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Estimated Aerobic Capacity Changes in Adolescents with Obesity Following High Intensity Interval Exercise

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Abstract

Vigorous aerobic exercise may improve aerobic capacity (VO_{2max}) and cardiometabolic profiles in adolescents with obesity, independent of changes to weight. Our aim was to assess changes in estimated VO_{2max} in obese adolescents following a 6-week exercise program of varying intensities. Adolescents with obesity were recruited from an American mid-west children's hospital and randomized into moderate exercise (MOD) or high intensity interval exercise (HIIE) groups for a 6-week exercise intervention, consisting of cycle ergometry for 40 minutes, 3 days per week. Heart rate was measured every two minutes during each exercise session. Estimated VO_{2max} measured via Åstrand cycle test, body composition, and physical activity (PA) enjoyment evaluated via questionnaire were assessed pre/post-intervention. Twenty-seven adolescents (age 14.7±1.5; 17 female, 10 male) completed the intervention. Estimated VO_{2max} increased only in the HIIE group (20.0±5.7 to 22.7±6.5 ml/kg/min, p=0.015). The HIIE group also demonstrated increased PA enjoyment, which was correlated with average heart rate achieved during the intervention (r=0.55; p=0.043). Six weeks of HIIE elicited improvements to estimated VO_{2max} in adolescents with obesity. Furthermore, those exercising at higher heart rates demonstrated greater PA enjoyment, implicating enjoyment as an important determinant of VO_{2max}, specifically following higher intensity activities.
Keywords: VO_{2max}, obesity, childhood obesity, aerobic capacity, high intensity interval exercise, physical activity

1. Introduction

In adults, aerobic capacity (VO_{2max}) has been identified as an independent predictor of all-cause mortality, such that low levels of fitness are associated with increased risk of cardiovascular disease (CVD), type 2 diabetes mellitus (T2DM), and death (Carnethon et al., 2003; Do Lee, Blair, & Jackson, 1999; Katzmarzyk, Church, Janssen, Ross, & Blair, 2005; Stevens, Cai, Evenson, & Thomas, 2002). Similar associations have been identified in adolescents, such that lower levels of fitness and subsequent reduced aerobic capacity contribute to dyslipidemia, increased blood pressure, and impaired glucose metabolism (Andersen et al., 2006; Carnethon, Gulati, & Greenland, 2005; Eisenmann et al., 2005). Furthermore, adolescents with obesity often demonstrate reduced VO_{2max} due to a combination of physical inactivity and deleterious comorbidities associated with obesity. In fact, a significant negative relationship has been found between measures of adiposity and VO_{2max} in adolescents (Joshi, Bryan, & Howat, 2012; F. B. Ortega et al., 2007; Winsley, Armstrong, Middlebrooke, Ramos-Ibanez, & Williams, 2006). On the contrary, adolescents within normal ranges for body composition have demonstrated higher levels of physical fitness including VO_{2max} (F. B. Ortega et al., 2007; Winsley et al., 2006).

Some of the current literature has identified greater reductions in cardiovascular risk factors in high intensity interval exercise (HIIE) when compared with moderate exercise (Buchan et al., 2011; Ciolac et al., 2010; Godfrey et al., 2013; Tjonna et al., 2008; Tjonna, Rognmo, Bye, Stolen, & Wisloff, 2011). HIIE has been found to partially or even fully reverse many cardiovascular risk factors found in adolescents with obesity, with the effects often lasting longer than those seen in moderate exercise (Buchan et al., 2011; Tjonna et al., 2009). The short, high intensity periods alternating with lower intensity recovery periods contribute to greater challenges to the pumping ability of the heart, resulting in improved stroke volume and subsequent increased VO_{2max} (Ciolac et al., 2010; Tjonna et al., 2009). Frequently, these improvements are seen independent of weight loss, suggesting a stronger link between VO_{2max} and all-cause mortality, including cardiovascular disease, than between obesity and cardiovascular mortality (Ciolac et al., 2010; Tjonna et al., 2009). Increasing VO_{2max} may be more beneficial than reducing weight in regards to decreasing cardiovascular risk factors. Rather than focus on weight loss, interventions should aim to implement and/or increase high intensity PA to improve vascular function (Hopkins et al., 2009).

