AUDIBLE BREATHING AND EXERCISE AT THE VENTILATORY THRESHOLD IN YOUTH

BY

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A Thesis submitted to the Faculty of Graduate Studies
in partial fulfillment of the requirements for the degree of

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FACULTY OF GRADUATE STUDIES
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ABSTRACT

Monitoring exercise intensity sufficient for inducing cardiorespiratory benefits using target heart rate (HR) or ratings of perceived exertion (RPE) is not always convenient or practical, especially during unstructured physical activities such as children's play. One alternative approach is the use of audible breathing as a simple indicator of exercise intensity. PURPOSE: To determine whether the onset of audible breathing during exercise, the audible breathing threshold (ABT), is coincident with the ventilatory threshold (VT) in youth. METHODS: Seven boys and nine girls (mean age = 13.1 years) performed two continuous incremental exercise tests on a treadmill to identify the oxygen consumption ($\dot{V}O_2$) at their ABT and at their VT. RESULTS: Mean peak $\dot{V}O_2$ for all subjects was 55.0±6.7 $mL \cdot kg^{-1} \cdot min^{-1}$. The ABT occurred at an exercise intensity equivalent to 76.1% of peak $\dot{V}O_2$ (41.9 $mL \cdot kg^{-1} \cdot min^{-1}$), while VT occurred at 70.9% of peak $\dot{V}O_2$ (39.3 $mL \cdot kg^{-1} \cdot min^{-1}$). Boys had significantly higher peak $\dot{V}O_2$ ($p<0.05$), VT ($p<0.01$), and ABT ($p<0.05$) than girls. Mean difference of ABT from VT was 6.7±7.9%. Subjects were exercising at a HR of 174±10 $beats \cdot min^{-1}$ (87.4% of peak HR) at their ABT. Regression between relative $\dot{V}O_2$ at ABT and VT showed that ABT was a significant predictor of VT ($R^2 = 0.74$, $p<0.001$). CONCLUSIONS: The ABT may be a convenient indicator of exercise intensity at or near the VT. Youth can be instructed to exercise to an intensity when they can just hear their breathing as an adjunct to target HR or RPE.

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LIST OF ABBREVIATIONS

Abbreviation	**Meaning**
ABT	audible breathing threshold
AT	anaerobic threshold
HR	heart rate
HRM	heart rate monitoring
HR_{max}	maximum heart rate
HR_{peak}	peak heart rate
HRR	heart rate reserve
LT	lactate threshold
RPE	rating of perceived exertion
RQ	respiratory quotient
$\dot{V}CO_2$	carbon dioxide production
$\dot{V}_E$	minute ventilation
$\dot{V}O_2$	oxygen consumption
$\dot{V}O_{2max}$	maximum oxygen consumption
$\dot{V}O_{2\,peak}$	peak oxygen consumption
$\dot{V}O_2R$	maximum oxygen consumption reserve
VT	ventilatory threshold

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1. INTRODUCTION

Recent reports from the Canadian Fitness and Lifestyle Research Institute revealed that the majority of Canadian children are not sufficiently physically active (16, 24, 25). According to the National Population Health Survey, 58% of Canadian youth aged 12-19 years can be considered physically inactive and up to 84% may not be active enough to meet international guidelines for growth and development (16).

In response to the childhood physical inactivity problem, Health Canada developed physical activity guides for both children and youth (40, 41). Both guides encourage Canadian children and youth to increase their current activity levels by at least 30 minutes per day, consisting of 20 minutes of moderate activity and 10 minutes of vigorous activity to promote cardiorespiratory fitness development. Although the guides provide examples of activities that are moderate (e.g., swimming and playing outdoors) and vigorous (e.g., running and soccer), intensity parameters for such activities are not defined and it is obvious that children can perform such activities at various intensities. Thus, better defined methods for children and youth to practically determine whether an activity is of moderate or vigorous intensity are needed.

2. LITERATURE REVIEW

2.1 Exercise Intensity Guidelines

Regular participation in physical activity is associated with health benefits, but it is difficult to define a quantity that is most effective. The American College of Sports Medicine (ACSM) has developed guidelines for the appropriate combination of intensity, frequency, and duration of exercise that is sufficient for inducing a cardiorespiratory training effect in healthy adults (4). The ACSM recommends that adults should engage in physical activity for 20-60 minutes of continuous or intermittent duration for 3-5 days per week to develop and maintain cardiorespiratory fitness. Activities should be accumulated in bouts of at least 10 minutes in duration throughout the day, with lower intensity activities being sustained for longer periods of time (e.g., 30 minutes or more) than activities of higher intensity (e.g., 20 minutes or more). Intensity of training should range from a minimum of 55-65% of maximum heart rate (HR_{max}) or 40-50% of maximum oxygen uptake reserve ($\dot{V}O_2R$) or heart rate reserve (HRR) to 90% of HR_{max} or 85% of $\dot{V}O_2R$ or HRR. Physical activity within this range is often referred to as being of a moderate-to-vigorous level. Since no similar guidelines have been established for children, these recommendations are often adapted for use in pediatric populations.

Continuous exercise at a wide range of exercise intensities can elicit a cardiorespiratory training effect, as measured by changes to maximum oxygen uptake ($\dot{V}O_{2max}$). For instance, 8- to 12-year-old boys undergoing a 14-week running program at training intensities equivalent to 50-75% of $\dot{V}O_{2max}$ exhibited a 13% increase in $\dot{V}O_{2max}$ (57). Similarly, 10- to 11-year-old children who completed a 13-week endurance training program involving 25-35 minutes of continuous exercise at an intensity greater than 80% of HR_{max} exhibited a 7% improvement in their $\dot{V}O_{2max}$ (59).

To enhance exercise prescription, it is valuable to define a threshold intensity for fitness benefits. The ACSM defines the minimal training intensity threshold for improvement in $\dot{V}O_{2max}$ as approximately 40-50% of $\dot{V}O_2R$ or HRR (55-65% of HR_{max}) (4). In the spectrum of exercise intensities, these percentages outline the range that is thought to be the lower limit sufficient for cardiorespiratory training effect in most healthy adults.

2.2 Ventilatory Threshold as an Exercise Intensity

2.2.1 Definition

The ventilatory threshold (VT) is defined as the point at which ventilation ($\dot{V}_E$) begins to increase out of proportion to the increase in oxygen consumption ($\dot{V}O_2$). Wasserman and McIllroy (85) first identified this point as the anaerobic threshold (AT) since the disproportionate increase in $\dot{V}_E$ is assumed to be due to an excess increase in carbon dioxide production ($\dot{V}CO_2$) resulting from the buffering of lactic acid by the bicarbonate system to maintain blood gas and pH homeostasis (55, 82, 86). AT was so labelled because work performed below the AT is considered principally aerobic, while work above it is primarily anaerobic (50, 84). However, since controversy remains over the extent to which work above the AT as defined by Wasserman and McIllroy is truly anaerobic, the term VT is often preferred as it refers to the use of ventilatory data in determining this threshold.

2.2.2 Identification

Popular methods for determining VT involve the graphing of gas exchange data and visual inspection for the first breakpoint of variables such as $\dot{V}_E$, ventilatory equivalents (i.e., $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$), and $\dot{V}CO_2$ against $\dot{V}O_2$ or time (10, 82). Such graphical methods using ventilatory data have been validated in children (32) and are extensively used for determining individual exercise training intensities (22, 71, 76) as well as for assessing and tracking changes in aerobic fitness (44, 58).

VT can be also be estimated by observing the deflection from linearity of HR (19). Known as the Conconi method, this procedure has been validated in children between 7-14 years of age (8, 33, 56). Although it requires that HR data be continuously measured and recorded, it is a useful method for when direct measure of ventilation is not available.

It has even been investigated whether a breakpoint from linearity in breathing frequency during continuous exercise can also be used to identify the VT. While there is some support for use of this method as a simple field test to estimate VT (17, 47, 63), several concerns about its accuracy have been raised. Use of this method within laboratory settings where subjects are required to wear a nose clip and breathe through a mouthpiece, is not recommended since breathing frequency can be influenced by these factors (49). Jones and Doust (49) investigated the assessment of the VT by breathing frequency in a sample of trained runners. Results indicate that in approximately half the subjects, a clear breakpoint in breathing frequency could not be identified. One possible reason suggested was that the subjects, as elite endurance runners, have entrained breathing patterns that inhibit abrupt increases in breathing frequency. Trained and untrained individuals who perform rhythmic activities such as cycling and rowing may exhibit entrained breathing patterns where there is an existence of an integer ratio between breathing frequency and exercise cadence (11, 49, 54, 68). Regardless of the effectiveness of this method, counting the number of breaths over a period of time during exercise is a tedious and awkward task that is not likely to be adopted by many individuals, particularly young people.

2.2.3 Relevance

There is evidence that the VT is a good index of endurance capacity and aerobic fitness, and can be more sensitive to exercise training than $\dot{V}O_{2max}$ (44, 48, 55, 75). VT is also physiologically relevant because its onset is near the lactate threshold (LT). LT is generally referred to the point during incremental exercise when a systematic increase in blood lactate occurs (80, 83). It has been shown that individuals can perform prolonged exercise below the VT or LT, but exercise duration decreases when intensity exceeds these thresholds (53). While methods of VT determination are non-invasive by nature because only gas exchange parameters are collected, LT must be, by definition, determined invasively by taking measurements of blood lactate. Because VT is closely associated with LT, and both thresholds have similar physiological significance for exercise training purposes, VT is often the preferred measure as its detection is more easily obtained.

Compared with defining exercise intensities as percentages of $\dot{V}O_{2max}$ or HR_{max}, basing exercise prescriptions on the VT minimizes the variability in physiological responses as it takes metabolic stress into account. Indeed, one study showed that the commonly prescribed exercise intensities of 85% of HR_{max} and 80% of $\dot{V}O_{2max}$ led about half the subjects (46% and 54%, respectively) to exercise above their VT (20). VT has been successfully used to individualize exercise training in sedentary adults (35) and older adults (31). Moreover, exercise training at the VT has been shown to be effective at improving the $\dot{V}O_{2max}$ of children who are asthmatic (22, 76) and the AT of obese children (2). The use of standardized target intensities is especially inappropriate for these populations as they are generally less fit, and the selected intensities can be too stressful for these individuals. Thus, exercise intensities at the VT or expressed as percentages of the VT individualizes training and may be particularly appropriate for unfit children and adults who need to be physically active the most. In addition, exercise at the VT is often within the moderate-to-vigorous intensity range recommended by the ACSM (3).

2.3 Monitoring Exercise Intensity

2.3.1 Heart Rate Monitoring

Heart rate monitoring (HRM) is a common means to determine exercise intensity since exercise intensity is often expressed as a percentage of HR_{max} or HRR. HRM usually involves a target HR that is calculated based on the estimation of HR_{max} using the equation $HR_{max} = 220 - \text{age}$. However, HR_{max} is not predicted by age alone and the HR_{max} of children and adolescents begins to decline only after maturity is reached (9). The HRR method attempts to reduce the error margin by taking into consideration resting HR ($HRR = HR_{max} - \text{resting HR}$). However, resting HR and HR response to a bout of exercise can be affected by a number of factors including gender, psychological state, fitness and fatness level, and medications (3). For instance, it has been suggested that children may exhibit higher resting HRs due in part to the excitement of experimental conditions (90). Moreover, there is evidence that girls have a higher HR than boys at any given exercise level (9). Thus, unless HR_{max} and exercise HR responses are directly measured, prescribing training intensities based on age-predicted HR_{max} may be inappropriate for some individuals.

The use of absolute target HR values has been shown to guide individuals to exercise at a wide range of exercise intensities. Traditional target HRs of 140 and 160 $beats \cdot min^{-1}$, representing 70 and 80% of HR_{max}, respectively, are commonly used to correspond to moderate and vigorous intensities of physical activity for individuals 20 years of age and under. Data from a sample of 12-year-old girls (1) and 14- to 15-year-old adolescents (29) suggest that such absolute HR values derived from predicted HR_{max} are inappropriate since individual differences exist between children. A HR of 140 $beats \cdot min^{-1}$ corresponded to 46% of $\dot{V}O_{2max}$ in the 12-year-old girls compared with 56% in the adolescents, while 160 $beats \cdot min^{-1}$ corresponded to 63% of $\dot{V}O_{2max}$ in the 12-year-old sample compared with 71% in the adolescents. In addition, fatness was found to have a significant relationship with oxygen consumption at the prescribed intensities in the 12-year-old girls (1) and a significant fitness effect was revealed among the 14- to 15-year-olds (29). Thus, factors that can mediate the HR-$\dot{V}O_2$ relationship, such as age, gender, fatness, and fitness, should be taken into consideration when using HRM in exercise prescription.

Other problems are inherent to HRM in children. In younger children particularly, counting and calculation errors are common when children are asked to palpate their own pulse (12). Even when the 6-second count is used so that children can simply add a ‘0’ to obtain a 1-minute exercise HR, large errors are reported. Although this method is time-efficient, one missed beat translates to an error of 10 beats·min^{-1}. Best and Steinhardt (12) examined the HRM ability of children in grades 3, 4, and 5. Results indicate that while the grade 5 children appeared to be accurate in counting their exercise HRs, the children in grades 3 and 4 were not accurate in their counting. Based on data collected using a 5-second HR count, the mean margin of error ranged from a low of 3±22 beats·min^{-1} in one grade 5 class to a high of 34±42 beats·min^{-1} in one grade 3 class. Even middle school-age boys appear to be unable to consistently report accurate self-pulse palpation counts (30). Sixty-three boys (mean age 12.7±1.0 years) were asked to palpate their pulse for 15 seconds upon completion of a 720 metre shuttle walk. In total, 56 of the 63 boys reported postexercise HRs lower than the actual telemetry recordings (143.6±31.3 beats·min^{-1} vs. 165.1±22.0 beats·min^{-1}, respectively). As HRM is often accomplished by palpation, the lack of reliability in HR counting and calculation should be considered, especially when applying HRM to young children.

Regardless of counting errors, children's ability to count exercise HR is influenced by the teacher. When comparing HR counts from three schools, children from one particular school consistently reported more accurate counts (12). In addition, children have a tendency to inflate or lower their responses according to teachers' expectations (12). The school environment may be the only place where students will receive instruction on and utilize HRM to monitor their exercise intensity. Thus, it must be considered that effectiveness of HRM can be significantly limited by poor teaching methods and that HRM is susceptible to misuse when applied to inappropriate contexts such as for student evaluation. Since many schools have incorporated HRM into their physical education curriculum, care must be taken to ensure proper instruction and suitable application of HRM.

2.3.2 Rating of Perceived Exertion

Since few individuals will actually calculate their training intensity from $\dot{V}O_2R$ or HRR, the ACSM also provides more practical intensity guidelines based on Borg's Rating of Perceived Exertion Scale (14). Although subjective, rating of perceived exertion (RPE) is more simple and practical compared to HRM in certain settings, as there is no need to stop exercise to take pulse rate. The Borg 15-graded rating scale uses values ranging from 6 to 20 (Table 1), and it has been suggested that the ratings reflect the HR range (60-200 $\text{beats}\cdot\text{min}^{-1}$) of "normal adults" when multiplied by 10 (64). The Borg scale is widely used and is often recommended as an adjunct to HRM in monitoring exercise intensity (4).

Table 1: Borg 6-20 Rating of Perceived Exertion Scale.

6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

As the Borg scale was developed with adults and for adults, various other scales have been developed specific for children. For example, the Children's Effort Rating

Table (CERT) (89) uses values ranging from 1 to 10 and more simplified terms to describe exercise intensity. A CERT rating can be translated to a HR by multiplying by 10 and adding 100. For instance, a rating of 1 is equivalent to a HR of 110 beats·min^{-1}, 2 is equivalent to 120 beats·min^{-1}, up to a maximum rating of 10, corresponding to a HR of 200 beats·min^{-1}.

Since written descriptors like those used in the Borg scale and CERT are not useful for children who cannot read, perceived exertion scales using pictorial descriptors are available. The Rating of Perceived Exertion adapted for Children (RPE-C) (39), the Pictorial Children's Effort Rating Table (PCERT) (92), and the Children's OMNI Scale of Perceived Exertion (70) all utilize caricatures of a child becoming progressively fatigued from physical activity. RPE-C utilizes the 6-20 RPE scale, while PCERT and the OMNI scale have simplified scales with exertion values ranging from 0 to 10 as well as written descriptors to aid children in identifying their level of exertion.

Although various RPE scales have been developed for children, such scales are not commonly available, so the standard Borg scale is often utilized. Ward, Jackman, and Galiano (79) compared children's ability to utilize the Borg 6-20 RPE Scale with that of adults. Seventeen children aged 8-14 years were compared with a group of adults in their ability to estimate and reproduce the workload necessary to elicit various RPEs during pace-controlled cycling and while running on a track. Results indicate that children were unable to discriminate the different RPE levels with the same accuracy as adults. The children exercised within a rather narrow range of intensities of between 77-92% of their age-predicted HR_{max}, eliciting HRs of 157-186 beats·min^{-1}, to represent a relatively large range of RPE levels (7 to 16). Moreover, the younger subjects experienced particular difficulty in adjusting their speed or pace during the cycling and running tasks.

Interestingly, both children and adults worked harder at the same RPE prescription level while running compared with cycling, possibly because whole body exercise is perceived to be more intense. In addition, applying RPE to whole body work may be a more difficult task than when only leg work is required (79). A gender effect was noted for the cycling task, but not for running. Girls executed the upper prescribed RPE intensities at relatively higher workloads than boys. Another study revealed that overweight children consistently overestimated intensities that corresponded to RPEs of 7, 10, 13, and 16 while walking or running on a track, although the subjects were able to effectively execute the prescribed RPEs on a cycle ergometer (78). These results indicate that various factors can affect the use of RPE, including the mode of exercise, age, gender, and weight status. Although practice can increase the effectiveness of using RPE for exercise prescription or intensity discrimination (79, 89), the use of RPE scales should be complemented by other methods.

Noble and Robertson (64) suggest that the mechanisms involved with the estimation of exertion (as done in a laboratory) and the production of exercise intensity (as done in a field setting) may not be identical. Children can discriminate changes in physiological strain, but have less ability to execute absolute values of perceived exertion (36). In addition, analogous to the problem of using absolute target HR values, prescribing intensities using absolute RPE values is limited by the high variability in perceived exertion between and within individuals. Moreover, RPE charts are not available in all exercise settings, especially in unstructured environments where much of children's active play takes place. It is unreasonable to expect children to commit the charts to memory and having to focus on RPE values can reduce the enjoyment of various physical activities. Thus, the use of RPE in the regulation of exercise intensity in children is limited.

