Sex Differences in Pulmonary Oxygen Uptake Kinetics in Obese Adolescents

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Objective To determine whether sex differences exist in the pulmonary oxygen uptake (VO_2) uptake on-kinetic response to moderate exercise in obese adolescents. We also examined whether a relationship existed between the VO_2 on-transient response to moderate intensity exercise, steady-state VO_2, and peak VO_2 between obese male and female adolescents.

Study design Male (n = 12) and female (n = 28) adolescents completed a graded exercise test to exhaustion on a treadmill. Data from the initial 4 minutes of treadmill walking were used to determine the time constant.

Results The time constant was significantly different (P = .001) between obese male and female adolescents (15.17 ± 8.45 seconds vs 23.07 ± 8.91 seconds, respectively). No significant relationships were observed between the time constant and variables of interest in either sex.

Conclusions Sex differences exist in VO_2 uptake on-kinetics during moderate exercise in obese adolescents, indicating an enhanced potential for male subjects to deliver and/or use oxygen. It may be advantageous for female subjects to engage in a longer warm-up period before the initiation of an exercise regimen to prevent an early termination of the exercise session. *(J Pediatr 2014;165:1161-5)*.

The study of the physiological mechanisms responsible for the oxygen consumption (VO_2) response to exercise is important in the context of understanding one's health, aerobic performance capabilities, and the metabolic activity of muscle.[1-3] VO_2 increases when external work is imposed, although the increase in VO_2 is not immediate and thus does not reflect initially the level expected for a specific workload at the initiation of exercise. Pulmonary VO_2 on-kinetics reflects the rate change in VO_2 during exercise, specifically the time needed for the cardiopulmonary system to deliver and skeletal muscle to consume the increased level of oxygen needed for aerobic metabolism.[4,5] A key portion and subsequent derived measure of VO_2 on-kinetic response is the phase II time constant (τ2), which represents the time taken to reach 63% of steady-state VO_2. In essence, individuals with a better health status and who participate in a regular aerobic exercise training program have a faster τ2. Comparatively, individuals with a poorer health status and/or lead a sedentary lifestyle have a slower τ2. In fact, τ2 has proven to be a valuable tool in providing information related to an individual's ability to tolerate physical activity.[2,3]

τ2 becomes progressively longer from adolescence into adulthood,[6,7] suggesting a maturation effect that significantly prolongs the moderate-intensity VO_2 on-kinetic response in adults.[6,8,9] Although there is no support for greater oxygen delivery capacity in adolescents, there is support for enhanced oxidative enzymatic activity[10,11] in adolescents compared with adults. Studies that have attempted to provide an explanation of the enhanced muscle enzymatic activity, as well as fiber type distribution, between adults and adolescents have solely focused on normal-weight male adolescents.[11,12] Moreover, recently it has been suggested that overweight children have an impaired exercise capacity compared with their normal-weight counterparts.[13] In several studies researchers have evaluated VO_2 on-kinetics between obese and nonobese children and adolescents. Earlier studies suggested that increased adiposity is not indicative of delayed VO_2 on-kinetics during submaximal exercise[13-15]; however, more recent findings have suggested that obese children and adolescents display a markedly slower τ2 during both moderate- and high-intensity exercise compared with their normal-weight counterparts.[16,17]

Only one study has evaluated sex differences in VO_2 on-kinetics in adolescents.[6] In it, the authors demonstrated nonsignificant sex differences between lean male and female adolescents. Interestingly, their results display moderate effect sizes (0.49), indicating that a larger sample size may have allowed for greater detection of differences between boys and girls. More importantly, studies have

τ2	Phase II time constant
HR	Heart rate
VO_2	Oxygen consumption
VO_{2peak}	Peak oxygen consumption
VT	Ventilatory threshold

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shown equivocal results regarding the impact increased adiposity may have on mitochondrial function in obese adolescents.[18,19]

The aim of this study was to investigate the VO_2 on-kinetic response to exercise performed below the ventilatory threshold (VT, ie, moderate intensity) in obese male and female adolescents. We also aimed to examine whether a relationship exists between the VO_2 on-kinetic response to moderate intensity exercise and both steady-state VO_2 and peak oxygen consumption (VO_{2peak}) in obese male and female adolescents.

Methods

Obese male and female adolescents between 11 and 16 years of age (body mass index ≥85th percentile for age and sex according to the 2000 Centers for Disease Control and Prevention Growth Charts) were recruited to participate in this study. Study procedures were explained, and parents provided written, informed consent and adolescents provided written assent before participation. A complete medical history, physical examination, and evaluation for participation in exercise testing were conducted by a physician. The physical examination included a standardized assessment of pubertal development via Tanner staging. To control for pubertal influence on VO_2 on-kinetics, the study was limited to adolescent males with a Tanner stage of at least II and females who had experienced menarche.[20] All procedures were approved by the Virginia Commonwealth University Institutional Review Board.