Therefore, our primary aim was to assess changes in estimated VO_{2max} in adolescents with obesity between moderate exercise (MOD) and HIIE following a 6-week exercise program, independent of changes to weight. In addition, we examined changes in reported level of PA enjoyment following the exercise intervention. We tested the hypotheses that: 1) higher intensities of PA would elicit a significant increase in estimated VO_{2max}; and 2) increased enjoyment of PA would result in improved estimated $VO_{2max.}$

2. Methods

2.1 Subjects

Healthy, sedentary, pubescent adolescents with obesity were recruited from clinics at Nationwide Children's Hospital in Columbus, OH. Obesity was defined as BMI ≥ 95^{th} percentile for age and sex as defined by the Centers for Disease Control (CDC) (Kuczmarski et al., 2002). Subjects were excluded from the study if they were participating in ≥ 30 minutes of vigorous exercise more than 2 days per week, reported an acute inflammatory disease or febrile illness, recent trauma or injury, asthma requiring steroid use or hospitalization within the prior 3 months, inflammatory/immune disorders (e.g. lupus), and any renal, cardiac, or liver disease.

Thirty-four subjects were randomized to MOD (n=16; 6 males and 10 females) or HIIE (n=18; 8 males and 10 females) via random number generator. All subjects and legal guardians provided written informed assent and consent, respectively. The study protocol was approved by the Institutional Review Boards of the participating institutions and with the Helsinki Declaration of 1975. The study trial has been registered at ClinicalTrials.gov (http://clinicaltrials.gov) under the trial number NCT01821313. Completion of the intervention was defined as having completed 75% of the visits (14 of 18 exercise sessions) and attended follow-up testing. Subjects unable to meet the completion requirements were excluded from analysis (n=1).

2.2 Study Measures

All study measures were obtained at baseline, prior to randomization, and within 3 – 7 days of completion of the 6-week exercise intervention.

2.2.1 Anthropometric Measurements

Height and body mass were measured in minimal clothing to the nearest 0.5 cm and 0.1 kg, respectively, with a stadiometer and scale, respectively. Waist and hip circumference (WC and HC) were measured to the nearest 0.5 cm using standard anthropometric tape midway between the lowest rib and iliac crest and at the point of greatest protrusion, respectively. Body fat percentage (BF%) was measured via Bod Pod air-displacement plethysmography (Life Measurements Instruments, Concord, CA). Density models were used based on age and gender (Lohman, 1989).

2.2.2 Fitness Assessment

Estimated VO_{2max} was assessed using the Åstrand Cycle Test (Astrand & Ryhming, 1954), a submaximal exercise test on a cycle ergometer. Subjects completed 6-8 minutes on an electronically braked cycle ergometer at a moderate resistance (125 W). Seat height was adjusted for each subject and recorded to ensure the same height was maintained throughout the intervention and assessments. Heart rate (HR) was recorded at the completion of each minute using a Polar HR monitor (Polar Electro, Lake Success, NY). After 3 minutes, resistance on the bike was adjusted based on the HR of each subject. Resistance was increased by 25 W if HR was below 140 bpm, or decreased by 25 W if HR was above 149 bpm. If steady state HR was achieved by minute 6 (defined as less than 10 bpm difference between HR at minute 5 and minute 6), the test was terminated. Otherwise, subjects continued to cycle for another 2 minutes. The average HR for minutes 5 and 6 (or 7 and 8, if necessary) was used as the submaximal HR in the equation to estimate VO_{2max}.

PA enjoyment was measured via the Physical Activity Enjoyment Scale (PACES). PACES is a questionnaire consisting of 18 bipolar statements with a 7 point continuum beginning with the stem "When I am physically active…" It is specifically designed to assess the level of enjoyment while participating in PA (Kendzierski & DeCarlo, 1991). Higher scores represent greater enjoyment of PA.

2.3 Intervention

Subjects were randomized to receive either MOD or HIIE. For both intervention groups, activity sessions were performed on a cycle ergometer (Lode, The Netherlands) and completed on 3 non-consecutive days per week over 6 weeks. Each subject began the intervention with a five-minute warm-up at 50-55% of age predicted maximal heart rate (APMHR) as determined by the following equation: APMHR= 220-age. Subjects were reminded of personal HR ranges and instructed to stay within the range during the entire session (MOD) or during the two-minute bouts (HIIE). Subjects in the MOD group were permitted to cycle at any speed and workload as long as they stayed within the specified target HR range. Following the warm-up, the MOD group cycled continuously for 30 minutes at 65-70% of APMHR. The HIIE group performed 10, two-minute cycling bouts at 90-95% of APMHR, with one minute of active recovery at 55% of APMHR between each interval for a total of 30 minutes. Subjects in the HIIE group were instructed to cycle at an "all-out" pace, while workload was adjusted, by the study staff, to maintain target HR range. Both MOD and HIIE ended with a 5-minute cool-down at 50-55% of APMHR. HR was measured with HR monitors every two minutes for both MOD and HIIE groups (Polar Electro Inc, Lake Success, NY). This protocol was designed based on previous research and modified to ensure this population would be able to maintain the pre-determined duration and intensity with limited risk of injury.

