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Relationship of Resting and Submaximal Cardiovascular Measures to VO_2max in Untrained Children

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by

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INTRODUCTION

Participation by children in organized sport continues to increase. A 1994 survey of 10,000 households by the National Sporting Goods Association (1994) found that approximately 40,000 children between the ages of 7-17 years participate in an organized sport or recreational activity annually. In the realm of organized sports, especially endurance activities, there continues to be interest in how cardiovascular fitness is attained and how it can be maximized. Measurement of cardiovascular fitness is an important piece to that puzzle.

The most common and most descriptive measure for children and adults, is the maximal oxygen uptake or VO_2 max (Astrand & Rodahl, 1977, p.318; Bar-Or, 1983, p.3; McArdle et al., 1994, p.125; Pollock, 1973). This refers specifically to the amount of oxygen required by the cells to produce energy for physical work at the body's maximal level (McArdle et al., 1994, p.66). Individual components of VO_2max are cardiac output (consisting of stroke volume and heart rate) and the arterio-venous oxygen difference (see Definition of Terms). It seems therefore, that an improvement in the efficiency of any of these factors would improve VO_2max and, in turn, cardiovascular fitness levels.

The relationship between cardiovascular fitness and each of its' individual components has been extensively reviewed for adults (American College of Sports Medicine, 1990; Andrew et al., 1966; Astrand & Rodahl, 1977, p.394; Clausen, 1977; Pollock, 1973; Rowell, 1986; Saltin, 1990; Scheuer & Tipton, 1977). The frequency, intensity and duration of exercise necessary for improving maximal oxygen consumption and therefore cardiovascular fitness for adults is also well established (American College of Sports Medicine, 1990; Pollock, 1973). The type of endurance training recommended to improve VO_2max (American College of Sports Medicine, 1990) causes adaptations in all the previously mentioned components of maximal oxygen uptake in adults. This includes an increase in cardiac output during submaximal and maximal exercise (Andrew et al., 1966; Astrand & Rodahl, 1977, p.394; Clausen, 1977; McArdle et al., 1994, p.263-264; Rowell, 1986; Saltin, 1990; Scheuer & Tipton, 1977). A decrease in the heart rate at rest and during submaximal exercise has also been reported and is considered a hallmark of aerobic fitness (American College of Sports Medicine, 1990; Andrew et al., 1966; Astrand & Rodahl, 1977, p.394; McArdle et al., 1994, p.366; Saltin, 1990; Scheuer, 1977). The decrease in heart rate associated with endurance training is related to stroke volume increases to support the increase in cardiac output during exercise and to maintain cardiac output at rest (Astrand & Rodahl, 1977, p.394; Clausen, 1977; McArdle et al., 1994, p.264; Rowell, 1986; Saltin, 1990; Scheuer & Tipton, 1977). Increases in arterio-venous oxygen difference have also been found to occur with endurance training in adults (Andrew et al., 1966; Astrand & Rodahl, 1977, p.394; Clausen, 1977; McArdle et al., 1994, p.366; Pollock, 1973; Rowell, 1986; Saltin, 1990; Scheuer & Tipton, 1977). Additional anatomical and physiological changes in the structure and function of the heart itself are improvements in the myocardial thickness, left ventricular volume, and thus cardiac contractility that occurs with endurance training in adults (Adams, 1978; Demaria et al., 1978; Ehsani, et al., 1978; Gilbert et al., 1977;

McArdle et al., 1994, p.366).

The relationships between VO_2max and it's individual components and the mechanisms of their improvement, however, are considered less clear in children (Bar-Or, 1983, p.45-46; Blimkie et al., 1980; Krahenbuhl et al., 1985; Mahon & Vaccaro, 1994; Mercier et al., 1987; Rowland & Boyajian, 1995; Rowland, 1996, p.106; Shepherd et al., 1988; Vaccaro & Mahon, 1987). There are distinct benefits to improving the understanding of the biological components of fitness in children. If the cardiovascular responses and adaptations to activity are well understood, the resulting well-constructed fitness programs will be of lasting value to healthy children, children with low fitness levels and children with disease or disability (Bar-Or, 1983, p.66-87; Blessing et al., 1995; Simons-Morton et al., 1987). To that end, one of the objectives of the U.S. Governments *Healthy People 2000* Health Initiatives is "to increase to 75% the proportion of children and adolescents aged 6-17 who engage in vigorous physical activity that promotes the development and maintenance of cardiorespiratory fitness three or more days per week for 20 or more minutes per occasion" (U.S. Department of Health and Human Services, 1996). A second benefit of improved identification of training adaptations would be improved safety and understanding of changes occurring during endurance training (Mahon & Vaccaro, 1994). Lastly, only two studies to the author's knowledge have attempted to make statistical correlations between fitness level as measured by VO_2max and it's components (i.e., cardiac output, stroke volume, heart rate and a-vO_2 difference) (Blimkie et al., 1980; Foster, 1972).