After an overnight fast, each adolescent underwent anthropometric measurement and fasting blood glucose assessment. Anthropometric measurements included height (to the nearest 0.5 cm), weight (to the nearest 0.25 kg), and body composition via whole body dual-energy X-ray absorptiometry (Hologic 4500a/Discovery scanner; Hologic Inc, Bedford, Massachusetts). Adolescents diagnosed with type 2 diabetes exhibit delayed VO_2 on-kinetics.[14] Therefore, this study was limited to participants who did not have impaired fasting glucose (>100 mg/dL).[21]

Participants were asked to refrain from exercise 24 hours before the exercise test and arrived at least 4 hours postprandial. VO_{2peak} and VO_2 on-kinetics were determined by the use of a maximal graded exercise test to exhaustion on a treadmill (Trackmaster TMX425C; Full Vision, Inc, Newton Kansas). Previous research has shown a high degree of reliability in using a single bout of exercise on a treadmill to measure VO_2 on-kinetics.[22] Additionally, the use of a treadmill requires a subject to move his or her own weight, potentially affecting the cardiovascular and metabolic responses to exercise and exercise intolerance. Oxygen consumption, obtained through breath-by-breath gas exchange variables, was measured via a VMAX Spectra Sensormedics gas analyzer (Sensormedics Corp, Yorba Linda, California). Heart rate (HR) responses were recorded at each minute during the test via heart rate monitor (Model E600; Polar Electro, Lake Success, New York) and ratings of perceived exertion (6-20 Borg Scale) were documented near the end of each stage.

After a 3-minute rest period of standing gas exchange, subjects began a step transition into a 4-minute stage at 2.5 mph and 0% grade. The progressive protocol continued with a 2-minute stage at 3 mph at 0% grade. Subsequent 2-minute stages were held constant at 3.0 mph whereas grade was increased to 2%, 5%, 8%, 11%, 14%, and 17.0%. Subjects were verbally encouraged to give maximal effort during the test until volitional exhaustion was achieved. The attainment of VO_{2peak} was determined by participants satisfying at least 2 of the following criteria: (1) a respiratory exchange ratio ≥1.00; (2) a maximum HR ≥90% of age predicated maximum HR; and (3) ratings of perceived exertion ≥18. VO_{2peak} was taken at the greatest recorded 20-second average during the maximal exercise test.[23] After the exercise test, VT was determined noninvasively by visual inspection using the V-slope method, which has shown good interobserver agreement between and across exercise protocols.[24] VT was defined as the inflection point in which carbon dioxide production begins to increase at a more rapid rate than VO_2.[25]

Data from the initial 4-minute stage were used for the exercise transition to assess VO_2 on-kinetics. A single bout of submaximal exercise on a treadmill has provided a high degree of reliability in measures of VO_2 on-kinetics[22]; however, exercise eliciting a response above the VT poses a likelihood of a secondary increase in VO_2 on-kinetics that may alter the reliability of the $\tau 2$.[3] Therefore, to determine an intensity similar to that used in a previous investigation evaluating sex-based differences in VO_2 on-kinetics during transition from rest to moderate intensity exercise, data analysis within this study was limited to subjects with an initial-stage VO_2 ($mLO_2 \cdot kg^{-1} \cdot min^{-1}$) less than 60% of VO_{2peak} and within 75-95% of their VT.[6]

To determine VO_2 on-kinetics, O_2 uptake during the last 2 minutes of rest and throughout the first stage of the exercise test was averaged over 10-second intervals to reduce noise and enhance the underlying physiological response characteristics.[22] Oxygen consumption at time zero was defined using the 2-minute averaged resting data. The initial 20 seconds of exercise were not included in the kinetic analysis given the cardiodynamic effects of phase 1. The remaining data set was fitted to a mono exponential curve with a delay relative to the onset of exercise of the form:

$$VO_{2\,(t)} = VO_{2\,(\text{resting})} + VO_{2\,(\text{amplitude})}\left[1 - e^{-(t/\tau VO_2)}\right]$$

where $VO_{2\,(t)}$ is O_2 uptake at any time t, $VO_{2\,(\text{resting})}$ is the mean O_2 uptake measured during rest, $VO_{2\,(\text{amplitude})}$ is the increase in O_2 uptake above rest (average of the last 2 minutes of exercise), e is the base of the natural logarithm, and τVO_2 is the $\tau 2$ or the fundamental component of the increase in VO_2 above baseline reported in seconds.[2,3,22]

Statistical Analyses

Independent sample t tests were used to investigate differences in anthropometric and exercise responses between the 2 groups. In addition, correlation coefficients were used