2.4 Statistical Analyses

The sample size calculation was based on previously reported data regarding VO_{2max} in overweight and obese adolescents following moderate and high intensity interval exercise. Tjonna et al. demonstrated a 9.2% difference in percent change of VO_{2max} between the moderate and high intensity groups from pre- to post-intervention (Tjonna et al., 2009). With a 2-sided, 0.05 significance level and VO_{2max} as the primary variable, 6 subjects in each group would allows us to detect a significant difference between exercise groups at 80% power.

IBM SPSS Statistics 21.0 (IBM Corp, Armonk, NY) was employed for all analyses. Reported p-values are two-tailed and $p < 0.05$ are considered statistically significant. All data are presented as means ± SD. A paired samples t-test was employed to assess the changes to VO_{2max}, anthropometric measurements, and PA behavior from pre- to post-intervention. To determine the influence of exercise group on VO_{2max}, anthropometrics, and PA enjoyment, a repeated measures ANOVA with one within subject factor was used for each exercise group, using a t-test for post hoc analysis. Missing data (n = 2) for estimated VO_{2max} was imputed using the means of pre- and post-intervention estimated VO_{2max} values.

3. Results

3.1 Baseline Characteristics

Of the 34 subjects, 27 (17 females and 10 males; mean age 14.7 ± 1.5 years) completed the exercise intervention and carried out 15.7 (87.3 ± 7.7%) of the scheduled training sessions. Baseline estimated VO_{2max} for all subjects was 19.7 ± 6.0 ml/kg/min. There were no significant differences in body composition or aerobic capacity between the MOD and HIIE groups at baseline (Table 1). Baseline estimated VO_{2max} for all subjects was negatively correlated with measures of body composition including baseline weight (r = -0.39; p = 0.046), waist circumference (r = -0.39; p = 0.044), body fat percentage (r = -0.49; p = 0.009), BMI (r = -0.49; p = 0.009), and BMIz (r= -0.43; p = 0.026).

Table 1. Subject characteristics at baseline

	Total (n = 27)	**MOD (n = 13)**	**HIIE (n = 14)**
Age (yrs)	14.7 ± 1.5	14.5 ± 1.4	14.9 ± 1.6
Height (cm)	167.2 ± 9.4	166.8 ± 9.9	167.4 ± 9.3
Weight (kg)	105.4 ± 20.7	108.3 ± 23.2	102.7 ± 18.5
BMI (kg/m^2)	37.6 ± 6.0	38.7 ± 6.7	36.5 ± 5.4
BMIz	2.38 ± 0.35	2.42 ± 0.37	2.34 ± 0.34
BF%	43.8 ± 7.1	44.3 ± 8.1	43.4 ± 6.2
WC (cm)	101.8 ± 13.0	103.8 ± 14.9	99.9 ± 11.3
WHR	0.85 ± 0.06	0.87 ± 0.06	0.84 ± 0.05
VO_{2max} (ml/kg/min)	19.7 ± 6.0	19.5 ± 6.6	20.0 ± 5.7

MOD = Moderate intensity; HIIE = High intensity interval exercise; BMI = Body mass index; BMIz = BMI z score; BF% = body fat percent; WC = waist circumference; WHR = waist-to-hip ratio; VO_{2max} = estimated maximal volume of oxygen consumed; All data are presented as means ± SD.

3.2 Body Composition

WHR decreased significantly from pre- to post-intervention in the entire sample (-0.02 ± 0.03; p = 0.020). There were no other significant differences in measures of body composition between or within the exercise groups following the intervention (Table 2).

