequently, this type of training requires the whole body to function as a unit in order to perform the movement correctly at the desired cadence. These are important considerations when discussing our findings because the acute cardiometabolic responses to exercise are dependent upon various factors including the intensity of muscle actions (e.g., low, moderate or high), the type of muscle actions (e.g., static or dynamic), the amount of muscle mass involved (e.g., upper body, lower body or both), volume, rest intervals, and the position of the body (e.g., supine or upright) (34, 35). In addition, the acute cardiometabolic responses to exercise and the kinetics of recovery after exercise are influenced by age and fitness level (2, 39). For example, children have been found to be less susceptible than adults to neuromuscular fatigue following resistance training (33) and the post-exercise decline in VO_2 is reportedly faster in children with a higher peak VO_2 compared with those with a lower peak VO_2 (40).

Participants in our study were active children (age range 7.8 to 12.2 yrs) with a peak aerobic capacity of 54.9 ± 10.1 $ml \cdot kg^{-1} \cdot min^{-1}$ and a peak HR of 198.9 ± 8.2 bpm. During the MBIT protocol, mean VO_2 and mean HR values increased from 15.5 ± 2.9 $ml \cdot kg^{-1} \cdot min^{-1}$ and 121 ± 12.3 bpm, respectively, during the first set of the first exercise to 34.9 ± 5.1 $ml \cdot kg^{-1} \cdot min^{-1}$ and 182.5 ± 10.8 bpm, respectively, during the second set of the last exercise. As shown on Table 3, the relative intensity of each medicine ball exercise expressed as a percentage of peak VO_2 and peak HR ranged from 28.2% to 63.6% and from 61.1% to 89.6%, respectively. When compared with a standard classification of physical activity intensity, these findings demonstrate that the overall intensity of our MBIT protocol could be characterized as “moderate” or “vigorous”(1).

Our HR data are consistent with findings with others who examined the acute physiological responses to interval training in youth (4, 16, 22). Faigenbaum and colleagues investigated the acute responses to a 10-minute bout of 5 progressive fitness rope exercises (30 s/exercise and 30 sec rest/set) in children and reported mean HR values during the last set of the protocol reached 168.6 ± 11.8 bpm (86.4% HR peak) (16). Baquet and colleagues characterized the acute aerobic responses to different protocols of high-intensity intermittent exercise in children and reported mean HR values of 169 ± 9 bpm to 198 ± 8 bpm (4). Unlike MBIT, the protocols in the aforementioned report consisted of short intermittent sprints (10-20 s/exercise and 10-20 s rest) at 100% to 130% maximal velocity or 5 s of sprints or maximal vertical jumps interspersed with 15 s of recovery (4). Since the structure of our protocol included 5 medicine ball exercises that progressed from a less intense exercise (marching twist) to a more intense exercise (double arm slam), the gradual increase in mean HR from 61% HR peak to nearly 90% HR peak was expected. Of note, participants recovered quickly from the physiological stress of MBIT as evidenced by heart rates of 133.3 ± 12.2 bpm, 110.5 ± 14.5 bpm and 100.1 ± 11.5 bpm after 1, 3 and 5 min of recovery, respectively (Figure 2).

Relative VO_2 values in the present study are consistent with those reported in other studies investigating different modes of high-intensity interval training in youth. During a similar protocol of progressive fitness rope interval training, VO_2 increased from 10.3 $ml \cdot kg^{-1} \cdot min^{-1}$ (22% VO_2 peak) to 30.0 $ml \cdot kg^{-1} \cdot min^{-1}$ (64.8% VO_2 peak) in children (16). The VO_2 in the present study was also comparable to findings from Harris and colleagues who reported mean VO_2 values of 24.9 $ml \cdot kg^{-1} \cdot min^{-1}$ and 33.8 $ml \cdot kg^{-1} \cdot min^{-1}$ in early adolescents during 12 sets of resistance training (body weight squat, push-up and supine pull) or high-intensity interval training (noncontact boxing and cycling), respectively (22). By comparison, Baquet and colleagues reported mean VO_2 values of

35.5 $ml \cdot kg^{-1} \cdot min^{-1}$ (64.6% VO_2 peak) to 47.0 $ml \cdot kg^{-1} \cdot min^{-1}$ (85.9% VO_2 peak) during high-intensity sprint interval exercise in boys and girls (4). While the acute physiological responses to any type of training are influenced by the manipulation of program design variables including exercise characteristics, workload duration and rest interval length, our findings demonstrate that child-specific interval training characterized by short repeated bouts interspersed with brief rest periods can be a potent cardiometabolic stimulus in youth.