RPE scales appear to be valid and reliable in experimental settings using progressive exercise tests, but evidence of their value in field settings is less convincing. For example, in a study examining whether elementary school children could self-regulate their exercise intensity in activities such as jogging, hopping, and skipping using the CERT, children were found to report inconsistent and inaccurate ratings (23). The age range of subjects, which was 6-11 years, was suggested as a factor, but CERT had been previously validated with children aged 8-9 years in a laboratory. Thus, it is evident that in this case, laboratory results could not be applied to a field setting. Future research should further examine the use of RPE scales in non-laboratory settings such as physical education class and during popular children's leisure-time activities.

2.3.3 Breathlessness

Although HRM and RPE are the most popular methods to monitor exercise intensity, Canada's Physical Activity Guides for Children (40) and Youth (41) do not describe the terms "moderate" and "vigorous" as target HRs or RPEs. Instead, the Teacher's Guides (42, 43) that are available with these publications provide written descriptions of "moderate" and "vigorous". Moderate or vigorous aerobic activities "are continuous activities that benefit the heart, lungs and circulatory system. They make you breathe deeper, your heart beat faster and your body sweat/perspire." (43: p.15).

The reference to breathing is worthy of examination. The degree of breathlessness, or dyspnea, has been used as a measurement and means of monitoring exercise intensity in individuals with respiratory disease (26). Breathlessness can be measured by the modified Borg category-ratio scale (CR-10) (14), which consists of 12 numerical points and up to 10 written descriptors of breathing intensity, ranging from 0 indicating “nothing at all” to 10 indicating “maximal” or “very, very severe”. Another dyspnea measure is the visual analog scale (VAS), which consists of a horizontal or vertical line with the leftmost or bottom point indicating no breathlessness, and the rightmost or upper point indicating greatest breathlessness (26).

In adults with chronic obstructive pulmonary disease, target measures of dyspnea have been successfully used in prescribing and monitoring exercise intensity (45, 46, 61). However, use of dyspnea ratings appears to be more effective at higher intensities such as 80% of peak $\dot{V}O_2$, than at lower intensities such as 50% of peak $\dot{V}O_2$ (45). In addition, different dyspnea ratings can represent different intensities for each individual. Thus, assessment of the intensities that various dyspnea ratings refer to is necessary prior to beginning an exercise program.

The CR-10 and VAS are subjective scales comparable to RPE scales where results cannot readily be used for comparisons between individuals since ratings can represent different intensities for different individuals. As a result, the 15-Count Breathlessness Score (69) was developed to provide clinicians with an objective measure of breathlessness. The 15-count score is the number of breaths required by subjects to count out loud to 15 after taking a deep breath. In children with cystic fibrosis, the 15-count score has been successfully used to measure breathlessness after the performance of various exercise tests (69). However, the scale appears to be useful only to individuals prone to breathlessness or healthy individuals that are undergoing very intense exercise. Moreover, the 15-count score can only be obtained post-exercise, where an individual must first stop exercise to count breaths. As a result, this scale is not applicable for continuous monitoring of exercise.

The sensation of breathlessness has been physiologically linked to the VT. The basis for VT is the existence of an identifiable point during continuous incremental exercise where there is a disproportionate increase in ventilation with respect to $\dot{V}O_2$. As workload continues to increase, there is a point when breath sounds first become noticeable by the exercising individual. It has been suggested that this audible breathing threshold (ABT) appears to be associated with the VT and that the ABT is a marker of an intensity sufficient for fitness development (37, 38, 62). Young men who maintained exercise at an intensity when they can "hear their breathing" were found to be exercising at 71% of HR_{max} (range 55-86%) compared with their VTs at 74% of HR_{max} (range 58-89%) (62). The subjects' ABT represented a range of workloads that are consistent with ACSM's recommendations for fitness development.

Older adults have successfully used their ABT to guide their jogging intensity in a 4-week exercise program (37). Participants were asked to exercise at an intensity where they can "just hear their breathing and can talk." This simple instruction was given to participants to attain and maintain a sufficient intensity that was sufficient to induce significant improvements in the subjects' VT and $\dot{V}O_{2max}$.

2.4 Summary

Current recommendations for physical activity require children and youth to exercise at moderate-to-vigorous intensities to promote cardiorespiratory fitness, but such intensities have not been well defined. Relative exercise intensities that are sufficient to induce a cardiorespiratory training effect are often expressed in terms of $\dot{V}O_2$, HR, and RPE. Thus, HRM and RPE are common methods to monitor exercise intensity. However, it is important to consider that both HRM and RPE have limitations when applied to children.

The VT demarcates the highest intensity at which prolonged aerobic exercise can be sustained, and the exercise training intensity corresponding to the VT is effective for the maintenance and development of cardiorespiratory fitness. In addition, expressing training intensities as a percentage of VT may be an appropriate way to individualize exercise programs.

Sensations of breathlessness have been used as indicators of physical exertion. A novel approach suggests that the onset of audible breathing may be an indicator of an exercise intensity that is at or near the VT. The ABT occurs at an intensity when breathing can just be heard by the exercising individual and may be a convenient indicator for an exercise intensity that is sufficient for improving cardiorespiratory fitness.

3. PURPOSE

Given the limitations of HRM and RPE in monitoring exercise intensity in young people, it is of interest to determine whether the ABT can be used to predict the VT. The purpose of this study is to investigate the hypothesis that in youth, the point at which they can just hear their breathing during continuous incremental exercise indicates an intensity that is at or near their VT.

4. METHODS

4.1 Subjects

Seven boys and 11 girls aged 11 to 14 years participated in this study. Participants were questioned about their current health status, with all subjects reporting that they were non-smokers with no known medical conditions that can affect exercise performance (e.g., asthma, heart conditions). All subjects received one page of written instructions along with the consent forms (Appendix A). Written informed consent was obtained from the subjects and one of their parents or guardians prior to the start of the study. Ethical approval was obtained from the Education/Nursing Research Ethics Board of the University of Manitoba (Protocol #E2003:095).

Subjects were asked to abstain from alcohol, caffeine, other drugs, and strenuous exercise for 24 hours, as well as not eat for 1 hour, prior to testing. Subjects reported to the laboratory on two separate occasions with visits scheduled at similar times of day, 2 to 10 days apart (mean = 5 days).

4.2 Measures

Each subject's height without shoes was measured using a stadiometer and recorded to the nearest 0.01 metre (m). Body mass was measured with the subject dressed in minimal clothing using a digital scale and recorded to the nearest 0.1 kilogram (kg). HR was continuously monitored and recorded at 20-second intervals using a HR monitor (Polar A5, Polar Electro, Kempele, Finland). Subjects wore a nose clip and breathed through a mouthpiece with saliva trap throughout the entire test. Minute ventilation ($\dot{V}_E$), oxygen consumption ($\dot{V}O_2$), and carbon dioxide expired ($\dot{V}CO_2$) were continuously monitored and recorded using a metabolic cart (SensorMedics Vmax

Spectra, Yorba Linda, California, US) calibrated prior to each test. Breath-by-breath data were averaged over 10 seconds.

4.3 Exercise Test Protocol

At each visit, subjects performed a continuous incremental exercise test on a motorized treadmill after a brief familiarization period and warm up. The familiarization period consisted of allowing subjects to become accustomed to running on a treadmill and teaching the subjects safety guidelines and hand signals for communicating with the tester. Warm up consisted of jogging for approximately 1 minute at a pace of between 4.5 to 5.0 miles·hour^{-1} (mph).

Since established treadmill protocols such as the Bruce and Balke protocols (3) have workload increments that may be inappropriate for the purposes of this study, a new treadmill protocol was devised (Table 2). Initial grade and speed of the exercise test were set at 2% and 4.5 mph, respectively. Grade was increased at minute 1 and every second minute thereafter by 2%, while speed was increased at minute 2 and every second minute thereafter by 0.5 mph.

Table 2: Treadmill protocol

Stage (min)	Grade (%)	Speed (mph)
0	2	4.5
1	4	4.5
2	4	5.0
3	6	5.0
4	6	5.5
5	8	5.5
6	8	6.0
7	10	6.0
8	10	6.5
9	12	6.5
10	12	7.0
11	14	7.0

4.4 Determination of Audible Breathing Threshold

At visit 1, subjects were asked to raise their hand at the first instant during the exercise test when they can hear their breathing. A sign with the instruction "put your hand up when you can hear your breathing" was posted on the wall directly in front of the treadmill at the subject's eye level. Subjects were not verbally reminded of this instruction during the exercise test. When subjects raised their hand, the exercise time was recorded and workload was not progressed in order to obtain steady state HR and ventilatory measures.

4.5 Determination of Peak Oxygen Consumption

During visit 2, subjects performed an exercise test to maximal exertion according to the same protocol as visit 1. Subjects were provided with strong verbal prompting (e.g., "good job" and "keep going") in an attempt to facilitate attainment of maximal effort. Maximal effort was considered achieved if HR exceeded 185 beats·min^{-1}, respiratory quotient was equal to or exceeded 1.10, and tester observed signs of intense effort in the subject such as hyperpnea and facial flushing. Since a plateau in $\dot{V}O_2$ is not being used as a criterion for maximal effort in this study, the highest $\dot{V}O_2$ value achieved during the test was defined as peak oxygen consumption ($\dot{V}O_{2peak}$).

4.6 Determination of Ventilatory Threshold

VT was estimated from graphs of $\dot{V}E$, $\dot{V}CO_2$, the ventilatory equivalent for oxygen ($\dot{V}E/\dot{V}O_2$), and carbon dioxide ($\dot{V}E/\dot{V}CO_2$) plotted against $\dot{V}O_2$. Criteria for VT determination (32, 55) were: 1) first disproportionate increase in $\dot{V}E$ with respect to $\dot{V}O_2$; 2) first disproportionate increase in $\dot{V}CO_2$ with respect to $\dot{V}O_2$; and 3) first increase in $\dot{V}E/\dot{V}O_2$ without a corresponding increase in $\dot{V}E/\dot{V}CO_2$.

Two experienced evaluators blinded to the identity of the subjects were asked to independently assess VT. Evaluators were asked to derive VT estimates from using the average of all criteria when possible. VT estimates from both evaluators were averaged if the values were within 0.5 $L \cdot min^{-1}$, otherwise, the subject was excluded from analysis.

4.7 Statistical Analysis

All statistical procedures were performed using SPSS for Windows (version 11.5, Chicago, Illinois, US). Means and standard deviations were calculated for all subject characteristics and exercise variables. Linear regression was used to determine how well the ABT predicts the VT. Correlation coefficients were computed to determine the significance and strength of the relationship between ABT and VT, HR_{VT}, $\dot{V}O_{2\,peak}$, and HR_{peak}. An independent t-test was used to identify any significant gender effects. Level of significance was set at $p < 0.05$.

5. RESULTS

Individual study results for all variables measured are presented in Appendix B.

5.1 Subject Characteristics

Sixteen of the 18 participants successfully completed both exercise tests. One individual withdrew from the study due to an injury incurred between the scheduled visits and another failed to meet the maximal effort criteria during visit 2.

There were no significant differences in age and anthropometric characteristics between boys and girls (Table 3). One female participant can be classified as overweight according to criteria defined by the International Obesity Task Force (18).

Table 3: Subjects' age and anthropometric characteristics [mean ± SD (range)].

Variable	**Total (n = 16)**	**Boys (n = 7)**	**Girls (n = 9)**
Age (y)	13.1 ± 1.1 (11-14)	12.9 ± 1.2 (11-14)	13.2 ± 1.1 (11-14)
Body Mass (kg)	50.4 ± 9.2 (36.4-65.9)	51.3 ± 11.3 (36.4-64.1)	49.7 ± 7.8 (39.1-65.9)
Height (m)	1.62 ± 0.10 (1.47-1.80)	1.66 ± 0.11 (1.50-1.80)	1.59 ± 0.08 (1.47-1.75)
Body Mass Index ($kg{\cdot}m^{-2}$)	19.1 ± 2.1 (16.2-22.9)	18.3 ± 1.9 (16.2-21.4)	19.7 ± 2.2 (17.0-22.9)

5.2 Peak oxygen consumption and ventilatory threshold characteristics

The inter-rater correlation for VT determination was 0.87 ($p<0.001$). Boys achieved significantly higher relative $\dot{V}O_{2\,peak}$ scores and had significantly higher VTs compared to girls (Table 4). However, there were no significant differences in absolute $\dot{V}O_{2\,peak}$ scores and VT expressed as a percentage of $\dot{V}O_{2\,peak}$. Compared with aerobic fitness norms (81), subjects had relatively high $\dot{V}O_{2peak}$ scores, and both boys and girls could be classified in the "very good" category (73). Nevertheless, the percentage of

$\dot{V}O_{2peak}$ at which VT occurred (73.9% in boys, 68.5% in girls) is consistent with other North American school-aged children (81).

Table 4: Subjects' peak oxygen consumption and VT characteristics [mean ± SD (range)].

Variable	**Total (n = 16)**	**Boys (n = 7)**	**Girls (n = 9)**
$\dot{V}O_{2\,peak}$ ($L \cdot min^{-1}$)	2.76 ± 0.55 (2.05-3.80)	3.03 ± 0.62 (2.05-3.80)	2.55 ± 0.40 (2.10-3.22)
$\dot{V}O_{2\,peak}$* ($mL \cdot kg^{-1} \cdot min^{-1}$)	55.0 ± 6.7 (43.2-64.8)	59.4 ± 4.6 (51.6-64.8)	51.5 ± 6.2 (43.2-62.7)
HR_{peak} ($beats \cdot min^{-1}$)	199.1 ± 6.1 (189-212)	198.9 ± 5.1 (190-203)	199.2 ± 7.0 (189-212)
$Time_{peak}$ (s)	521.3 ± 118.7 (340-740)	585.1 ± 111.9 (424-740)	471.6 ± 103.4 (340-656)
VT ($L \cdot min^{-1}$)	1.98 ± 0.48 (1.41-2.89)	2.24 ± 0.55 (1.60-2.89)	1.78 ± 0.31 (1.41-2.40)
VT* ($mL \cdot kg^{-1} \cdot min^{-1}$)	39.3 ± 5.6 (30.3-50.1)	43.7 ± 4.1 (37.6-50.1)	36.0 ± 4.2 (30.3-43.7)
VT (% $\dot{V}O_{2\,peak}$)	70.9 ± 7.2 (61.5-87.5)	73.9 ± 9.2 (61.5-87.5)	68.5 ± 4.3 (63.3-75.8)
HR_{VT} ($beats \cdot min^{-1}$)	166.2 ± 9.7 (147-185)	165.3 ± 12.5 (147-185)	166.9 ± 7.5 (155-177)
HR_{VT} (% HR_{peak})	83.5 ± 4.8 (72.4-91.6)	83.2 ± 6.5 (72.4-91.6)	83.8 ± 3.4 (78.0-88.9)

* significant difference between boys and girls ($p < 0.05$)

5.3 Audible breathing threshold characteristics

Subjects identified their ABT between -8.1 to 21.2% (mean = 6.7%) from their VT (Table 5). Regression relative to the line of identity indicates that most subjects' ABT was above their VT (Figure 1).

The ABT of boys was closer to their VT than girls (3.5% vs. 9.2%, respectively). Boys were able to identify their ABT at significantly higher $\dot{V}O_2$ values and later times than girls. However, boys and girls did not differ in the percentage of $\dot{V}O_{2\,peak}$ and HR at which they identified their ABT.

Table 5: Subjects' ABT characteristics [mean ± SD (range)].

Variable	**Total (n = 16)**	**Boys (n = 7)**	**Girls (n = 9)**
ABT ($L\cdot min^{-1}$)	2.11 ± 0.50 (1.47-3.00)	2.33 ± 0.60 (1.47-3.00)	1.94 ± 0.35 (1.53-2.55)
ABT* ($ml\cdot kg^{-1}\cdot min^{-1}$)	41.9 ± 5.8 (31.5-50.4)	45.1 ± 3.5 (40.4-50.4)	39.4 ± 6.1 (31.5-48.4)
ABT (% $\dot{V}O_{2\,peak}$)	76.1 ± 5.5 (67.3-87.8)	76.1 ± 7.2 (67.3-87.8)	76.1 ± 4.2 (68.6-82.6)
$Time_{ABT}$* (s)	210.0 ± 85.8 (100-360)	257.1 ± 88.3 (160-360)	173.3 ± 67.1 (100-320)
HR_{ABT} ($beats\cdot min^{-1}$)	173.9 ± 9.6 (157-187)	173.1 ± 10.6 (157-187)	174.6 ± 9.3 (157-182)
HR_{ABT} (% HR_{peak})	87.4 ± 4.2 (78.5-92.6)	87.1 ± 4.5 (80.9-92.6)	87.6 ± 4.2 (78.5-91.4)
Difference from VT (%)	6.7 ± 7.9 (-8.1-21.2)	3.5 ± 6.5 (-8.1-9.4)	9.2 ± 8.3 (-4.4-21.2)

* significant difference between boys and girls

5.4 Prediction of VT by ABT and peak oxygen consumption

Both ABT and $\dot{V}O_{2oeak}$ are significantly correlated with VT (Table 6). Stepwise linear regression analysis revealed that absolute $\dot{V}O_2$ ($L\cdot min^{-1}$) at VT is best predicted by absolute $\dot{V}O_2$ ($L\cdot min^{-1}$) at ABT ($R^2 = 0.92$, $p<0.001$) (Figure 3) and absolute $\dot{V}O_{2peak}$ ($L\cdot min^{-1}$) ($R^2 = 0.83$, $p<0.001$). Relative $\dot{V}O_2$ ($mL\cdot kg^{-1}\cdot min^{-1}$) at VT is best predicted by relative $\dot{V}O_2$ at ABT ($R^2 = 0.74$, $p<0.001$) (Figure 2) and to a lesser extent relative $\dot{V}O_{2\,peak}$ ($R^2 = 0.55$, $p<0.01$). Regression between HR_{VT} and HR_{ABT} was also significant ($R^2 = 0.65$, $p<0.001$).