Table 2. Changes in body composition pre- to post-intervention

	Total (n = 27)	**MOD (n = 13)**	**HIIE (n = 14)**	**p-value**
Weight (kg)	0.82 ± 2.57	1.45 ± 3.23	0.24 ± 1.58	0.241
BF%	−0.47 ± 1.95	−0.22 ± 2.08	−0.71 ± 1.87	0.532
WC (cm)	−1.39 ± 4.61	−0.62 ± 3.90	−2.11 ± 5.24	0.407
WHR	−0.02 ± 0.03*	−0.01 ± 0.04	−0.02 ± 0.03	0.811
BMI (kg/m^2)	0.16 ± 0.85	0.19 ± 1.08	0.14 ± 0.60	0.887
BMIz	−0.001 ± 0.057	−0.002 ± 0.069	0.000 ± 0.047	0.920

MOD = Moderate intensity; HIIE = High intensity interval exercise; BF% = body fat percent; WC = waist circumference; WHR = waist-to-hip ratio; BMI = Body mass index; BMIz = BMI z score; All data are presented as means ± SD; *significant change from pre- to post-intervention, p = 0.020

3.3 Aerobic Capacity

Independent samples t-test and repeated measures ANOVA revealed no overall difference in estimated VO_{2max} between the two groups following the intervention (p = 0.260), but a near significant increase with time (p = 0.057). There was also a near significant group by time interaction (p = 0.069). Post hoc testing revealed that following HIIE, estimated VO_{2max} significantly increased (p = 0.015), but did not change following MOD (p = 0.947) (Table 3). The HIIE group also demonstrated a significantly greater percent change in VO_{2max} compared to the MOD group (15.1% versus 0.08%, respectively) (p = 0.038).

Table 3. Aerobic capacity and physical activity enjoyment pre- and post-intervention

	MOD		HIIE	
	Pretest (Mean ± SD)	**Posttest (Mean ± SD)**	**Pretest (Mean ± SD)**	**Posttest (Mean ± SD)**
VO_{2max} (ml/kg/min)	19.5 ± 6.6	19.6 ± 7.6	20.0 ± 5.7	22.7 ± 6.5*
PACES	85.6 ± 18.5	89.8 ± 21.9	78.1 ± 16.3	85.2 ± 13.9

VO_{2max} = estimated maximal volume of oxygen consumed; PACES = Physical Activity Enjoyment Scale; * = significant pre- to post-intervention, p = 0.015; All data are presented as means ± SD.

3.4 Physical Activity Enjoyment

Subjects in the MOD group attained an average heart rate of 67.1% ± 1.2% while the HIIE group achieved an average percent of APMHR of 87.5% ± 7.8%. A positive correlation was identified between average percent of APMHR sustained during the intervention and change in PA enjoyment in the HIIE group (r = 0.55; p = 0.043) (Figure 1), but not in the MOD group. There were no significant interactions between PA enjoyment and exercise group.

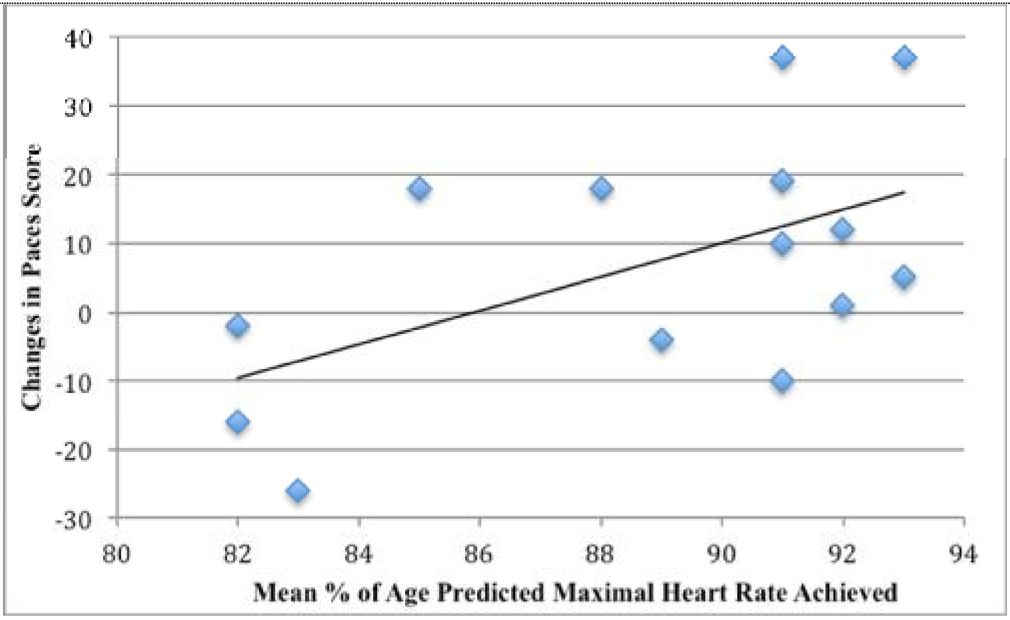

Figure 1. Positive Association Between Increased PACES Score From Pre- to Post-intervention and Greater Percent of Age Predicted Maximal Heart Rate Achieved During High Intensity Interval Exercise

