Pain Response after Maximal Aerobic Exercise in Adolescents across Weight Status

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ABSTRACT

STOLZMAN, S., M. DANDURAN, S. K. HUNTER, and M. HOEGER BEMENT. Pain Response after Maximal Aerobic Exercise in Adolescents across Weight Status. *Med. Sci. Sports Exerc.*, Vol. 47, No. 11, pp. 2431–2440, 2015. **Introduction**: Pain reports are greater with increasing weight status, and exercise can reduce pain perception. It is unknown, however, whether exercise can relieve pain in adolescents of varying weight status. The purpose of this study was to determine whether adolescents across weight status report pain relief after high-intensity aerobic exercise (exercise-induced hypoalgesia (EIH)). **Methods**: Sixty-two adolescents (15.1 ± 1.8 yr, 29 males) participated in the following three sessions: 1) pressure pain thresholds (PPT) before and after quiet rest, clinical pain (McGill Pain Questionnaire), and physical activity levels (self-report and ActiSleep Plus Monitors) were measured, 2) PPT were measured with a computerized algometer at the fourth finger's nailbed, middle deltoid muscle, and quadriceps muscle before and after maximal oxygen uptake test ($\dot{V}O_{2max}$ Bruce Treadmill Protocol), and 3) body composition was measured with dual-energy x-ray absorptiometry. **Results**: All adolescents met criteria for $\dot{V}O_{2max}$. On the basis of body mass index *z*-score, adolescents were categorized as having normal weight ($n = 33$) or being overweight/obese ($n = 29$). PPT increased after exercise (EIH) and were unchanged with quiet rest (trial × session, $P = 0.02$). EIH was similar across the three sites and between normal-weight and overweight/obese adolescents. Physical activity and clinical pain were not correlated with EIH. Overweight/obese adolescents had similar absolute $\dot{V}O_{2max}$ ($L \cdot min^{-1}$) but lower relative $\dot{V}O_{2max}$ ($mL \cdot kg^{-1} \cdot min^{-1}$) compared with normal-weight adolescents. When adolescents were categorized using FitnessGram standards as unfit ($n = 15$) and fit ($n = 46$), the EIH response was similar between fitness levels. **Conclusions**: This study is the first to establish that both overweight and normal-weight adolescents experience EIH. EIH after high-intensity aerobic exercise was robust in adolescents regardless of weight status and not influenced by physical fitness. **Key Words:** PAIN RELIEF, CHILDREN, BODY MASS INDEX, $\dot{V}O_{2MAX}$, PHYSICAL ACTIVITY, PHYSICAL FITNESS

Exercise can decrease pain (i.e., exercise-induced hypoalgesia (EIH)) in adults and is dependent on both the intensity and duration of the exercise stimulus (19). To maximize EIH, aerobic exercise should be performed at a moderate/high intensity and for longer duration (19,39). EIH is systemic in that pain relief is not localized to the exercising muscle, although some studies show that EIH is more robust in the exercising body part compared with nonexercising body parts (20,39). All of these studies have been conducted on adults. To our knowledge, there are no studies investigating the effect of exercise on pain perception in adolescents. Identifying the EIH response in pediatric populations will help establish the potential benefits of exercise as a nonpharmacological pain management tool.

Weight status is an understudied factor in pain perception. Of the few studies, obese adults have lower pain sensitivity to a noxious stimulus (higher pain thresholds) compared with nonobese adults (7,30). In contrast, clinical pain reports tend to increase as the weight status of both adults and adolescents increases (27,33). Unfortunately, pain is commonly overlooked as a health outcome despite most obese youth reporting that they currently feel pain (14). Physical and psychosocial consequences of obesity include development of musculoskeletal dysfunction, poor quality of life, missed school, and social withdrawal (13,17). Thus, strategies to manage pain in obese adolescents are important for quality of life and health.

Physical inactivity is a major contributor to the obesity epidemic (22) and is associated with the increase in pain reported in this population (33). Pediatric barriers to participation in physical activity include age (adolescents are at greater risk than younger children) (10), weight status (obese youth are at greater risk than normal-weight youth) (10), and presence of pain (24). Thus, overweight adolescents with pain may be at high risk for sedentary behavior, resulting in poor physical fitness levels. Finally, self-reported physical activity is associated with endogenous pain modulation (23); individuals that report higher levels of physical activity have more efficient descending pain modulatory function. Furthermore, several chronic pain

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conditions (e.g., fibromyalgia, irritable bowel syndrome, headache, etc.) often exhibit decreased endogenous pain modulation (31). Because endogenous pain modulation is one of the mechanisms for pain relief associated with exercise, individuals that are more physically active may experience greater reduction in response to a pain stimulus with exercise (i.e., EIH) whereas individuals that report current pain may experience less EIH.

Understanding how pain changes with exercise will provide a scientific rationale to better use exercise in the management of pain in pediatric populations. The purpose of this study was to compare the magnitude of EIH in normal-weight and overweight/obese adolescents after a single session of intense aerobic exercise. To determine the possible modifying effect of baseline fitness, we also compared EIH in adolescents of varying levels of physical fitness in both normal-weight and overweight/obese adolescents. We hypothesized that normal-weight and overweight/obese adolescents would experience similar levels of EIH but those who were more physically fit would experience greater EIH. Because physical activity levels, presence of pain, and psychosocial influences (i.e., pain catastrophizing and quality of life) have been implicated in pain modulation, we examined their influence on EIH in the adolescents.

METHODS

Subjects

Sixty-two adolescents (15.1 ± 1.8 yr (12.0–17.9 yr); 29 boys and 33 girls) and their parent/legal guardian were recruited from a Midwestern United States metropolitan area (Milwaukee, WI) through community flyers, the Marquette University electronic newsletter, a monthly parenting magazine advertisement, and a Facebook advertisement. The adolescents were enroled as part of a larger study that investigated the association among inflammatory markers, physical fitness, and pain in adolescents of varying weight status. All adolescents were screened via phone conversation with a parent/legal guardian about the study components and exclusionary criteria. Adolescents in good health were eligible for participation in the study, with the following exclusions: 1) body mass index (BMI) below the 10th percentile for age and sex, 2) inability to report pain threshold (i.e., tissue trauma or neurological condition that would affect sensory perception), 3) unable to tolerate ice water submersion (e.g., Raynaud disease or cold urticaria), 4) exercise contraindications, 5) non-English speaking participants, 6) cognitive delays, 7) pregnancy, 8) claustrophobia, or 9) history of mental health disorder. The protocol was approved by the institutional review board at the Marquette University.