Table 6: Prediction of VT by ABT and peak oxygen consumption.

Variable	**Correlation Coefficient (r)**	R^2	**P-value**
ABT ($L \cdot min^{-1}$)	0.96	0.92	<0.001
ABT ($ml \cdot kg^{-1} \cdot min^{-1}$)	0.86	0.74	<0.001
ABT (% $\dot{V}O_{2\ peak}$)	0.59	0.35	<0.05
HR_{ABT} ($beats \cdot min^{-1}$)	0.81	0.65	<0.001
HR_{ABT} (% HR_{peak})	0.81	0.65	<0.001
$\dot{V}_{O2\ peak}$ ($L \cdot min^{-1}$)	0.91	0.83	<0.001
$\dot{V}_{O2\ peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	0.74	0.55	<0.01

Figure 1: Regression between absolute ABT and VT (L·min^{-1}).

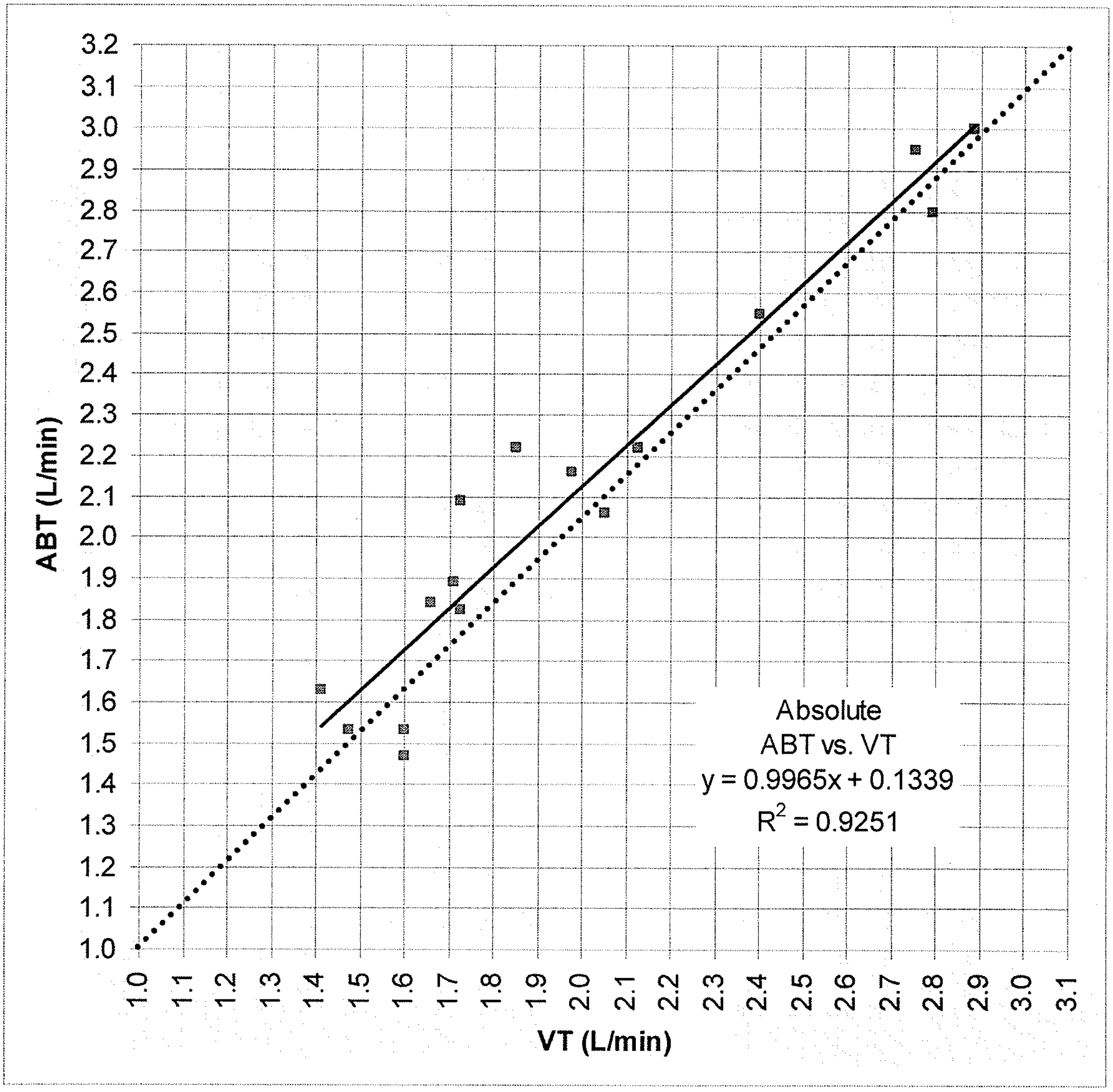
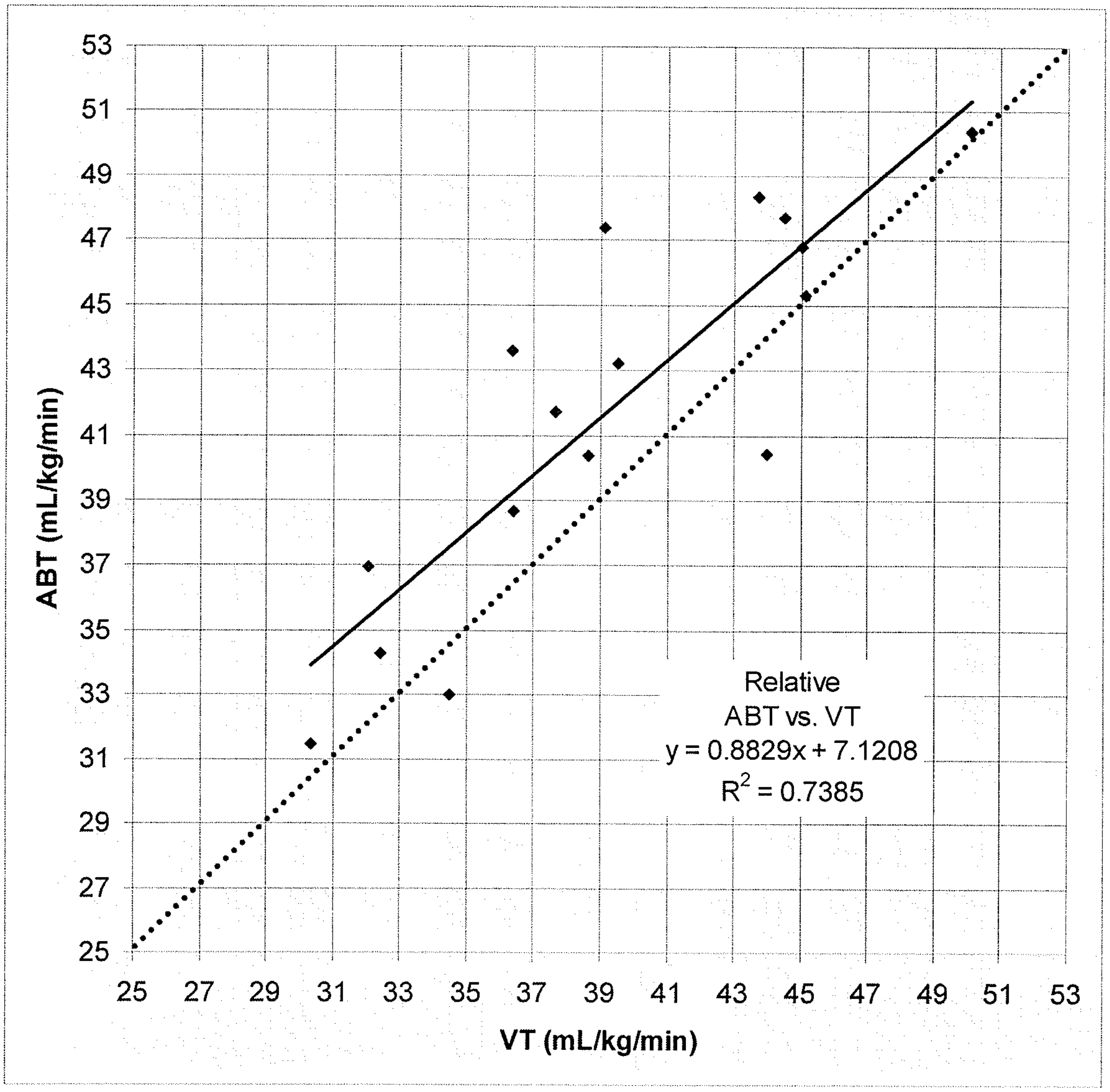


Figure 2: Regression between relative ABT and VT (mL·kg^{-1}·min^{-1}).



5.5 Relationship between VT and ABT to peak oxygen consumption

Both VT and ABT were significantly correlated with $\dot{V}O_{2\,\mathrm{peak}}$ (Table 7). ABT had higher correlations with $\dot{V}O_{2\,\mathrm{peak}}$ than VT.

Table 7: Correlations of peak oxygen consumption with ABT and VT.

		$\dot{V}\mathbf{O}_{2\,\mathbf{peak}}$	
		Absolute (L·min^{-1})	**Relative (mL·kg^{-1}·min^{-1})**
VT	**L·min^{-1}**	0.91*	0.25
	mL·kg^{-1}·min^{-1}	0.44	0.74*
ABT	**L·min^{-1}**	0.95*	0.31
	mL·kg^{-1}·min^{-1}	0.51*	0.85*

*significant at the $p<0.05$ level

6. DISCUSSION

The results of this study indicate that when children reach a point during continuous incremental exercise when they can just hear their breathing, their audible breathing threshold, they are exercising at an intensity at or near their ventilatory threshold. Whether or not an individual is exercising at their ABT level can be determined instantly at any point during a bout of exercise, merely requiring subjects to decide whether or not they can hear their breathing.

An exercise intensity corresponding to the ABT was equivalent to a workload that is within 7% of the ventilatory threshold. The subjects were exercising at approximately 76% of their $\dot{V}O_{2peak}$ when they could just hear their breathing, compared with their VT level at 71% of $\dot{V}O_{2peak}$. The ABT represented a range of intensities (67.3-87.8% of $\dot{V}O_{2peak}$) that is within the current exercise guidelines recommended by the ACSM for the development of cardiorespiratory benefits (3).

Assessment of the ABT is possible even in situations with sudden increases in intensity since its estimation is done instantaneously. Traditional methods of prescribing exercise at the VT involve laboratory determination of VT based on the plotting of continuous data from incremental exercise tests with gradual increases in workload. After VT is determined, it is possible to derive a target HR that corresponds to the VT from the HR-$\dot{V}O_2$ relationship. The ABT technique, however, does not require any laboratory exercise testing or the collection of continuous ventilatory data and is applicable to a variety of physical activities.

The strong correlation between the ABT and the VT may be explained by breathing control mechanisms that respond to incremental exercise. As the VT is closely associated with the LT, the abrupt increase in drive to breathe at the VT is thought to be due to increased blood lactate concentration. Lactic acid is totally dissociated in the cell, requiring its hydrogen ion to be immediately buffered by bicarbonate, producing carbon dioxide. Increased hydrogen ion concentration and partial pressure of carbon dioxide increase stimulation of the central and peripheral chemoreceptors that increase ventilatory drive (60, 83, 87, 88). As exercise continues, there is an increase in breathing intensity.

Although sensations of breathing are difficult to quantify physiologically, the existence of the ABT appears to be based on the existence of the VT. The basis for the VT is an identifiable breakpoint during continuous incremental exercise when there is a disproportionate increase in ventilation with respect to $\dot{V}O_2$. In the same way, the ABT is based on an identifiable breakpoint when breathing shifts from being imperceptible to becoming just audible to the exercising individual.

The correlation between absolute $\dot{V}O_2$ at VT and ABT was higher than that between the relative $\dot{V}O_2$ measures, suggesting that body mass may have an effect on the VT-ABT relationship. The extent to which body mass affects breathing parameters or sensations was not investigated in this study. However, it is notable that ventilation is a function of tidal volume and breathing frequency, and individuals with lower body masses likely exhibit lower tidal volumes. Visual inspection of scatterplots between tidal volume and breathing frequency against $\dot{V}O_2$ (Appendix C) show that the $\dot{V}O_2$ at which a non-linear increase occurs in both these measures is close to the $\dot{V}O_2$ at ABT. However, it is unclear whether the relationship between VT and ABT is more dependent on variations in tidal volume or breathing frequency, or similarly dependent on both. This is worthy of further examination in future studies.

Although most subjects identified their ABT as being slightly above their VT, the magnitude of this difference does not translate to a significant elevation in workload. For sedentary adults, workload fluctuations in the order of 15% above or below the VT do not result in significant effects on the training response (62). Subjects who exercised at fluctuating intensities corresponding to ±15% of their VT showed similar increases in VT and $\dot{V}O_{2max}$ as subjects who consistently exercised at their VT throughout an 8-week running program. Moreover, in field settings, the ABT's difference from the VT is probably negligible as most children are likely to participate in activities of constantly fluctuating intensities.

The ABT of girls exceeded the VT by significantly greater magnitudes than that of boys, although boys and girls were exercising at a similar HR at their ABT (173 vs. 175 beats·min^{-1}, respectively), corresponding to approximately 83% of HR_{peak} for both groups. However, four of the nine girls identified their ABT at a $\dot{V}O_2$ that was more than 10% higher than their VT. Although the basis of this gender effect is unclear, one possible reason may be that girls had peak exercise times that were almost 2 minutes lower than boys. In combination with their significantly lower relative VT values, it is expected that girls reached their VT, and theoretically their ABT, earlier in the protocol than boys. It is conceivable that many girls may have in fact reached their ABT very soon after they began exercise, but did not let the tester know because of the 'testing' situation and perceived expectations.

The ABT, however, has been shown to be a reliable measure. A pilot study has investigated the reproducibility of the ABT (Appendix D). Nine adolescents (5 boys, 4 girls; mean age = 14.6 years) completed two different incremental exercise protocols on a bicycle ergometer 1 week apart and were asked to identify their ABT during each session. Results indicate that the subjects were able to identify the same exercise intensity (as indicated by workload, HR, and exercise time) during the subsequent visit. These findings suggest that the ABT can be applied with consistent results.

Effectiveness of ABT assessment in monitoring exercise intensity may improve if it is applied in conjunction with the Talk Test. Like the ABT, the Talk Test is a subjective measure. It requires the individual to assess whether effortless talking is still possible at a particular exercise intensity. In healthy adults (27) as well as a sample of cardiac patients (77), the highest intensity at which subjects can still talk comfortably was strongly correlated with the VT. Subjects clearly failing the Talk Test were consistently at an exercise intensity above their VT. The Talk Test appears to set the upper limit for individuals who wish to maintain exercise at or below their VT. At the same time, the ABT can be designated as an indicator of the minimum intensity. Thus, when both methods are used in combination, individuals are likely exercising at an intensity at or near their VT. This workload can be maintained as long as one can hear their own breathing, but can still talk comfortably.

Pilot work examining a program of just 10 minutes of physical activity using the ABT and the Talk Test, 3 times per week, for a period of 4 weeks in a physical education class, was sufficient to significantly improve the physical working capacity of a sample of adolescent females (Appendix E). Additional findings of the study were that the subjects easily applied the ABT assessment to their activity with minimal instruction.

As physical educators must be able to teach skills and provide opportunities for students to be active within the allotted class time, a practical way to incorporate moderate-to-vigorous activities into a class is to do short bouts of activity at the ABT level. This approach accommodates many children's dislike for continuous high intensity activities that many adults prefer (e.g., jogging for 30 minutes) (7, 21) and the physical activity guides for children and youth (40, 41) emphasize that physical activity can be accumulated in periods of 5-10 minutes. Using the ABT to guide exercise intensity requires no equipment such as HR monitors or RPE charts, and students will not have to stop to take their HR or assess their exertion level.

In guiding students towards being able to exercise independently, teaching students to monitor exercise intensity can be beneficial. Giving children and youth an understanding of what a moderate-to-vigorous exercise intensity level feels like will help them successfully continue a particular activity for more extended periods of time (28). Many children have a tendency to overexert themselves at the outset of activity. Having to persist in a particular activity for a prolonged period of time can be perceived as boring and it can be difficult to motivate some children to engage in activities of long duration. If children are consistently pushed to perform such activities, particularly in physical education class, negative attitudes towards physical activity in general may develop. As the concept of 'pacing' can be difficult for many youngsters to grasp, teaching students how to differentiate between light, moderate, and vigorous activities at a young age has been suggested as a way to help children sustain physical activity and to promote adoption of a physically active lifestyle (28).

Teaching children to exercise at a sufficient intensity and duration to induce cardiorespiratory fitness improvements is beneficial to their overall health. Individuals that are physically fit have a lower risk for mortality from all causes (5, 13).

Cardiovascular fitness appears to have a protective effect on the development of type 2 diabetes (52) and cardiovascular disease (51). Physically fit children exhibit fewer cardiovascular risk factors (74) and are also more likely to remain active compared to children with lower fitness levels (15, 72).

There were several limitations to this study. First, this study was completed in a laboratory setting where the pace of activity was gradually increased and subjects exercised while wearing laboratory equipment. Some subjects expressed discomfort in wearing the mouthpiece. The mouthpiece and the nose clip may have interfered with the subjects' ability to hear their breathing, which may account for the subjects' identification of the ABT systematically later than their VT. Several investigators have demonstrated that the use of a respiration apparatus during exercise testing results in altered breathing patterns (6, 49, 66). Compared with subjects breathing unencumbered, subjects breathing through a mask or nose clip and mouthpiece show increased $\dot{V}_E$ due to increased tidal volume and reduced breathing frequency. These altered ventilatory parameters may have led the subjects of this study to indicate reaching their ABT at a later time than if they were not breathing through a nose clip and mouthpiece. While it is unclear whether or not the nose clip and mouthpiece did indeed influence the results of this study, it is worthy to consider this issue with respect to the fact that children will not normally be exercising while wearing measurement equipment. Future studies should explore the identification of the ABT in subjects exercising with and without the use of a respiratory apparatus.

Second, determination of the VT by visual inspection is subjective in nature and errors may be uncontrollable. Although the use of computerized methods may help minimize bias (65), the current literature does not support its use over independent evaluators. VT determination by visual inspection has been found to be both valid and reliable and is optimal when a combination of methods is used (34).