Statement of Problem

The purpose of this study is to describe the relationship between VO_2max (ml• kg^{-1}• min^{-1}) and it's components (i.e., cardiac output, stroke volume, heart rate and a-vO_2 difference) at rest and during submaximal exercise in untrained children.

Need For Study

Information is needed to determine which components of VO_2max most contribute to differences in fitness of children. This study will provide baseline data for predictions of VO_2max based upon measurement of it's components (i.e. cardiac output, stroke volume, heart rate, arterio-venous oxygen difference). These data will be compared with normative data of the measures of VO_2max, cardiac output, stroke volume, heart rate and arterio-venous oxygen difference for children aged 11-14 years at rest and submaximal exercise.

Null Hypothesis

The null hypothesis will be set as the following: There will be no correlation above the level of $r=0.40$ between the measure of VO_2max (ml• kg^{-1}• min^{-1}) and cardiac output, stroke volume, heart rate or arterio-venous O_2 difference at rest and during submaximal exercise in male and female children between the ages of 11 and 14 years.

Assumptions

1. Subjects were participating at similar levels of daily activity.
2. Subjects followed all conditions and instructions of the present study.

Delimitations

1. Subjects were males and females between the ages of 11 and 14 years.
2. Subjects' cardiac output, arterio-venous oxygen difference and stroke volume were measured at upright rest and at 47% of VO_2max.
3. Subjects cardiovascular function was not measured following a prescribed exercise program of any type.
4. Subjects were tested using a motorized treadmill and electrically braked cycle ergometer.
5. All testing for each subject was performed on the same day.
6. All testing was performed in the morning or early afternoon hours.

Definition Of Terms

1. Maximal Oxygen Uptake (VO_2max): VO_2max is the product of the cardiac output (Q) and the arterio-venous oxygen difference(a-vO_2 diff.) (Astrand & Rodahl, 1977, p.147; McArdle et al., 1994, p.271; Pollock, 1973; Rowell, 1986; Saltin, 1990).

2. Cardiac Output (Q): Cardiac output is the product of the stroke volume and heart rate or the amount of blood pumped by the ventricles of the heart per minute (Astrand & Rodahl, 1977, p.147; Van De Graff & Fox, 1986, p.671).

3. Stroke Volume (SV): Stroke volume refers to the amount of blood ejected from

each ventricle of the heart with each heart beat or contraction (Astrand & Rodahl, 1977, p.147; McArdle et al., 1994, p.261; Van De Graff & Fox, 1986, p.671).

4. Heart Rate (HR): The heart rate refers to the number of times the heart contracts or beats in one minute (Astrand & Rodahl, 1977, p.147; McArdle et al., 1994, p.261; Van De Graff & Fox, 1986, p.671).

5. Arterio-venous oxygen difference (a-vO_2 diff.): The arterio-venous oxygen difference refers to the difference in oxygen content between arterial blood and venous blood (Astrand & Rodahl, 1977, p.147; McArdle et al., 1994, p.261) and represents the body's efficiency in extracting oxygen from the blood to be used by working tissue.

LITERATURE REVIEW

Trainability of VO_2max In Children

Most of the VO_2max research with children has studied the inability to improve VO_2max with training (Bar-Or, 1983, p.45; Krahenbuhl et al., 1985; Rowland & Boyajian, 1995; Rowland, 1996, p.101; Vaccaro & Mahon, 1987). Current consensus is that training of high enough intensity, frequency and adequate duration can improve VO_2max (Krahenbuhl et al., 1985; Rowland & Boyajian, 1995; Rowland, 1996, p.104; Vaccaro & Mahon, 1987). Several early studies of VO_2max training with children did not produce significant improvements.

One suitable example of a training program that did not produce VO_2max improvements is a study conducted by Bar-Or and Zwiren (1973). The VO_2max was measured for 46 males and females between the ages of 9 and 10 years before and after initiation and completion of an exercise program. Subjects performed 145 meter runs at maximum speed 2-4 days weekly for a total of nine weeks. The number of runs performed daily progressed from five per day to ten per day over the nine weeks. No significant improvements were observed for VO_2max. A decrease in heart rate at submaximal intensities of exercise was observed. The intensity level and duration of each training session were thought to be less challenging than the level needed to induce training adaptations (Bar-Or & Zwiren, 1973).