Experimental Protocol

Adolescents participated in three experimental sessions with approximately 1 wk between sessions. The respective parent/legal guardian completed questionnaires related to the adolescent's health and wellness. At the start of the first session, the adolescent and parent completed the assent and consent, respectively. During this session, resting vitals, weight status, experimental pain (i.e., pressure pain thresholds (PPT)) before and after 20 min of quiet rest, clinical pain, and self-report physical activity levels were measured. Adolescents were also instructed on wearing the physical activity monitors. After the first session, adolescents participated in either the treadmill or dual-energy x-ray absorptiometry (DXA) sessions in a counterbalanced manner. The treadmill session involved the measurement of experimental pain before and after a maximal aerobic treadmill test (maximal oxygen uptake test ($\dot{V}O_{2max}$)) along with psychosocial assessments (i.e., quality of life and pain catastrophizing). The DXA session measured body composition.

Weight Status and Body Composition

From height (cm) and mass (kg) measurements, BMI was calculated and plotted for percentiles and *z*-scores. On the basis of BMI *z*-scores, 33 adolescents were classified as having normal weight (BMI *z*-score < 1.00), and 29, as overweight/obese (BMI *z*-score ≥ 1.00) (29).

Total body DXA scans were performed with the Lunar GE Prodigy (GE, Madison, WI) bone densitometer to determine body composition. Before each scan, a quality assurance protocol was completed, a phantom was scanned for calibration purposes, and female adolescents completed a pregnancy test. Scans were analyzed using the Lunar GE Prodigy pediatric software to quantify fat body mass (kg), lean body mass (kg), total body fat (%), android fat (%), gynoid fat (%), and android/gynoid (A/G) ratio. Adolescents were classified as either android (A/G ratio ≥ 1.0) or gynoid (A/G ratio < 1.0). Total body fat *z*-scores for age and sex were determined using the online Baylor College of Medicine Body Composition Laboratory Pediatric Body Composition Reference Charts (18).

Experimental Pain—PPT Testing

PPT were measured during the first experimental session (before/after 20-min quiet rest) and before/after maximal aerobic exercise (treadmill session) at three sites: left fourth finger's nailbed, left middle deltoid muscle (one-quarter the distance from the acromion to the lateral epicondyle), and right quadriceps muscle (half the distance from the anterior superior iliac crest to the superior patella) (2). Three trials were completed at each site with a 10-s interstimulus interval, and the site order was randomized at each session. A battery-operated pressure algometer (Algomed) with a 1-cm^2 probe was placed on each site at a rate of 50 kPa·s^{-1} (16). The adolescents were seated and instructed to push the patient response unit when they first felt pain (i.e., pain threshold), which was electronically recorded in kilopascals.

Pain and Quality of Life Assessments

McGill questionnaire (MPQ). Participants completed the MPQ during the first session. This questionnaire evaluates the multidimensional aspect of pain (sensory, affective, and cognitive) related to current pain. Higher scores represent more pain.

Pain catastrophizing scale–child and parent (PCS-C and PCS-P). To address pain catastrophizing (i.e., negative mental response to anticipated or actual pain), the adolescent and respective parent completed the PCS-C and PCS-P during the treadmill session. The questionnaire has 13 statements that are scored in a Likert Scale (0–5) with three subcategories: rumination, magnification, and helplessness. Higher PCS scores are indicative of higher pain catastrophizing with clinical reference points for the PCS-C as low (0–14), moderate (15–25), and high (>26) (28).

Pediatric quality of life inventory (PedsQL). All adolescents and respective parents completed the PedsQL for child (8–12 yr of age) or teen (13–18 yr of age) with the corresponding parent version. The PedsQL is a valid and reliable measurement of pediatric health-related quality of life and has been used in youth of varying weight status (40). The PedsQL was completed during the treadmill session and was scored for total, physical, social, emotional, and school domains. Higher PedsQL scores represent higher quality of life. Total PedsQL cutoff scores for impaired quality of life are 69.7 for the child/teen and 65.4 for the parent (40).

Physical Activity Assessments

Physical activity was quantified with accelerometers and self-reported physical activity levels. Adolescents were instructed to wear the ActiGraph monitor (ActiSleep Plus Monitor, Pensacola, FL) (9) on the nondominant wrist for seven consecutive days, complete daily logs (awake/sleep times, physical activity participation, and removal/reapplication of the device), and return the device at session 2. Data were downloaded via the ActiLife 6 Data Analysis Software (ActiGraph, Pensacola, FL) at 60-s epochs. Wear time validation was done (4), and adolescents were included in data scoring if they met the youth wearing recommendations for ActiGraph monitors (at least one weekend day and four weekdays for > 950 min·d^{-1}) (3). Next, the data were scored using pediatric cutoffs (11) to quantify length of time (min) in sedentary activity, light activity, and moderate/vigorous activity along with vector magnitude counts per minute and step counts. Additional sedentary analysis was completed to determine the average length of sedentary bouts (min), as defined by ≥10 min with ≤99 counts per minute (37). Wear time of the ActiGraph monitor was compared with the written activity logs completed by each adolescent.

Self-reported physical activity was quantified using the Physical Activity Questionnaire–Elementary School and High School Versions (PAQ). The PAQ is a reliable and valid instrument that provides a general measure of physical activity for youth from grades 4 to 12 (approximate age of 8–20 yr). Higher PAQ scores represent higher general physical activity. Cutoff points have been proposed to categorize youth as "at risk" or "no risk" for metabolic syndrome. Cutoff points for "at risk" are <2.9/5 for boys and <2.7/5 for girls (41).