Third, VT changes with maturation (67) and responds to training (58), changing significantly in as little as 4 weeks (37). Thus, if VT is not reassessed regularly, the selected target intensity may become an inadequate or inappropriate stimulus within a short period of time. The present study was not able to examine whether the ABT changes with the VT.

Fourth, HR was recorded every 20 seconds. Although the number of data points obtained was sufficient for observing maximal effort and general relationships between HR and workload, there were insufficient readings for assessing any threshold relationships. It was also not possible to interpolate the exact exercise HR at which the VT occurred from the data collected, particularly for subjects who had low peak exercise times, and therefore, fewer HR data points.

Fifth, no control or alternate conditions were used. It is possible that subjects would be able to approximate their VT by using other methods just as effectively. In addition to general RPE, perceptible physiological adaptations during a bout of exercise include changes in HR and perspiration, but defining demarcations that correspond to the VT for these responses is difficult. Although it has been shown that a break from linearity in HR occurs at the VT, it is difficult to perceptually isolate this point with human sensations. Similarly, although the onset of sweating is easily perceived, perspiration responses are highly individual and can be significantly influenced by external factors such as ambient temperature and the amount of clothing worn.

Sixth, subjects of this study have diverse levels of maturity, fitness levels, and other physiological characteristics that may moderate the ABT-VT relationship. In particular, subjects in this study were found to have above-average aerobic fitness levels. Moreover, only one subject could be classified as overweight, while approximately one-third of Canadian children and youth are overweight or obese (91). Weight status has been identified as a factor affecting the effectiveness of HRM and RPE. Thus, it is possible that the degree of overweight may also affect the use of the ABT in monitoring exercise intensity at the VT. Future studies should explore this possibility.

Seventh, there were only 16 subjects who completed this study. Thus, this study may be underpowered for demonstrating additional relationships and other gender or fitness effects. Future studies using similar procedures, but with larger sample sizes may be able to show other significant relationships between VT, ABT, and $\dot{V}O_{2peak}$.

Finally, several external factors can affect ABT determination. Swimming is one activity where the application of the ABT may be difficult. High levels of ambient noise can affect an individual's ability to hear breath sounds. Motor driven exercise equipment such as the treadmill used in this study may affect the ABT. However, few physical activities take place in completely quiet environments, especially for children and adolescents. Future studies should examine the extent to which ambient noise affects the ABT.

The efficacy of applying the assessment of ABT for the purposes of monitoring exercise intensity should be examined in a variety of field, school, and exercise prescription settings. The ABT may be a useful indicator of exercise intensity in clinical populations such as individuals with respiratory disease or obesity. Longitudinal investigations can examine the intra-individual reliability of ABT, especially if VT or $\dot{V}O_{2peak}$ significantly changes.

In conclusion, the ABT has been shown to be good predictor of VT in a sample of fit, 11- to 14-year-old children. The ABT appears to be a convenient indicator of an exercise intensity that is necessary for improvements in cardiorespiratory benefits. Because of significant limitations in the application of HRM and RPE in children and youth, the ABT can be used as a simple and practical adjunct to monitoring exercise intensity with previously established methods.

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APPENDIX A: CONSENT FORMS AND INSTRUCTIONS TO PARTICIPANT

Parent or Guardian's Consent to Participate

Dear Parent or Guardian:

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

My name is Carmina Ng and I am currently a graduate student with the Faculty of Physical Education and Recreation Studies at the University of Manitoba. I am conducting a study to investigate a new method of monitoring exercise intensity in children that uses their own breathing to gauge how hard they are exercising. Many children and youth are not active enough for health benefits and this study will help develop ways to encourage them to move more and for longer periods of time.

I would like to ask your son or daughter to participate. Your child's participation is completely voluntary. To participate in this study, your son or daughter must be apparently healthy and never had any serious illnesses or diseases. S/he will be asked to perform two exercise tests on a treadmill about one week apart at the University of Manitoba. Your approval will be required for when the visits will be scheduled. You are welcome to be in the laboratory with your child during the tests. I will be conducting both tests and to ensure safety, I have been trained to operate all equipment that your child will be using and am certified in first aid and CPR. Please refer to the attached "Summary of Project" and "Instructions to Participant" for further details of the study. Keep in mind that there will be no penalty if at any time, your child wishes to stop participating. All information will be kept confidential and your child's name will be replaced with numbers on all reports about this study.

If you have any questions, please feel free to contact me at or my project supervisor, Dr. Joannie Halas at

This research has been approved by the University of Manitoba Education/Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Secretariat at . A copy of this consent form has been given to you to keep for your records and reference.

Please turn to page 2…

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to allow your child to participate as a subject. In no way does this waive your child's legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. Your child is free to withdraw from the study at any time, and/or refrain from answering any questions s/he prefers to omit, without prejudice or consequence. Your child's continued participation should be as informed as his/her initial consent, so s/he should feel free to ask for clarification or new information throughout his/her participation.

Sincerely,

Carmina Ng
Graduate Student
Faculty of Physical Education and
Recreation Studies
University of Manitoba

Dr. Joannie Halas, PhD
Associate Professor
Faculty of Physical Education and
Recreation Studies
University of Manitoba

____
Child's Name

____
Parent/Guardian's Signature Date

____
Researcher's Signature Date

If you would like a copy of the results of this study, fill in your preferred means of contact (optional):

Address __________________________

____

____

Email ____________________

Participant's Consent to Participate

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

I understand that I have been asked to be in a project that looks at a way to measure how hard I am exercising. If I agree to participate in this project, I will have to do two exercise tests at the University of Manitoba. The person doing the testing is trained to operate all equipment I will be using and is certified in CPR and first aid. During these tests, I will have to run on a treadmill. As the test goes on, I will have to run harder and faster to keep up with the treadmill. My height, weight, breathing, and heart rate will be measured. I have read and understood the "Instructions to Participant" attached to this page.

I understand that I don't have to participate in this project and that if I agree to do this, I can quit any time and not have to feel bad. I understand that my name won't be used and my test results will be kept private.

If I have any questions about this project, I can talk to my instructor, my parents, or call Carmina Ng at or Dr. Joannie Halas at

This research has been approved by the University of Manitoba Education/Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Secretariat at .. A copy of this consent form has been given to you to keep for your records and reference.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and/or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

I understand what this project is about and what I am supposed to do. I volunteer for this project.

____

Participant's Name Participant's Signature Date

____

Researcher's Signature Date

If you would like a copy of the results of this study, fill in your preferred means of contact (optional):

Address ______________________ Email ____________________

____

____

Instructions to Participant

You will need to visit the laboratory twice. Visits will be scheduled 2-10 days apart, with each visit being between 30-45 minutes in duration.

Before the tests...

1. You should not be sick (with a cold, for example) or on any medications.
2. Do not engage in very strenuous exercise a day before testing or eat a large meal 1 hour before testing. Do not consume any drinks containing caffeine (e.g., cola) on the day of the test.
3. Do drink plenty of water or other fluids about 1 hour before your test times and bring a bottle of water with you.
4. Dress comfortably and wear running shoes.

At the laboratory...

1. The tester will need to measure your height and weight.
2. You will be fitted with a pneumotach, which is a mouthpiece that is connected to a machine that measures the amount of air you're breathing in and out. (For the first test, you won't need this until a couple of minutes into the test. For the second test, you will need to breathe through this instrument the whole time.)
3. You will also be fitted with a heart rate monitor that is worn across your chest.
4. You will be given time to get used to running on a treadmill. During this time, make sure that you are able to run comfortably. Once you are comfortable, you can warm up for about 1 minute.
5. Whenever you are ready, the test will start.

If at any time during the tests you feel any discomfort (e.g., dizziness, chest pain, headache) or want to stop, ***let the tester know right away.***

The exercise tests you will be performing are called graded exercise tests. You will gradually need to run harder and faster as the tester increases the grade (steepness) and speed of the treadmill.

Visit 1 – Determining the Breath Sound Check

The first test should last between 5-10 minutes. When you feel that you are exercising hard enough that you can ***clearly hear your breathing***, let the tester know by putting up your hand or saying, "I can hear my breathing", but *don't stop running!* At this time, the tester will help you put on the pneumotach. You may wish to hold on to the handrails while this is being done...but *keep running!* You will need to keep running at this pace for about 2 more minutes so that the tester can record your heart rate and breath measurements. When this is done, the intensity of the treadmill will be gradually reduced to allow you to cool down.

Visit 2 – Determining the Ventilatory Threshold

The second test should last between 10-15 minutes. For this test, you will need to breathe through the pneumotach for the entire test. This test is an exercise test to ***voluntary exhaustion***. The tester will keep increasing the grade and speed until you feel you've reached your maximum and can't keep up with the treadmill anymore. At this point, you should be very exhausted and can't run any harder. As soon as you've reached your maximum, let the instructor know right away either by saying so or by raising your hand. The tester will immediately begin reducing the intensity of the treadmill so that you can cool down.

Note: It is important that you cool down for 3-5 minutes before you get off the treadmill. Please don't attempt to get off the treadmill at any time without letting the tester know.

If you have any questions, please ask! Thank you for your participation in this study!

APPENDIX B: INDIVIDUAL RESULTS

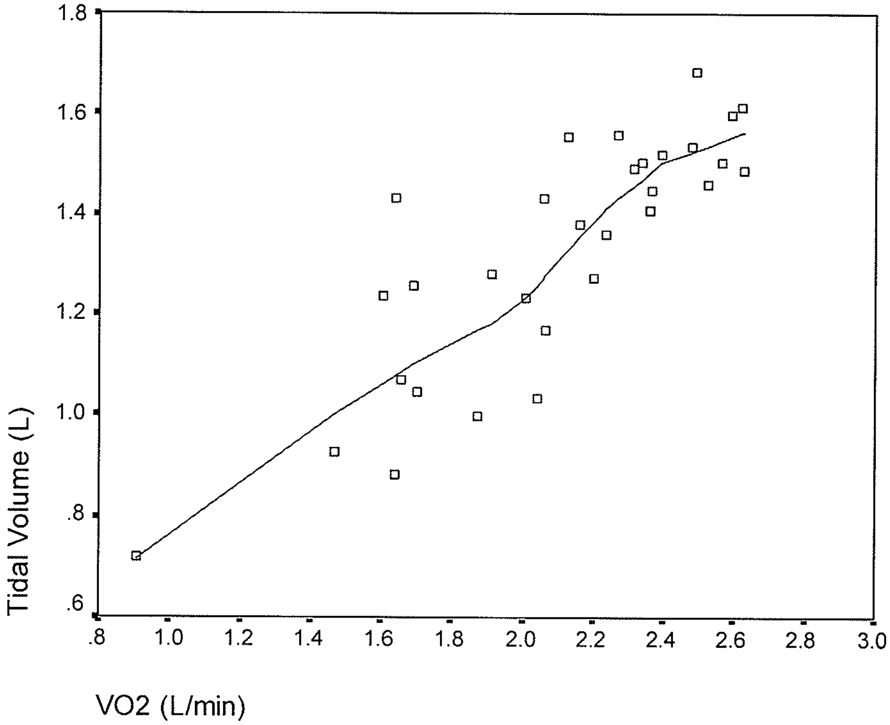
ID	Gender	Age (y)	Height (m)	Body Mass (kg)	% Difference $\frac{\text{ABT-VT}}{\text{ABT}}$	Ventilatory Threshold			Audible Breathing Threshold		
						$L \cdot min^{-1}$	$mL \cdot kg^{-1} \cdot min^{-1}$	$\% \dot{V}O_{2peak}$	$L \cdot min^{-1}$	$mL \cdot kg^{-1} \cdot min^{-1}$	$\% \dot{V}O_{2peak}$
1	M	14	1.57	44.1	10.8	1.66	37.6	62.6	1.84	41.7	69.4
2	M	12	1.70	61.8	7.3	2.75	44.5	72.4	2.95	47.7	77.6
3	M	13	1.80	64.1	4.0	2.89	45.0	78.2	3.00	46.8	81.3
4	M	14	1.78	61.8	0.4	2.79	45.1	87.5	2.80	45.3	87.8
5	M	12	1.57	40.9	0.5	2.05	50.1	77.4	2.06	50.4	77.7
6	M	14	1.70	50.0	9.4	1.98	39.5	61.5	2.16	43.2	67.3
7	M	11	1.50	36.4	-8.1	1.60	44.0	78.0	1.47	40.4	71.7
8	F	14	1.57	44.1	15.4	1.41	32.0	66.9	1.63	37.0	77.3
9	F	14	1.60	48.6	3.7	1.48	30.3	70.2	1.53	31.5	72.9
10	F	13	1.55	50.9	20.0	1.85	36.3	65.6	2.22	43.6	78.7
11	F	14	1.57	44.1	21.2	1.73	39.1	68.2	2.09	47.4	82.6
12	F	11	1.52	53.2	5.8	1.73	32.4	64.8	1.83	34.3	68.6
13	F	14	1.75	65.9	6.3	2.40	36.4	74.5	2.55	38.7	79.2
14	F	14	1.65	46.4	-4.4	1.60	34.5	75.8	1.53	33.0	72.5
15	F	13	1.57	55.0	4.5	2.13	38.6	66.9	2.22	40.4	76.2
16	F	12	1.47	39.1	10.5	1.71	43.7	63.3	1.89	48.4	77.1
Mean		13.1	1.62	50.4	6.7	1.98	39.3	70.9	2.11	41.9	76.1
SD		1.1	0.10	9.2	7.9	0.48	5.6	7.2	0.50	5.8	5.5

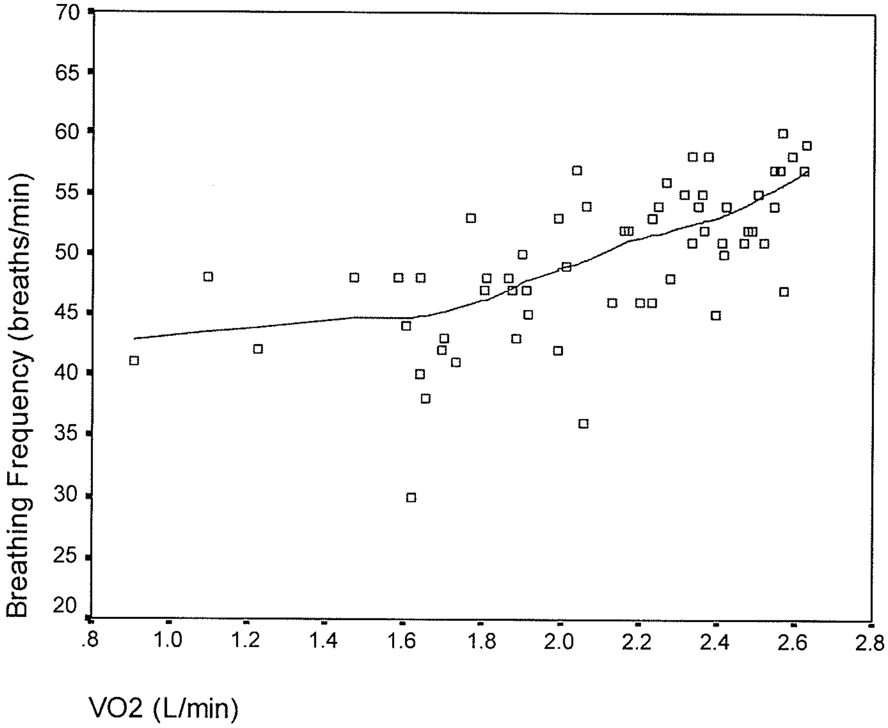
APPENDIX B: INDIVIDUAL RESULTS (CONT'D)

ID	**$\dot{V}O_{2peak}$**		**HRpeak (beats·min^{-1})**	**HR_{VT}**		**HR_{ABT}**		**Peak Time (s)**	**ABT Time (s)**	**RQ**
	L·min^{-1}	**mL·kg^{-1}·min^{-1}**		**beats·min^{-1}**	**%HR_{peak}**	**beats·min^{-1}**	**%HR_{peak}**			
1	2.65	60.1	204	166	81.4	180	88.2	620	200	1.11
2	3.80	61.5	203	147	72.4	165	81.3	552	160	1.13
3	3.69	57.6	199	170	85.4	181	91.0	680	360	1.23
4	3.19	51.6	190	169	88.9	167	87.9	470	340	1.21
5	2.65	64.8	202	185	91.6	187	92.6	610	340	1.20
6	3.21	64.2	194	152	78.4	157	80.9	740	240	1.17
7	2.05	56.4	200	168	84.0	175	87.5	424	160	1.12
8	2.11	47.9	200	156	78.0	157	78.5	553	180	1.23
9	2.10	43.2	189	155	82.0	161	85.2	340	180	1.10
10	2.82	55.4	197	164	83.2	180	91.4	656	320	1.21
11	2.53	57.4	200	168	84.0	182	91.0	459	180	1.10
12	2.66	50.0	205	170	82.9	180	87.8	450	100	1.12
13	3.22	48.9	199	177	88.9	176	88.4	424	140	1.11
14	2.11	45.5	212	172	81.1	180	84.9	374	120	1.16
15	2.91	53.0	201	173	86.1	182	90.5	410	120	1.17
16	2.45	62.7	190	167	87.9	173	91.1	578	220	1.11
Mean	2.76	55.0	199.1	166	83.5	174	87.4	521	210	1.16
SD	0.55	6.7	6.1	10	4.8	10	4.2	119	86	0.05