4. Discussion

In this study, adolescents randomized to HIIE demonstrated improved estimated VO_{2max} following a 6-week exercise intervention without significant changes to weight or body fat percentage. Declining levels of physical fitness from childhood to adulthood is a strong predictor of adult cardiovascular disease risk, even greater than the risk associated with low levels of fitness during childhood alone (Dwyer et al., 2009). Therefore, the reduced aerobic capacity in our subjects may make them susceptible to CVD earlier in their adult lives. The alarmingly low estimated VO_{2max} values in our subjects were significantly below normal values for 12-18 year old boys (47.3 ± 0.6 ml/kg/min) and girls (39.6 ± 0.4 ml/kg/min), and remained well below the 'at risk' zones for age and sex following the intervention (38.6-41.2 ml/kg/min and 39.7-38.8 ml/kg/min for 13-17 year old boys and girls, respectively) (Welk, Laurson, Eisenmann, & Cureton, 2011). Yet, small improvements to VO_{2max}, similar to those demonstrated by the HIIE group in the current study, may be of significant importance.

The 2.7 ml/kg/min increase in aerobic capacity demonstrated by the HIIE group following 6 weeks of exercise may be a clinically relevant difference for this population, as it demonstrates potential adaptation of the vasculature and skeletal muscle following HIIE. While these results are similar to previous research in this population (Buchan et al., 2011; Gutin et al., 2002; Tjonna et al., 2009), this study adds the novel notion that the same duration of exercise (120 minutes/week) can elicit different responses within the cardiovascular system based on exercise intensity, with HIIE resulting in greater improvements to aerobic capacity. This may be of particular interest to physical education teachers and those leading clinical exercise programs as their participants may achieve greater benefits during the same amount of time through higher intensity exercises. Furthermore, even though our subjects remained well below normal VO_{2max} values following the intervention, the improvement in the HIIE group occurred in only 6 weeks, implicating the role of vigorous exercise in enhancing cardiorespiratory health and fitness.

While the prescribed intensity for the HIIE group was 90-95% of APMHR, our subjects were only able to maintain a mean percent APMHR of 88.8% during the two-minute exercise bouts. Yet, these subjects still demonstrated a positive correlation between percent of APMHR and PACES ($r = 0.55$; $p = 0.043$) (Figure 1), highlighting a relationship between higher exercise intensities and PA enjoyment. On the contrary, there was no significant relationship between exercise intensity and PA enjoyment in the MOD group. While self-efficacy was not measured in the current study, participation in HIIE may have improved PA self-efficacy, resulting in greater enjoyment of PA. Likewise, habitual participation with higher intensity exercises may have altered the subject's perceived difficulty of the exercise.

HIIE may equip adolescents with the tools they need to increase competency in PA. Previous research has identified a significant positive relationship between enjoyment with physical education (PE) and perceived competence in PE among this population. Those experiencing greater feelings of competency in PE tend to enjoy participating in PE (Fairclough 1, 2003). Furthermore, the intermittent nature of the HIIE protocol is similar to observed PA behavior among this age group. During PA, children often fluctuate between rest and short bouts of high intensity activity. In fact, Baquet et al. (2007) found that participation in higher intensity activities lasted less than 10 seconds (Baquet, Stratton, Vanpraagh, & Serge, 2007). It is possible that adolescents maintain similar activity patterns. In the current study, HIIE may have not only taught our subjects how to by physically active at higher intensities, allowing them to gain confidence in their ability to be physically active, but also may have been similar to current activity patterns, resulting in increased enjoyment.