Maximal Aerobic Treadmill Test ($\dot{V}O_{2max}$)

Adolescents completed a maximal aerobic treadmill test (T-2100 Treadmill; GE Healthcare, El Paso, TX) with a $\dot{V}O_{2max}$ Bruce protocol, which involved an increase in the grade and speed of the treadmill every 3 min (8). Twelve-lead EKG (CASE Cardiosoft V6.61; GE Healthcare, El Paso, TX) was obtained, and metabolic monitoring (Encore 29c; VMAX, Palm Springs, CA) of expired gases (O_2 and CO_2) and volumes were measured continuously online with 20-s averaging. Variables assessed from the $\dot{V}O_{2max}$ protocol include peak respiratory rate (RR), relative $\dot{V}O_{2max}$ (mL·total body mass kg^{-1}·min^{-1}), and absolute $\dot{V}O_{2max}$ (L·min^{-1}). Lean $\dot{V}O_{2max}$ (mL·lean body mass kg^{-1}·min^{-1}) was also calculated by dividing absolute $\dot{V}O_{2max}$ by the lean body mass (kg) (21); the lean body mass was obtained from the DXA scan.

Adolescents reported RPE (0–10) at the end of each 3-min stage and at termination. Verbal encouragement was given throughout the test until the subject signaled that they wanted to terminate the test. Criteria for establishing $\dot{V}O_{2max}$ was based on meeting at least two of the following four criteria: 1) volitional fatigue (RPE > 8), 2) respiratory quotient (RQ) > 1.0, 3) HR > 85% age-predicted HR_{max} (42), and 4) plateau in O_2 consumption. Upon completion of the treadmill test, recovery included walking (2 min) followed by sitting (2 min). Immediately after the 4-min recovery, measurement of postexercise experimental pain (PPT) was completed.

Adolescents were categorized as "fit" or "unfit" according to their relative $\dot{V}O_{2max}$ (mL·kg^{-1}·min^{-1}) and FitnessGram standards. Specifically, the FitnessGram has established criteria (age and sex specific) to classify a youth's aerobic capacity (mL· kg^{-1}·min^{-1}) as being in the healthy fitness zone. This threshold for aerobic capacity, which varies according to age and sex, represents the minimum fitness level to offer protection against diseases that result from sedentary living (34). For example, the healthy fitness zone for a 12-yr-old female is ≥40.1 mL· kg^{-1}·min^{-1}, whereas the healthy zone for a 17-yr-old male is ≥44.2 mL· kg^{-1}·min^{-1}. Using these $\dot{V}O_{2max}$ criteria, each adolescent was categorized into either the "fit" group (within the healthy fitness zone) or the "unfit" group (below the healthy fitness zone).

Statistical Analysis

Data were analyzed using Statistical Package for the Social Sciences (SPSS version 21; IBM, Chicago, IL) and reported as mean ± SD within the text and table and the mean ± SE in the figure. A P value ≤ 0.05 was used for statistical significance.

PPT was calculated by averaging the three thresholds at each site (nailbed, deltoid muscle, and quadriceps muscle). Mixed-design multivariate repeated-measures ANOVA was used to assess for change in PPT (trial (before and after) × session (baseline and treadmill) × site (nailbed, deltoid muscle, and quadriceps muscle)). Weight status (normal weight or overweight/obese), fitness level (fit or unfit), and body composition (android or gynoid) were between-subject factors. When a significant effect was found, Bonferroni-corrected *t*-tests for *post hoc* multiple comparisons were used to identify differences. Pearson correlations were calculated to determine associations between EIH (before/after PPT at combined sites) and dependent variables.

RPE during the treadmill test was analyzed using repeated-measures ANOVA (time: end of stage 1, midpoint, and termination) using between-subject factors of weight status (time × weight status (normal weight or overweight/obese)) and fitness levels (time × fitness levels (fit or unfit)). *Post hoc* independent *t*-tests were used when appropriate. Independent *t*-tests were completed between the weight (normal weight or overweight/obese) and fitness (fit or unfit) groups to identify potential differences in demographics, weight and body composition, physical activity, physical fitness, health, pain (MPQ, present pain intensity, and baseline (preexercise) PPT), and psychosocial measures. Additional independent *t*-tests were used to compare adolescents at risk and adolescents at no risk for metabolic syndrome.

Physical activity monitor data were analyzed via the ActiLife 6 Data Analysis Software (ActiGraph, Pensacola, FL) (Fig. 1). Twelve subjects were not included in wear time analysis because of the following: 1) loss of monitor (n = 4; one normal-weight fit, one overweight/obese fit, and two overweight/obese unfit adolescents), 2) refusal to wear the monitor for the full duration (n = 4; two normal-weight fit and two overweight/obese fit adolescents); and 3) choice of not wearing the monitor because of participation in organized swimming or baseball regulations (n = 4; all normal-weight fit adolescents). Data from 50 adolescents underwent ActiLife pediatric wear time validation (4), and four adolescents were excluded because they did not wear the device for the minimum time (3). Final data scoring from 46 adolescents (n = 27 normal weight, 23 fit and two unfit; and n = 19 overweight/obese, 12 fit and seven unfit) was completed to quantify levels of physical activity (11). Of the 46 adolescents, 11 adolescents (n = 6 normal weight, five fit and one unfit; and n = 5 overweight/obese, four fit and 1 unfit) were required as per coach/referee rules to remove the device during practices and/or competitive sporting events.