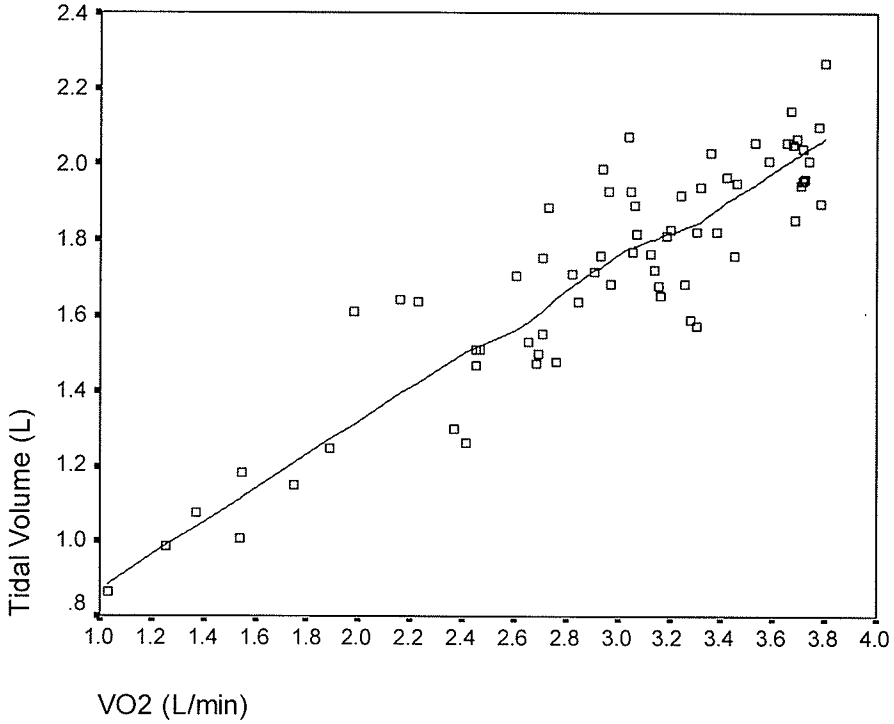
APPENDIX C: SCATTERPLOTS OF TIDAL VOLUME AND BREATHING FREQUENCY VS. OXYGEN CONSUMPTION