During MBIT oxygen uptake increased as the protocol progressed from standing marches (EX1) to double arm slams (EX5). This increase may have been due to several factors including the cumulative effects of fatigue on subsequent exercise performance, cardiovascular drift, and the greater complexity or perceived intensity of the exercises towards the end of the MBIT protocol. As previously observed in children (16) and adults (19, 34), the rope double-arm slam was found to be a relatively intense exercise because it had a substantial lower body contribution that requires participants to forcibly slam the rope against the floor at near maximal or maximal velocity during each repetition. In support of these observations, Ratamess and colleagues quantified the acute responses to 13 different resistance exercise protocols in adults and found that the rope double arm slam elicited the largest acute cardiometabolic responses compared with all other traditional resistance training and body weight exercises (34). We observed medicine ball exercises that required greater muscle mass activation, such as double arm slams, posed a more intense cardiometabolic stimulus than movements which required less motion of the upper body, hips, knees and ankles, such as standing marches. Collectively, these findings indicate that the choice of exercise is a primary determinant of the cardiometabolic responses to MBIT.

In our investigation, the structure of the MBIT protocol was based on previous pediatric investigations and included 30 sec of exercise followed by a 30 sec rest interval with a 2.3 kg medicine ball (13, 14). Due to the relative intensity of selected exercises in our MBIT protocol, passive recovery intervals were arguably required to allow each exercise to be performed correctly with energy and enthusiasm. Moreover, it is important to note that the aim of our investigation was to quantify the acute cardiometabolic responses to one novel MBIT protocol and not to disentangle the acute effects of each medicine ball exercise. Our mixed exercise approach added variety to our program and reflects how children may actually perform interval training at school or during recreation time. Thus, the result of our investigation should be interpreted within the context of the non-randomized sequence by which the exercises were performed and understand that the cardiometabolic responses to each exercise were likely influenced by the subsequent fatigue induced by the previous exercise. These matters notwithstanding, our findings provide preliminary reference values for VO_2 and HR during a specific MBIT protocol and highlight the versatility of MBIT because different exercises or combinations of exercises could be used for moderate, vigorous, or variable intensity interval training depending upon the needs, goals and abilities of the participants.

Our cardiometabolic data are consistent with the participant's RPE which increased from 1.0 ± 9.6/10 ("very, very light") after EX1 to 6.7 ± 1.3/10 ("hard" or "very hard") after EX5. Perceived exertion scales have been found to be a useful and practical measure for assessing the intensity of different modes of youth resistance training (18, 38). For example, Robertson and colleagues found that children could rate their perceived intensity during upper and lower body resistance training (38) and Faigenbaum and colleagues reported a significant increase in perceived exertion from 0.5 ± 0.7/10 to 7.3 ± 2.0/10 during a progressive 10-minute bout of fitness rope training (16). Others found that RPE could be used to quantify the training load and overall "session" load of body weight resistance training or high intensity interval training in early adolescents (22). Our data support the use of RPE to monitor the intensity of MBIT and demonstrate exercise-specific perceptual and cardiometabolic responses to interval training in children.

The present data support the integration of MBIT into youth fitness programs due to the sufficient cardiometabolic responses to this type of training. While the complexity, intensity, cadence and rest intervals between sets and exercises can influence the responses to MBIT, the structure of our protocol allowed all participants to complete 2 sets of 5 exercises that gradually progressed in exercise intensity. We also observed that our child-specific MBIT was a challenging and appealing method of exercise for the participants. This was evidenced by 100% compliance with research instructions and testing protocols. While enjoyment was not objectively assessed in our investigation, Malik and colleagues found that enjoyment measured with the physical activity enjoyment scale was higher following high intensity interval training than continuous moderate intensity exercise in 12 to 15 year-old boys and girls (28). Although further examination of the affective response to different modes of exercise is needed, the available data indicate that high intensity interval training may be an enjoyable, effective and time efficient mode of training for youth.

There are several limitations to our study that should be acknowledged. The maturity status of the participants was not assessed and therefore we were unable to determine if all participants were prepubertal. It is also important to consider the design of our MBIT program because the acute program variables will impact the cardiometabolic and perceptual responses to this type of training. Our descriptive data are from one 10-min MBIT session of 5 different exercises using a 2.3 kg medicine ball with a 30-sec rest interval between sets and exercises. Therefore, it is important to consider the cumulative effects of fatigue and cardiovascular drift when interpreting our results. While others typically used short bursts of running-based exercises or sprint intervals on a cycle ergometer for interval training (4, 12, 25), it is unlikely that children would be able to perform and enjoy 10 minutes of vigorous MBIT without longer rest intervals. Given that our MBIT protocol was based on previous pediatric research (13, 14), the design of our MBIT protocol arguably provides greater translatability to primary school settings in which the training experience of children can vary widely. Lastly, the participants in our study were healthy children so the homogeneity of the sample limits generalizability to other populations including those with clinical conditions.

The present study demonstrated that the intensity of child-specific MBIT could be characterized as "moderate" or "vigorous". Given the known neuromuscular benefits of resistance training (27), MBIT performed at the requisite weekly frequency has the potential to enhance both cardiometabolic and neuromuscular fitness. In light of recent findings that indicate the amount of time primary school children spend in MVPA during physical education is falling short of expectations (23), MBIT could be a worthwhile addition to school-based interventions. The potent cardiometabolic responses to MBIT along with high compliance to study procedures provide support for use of this exercise modality in youth fitness programs. Additional pediatric research is needed to examine the acute and chronic effects of interval training that integrates mixed modes of resistance training into developmentally appropriate exercise sessions.

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