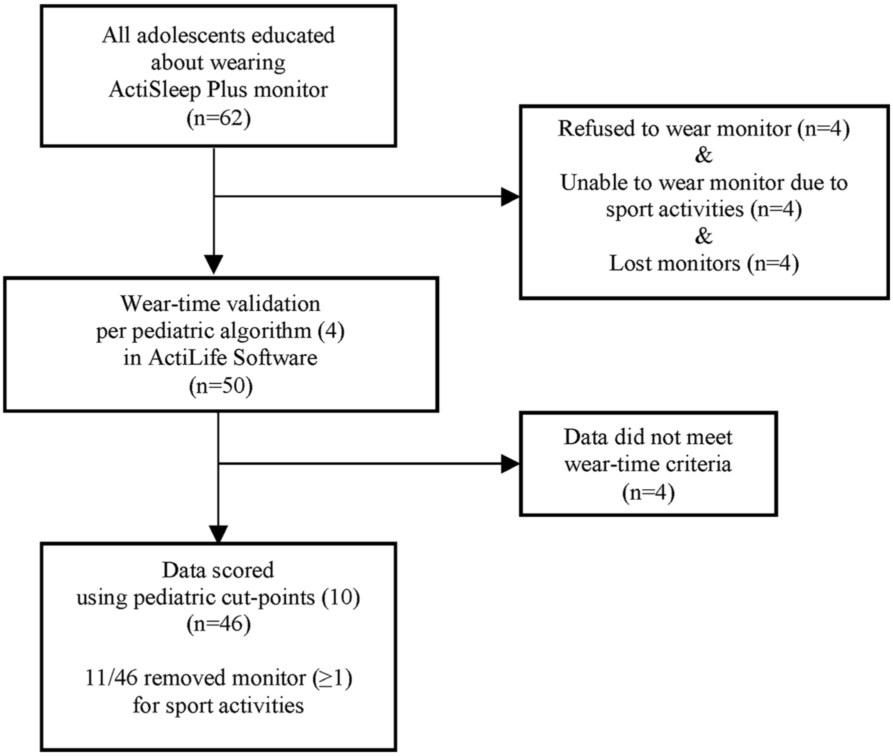

FIGURE 1—ActiGraph data analysis flow chart.

RESULTS

Subjects

Of the 62 adolescents (and respective parent/legal guardian) that participated in this study, one adolescent was excluded from each of the EIH, DXA, and $\dot{V}O_{2max}$ analyses because of technical difficulties with the software, positive pregnancy test result, and operational error, respectively.

Baseline Measures in Normal-Weight versus Overweight/Obese Adolescents

On the basis of the BMI *z*-score classification, 33 adolescents were of normal weight and 29 were overweight/obese (Table 1). Overweight/obese adolescents had higher total body fat percentage, total body fat *z*-score, and fat mass (all $P < 0.0001$) but similar lean body mass ($P > 0.05$) compared with normal-weight adolescents. All adolescents were classified as either gynoid ($n = 41$; 18 males and 23 females; 31 of normal weight, 10 overweight/obese) or android ($n = 20$; 11 males and nine females; two of normal weight, 18 overweight/obese) on the basis of the DXA scan.

Self-reported physical activity (PAQ) was similar between the normal-weight and overweight/obese adolescents (Table 1); however, PAQ was inversely correlated with total body fat *z*-score ($r = -0.263$, $P = 0.04$), so that adolescents with more body fat reported less physical activity. On the basis of accelerometry ($n = 46$), normal-weight and overweight/obese adolescents had similar physical activity levels with the exception of average length of sedentary bouts (min) where overweight/obese adolescents had longer sedentary time ($P = 0.005$).

Overweight/obese adolescents had lower relative $\dot{V}O_{2max}$ ($mL \cdot kg^{-1} \cdot min^{-1}$) ($P < 0.0001$) and decreased time to exhaustion during the aerobic capacity test ($P < 0.0001$) compared with the normal-weight adolescents (Table 1). Absolute $\dot{V}O_{2max}$ and lean $\dot{V}O_{2max}$ were the same between the weight groups.

For the pain measures, baseline (preexercise) PPT were similar between the two weight groups. Furthermore, clinical pain and quality of life were similar between the weight groups, with the exception of current pain intensity (MPQ visual analog scale (VAS), $P = 0.05$) where normal-weight adolescents reported higher pain than the overweight/obese adolescents. In addition, parent's perspective for physical quality of life ($P = 0.04$) was higher in the normal-weight group and pain catastrophizing rumination ($P = 0.03$) was lower in the normal-weight group in contrast to that in the overweight/obese group (Table 1).

Baseline Measures in Fit versus Unfit Adolescents

On the basis of the FitnessGram performance standards using relative $\dot{V}O_{2max}$, adolescents were classified as fit ($n = 46$; 30 normal weight and 16 overweight/obese) or unfit ($n = 15$; two of normal weight and 13 overweight/obese) (Table 1). The two groups differed in that fit adolescents had higher absolute $\dot{V}O_{2max}$ ($P = 0.02$), lean $\dot{V}O_{2max}$ ($P < 0.0001$), peak RR ($P = 0.002$), and time to exhaustion ($P < 0.0001$ (Table 1) than unfit adolescents. The fit group also had higher self-reported physical activity ($P = 0.03$), lower resting HR ($P < 0.0001$), and lower resting systolic pressure ($P = 0.03$) and diastolic pressure ($P = 0.03$). On the basis of ActiGraph monitoring, fit and unfit adolescents had similar physical activity levels, with the exception of average length of sedentary bouts (min) where fit adolescents had shorter sedentary time ($P = 0.018$). With respect to body composition and weight status, fit adolescents compared with unfit adolescents had lower BMI *z*-scores, body fat percentage, total body fat *z*-scores, fat mass, android fat, and gynoid fat (all $P < 0.0001$) but similar lean body mass.

Specific to pain measures, baseline (preexercise) PPT were similar between the fit and unfit adolescents (Table 1). There were no differences between the fit and unfit group for the adolescent's clinical pain (MPQ) and the child's and parent's perspectives for pain catastrophizing ($P > 0.05$). Quality of life from the child's perspective (total quality of life ($P = 0.02$), physical functioning ($P = 0.02$), and social functioning ($P = 0.02$) were significantly higher in the fit adolescents compared with that in the unfit. Quality of life assessment from the parent's perspective (total quality of life ($P = 0.02$), physical functioning ($P = 0.02$), and school functioning ($P = 0.01$) were significantly higher in the fit adolescents (Table 1).

Exercise Response

All adolescents, regardless of weight status, met the American College of Sports Medicine criteria for the completion of a $\dot{V}O_{2max}$ test, as follows: peak RPE (9.1 ± 1.4), RQ (1.1 ± 0.1), and HR_{max} (96.5% ± 11.1%). There was no difference in peak RPE or percentage of HR_{max} by weight status or physical fitness levels (Table 1). RQ differed between fitness levels in that unfit adolescents had lower RQ values than fit adolescents ($P = 0.02$) but did not differ with weight status (Table 1).