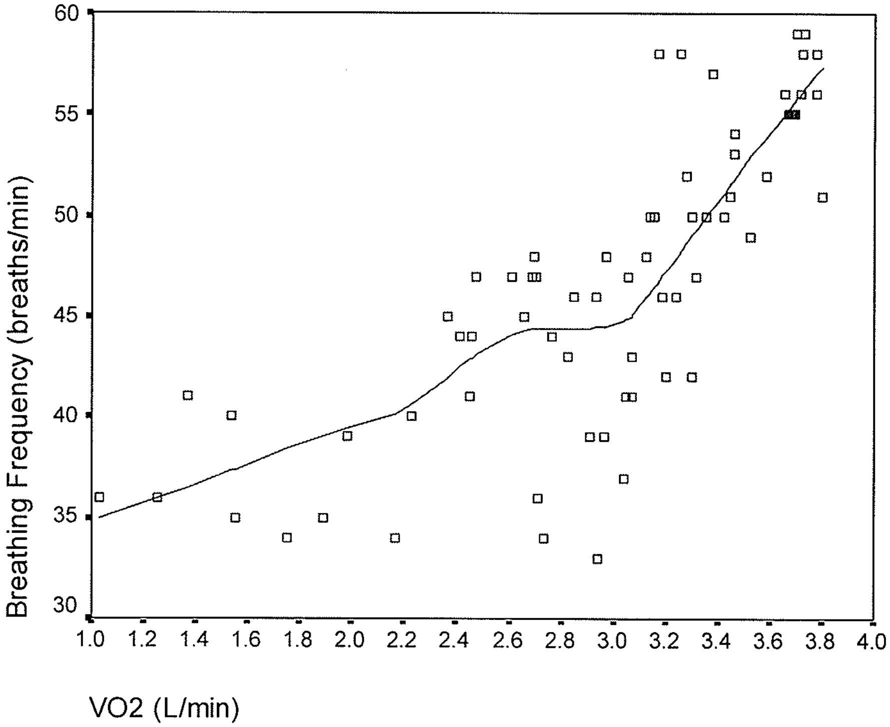
Subject 1 – ABT: 1.84 L·min^{-1}



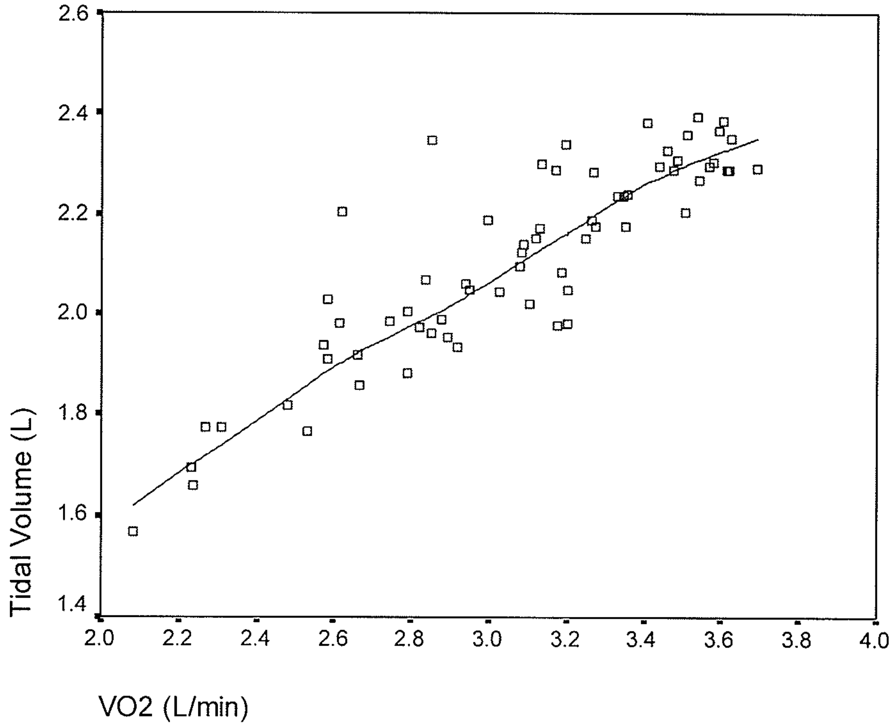


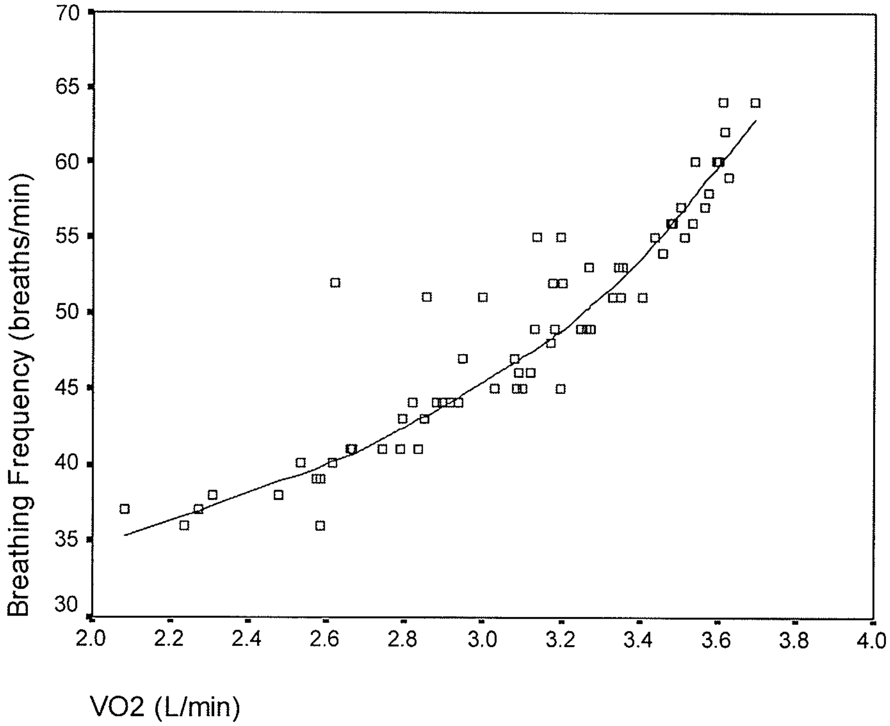
Subject 2 – ABT: 2.95 L·min^{-1}



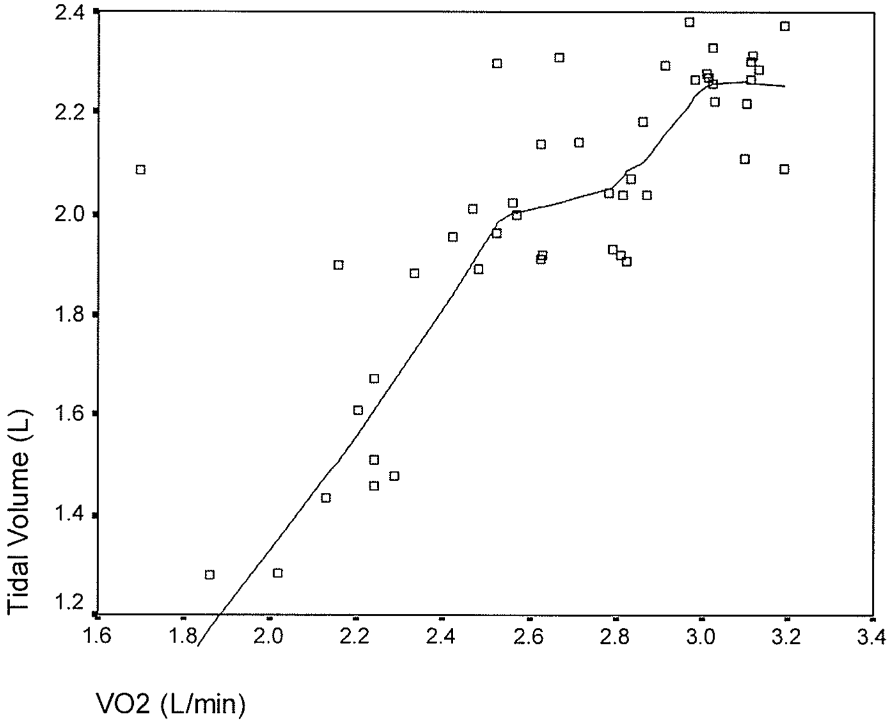


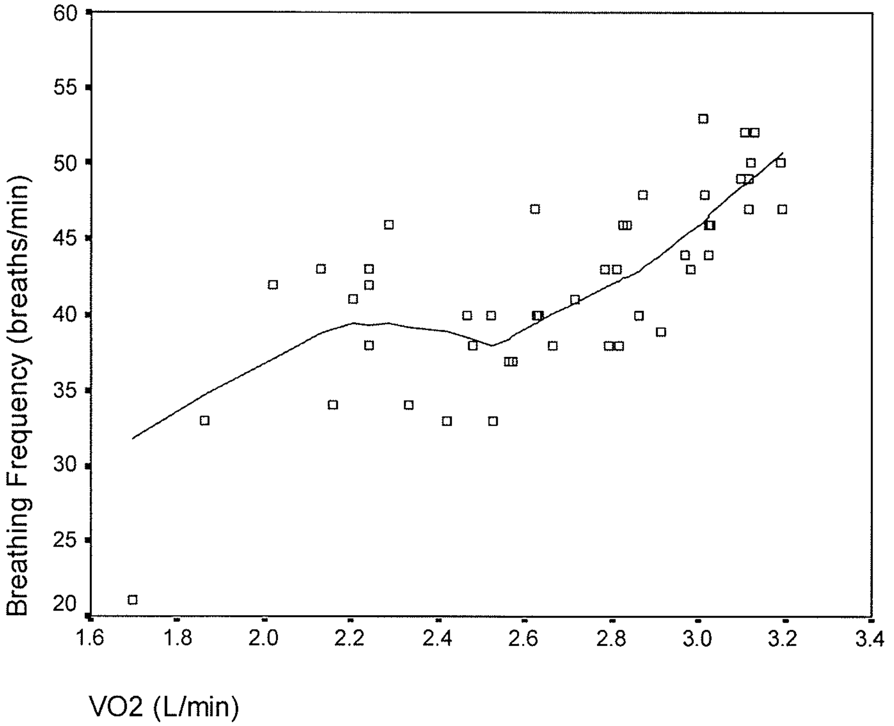
Subject 3 – ABT: 3.00 L·min^{-1}



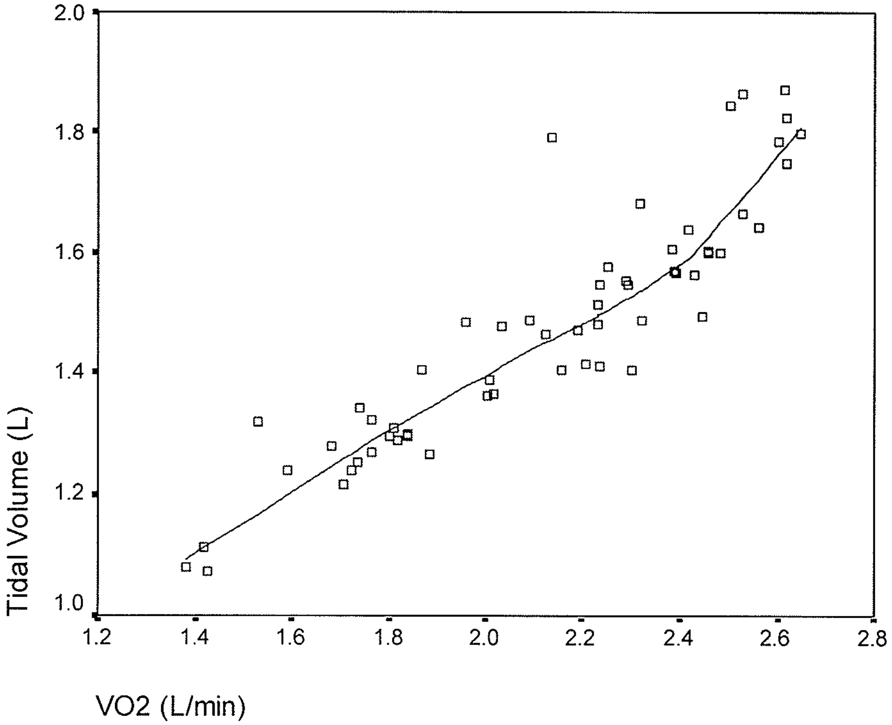


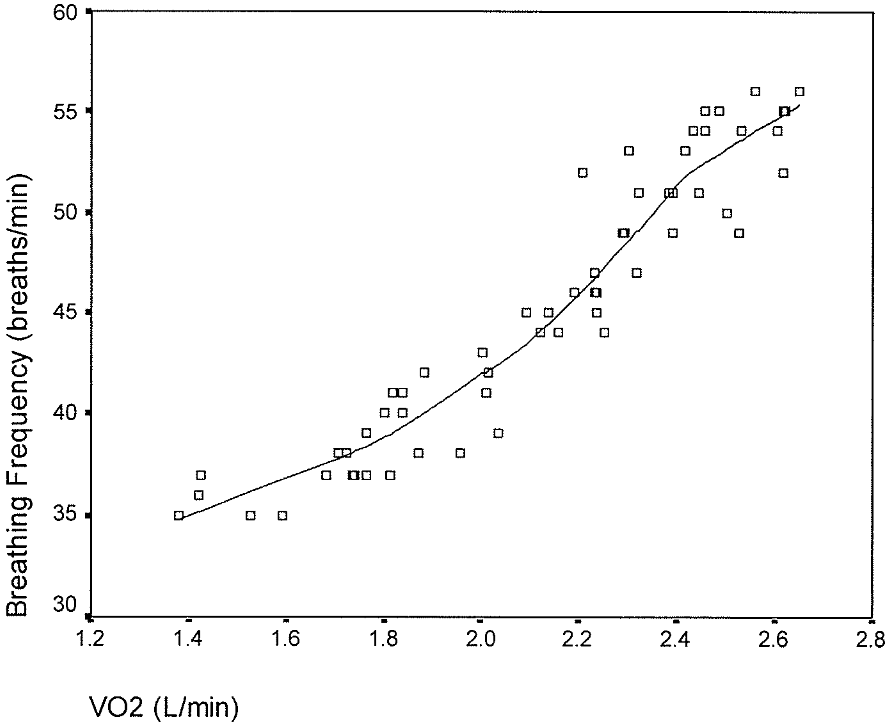
Subject 4 – ABT: 2.80 L·min^{-1}



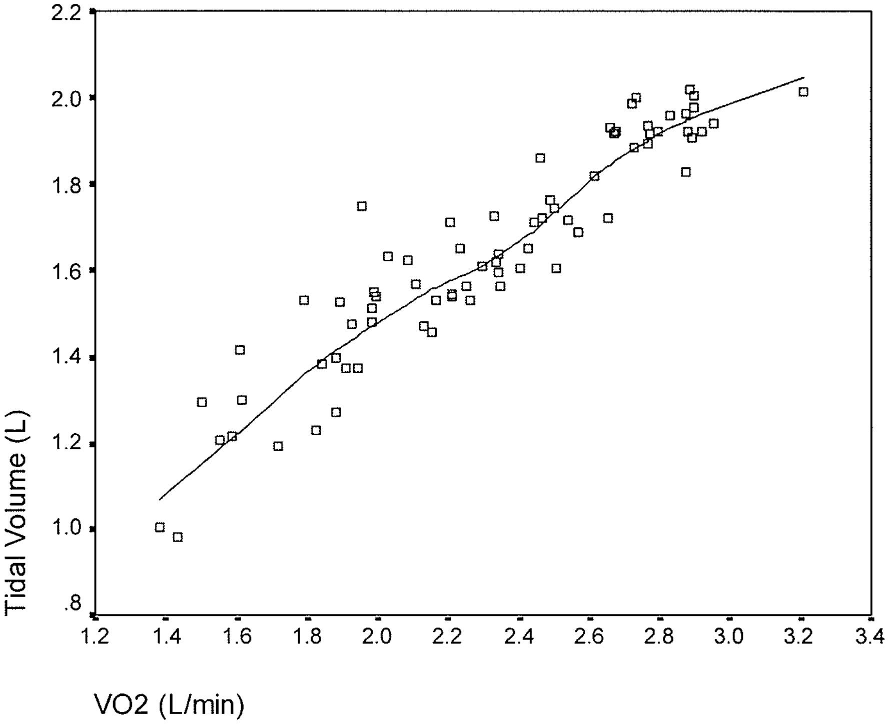


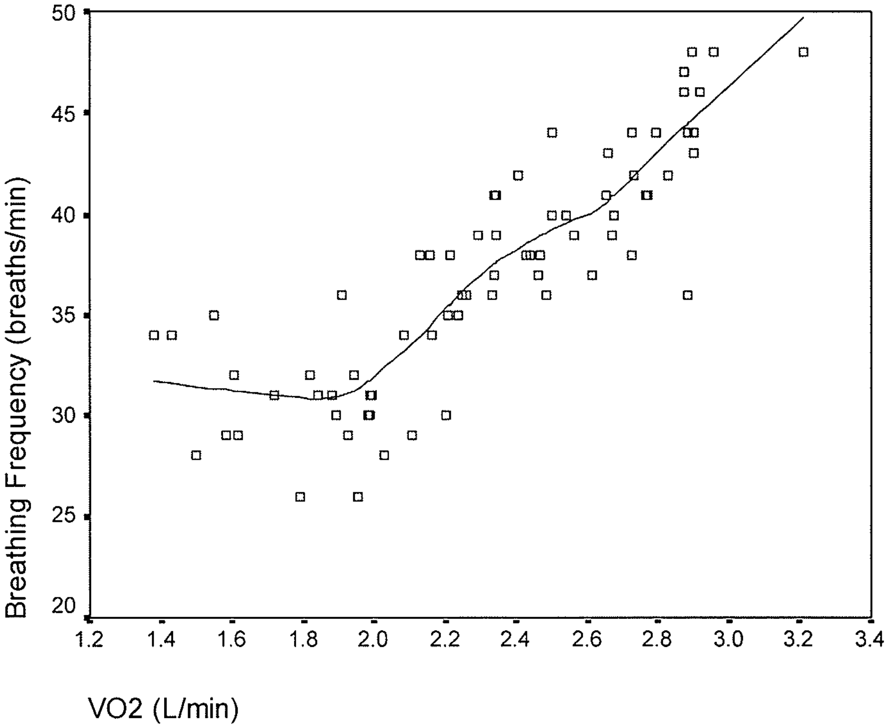
Subject 5 – ABT: 2.06 L·min^{-1}



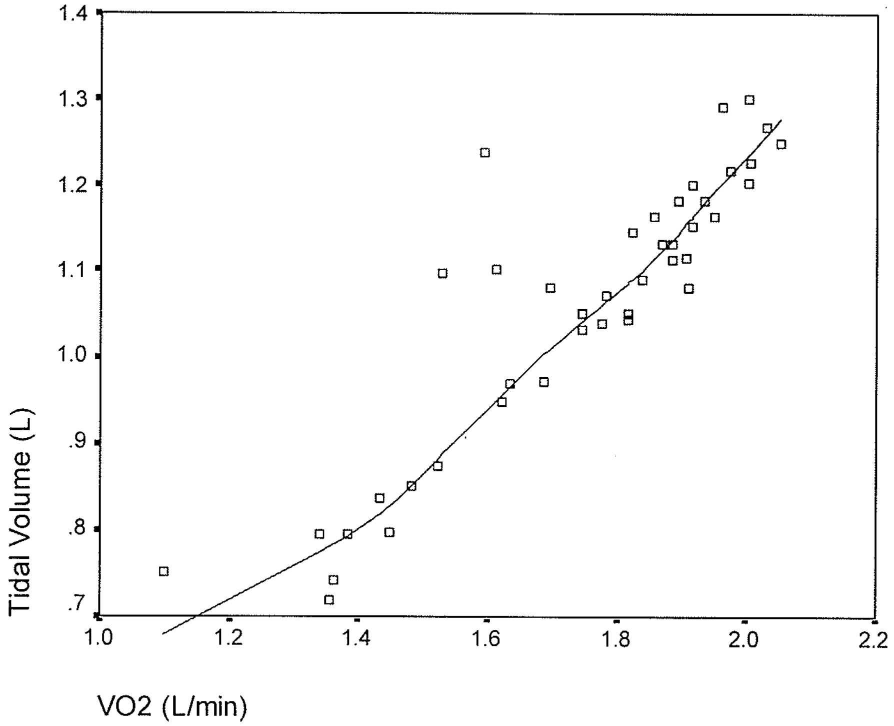


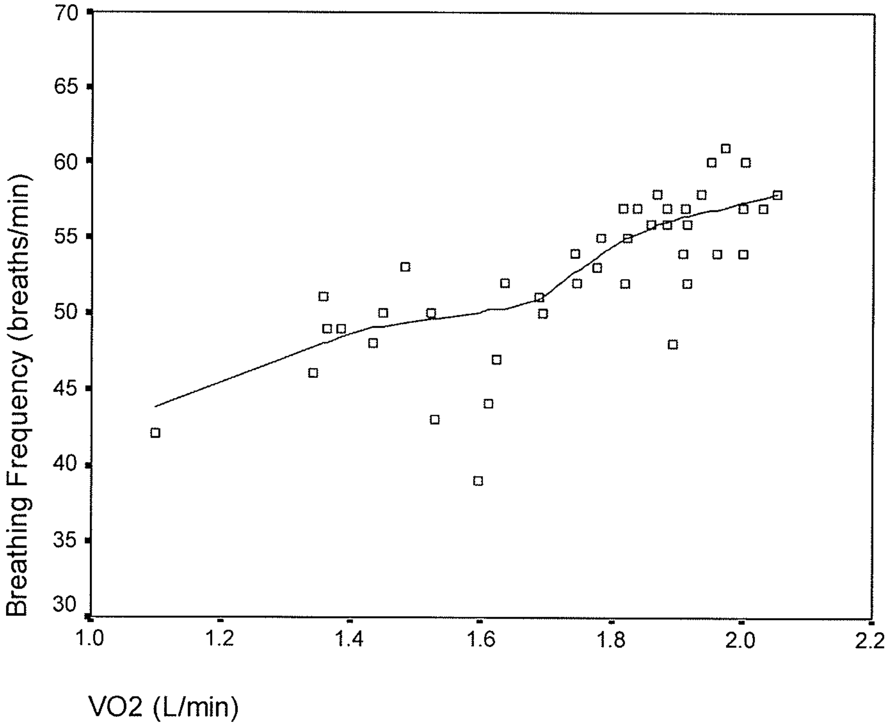
Subject 6 – ABT: 2.16 L·min^{-1}



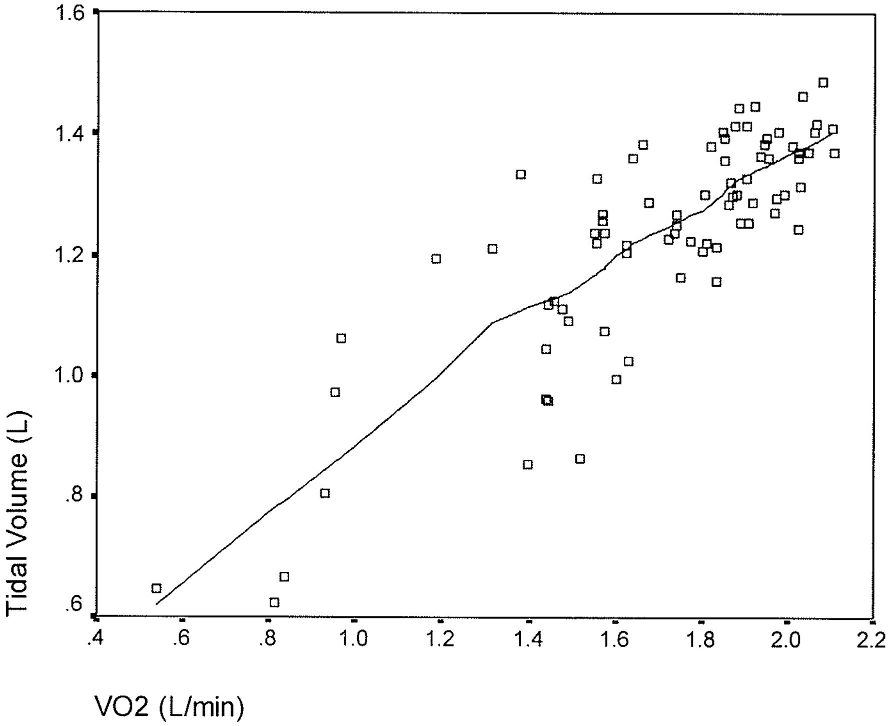


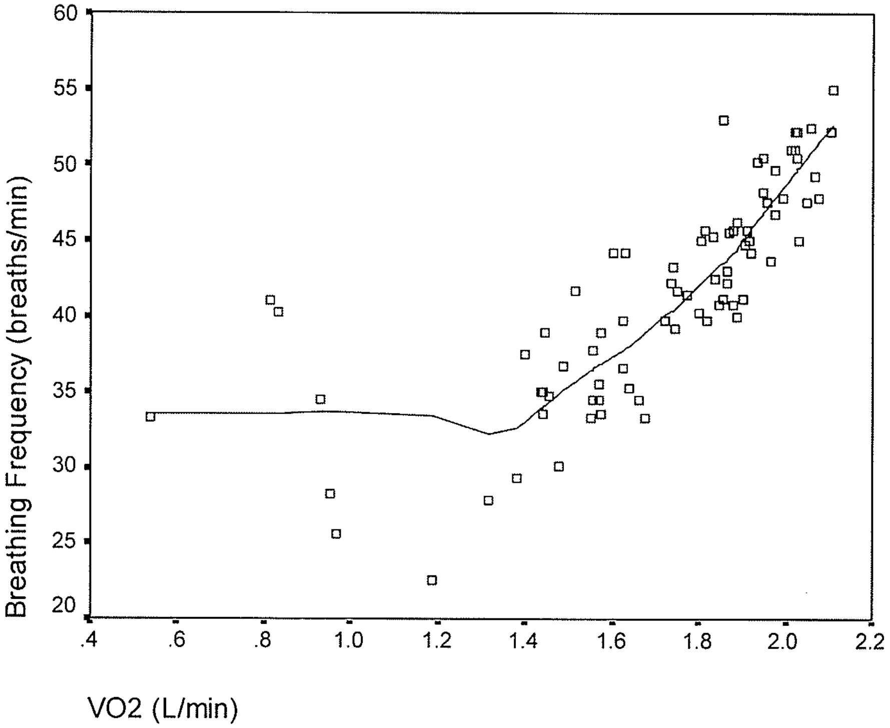
Subject 7: 1.47 L·min^{-1}



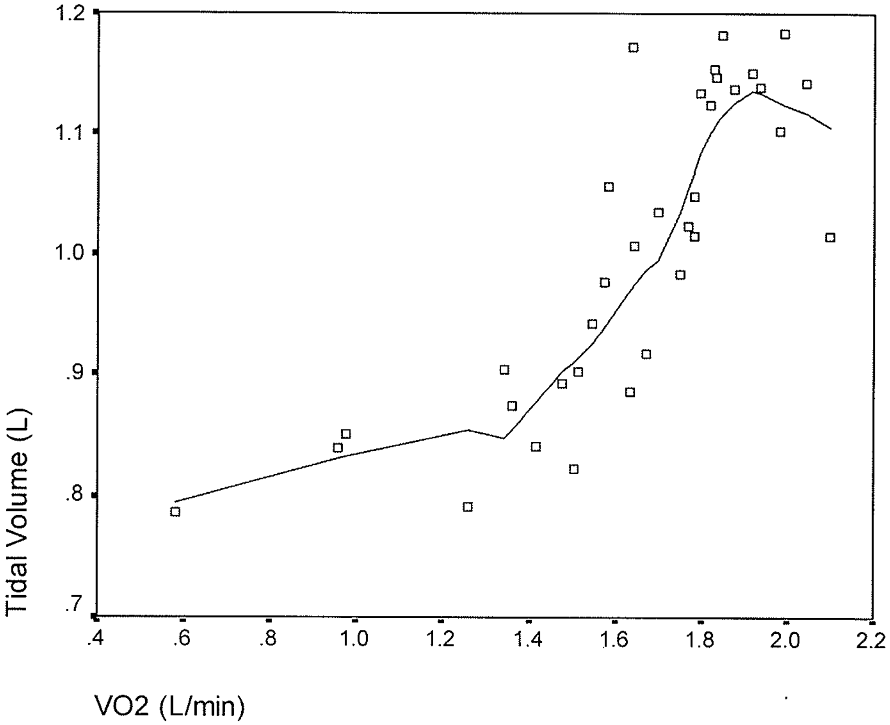


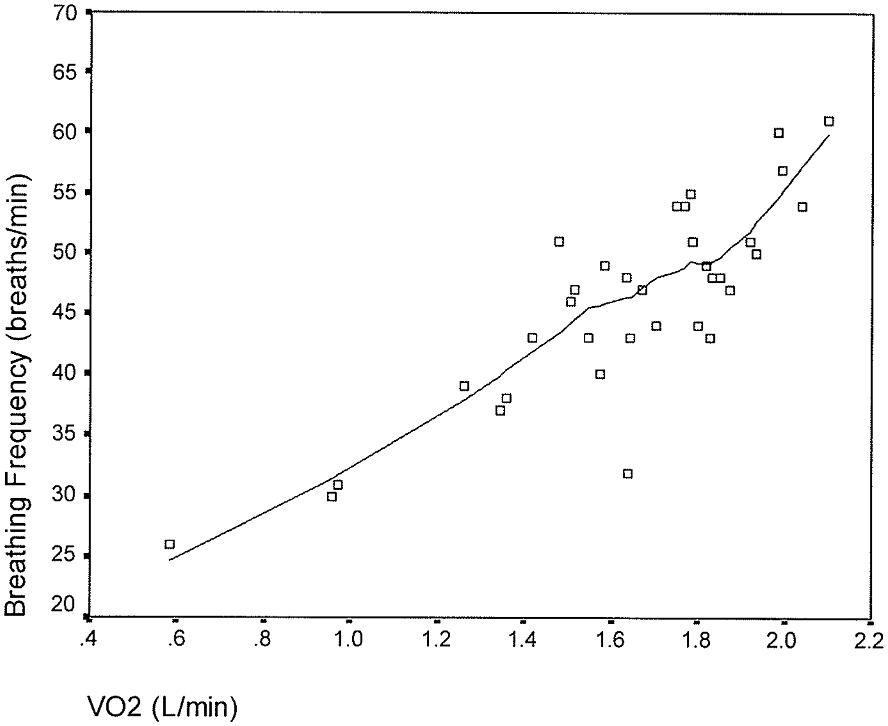
Subject 8 – ABT: 1.63 L·min^{-1}



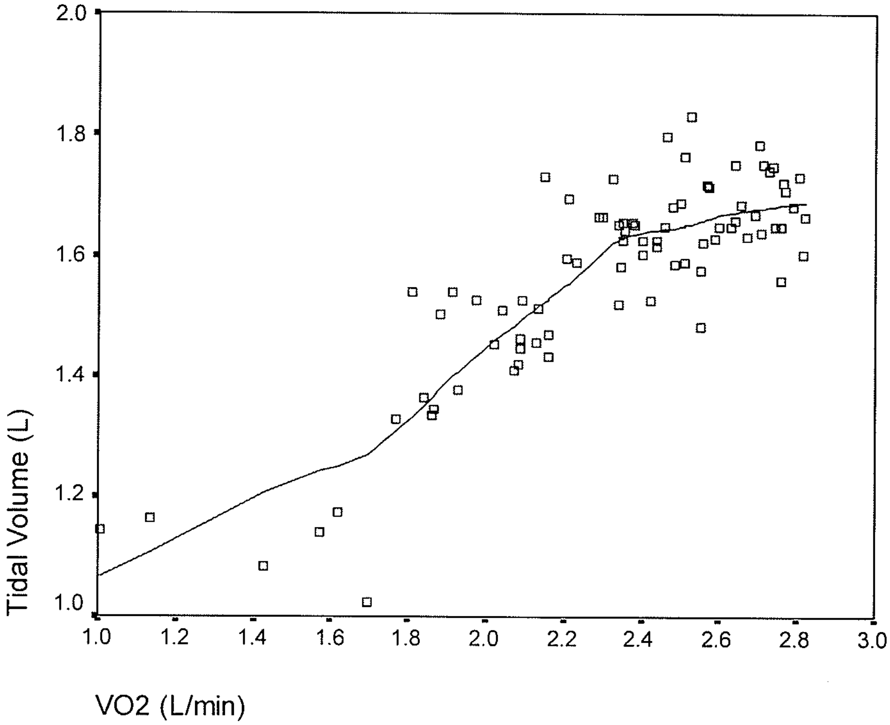


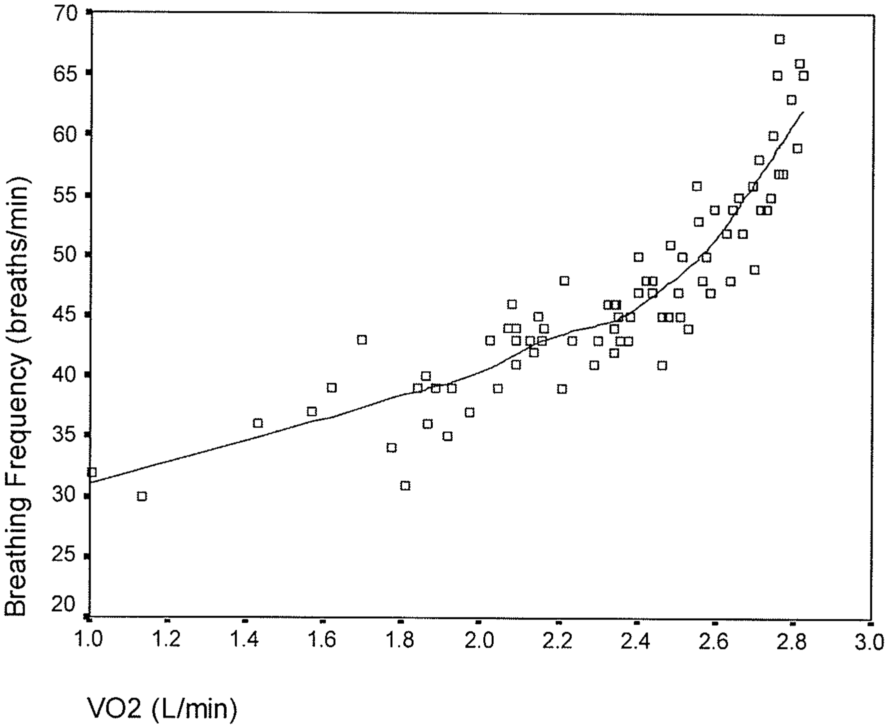
Subject 9 – ABT: 1.53 L·min^{-1}



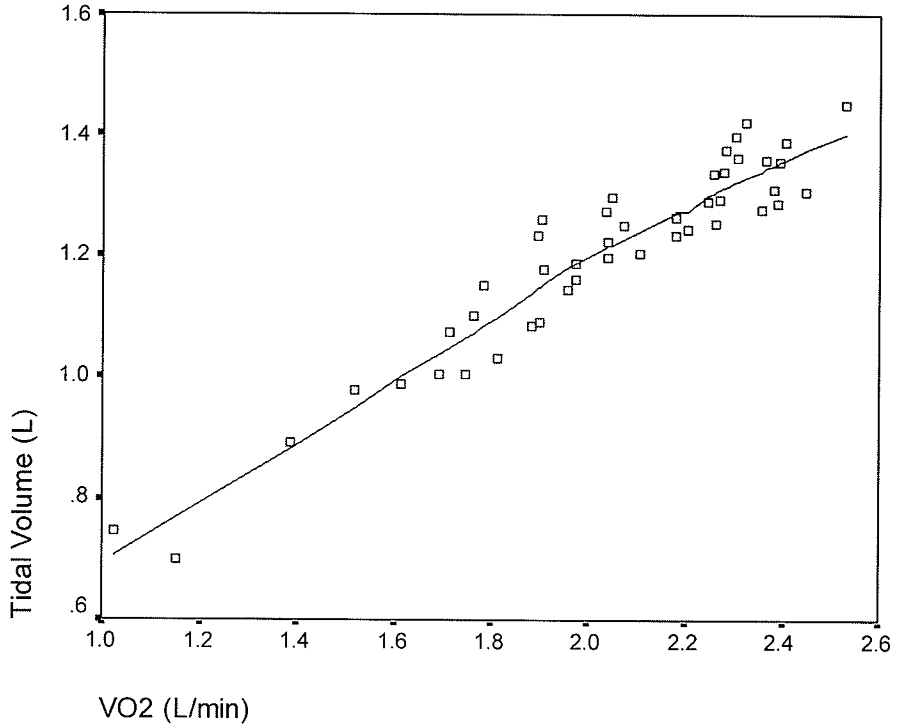


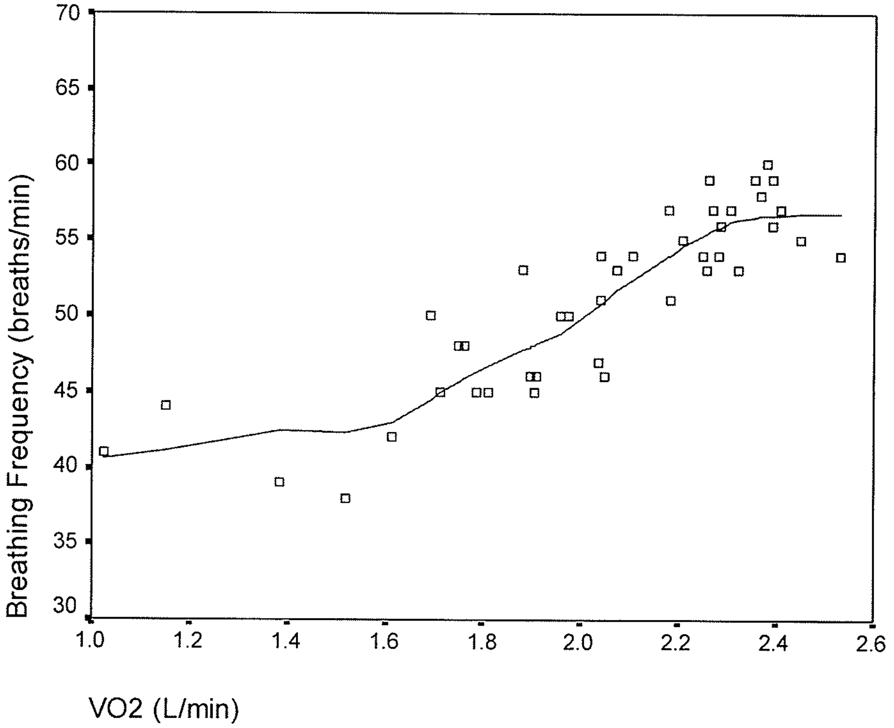
Subject 10 – ABT: 2.22 L·min^{-1}



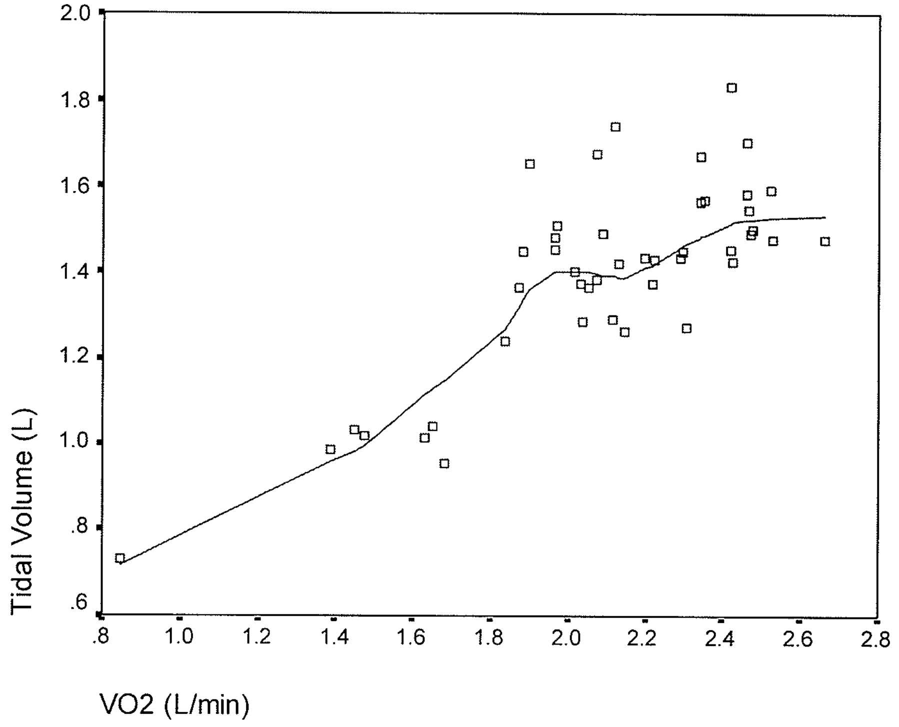


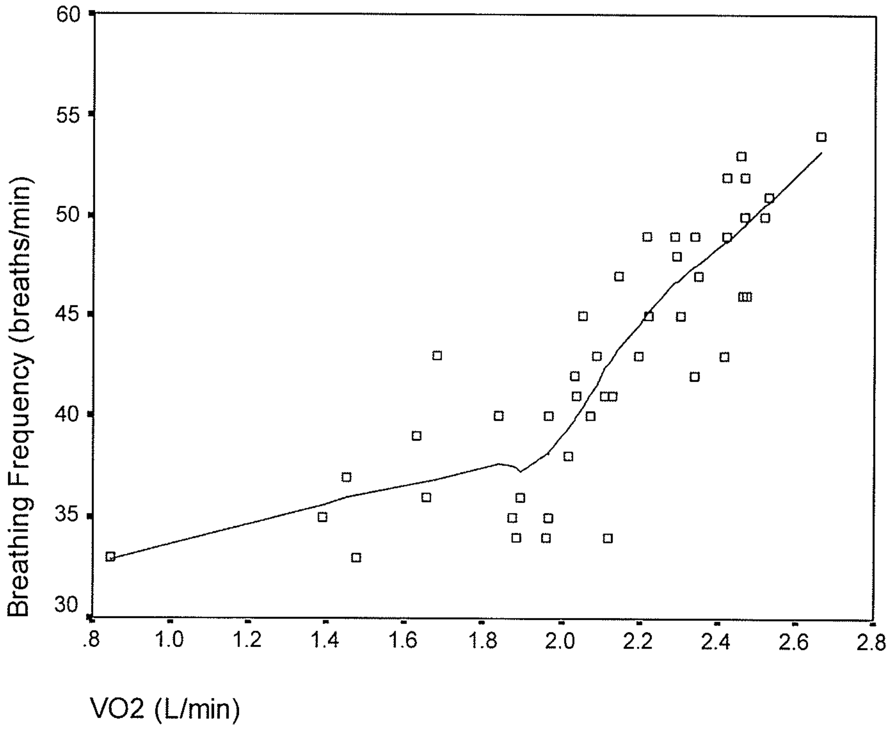
Subject 11 – ABT: 2.09 L·min^{-1}



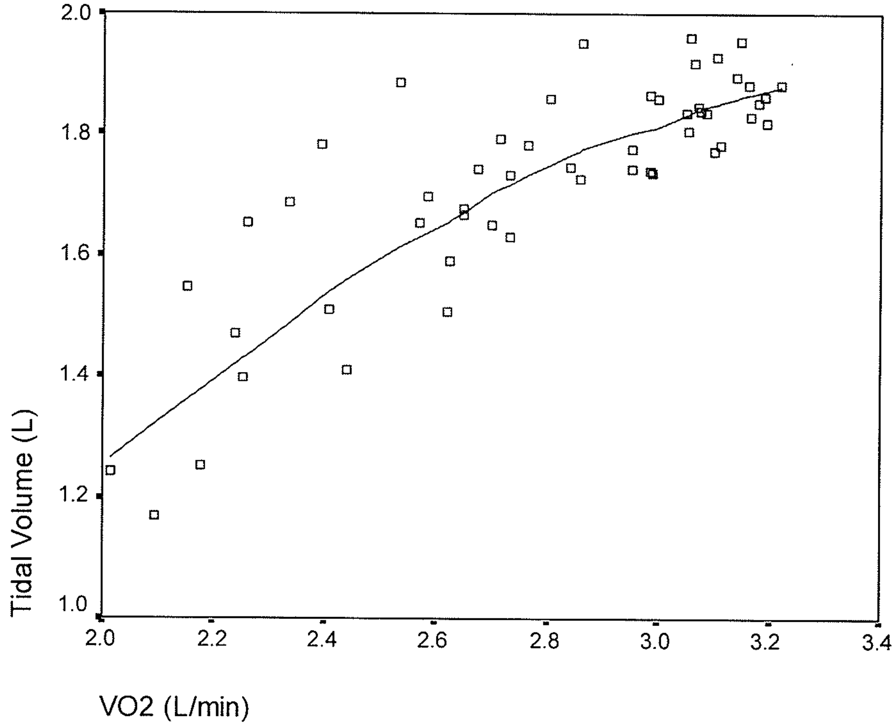


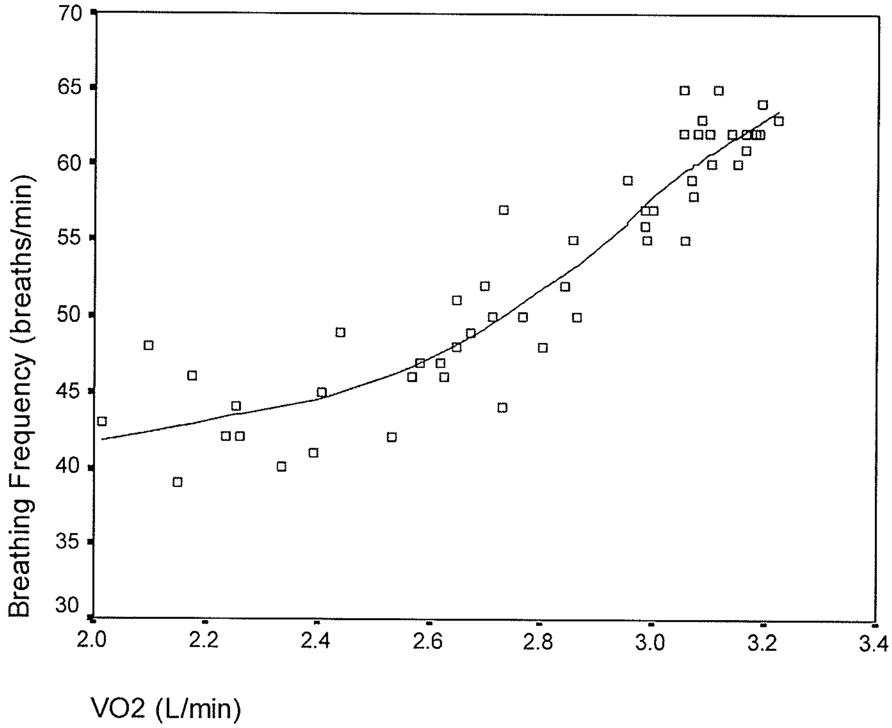
Subject 12 – ABT: 1.83 L·min^{-1}



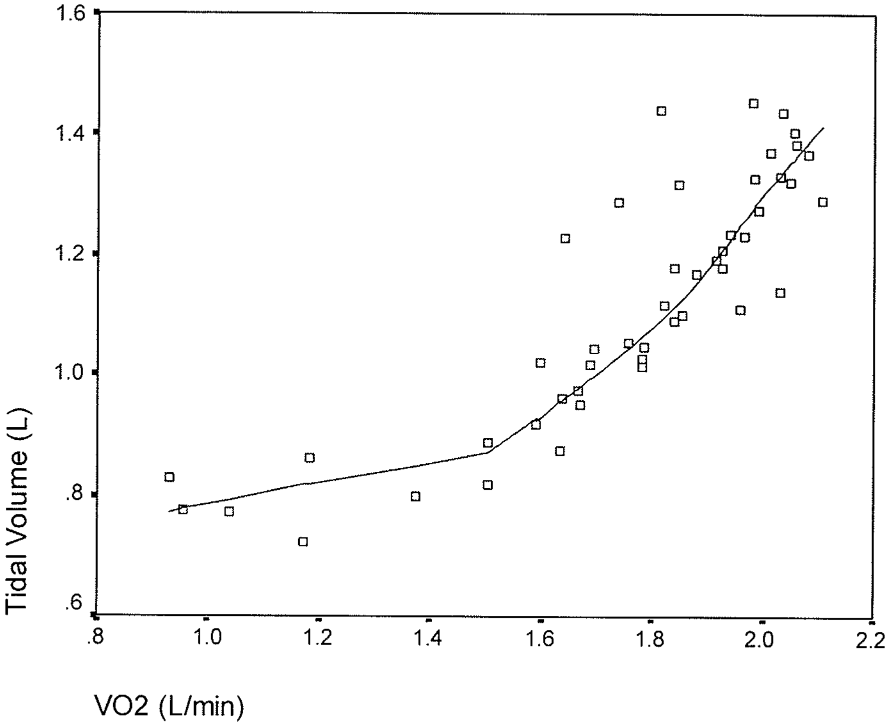


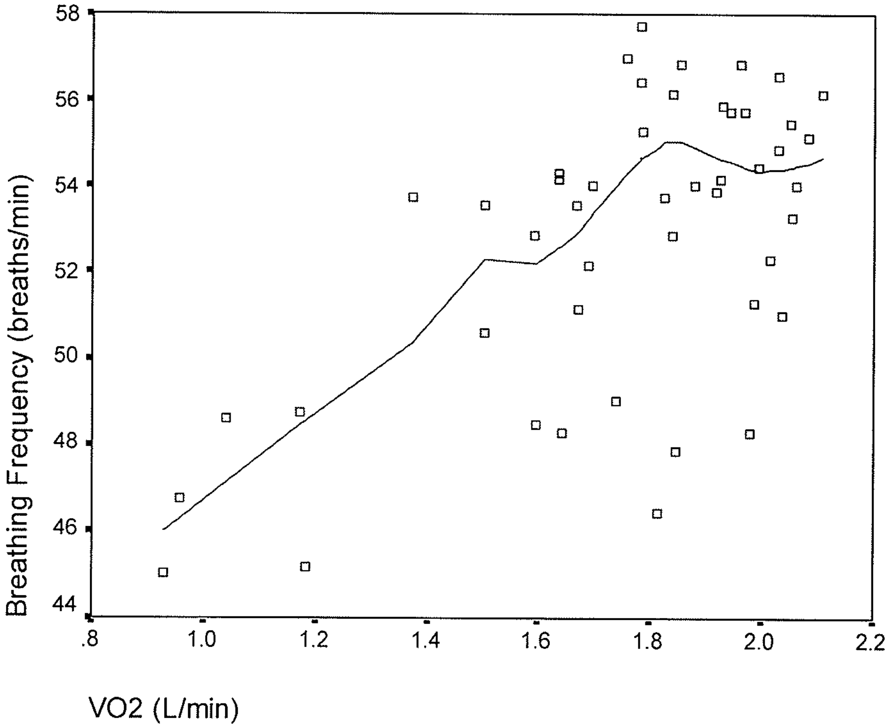
Subject 13 – ABT: 2.55 L·min^{-1}



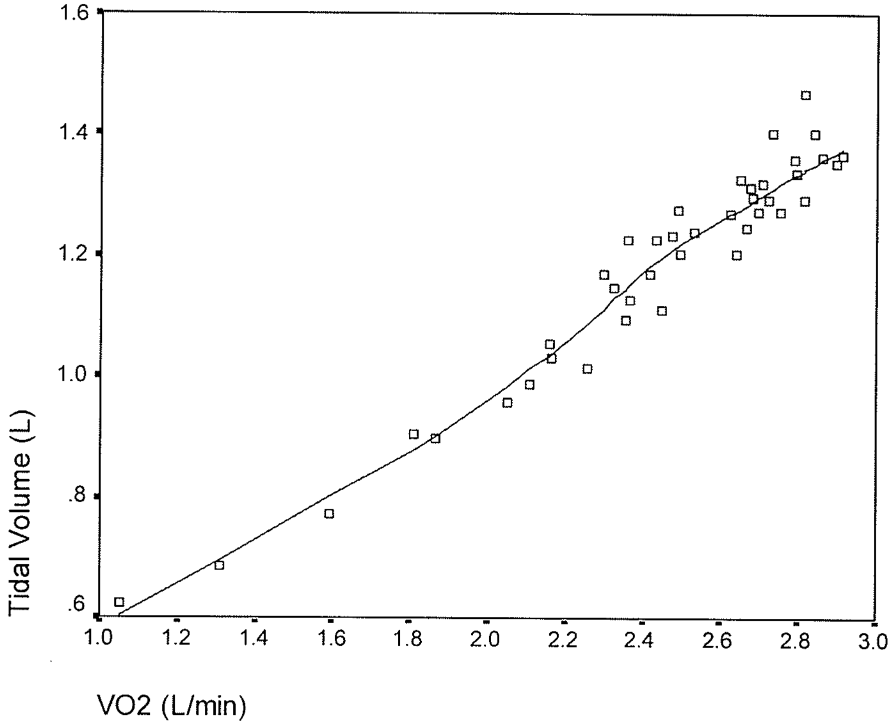


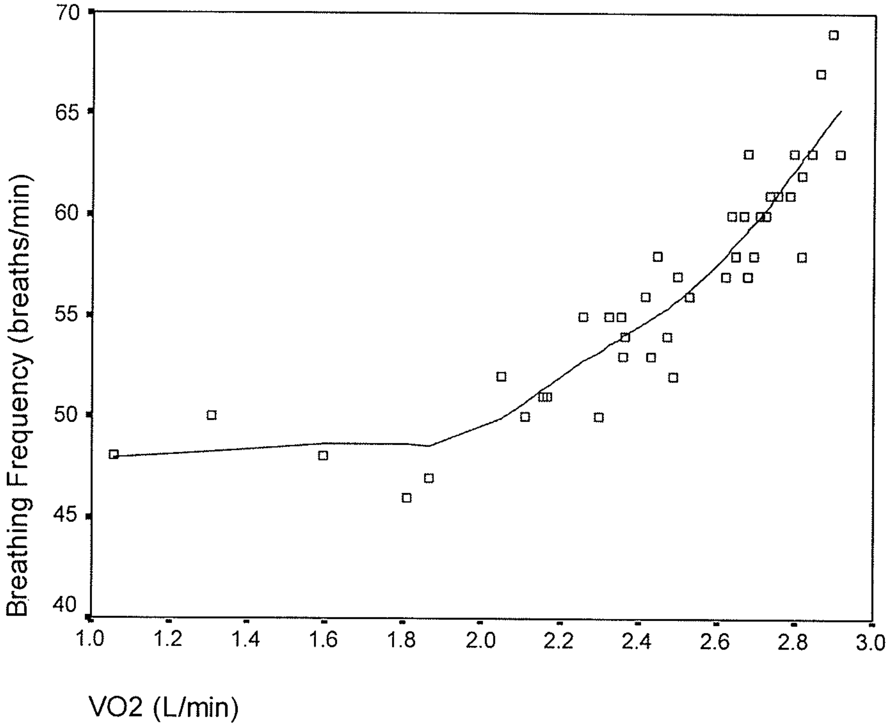
Subject 14 – ABT: 1.53 L·min^{-1}



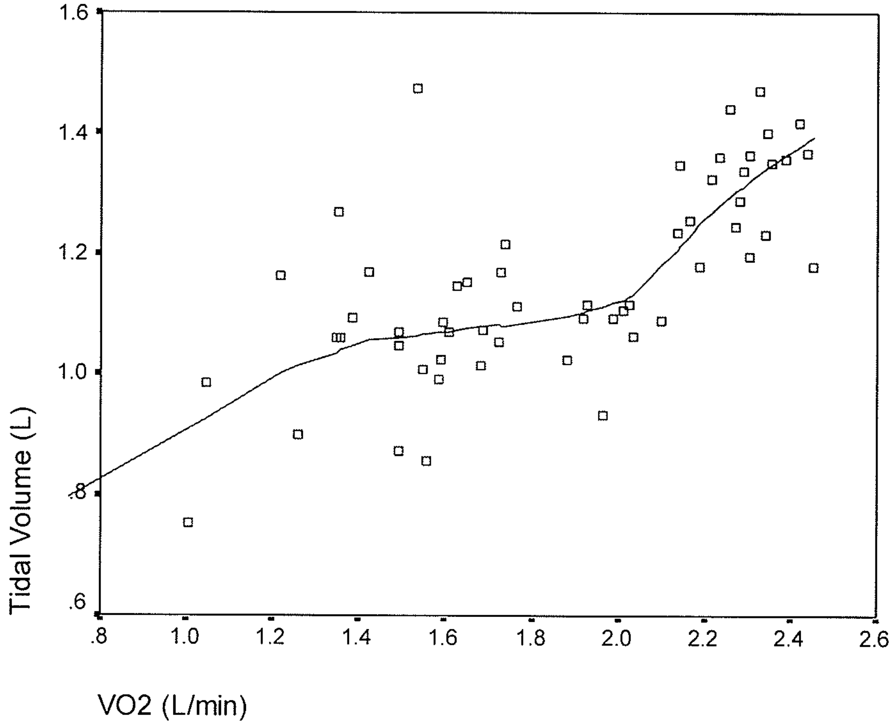


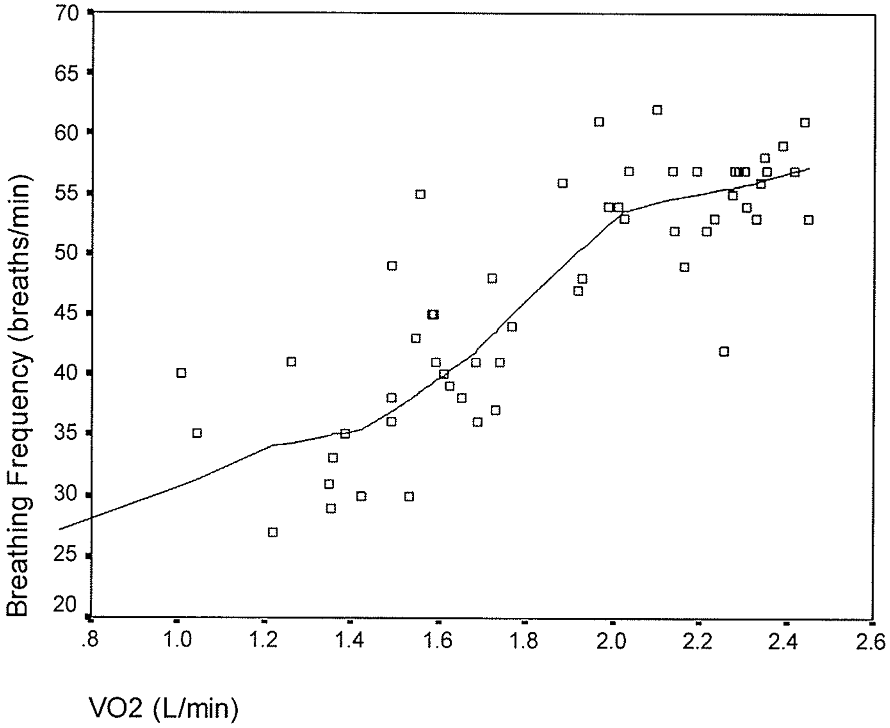
Subject 15 – ABT: 2.22 $L \cdot min^{-1}$





Subject 16 – ABT: 1.89 L·min^{-1}





APPENDIX D: ABT REPRODUCIBILITY

PURPOSE

The purpose of this study is to establish the reproducibility of the audible breathing threshold (ABT) in children.

METHODS

Subjects

Ten boys and girls were recruited from an ethnically diverse middle school in the Winnipeg area. Participants were non-smokers with no known medical conditions that can affect exercise performance (e.g. asthma, heart conditions). Written informed consent was obtained from the subjects and one of their parents or guardians prior to the beginning of the study. Ethical approval was obtained from the Education/Nursing Research Ethics Board of the University of Manitoba.

Protocol

Subjects were asked to abstain from alcohol, caffeine, other drugs, and strenuous exercise for 24 hours, as well as not eat for one hour, prior to testing. Each subject's height was measured using a measuring tape fixed against a wall and weight was measured using a Taylor Professional scale. Heart rate was monitored continuously during each test using a heart rate monitor (Polar A5, Polar Electro, Finland). All subjects performed two continuous incremental exercise tests on a calibrated Monark cycle ergometer one week apart. During each test, subjects were asked to indicate when they have reached the workload where they can clearly hear their breathing (ABT).

To reduce the possibility of a learning effect, two different exercise protocols were used. Five subjects were randomly assigned to perform version A of the test first while the remaining five subjects performed version B of the test first. Both tests began with a brief warm-up and an initial workload of 0 kiloponds (kp). Pedal speed was set at 60 revolutions per minute (rpm) for all subjects and subjects were asked to try to maintain this pedal speed with the help of a metronome. For version A, workload was increase by 0.5 kp at one minute and every minute thereafter until the subjects indicated that they were at their ABT. For version B, workload was increased by 0.25 kp at 30 seconds and every 30 seconds thereafter until the subjects reached their ABT.

Subjects were asked to indicate when they can hear their own breathing by saying, “I can hear my breathing”. At this time, workload was recorded as workload at BSC and held constant for 1 minute so that a steady state HR can be recorded. Workload was then gradually lowered while the subject cools down.

Statistical Analysis

Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS for Windows 11.5, Chicago, Illinois). A paired samples t-test was used to determine whether there were any significant differences in workload at ABT, HR at ABT, and time to ABT measurements between the two tests. Correlation analysis was used to determine how well workload at ABT, HR at ABT, and time to ABT measurements from both tests relate to each other. In addition, correlation analysis was used to determine whether any significant relationships exist between body mass index (BMI) and the ABT variables. Level of significance was set at $p<0.05$.

RESULTS

Descriptive characteristics of the participants are illustrated in Table 1. All subjects were 14 or 15 years old and had similar body mass index (BMI) values. Nine subjects (males n = 5, females n = 4) completed both tests while one failed to return to complete test 2 and was excluded from this analysis. Five subjects completed version A of the test first and four completed version B of the test first.

Mean values (± SD) for workload and heart rate at the ABT and time to ABT for both tests are listed in Table 2. A paired samples t-test revealed no significant differences between test 1 and test 2 for any of the ABT variables measured. Seven of the nine subjects identified the same workload at ABT for both tests. Two subjects identified their workload at ABT to be 0.5 kp higher for test 2 than test 1.

Pearson correlation analysis showed that test 1 results were significantly correlated to those of test 2 for all variables ($r=0.94$, $p<0.001$ for workload at ABT, $r=0.96$, $p<0.001$ for heart rate at ABT, and $r=0.95$, $p<0.001$ for time to ABT). No significant relationships were found between BMI and any of the ABT variables measured.

Table 1: Subject characteristics.

No.	Gender	Age (yrs)	Height (cm)	Weight (kg)	BMI ($kg \cdot m^{-2}$)
1	M	14	170	53.2	18.4
2	F	15	160	54.6	21.3
3	F	15	162	63.6	24.2
4	M	15	174	57.7	19.1
5	F	14	171	54.6	18.7
6	M	15	170	65.0	22.5
7	M	14	165	50.0	18.4
8	F	15	170	66.8	23.1
9	M	14	168	62.3	22.1
	mean±SD	14.6±0.5	167.8±4.6	58.6±5.9	20.9±2.2

Table 2: Means ± SD for workload and heart rate at ABT and time to ABT for Test 1 and Test 2.

No.	Version	WL 1 (kp)	WL 2 (kp)	Change	HR 1 (bpm)	HR 2 (bpm)	Change	Time 1 (s)	Time 2 (s)	Change
1	A	3.0	3.0	0	164	155	-9	185	188	+3
2	A	3.0	3.0	0	146	142	-4	182	181	-1
3	A	3.5	3.5	0	156	156	+0	213	220	+7
4	A	4.0	4.0	0	170	173	+3	245	260	+15
5	A	3.0	3.0	0	144	145	+1	192	181	-11
6	B	3.5	4.0	+0.5	146	150	+4	214	244	+30
7	B	4.0	4.0	0	186	189	+3	256	262	+6
8	B	3.5	4.0	+0.5	155	156	+1	210	243	+33
9	B	5.0	5.0	0	150	153	+3	324	319	-5
	mean±SD	3.6±0.6	3.7±0.7	0.1±0.2	157.4±13.8	157.7±14.6	0.2±4.2	224.6±45.0	233.1±45.8	8.6±15.0

APPENDIX E: EXERCISE TRAINING USING THE ABT & THE TALK TEST

PURPOSE

To determine whether exercise at the audible breathing threshold (ABT) and Talk Test (TT) can easily and effectively be used by children to control exercise intensity and whether a short period of activity at the ABT and TT level is sufficient to induce a cardiovascular training effect, as measured by the Physical Work Capacity test at a heart rate of 170 bpm (PWC_{170}), in a school-based physical education program.

METHODS

Subjects

Nine girls (mean age = 14 years, mean weight = 61.8 kilograms), who did not participate in extracurricular athletics, volunteered for this study. Subjects were recruited from two grade nine, female-only physical education classes at University of Toronto Schools. All subjects had no known medical conditions that can affect exercise performance at the time of the study.

Determination of Cardiorespiratory Fitness

The PWC_{170} test was chosen as the measure of cardiorespiratory fitness. Subjects cycled on a Monark bicycle ergometer for four and a half minutes at each of three consecutive, progressive workloads. After a brief warm-up with workload set at 0 kiloponds (kp), initial workload was set so that the subject's heart rate was between 110 to 120 bpm. Heart rate was determined by palpating the subject's carotid artery for 30 seconds. Subsequent workloads were set at 0.5 kp above previous workload if the subject weighed 45 kilograms (kg) or less, or 1 kp above if the subject weighed greater than 45 kg. Subjects maintained a pedal speed of 50 revolutions per minute with the assistance of a metronome. At four minutes of each workload, heart rate was determined before workload was increased. Each subject's three heart rates were plotted against workload and a regression line was interpolated or extrapolated to a heart rate of 170 bpm. The PWC_{170} score was the workload at 170 bpm converted to kilopond·metres per kilogram per minute ($kpm \cdot kg^{-1} \cdot min^{-1}$). All subjects were instructed to refrain from excessive exercise prior to testing.