Brown et al. (1972) observed VO_2max improvements with training. They studied 16 young women between the ages of 8 and 13 years who were participating in cross-country run training. The young women were equated into two groups. The first group (n=9) performed runs of 60-120 minutes of 4 to 7 miles each. These training runs would be performed 4-5 days per week for six weeks. The training routine for Group Two (n=7) was identical but performed for 12 weeks. VO_2max was then measured for all subjects. Results of VO_2max testing at completion of the training programs showed a significant increase in VO_2max for both groups. No significant difference was noted however between the groups. A decrease in heart rate at intensities of 60-75% of VO_2max was also present for both groups. The authors concluded that females in this age group will have increases in aerobic fitness as measured by VO_2max with this type of endurance training (Brown et al., 1972).

A more recent example of this trainability of aerobic fitness was performed by Blessing et al. (1995). The subjects consisted of 15 males and 10 females between the ages of 13 and 18 years. The study measured blood lipid responses of this age group to endurance exercise training. Pre and post-training measures of work capacity in kilopond meters per minute per kilogram, resting heart rate and skinfolds were also included. The training program consisted of cycling or treadmill exercise for 40 minutes, three times per week for 16 weeks. Exercise intensity corresponded to a heart rate that was 90% of the maximum attained during the physical working capacity test. At the conclusion of the 16-week training program a significant improvement in working capacity as well as resting heart rate compared to matched controls was reported (Blessing et al., 1995).

Cardiovascular Adaptations To Training In Children

Several studies have also examined the changes in VO_2max with training but have added the measurement of the various components of VO_2max to learn which of these contributed to the improvements of aerobic fitness. One of the earlier studies, by Eriksson and Koch (1973), recruited nine males between the ages of 11 and 13 years. No control group was used. VO_2max and stroke volume were measured for all subjects. An endurance training program consisting of 60 minutes of run training three days per week for five months was performed. At the conclusion of the program, a significant increase in VO_2max had occurred and this improvement was mediated by a 20% increase in stroke volume and a decrease in heart rate at submaximal intensities.

The results support the concept that VO_2max is trainable in children. There, are however, some methodological flaws in the studies presented above. These include a lack of control groups (Bar-Or & Zwiren, 1973; Brown et al., 1972; Eriksson & Koch, 1973). This becomes a problem because improvement in the components of VO_2max is a normal occurrence with physical maturity (Bar-Or, 1983, p.38; Rowland, 1996, p.110-111), and it becomes difficult to determine whether the improvements were a function of the training program or of puberty. Other problems include small sample groups (Brown et al., 1972; Eriksson & Koch, 1973), the possibility of preexisting high levels of fitness (Brown et al., 1972), the lack of monitoring of the intensity levels of the exercise (Bar-Or & Zwiren, 1973; Brown et al., 1972; Eriksson & Koch, 1973) and exercise of too short a duration or too low of an intensity level to have an adequate training effect (Bar-Or & Zwiren, 1973).

More recent investigations, however, have addressed these shortcomings in their study designs and produced evidence supporting the concept of VO_2max trainability in children. Lussier and Buskirk (1977) studied 16 male and female subjects between the ages of 8 and 12 years. A group of ten subjects acted as matched controls. Both groups underwent VO_2max measurement and measurement of cardiac output at submaximal intensities of 40 and 68% of VO_2max. The experimental group then underwent a 12 week training program that consisted of running for bouts of 35 minutes at an intensity of 80% of VO_2max two days per week. The training program included an additional two days per week of games involving running lasting approximately 35 minutes per session. Post training testing revealed an increase in VO_2max of 7% for the experimental group. A nonsignificant improvement of approximately 10% occurred in cardiac output at exercise intensities of 40 and 68% of VO_2max. No improvements were found however for arterio-venous O_2 difference in the experimental group. Based upon this result the authors concluded that the improvement in VO_2max could be attributed to the improvement in cardiac output, which was manifested in decreases in heart rate and increases in stroke volume at both submaximal intensities (Lussier & Buskirk, 1977).

Gatch and Byrd (1979) examined cardiovascular changes in prepubescent children as well. Thirty-two male subjects between the ages of nine and 10 years were evenly divided between experimental and control groups. A PWC_{170} test, steady state oxygen consumption and cardiac outputs were measured before initiation of the training program. Cardiac output was measured utilizing a CO_2 rebreathing technique. Stroke volume, arterio-venous O_2 difference and maximum oxygen pulse (VO_2max/maximum heart rate) were then calculated. The experimental group performed exercise on a cycle ergometer five days per week for eight weeks. Each exercise session consisted of four four-minute exercise bouts at a heart rate of 80-90% of the estimated maximum heart rate. These work bouts were interspersed with rest periods of three minutes. At the end of the training period PWC_{170} and cardiac output were measured and stroke volume, a-v O_2 difference and maximum oxygen pulse were calculated. The investigators found that the exercise group significantly improved work capacity as measured by the PWC_{170} test, improved stroke volume during steady state exercise and improved oxygen pulse as well. No significant difference was found however for a-v O_2 difference. The investigators concluded that the improvement in work capacity could be credited to the improvement in stroke volume (Gatch and Byrd, 1979).