Perceived exertion increased during the aerobic capacity treadmill test (time, $P < 0.0001$). This increase was similar between fitness groups (time × fitness levels, $P > 0.05$). In contrast, the increase in perceived exertion differed by weight status (time × weight status, $P = 0.04$). *Post hoc* analyses showed that perceived exertion at the end of stage 1 was greater for the overweight/obese adolescents (1.8 ± 2.0) compared with that for the normal-weight adolescents (0.8 ± 0.9, $P = 0.04$). There were no differences in perceived exertion at midpoint or termination of the treadmill.

Experimental Pain after Quiet Rest and Exercise Sessions

Pain thresholds increased after exercise (i.e., EIH) but were unchanged after quiet rest (trial × session, $P = 0.02$)

TABLE 1. Descriptives of adolescent subjects by weight status and physical fitness levels.

	Normal Weight (*n* = 33)	**Overweight/Obese (*n* = 29)**	**Fit (*n* = 46)**	**Unfit (*n* = 15)**
Demographics				
Sex (males)	17	12	23	6
Age (yr)	15.5 ± 1.8	14.6 ± 1.8	15.3 ± 1.8	14.7 ± 1.8
Ethnicity				
Caucasian	31	16	40	6
African-American	0	9	3	6
Hispanic	2	4	3	3
Vitals	*n* = 33	*n* = 29	*n* = 46	*n* = 15
Resting HR (bpm)	72.5 ± 11.4	78.0 ± 11.9	71.7 ± 11.3	85.5 ± 7.0*
Resting systolic BP (mm Hg)	107.1 ± 10.7	115.7 ± 11.3**	109.4 ± 11.7	116.8 ± 10.6***
Resting diastolic BP (mm Hg)	71.3 ± 6.8	74.1 ± 8.7	71.6 ± 6.9	76.5 ± 8.8***
Resting MAP (mm Hg)	83.2 ± 6.4	87.9 ± 8.6***	84.2 ± 7.0	90.0 ± 8.6***
Resting pulse ox (%)	97.3 ± 1.1	97.5 ± 1.1	97.4 ± 1.2	97.3 ± 0.9
Weight status and body composition	*n* = 33	*n* = 28	*n* = 46	*n* = 14
BMI ($kg \cdot m^{-2}$)	21.1 ± 1.9	30.5 ± 6.8*	23.2 ± 3.4	33.4 ± 8.4*
BMI *z*-score	0.27 ± 0.47	1.87 ± 0.50*	0.72 ± 0.75	2.04 ± 0.64*
Total body fat (%)	20.9 ± 9.2	40.8 ± 7.6*	26.7 ± 11.9	41.8 ± 10.2*
Total body fat *z*-score (age and sex)	−0.80 ± 1.00	1.60 ± 0.47*	−0.05 ± 1.34	1.58 ± 0.88*
Android fat (%)	22.3 ± 11.5	47.1 ± 8.6*	29.6 ± 14.6	48.3 ± 12.2*
Gynoid fat (%)	29.0 ± 10.7	46.6 ± 6.7*	34.4 ± 12.4	46.3 ± 8.8*
A/G ratio	0.74 ± 0.19	1.0 ± 0.11*	0.82 ± 0.19	1.03 ± 0.16*
Lean body mass (kg)	45.40 ± 10.55	47.61 ± 12.23	45.22 ± 10.30	51.48 ± 13.05
Fat body mass (kg)	11.91 ± 5.52	33.90 ± 13.39*	16.98 ± 9.16	39.56 ± 16.81*
Physical activity				
Self-reported physical activity	*n* = 33	*n* = 29	*n* = 46	*n* = 15
PAQ score (0–5)	2.7 ± 0.6	2.5 ± 0.7	2.7 ± 0.6	2.3 ± 0.7***
ActiGraph accelerometry	*n* = 26	*n* = 20	*n* = 35	*n* = 10
Average length of sedentary bouts (min)	22.9 ± 2.7	25.1 ± 2.0**	23.3 ± 2.7	25.6 ± 1.7***
Sedentary (%)	53.7 ± 5.6	54.15 ± 5.7	53.4 ± 5.6	54.9 ± 5.6
Light activity (%)	11.6 ± 1.6	11.9 ± 1.4	11.6 ± 1.5	12.3 ± 1.6
Moderate/vigorous activity (%)	34.7 ± 5.3	34.0 ± 5.7	35.0 ± 5.4	32.8 ± 5.4
Steps count	72,100.2 ± 17,599.5	72,527.3 ± 15,938.1	73,781.1 ± 17,015.0	68,003.7 ± 16,250.2
Vector magnitude counts per minute	1988.5 ± 459.6	1852.2 ± 421.9	2002.6 ± 444.6	1695.8 ± 389.4
Physical fitness	*n* = 31	*n* = 29	*n* = 46	*n* = 15
Absolute $\dot{V}O_{2max}$ ($L \cdot min^{-1}$)	3.48 ± 1.01	3.20 ± 0.90	3.51 ± 0.94	2.86 ± 0.86***
Relative $\dot{V}O_{2max}$ ($mL \cdot TBW\ kg^{-1} \cdot min^{-1}$)	57.4 ± 12.7	38.9 ± 11.3*	54.4 ± 12.1	30.9 ± 8.3*
Lean $\dot{V}O_{2max}$ ($mL \cdot LBM\ kg^{-1} \cdot min^{-1}$)	75.5 ± 10.9	69.1 ± 14.3	77.4 ± 9.9	56.5 ± 7.6*
RR Peak (breaths per minute)	49.3 ± 5.9	46.8 ± 9.1	49.7 ± 6.5	43.0 ± 8.9**
HR exercise slope	8.42 ± 1.56	10.12 ± 2.46**	8.68 ± 1.54	10.65 ± 3.09***
HR recovery slope	−18.87 ± 8.48	−15.43 ± 7.49	−18.08 ± 7.55	−14.49 ± 9.65
RQ	1.08 ± 0.07	1.05 ± 0.06	1.08 ± 0.07	1.03 ± 0.1***
O_2 pulse (mL per beat)	17.5 ± 5.2	17.2 ± 5.1	17.8 ± 5.0	16.0 ± 5.5
Time to exhaustion (min)	13.4 ± 2.4	10.2 ± 2.4*	13.0 ± 2.4	9.1 ± 2.4*
Exercise tolerance	*n* = 31	*n* = 29	*n* = 46	*n* = 15
Peak RPE during $\dot{V}O_{2max}$ (0–10)	9.2 ± 1.1	9.0 ± 1.7	9.0 ± 1.5	9.1 ± 1.2
HR_{max} (%)	97.3 ± 8.2	95.6 ± 13.7	98.0 ± 9.2	92.0 ± 15.2
Experimental pain	*n* = 32	*n* = 29	*n* = 45	*n* = 15
Preexercise PPT (all sites combined) (kPa)	380.3 ± 201.3	425.7 ± 273.9	379.9 ± 207.7	468.5 ± 311.3
Postexercise PPT (all sites combined) (kPa)	411.4 ± 235.7	462.3 ± 314.3	414.6 ± 238.8	502.2 ± 363.4
Clinical pain and quality of life	*n* = 33	*n* = 29	*n* = 46	*n* = 15
MPQ				
MPQ (total, 0–78)	4.48 ± 6.20	3.76 ± 8.72	4.74 ± 8.29	2.27 ± 3.81
MPQ (PPI, 0–5)	0.82 ± 0.98	0.48 ± 0.74	0.67 ± 0.92	0.53 ± 0.74
MPQ (VAS, 0–10 cm)	1.13 ± 1.42	0.48 ± 1.11***	0.89 ± 1.4	0.44 ± 0.67
PCS				
PCS-C (total, 0–52)	16.39 ± 10.22	17.07 ± 10.04	16.20 ± 10.11	18.67 ± 10.21
PCS-P (total, 0–52)	13.52 ± 9.05	18.00 ± 10.85	14.78 ± 9.74	18.87 ± 10.88
PCS-P (magnification, 0–12)	2.70 ± 2.08	3.34 ± 2.48	2.83 ± 2.18	3.67 ± 2.50
PCS-P (rumination, 0–16)	6.52 ± 3.51	8.72 ± 4.11***	7.24 ± 3.97	8.80 ± 3.65
PCS-P (helplessness, 0–24)	4.30 ± 4.20	5.93 ± 5.23	4.72 ± 4.47	6.40 ± 5.50
PedsQL (all, 0–100)				
PedsQL child (total)	84.3 ± 8.3	84.3 ± 11.8	86.1 ± 8.8	78.9 ± 12.2***
PedsQL child (physical)	86.1 ± 10.1	84.8 ± 11.9	87.4 ± 10.4	80.0 ± 11.4***
PedsQL child (social)	91.5 ± 10.3	88.8 ± 13.3	92.1 ± 10.0	84.0 ± 15.0***
PedsQL child (emotional)	80.8 ± 13.4	81.6 ± 18.1	82.5 ± 14.1	76.3 ± 19.8
PedsQL child (school)	77.7 ± 12.9	81.7 ± 15.3	81.6 ± 12.2	74.7 ± 17.9
PedsQL child (psychosocial health summary)	83.3 ± 9.7	84.0 ± 14.0	85.4 ± 10.0	78.3 ± 15.7
PedsQL parent (total)	88.8 ± 10.3	82.7 ± 18.5	89.2 ± 10.3	75.4 ± 21.6***
PedsQL parent (physical)	92.3 ± 8.2	83.4 ± 21.0***	92.3 ± 8.7	74.8 ± 25.0***
PedsQL parent (social)	94.1 ± 9.7	86.21 ± 20.2	93.5 ± 10.3	80.3 ± 24.8
PedsQL parent (emotional)	82.0 ± 17.1	81.4 ± 20.2	83.8 ± 16.4	74.7 ± 23.5
PedsQL parent (school)	84.8 ± 16.7	79.5 ± 20.0	85.7 ± 15.9	72.0 ± 22.5***
PedsQL parent (psychosocial health summary)	87.0 ± 12.5	82.4 ± 18.2	87.6 ± 12.0	75.7 ± 21.5