Protocol

Subjects were randomly divided into a training group (n = 6) and a control group (n = 3). Table 1 summarizes the protocol for both groups. All testing and activity was performed during the scheduled physical education class times, which were 50 minutes in length, three times per week. Baseline PWC_{170} scores were obtained in week one. For the following four weeks, the control group participated in 12 physical education classes consisting of the following activities: aerobics (3 classes), floor hockey (2 classes), swimming (2 classes), stair climbing (1 class), and in-classroom health (4 classes). Subjects in the training group participated in the two swimming classes but for the other 10 classes, they were required to run on a treadmill at an intensity where they could just hear their breathing and can talk. The subjects would then continue running at this intensity for 10 minutes. In week six, subjects were re-tested for their PWC170 scores.

Table 1. Summary of Study Protocol

Group	Control	Training
Week 1	PWC_{170} testing	
Week 2	12 sessions of regular PE class, lasting 50 minutes each, consisting of: aerobics, floor hockey, swimming, stair climbing, in-classroom health	2 sessions of swimming class and 10 sessions of treadmill running for 10 minutes at speed where subject could just hear her breathing and could talk
Week 3		
Week 4		
Week 5		
Week 6	PWC_{170} testing	

Statistical Analysis

Mean pre- and post-test PWC_{170} scores for both groups were compared using a paired t-test. Significance level was set at $p < 0.05$.

RESULTS

All subjects successfully completed their assigned protocol. Individual pre- and post-test PWC_{170} scores for training group subjects and control group subjects are summarized in Table 2 and Table 3, respectively. All subjects in the training group showed a significant improvement in their PWC_{170} scores, except for Subject 2, who showed no change in her score. Figure 1 illustrates the mean pre- and post-test PWC_{170} scores for training group subjects and control group subjects. The training group demonstrated a significant improvement in physical work capacity (16.9%, $p < 0.01$) while the control group showed no change (-2.0%, NS).

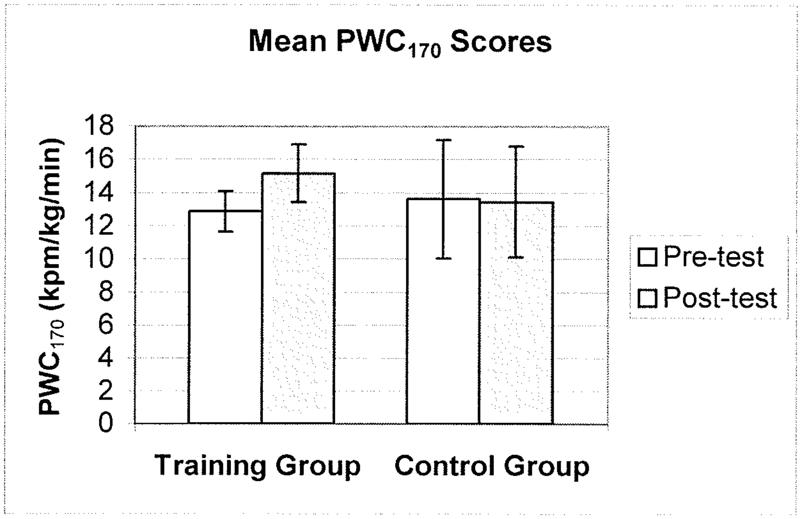
Table 2: Individual pre- and post-test PWC_{170} scores for training group with percent change and means

Subject	Pre-test PWC170 (kpm/kg/min)	Post-test PWC170 (kpm/kg/min)	Change (%)
1	13	16	23.1
2	14	14	0.0
3	11	14	27.3
4	14	17	21.4
5	12	13	8.3
6	14	17	21.4
mean	13.0	15.2	16.9

Table 3: Individual pre- and post-test PWC_{170} scores for control group with percent change and means

Subject	Pre-test PWC170 (kpm/kg/min)	Post-test PWC170 (kpm/kg/min)	Change (%)
1	17	16	-5.9
2	10	10	0.0
3	14	14	0.0
mean	13.7	13.3	-2.0

Figure 1: Mean pre- and post-test PWC_{170} scores for training group subjects and control group subjects.



DISCUSSION

In the present study, 10 minutes of physical activity at the ABT and TT level, three times per week for a period of four weeks, was sufficient to induce a cardiovascular training effect, as evidenced by a significant improvement in physical work capacity at a HR of 170 bpm, in school-age females. The ABT and TT were easily applied by the subjects and the exercise program caused little disruption to their current physical and health education curriculum. All subjects in the training group demonstrated a significant improvement in their PWC_{170} scores except for Subject 2. Although all subjects were asked to avoid caffeinated foods and beverages that may affect HR prior to testing, Subject 2 had indicated that she had consumed coffee shortly before her post-test. Reanalysis of the data with the removal of this possible outlier shows a significant increase in the percent change in PWC_{170} of the remaining training group subjects, from 16.9% ($n = 6$, $p < 0.01$) to 20.3% ($n = 6$, $p < 0.005$). As the control group showed no change in their PWC170 scores, the results also suggest that some physical education classes may not be sufficiently intense to provide fitness benefits.