To date, there have been few studies that have investigated the effects of HIIE on cardiovascular fitness in adolescents with obesity (Buchan et al., 2011; Corte de Araujo et al., 2012; Gutin et al., 2002). Much of the research has focused on interventions that include diet, exercise and/or behavior modification to treat obesity in children and adolescents (J. J. Reilly & McDowell, 2003; Siegrist, Hanssen, Lammel, Haller, & Halle, 2011). The current results are comparable to those in a study by Gutin et al. (2002), where HIIE was found to yield a significant change in aerobic fitness compared to a lifestyle education group, while the moderate group showed no such change. The same study also found no significant difference to changes in body composition between the two exercise groups, highlighting that the improved aerobic capacity in the high intensity group was not a result of weight loss (Gutin et al., 2002). Compared to moderate exercise, the effects of HIIE may, therefore, result in greater reductions in CVD risk, which is often found in adolescents with obesity.

While currently a great source of contention, it may be that the health outcomes associated with increasing physical activity may provide greater overall benefit than weight loss alone. Independent of weight loss, adolescents participating in exercise, particularly of higher intensities, demonstrated improved endothelial function, blood pressure, and insulin sensitivity (Bell et al., 2007; Buchan et al., 2011; Gutin et al., 2002). Although recent research has identified obesity as an independent marker of cardiovascular mortality, aerobic capacity appears to have a stronger link with mortality (Carnethon et al., 2005; Francisco B Ortega et al., 2005; J. Reilly & Kelly, 2010). Some studies highlight improved aerobic capacity following HIIE in combination with weight loss (Tjonna et al., 2008), while others have found improvements independent of changes to body composition (Gutin et al., 2002). While weight loss is certainly an appropriate goal for some adolescents with obesity, improving aerobic capacity may be a new target for this population. Therefore, instead of focusing solely on weight loss, it may be of equal or greater importance to increase physical activity and potentially incorporate HIIE in order to reduce cardiometabolic risk factors in adolescents both with and without obesity.

4.1 Limitations

The study had some major and minor limitations. The small sample size was one major limitation to the study. While adequately powered, the findings may have shown even greater significance had a larger number of subjects participated in the intervention. Future studies should examine these outcomes in a larger sample. Another major limitation was the use of submaximal testing to obtain estimated VO_{2max} values. This population, sedentary adolescents with obesity, may have struggled to complete and/or achieve a VO_{2max} test. Therefore, the authors felt it appropriate to use submaximal testing to achieve estimated values and interpret those results. Furthermore, in the absence of VO_{2max} testing, the current study relied on APMHR as a measure of intensity. Future research may wish to consider using maximal exercise testing to acquire actual VO_{2max} values and maximal HR values by which to prescribe individualized exercise HR. In addition, current literature has recently found that the equation 220 – age may not be appropriate for estimating maximal heart rate in adolescents (Verschuren, Maltais, & Takken, 2011). Therefore, future research should identify actual maximal heart rates using maximal exercise testing to create an appropriate exercise prescription. Lastly, the current study utilized cycle ergometry as the sole form of exercise during the intervention, potentially contributing to lower than expected exercise HR. Weight-bearing exercises are suggested for future research to elicit higher exercise HR.

This study sought to investigate the effects of varying exercise intensities to aid in the identification of appropriate exercise intensity to improve PA enjoyment and, ultimately, aerobic capacity. The knowledge gained from this study can aid in the implementation of new PA and PE policies for local schools. Furthermore, these results can also be used to create exercise protocols for other pediatric populations with inflammatory diseases such as diabetes, cancer, and other metabolic, pulmonary, cardiovascular, and renal disorders. Specifically, the findings indicate that shifting the focus from weight loss to increasing physical activity, specifically of higher intensities may be just as appropriate in the attempts to improve cardiometablic profiles of adolescents.

In conclusion, we found that a 6-week exercise intervention of HIIE elicited significant improvements to estimated VO_{2max} in adolescents with obesity. Further, the HIIE group also experienced significant positive correlations between intensity of exercise achieved during the intervention and changes in PA enjoyment. Therefore, enjoyment of PA appears to plays an important role in improving VO_{2max}, specifically following higher intensity activities. This is particularly important information for health practitioners and educators who have the opportunity to design and implement physical activity programs for adolescents. It may be critical to focus on improving self-efficacy and confidence in young individuals with obesity to assist in increasing time spent with physical activity. Subsequently, increased physical activity may then contribute to improved aerobic capacity and optimal health. Future research may wish to employ a similar high intensity protocol, but use weight-bearing exercises such as running or stepping to elicit greater heart rates. It may also be useful to measure changes in time spent with physical activity and sedentary behavior following the intervention to assess if exercise intensity affects physical activity behavior outside of the intervention.

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