Data are represented as mean ± SD.

*$P < 0.0001$.

**$P < 0.01$.

***$P < 0.05$.

BP, blood pressure; LBM, lean body mass; MAP, mean arterial pressure; PPI, present pain intensity; TBW, total body weight.

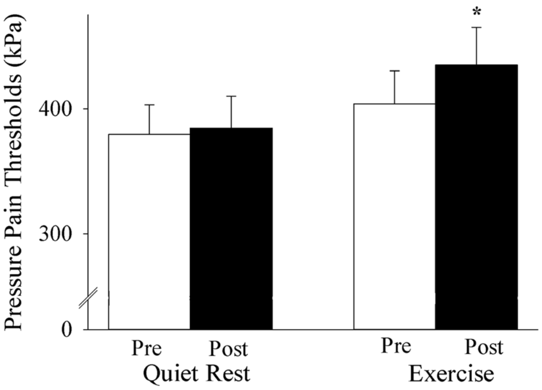

FIGURE 2—EIH versus quiet rest. PPT increased after maximal aerobic exercise and were unchanged after quiet rest (trial × session, P = 0.02). Data are represented as mean ± SEM.

(Fig. 2). This response was similar across the sites assessed for pain (trial × session × site, $P > 0.05$).

EIH: weight status and body composition. EIH was similar between the normal-weight and overweight/obese adolescents ($P > 0.05$). Regardless of weight status, gynoid and android adolescents reported similar EIH (trial × android/gynoid, $P > 0.05$). Lean body mass (kg) was weakly correlated with EIH ($r = 0.146$, $P = 0.05$) (Fig. 3); adolescents with higher total body lean mass experienced greater EIH, yet fat mass (kg) was not correlated ($P > 0.05$).

EIH: physical fitness and activity. Fit and unfit adolescents (based on relative $\dot{V}O_{2max}$), reported similar EIH (trial × fitness, $P > 0.05$). EIH was not correlated with relative $\dot{V}O_{2max}$, absolute $\dot{V}O_{2max}$, lean $\dot{V}O_{2max}$, and peak RR. Self-reported physical activity (PAQ) was not correlated with EIH, but total sedentary bouts ($r = -0.189$, $P = 0.03$) from the ActiGraph monitors were weakly inversely correlated with EIH; adolescents with greater sedentary time experienced less EIH. Furthermore, adolescents at risk for metabolic syndrome ($n = 38$; 19 normal weight and 19 overweight/obese) reported similar EIH compared with those not at risk for metabolic syndrome ($n = 24$; 14 normal weight and 10 overweight/obese).

EIH: clinical pain and quality of life. Clinical pain measured with the MPQ was not correlated with EIH. PedsQL Child/Teen physical functioning was weakly correlated with EIH ($r = 0.149$, $P = 0.05$); adolescents with greater physical functioning experienced greater EIH. PCS-C and PedsQL Parent were not associated with EIH ($P > 0.05$).

DISCUSSION

This study is the first to demonstrate that overweight/obese adolescents report reduced response to a pain stimulus after intense aerobic exercise, and this response was analogous to normal weight adolescents. The increase in pain threshold was similar across body sites (nailbed, deltoid muscle, quadriceps muscle) demonstrating a systemic response, which has important clinical implications and possibilities as a strategy for pain relief in adolescents. The decrease in pain perception throughout the body indicates that pain relief after exercise is not isolated to the exercising muscle. Thus, aerobic exercise has strong potential as a nonpharmacological pain management tool in adolescents regardless of their weight status.

Few studies have investigated the effect of weight status on EIH. Comstock et al. (5) showed that after a single exercise session of moderately heavy resistance training, lean and obese men reported similar levels of soreness and fatigue; pain perception was not specifically addressed in this study. Most studies that focus on overweight/obese individuals tend to focus on changes in health-related quality of life in conjunction with weight loss. Our results specifically address the role of exercise in decreasing pain perception in overweight/obese adolescents and parallel other findings that have shown that exercise gains extend beyond weight loss (35). For individuals with knee osteoarthritis, decreasing body fat and increasing physical activity were more important than weight loss for symptomatic relief (35). Similarly, in the current study, EIH was weakly associated with lean body mass but not total body mass and lean mass was similar between the weight groups. For individuals who are overweight/obese, the benefits of exercise are manifold and significant improvements in health may occur independent of weight loss (32).

When the adolescents were categorized on the basis of physical fitness, EIH was similar between the fit and unfit groups. In addition, self-reported physical activity was not associated with EIH. Previously, we have shown that self-reported physical activity was not associated with pain relief after isometric contractions in young and older healthy adults (23). In contrast, there are some reports that inactive individuals may not experience the same benefits with exercise and may even report increase in pain (38); our data

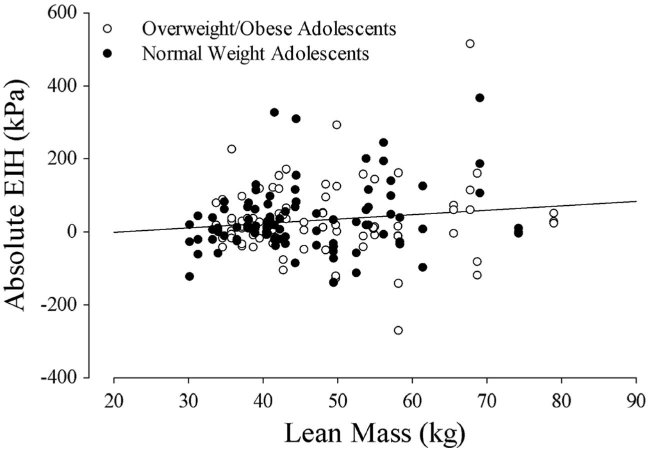

FIGURE 3—EIH and lean mass by weight status. EIH is positively correlated with lean mass (r = 0.146, P = 0.05). Normal-weight adolescents are shown as *filled circles*, and overweight/obese adolescents, as *open circles*. The distribution of normal-weight and overweight/obese adolescents demonstrates that they have similar lean mass and EIH.

concurs that inactive adolescents with more sedentary bouts experience less pain reduction after exercise. However, when adolescents were identified as being "at risk" for metabolic syndrome using published cutoff scores for self-reported physical activity (PAQ) (41), similar EIH occurred between the adolescent groups "at risk" and "no risk."

Weight status. Adolescents with higher BMI levels were categorized in the overweight/obese category, with most of these adolescents designated as obese. Of the 29 overweight/obese adolescents, 16 were classified as fit and 13 were classified as unfit. All of the weight status and body composition values, except lean body mass, were significantly different between the normal-weight and overweight/obese groups. In relation to physical fitness, relative $\dot{V}O_{2max}$ ($mL\cdot kg^{-1}\cdot min^{-1}$) was lower for the overweight/obese adolescents. There was no difference between the weight groups when lean $\dot{V}O_{2max}$ (relative to lean body mass) was compared. Thus, the lower relative $\dot{V}O_{2max}$ in overweight/obese adolescents was due to their elevated fat mass. Several studies have reported comparable results between obese and normal-weight participants; obese individuals tend to have lower relative $\dot{V}O_{2max}$ when calculated relative to total body mass and similar levels as those of normal-weight individuals when computed in relation to lean body mass (6,12,36). Overall, these results indicate that when total body mass is used as part of the physical fitness calculation, adolescents with greater mass have lower oxygen uptake. From a functional standpoint, they may have lower aerobic capacity when performing activities that necessitate movement of their body mass (12). In contrast, on the basis of the lean $\dot{V}O_{2max}$, overweight/obese adolescents and normal-weight adolescents have similar maximal aerobic capacity.

Several investigators have shown that pain reports increase and quality of life decreases with increasing weight status (14,15,43). The adolescents in this study reported minimal to no current pain intensity. Surprisingly, the normal-weight adolescents reported slightly higher current pain intensity (VAS) compared with the overweight/obese adolescents; both pain intensity reports, however, were not clinically relevant. In contrast, Hainsworth et al. (14) found that 50% of obese youth (class 2 and 3 obesity) in a clinical setting reported current pain. In the current study, adolescents had a lower overall obese classification and were not participating in a clinical weight management program, which may help explain the differences in pain reports. Quality of life was also similar between the two weight groups and within normal limits for both the child and parent's perspectives (40). The only difference between the two weight groups was from the parent's perspective. Parents of overweight/obese adolescents reported lower physical functioning of their adolescent compared with parents of normal-weight adolescents. Although several studies have shown lower health-related quality of life with increasing weight status (43,44), this relation between quality of life and weight status tends to be more distinct in clinical populations than community-based sampling (43). Using community-based sampling, our results demonstrate that normal-weight and overweight/obese adolescents have minimal pain reports and comparable quality of life.

Physical fitness. When the adolescents were categorized on the basis of physical fitness levels, most of the adolescents (75%) were determined to be in the healthy fitness zone (i.e., fit). All of the weight status and body composition measures, except lean body mass, were different between the fit and unfit groups. In relation to quality of life, fitness levels appeared to have a much bigger impact, both from the child and parent's perspectives, than weight status. Only one quality of life measure was different when comparing weight groups (parent—physical domain). When comparing fitness groups, however, six quality of life measures differed (three in the child and three in the parent). This finding emphasizes the need to view weight status and physical fitness as separate entities when addressing health outcomes (12,21). Despite the differences in quality of life, experimental and clinical pain reports were similar for the fit and unfit adolescents.

As anticipated, self-reported physical activity and sedentary time (ActiGraph monitoring) were lower in the unfit than those in the fit adolescents. Self-reported physical activity level was then used to identify adolescents at risk for metabolic syndrome (boys, <2.9; girls, <2.7) (41). The average physical activity for the unfit adolescents indicates that this group was at risk for metabolic syndrome. Surprisingly, the average for the fit adolescents (2.7) is borderline for metabolic syndrome. These results highlight the lack of physical activity in adolescents; only 8% of adolescents (12–19 yr) meet the US Department of Health and Human Services recommendations of 60 min of moderate-to-vigorous daily physical activity (26).

Objective physical activity measurement is considered more valid and reliable than self-report. Unfortunately, this study demonstrates that considerable data can be lost in adolescent participants that compete in sporting activities because referees and/or coaches require the adolescents to remove the device. The missing data no doubt affect the results for moderate/vigorous physical activity levels with a greater effect between the fitness levels than that in weight groups. For example, of the 11 adolescent athletes that were told to remove the device, the missing data were evenly distributed between normal-weight ($n = 6$) and overweight/obese ($n = 5$) adolescents. In contrast, nine of the 11 adolescents were "fit" versus two who were "unfit." As a result, this may have contributed to the lack of difference in physical activity, specifically for moderate/vigorous activity between fitness levels. These results highlight the challenges in capturing wrist-based accelerometry in an active pediatric population.

Exercise response. Although maximal aerobic exercise is not typically prescribed for pain management in adolescents, we chose this exercise dose because it is a measure of physical fitness and it allowed us to determine the EIH at maximal dose. It also allowed us to investigate whether adolescents could tolerate maximal aerobic exercise. One reason for the lack of evidence on whether obese individuals experience EIH is the concern that they cannot tolerate regular exercise and are at higher risk for injury (25). In this study, perceived exertion was similar between the normal-weight and overweight adolescents except at the initiation of the treadmill test when obese adolescents reported slightly higher perceived exertion. Furthermore, all of the adolescents tolerated and met the American College of Sports Medicine criteria for termination of the $\dot{V}O_{2max}$ test, and none of the adolescents experienced any contraindications for early termination. This exercise protocol is in line with Expert Committee recommendations for the prevention and treatment of child and adolescent overweight/obesity by promoting moderate-to-vigorous physical activity for at least 60 $min \cdot d^{-1}$ (1). Although maximal $\dot{V}O_2$ testing is not typically used as an exercise stimulus in the clinic, our results indicate that adolescents of different weight status tolerate and experience pain relief after maximal aerobic exercise.

Taking into account the differences in the $\dot{V}O_{2max}$ in relation to total body mass and lean mass, exercise tolerance could be affected on the basis of the degree of body mass movement (e.g., running vs cycling). Because of the shorter time to exhaustion and lower $\dot{V}O_{2max}$ relative to total body mass, obese adolescents may have more difficulty in the performance of weight-bearing activities (12), although this was not reflected in their perceived exertion at the midpoint or termination of the treadmill protocol. Thus, different $\dot{V}O_{2max}$ calculations (total body mass vs lean mass) may be used to calculate physical fitness and help establish performance levels during weight-bearing vs non–weight-bearing activities.

Limitations. Although this study helps lay the foundation for the prescription of maximal aerobic exercise in the management of pain, there are some limitations. First, the population sample should be expanded to include more distinct weight groups (overweight through class 3 obesity). These distinctions would help identify whether any changes in pain at rest and after exercise occur similarly at each level of weigh status. Second, physical activity measured by self-report has the potential for inaccuracies, as both over- and underreporting have been described in youth. However, objective physical activity monitoring may also be limited when adolescents participate in organized competitive sports. Third, an order effect may be present in this study's design, with the quiet rest condition always occurring before the exercise condition. Finally, we categorized the adolescents as fit or unfit on the basis of their relative $\dot{V}O_{2max}$ ($mL \cdot kg^{-1} \cdot min^{-1}$). Although this is the primary calculation used in determining physical fitness levels, excess adiposity in obese individuals may result in lower perceived physical fitness levels than if the $\dot{V}O_{2max}$ was based on lean mass. Despite this equivocality, there are no standardized data to use $\dot{V}O_{2max}$ per lean mass as a marker for physical fitness.

CONCLUSIONS

These results significantly add to the literature by providing much needed evidence in the prescription of therapeutic exercise as a pain management tool for adolescents of varying weight and fitness levels. Both normal-weight and overweight/obese adolescents experienced similar levels of EIH after maximal aerobic exercise. In addition, physical fitness levels did not influence the magnitude of EIH, but sedentary time was associated with EIH. Nevertheless, physical fitness levels may be more important than weight status when determining quality of life in adolescents. When measuring physical fitness, the influence of total body mass and lean mass on $\dot{V}O_{2max}$ should be assessed for a broader understanding of physical fitness levels and implications for weight-bearing and non–weight-bearing activities. Additional pediatric research is warranted in identifying the effect of weight status on pain perception at rest and after exercise with multiple stages of obesity and community-based versus clinically based populations.

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