A more recent investigation of swimmers studied the mechanisms of VO_2max improvement. Mercier et al. (1987) recruited 38 male swimmers between the ages of 10 and 14 years of age. Twenty-three subjects were placed in a group slated to train seven hours a week. Fifteen subjects were placed in a group scheduled to train 14 hours per week. The exercise groups were further separated into groups by age; a 10, 11, 12, 13, 14 year old group. VO_2max and maximal oxygen pulse were then measured. The training program consisted of swim training of bouts of 1-2 km for either seven or fourteen hours per week with intensities set at a heart rate of 160 bpm. The training program lasted for two years. VO_2max was found to be improved significantly in the 14 hour/week training group, but only in the 13 and 14 year old groups. The 14 hour/week, 13 and 14 year old groups also showed significant improvement in the maximal oxygen pulse. The authors concluded that the VO_2max improvements were due to improvements in either the stroke volume and/or the arterio-venous oxygen difference (Mercier et al., 1987).

The lack of control groups and the relatively moderate exercise intensities makes it difficult to determine whether the VO_2max improvements to the training program as opposed to improvements expected with normal growth. This is especially true for the 13 and 14 year old groups, considering this is generally the age that the pubertal growth spurt occurs (Van De Graff & Fox, 1986, p.928).

A study by Soong (1993) attempted to evaluate the effect of endurance training on VO_2max, cardiac output and $a\text{-}vO_2$ difference. Twenty children between the ages of 8-12 years were recruited to embark on an eight-week bicycle endurance training program. Ten of the subjects were assigned to a group that trained at an intensity of 40% of VO_2max and ten of the subjects were assigned to a group that exercised at an intensity of 70% of VO_2max. The two groups were scheduled to train three times per week for 30 minutes per session. An age, height and weight matched control group of eight subjects was used. Before and after the training program VO_2max was measured. Cardiac outputs at 50 and 75% of VO_2max were also measured. Cardiac output was measured utilizing the CO_2 rebreathing method. After the eight weeks of training the exercise group had significantly improved their VO_2max. Cardiac output and stroke volume at the submaximal exercise intensities were also improved compared to the control group. Heart rate and a-vO_2 difference at the submaximal intensities showed no differences between the exercise and control groups however.

The most recent study obtained by the author that studied improvements in VO_2max and its individual components with training was performed by Mahon and Vaccaro (1994). Subjects included 13 males between the ages of 8 and 12 years. A control group of age matched controls were utilized. VO_2max was determined utilizing a progressive treadmill exercise test. Oxygen consumption, heart rate and cardiac output were measured at 50 and 75% of the previously measured VO_2max both before and after the training program period. Cardiac output was determined utilizing the CO_2 rebreathing method with equilibration. Stroke volume and arterio-venous oxygen difference were then calculated. The training group then participated in a 14 week running program with exercise bouts that alternated between continuous running and interval running. Continuous running at a steady-state intensity of 70-80% of previously determined VO_2max was performed and progressed from bouts of 10 minutes and progressed to 35 minutes in duration. Intervals involved running repeated distances of 200 to 800 meters and totaled 1.5 km during the fourth week of the program and progressed to 4 km by the final week of the program. Intensity of these sessions corresponded to 90-100% of VO_2max. This training occurred at a frequency of three days per week. VO_2max and cardiac output were then measured as had been done at the beginning of the training program. Changes at the end of the 14-week training program included a significant improvement in VO_2max for the exercise group. This was accompanied by a significant increase in the arterio-venous oxygen difference and a non-significant increase in cardiac output. Authors attributed the improved VO_2max to the positive changes in cardiac output and arterio-venous oxygen difference. The authors further stated that the effects of training on cardiac output and arterio-venous oxygen difference are still unclear and further research needs to be performed to elucidate these mechanisms (Mahon & Vaccaro, 1994).

Based on this literature review, it appears that aerobic fitness in children as measured by VO_2max and physical work capacity can be improved with a training program of sufficient intensity, duration and frequency. What continues to be equivocal however, are the mechanisms of this improvement. As mentioned previously, the improvements in VO_2max in adults are mediated by improvements in both stroke volume and arterio-venous oxygen difference (Andrew et al., 1966; Astrand & Rodahl, 1977, p.394; Clausen, 1977; McArdle et al., 1994, p.264; Pollock, 1973; Rowell, 1986; Saltin, 1990; Scheuer & Tipton, 1977). Improvements in stroke volume in children, however, are not consistently accompanied by improvements in arterio-venous oxygen difference (Gatch & Byrd, 1979; Lussier & Buskirk, 1977; Soong, 1993). This would suggest a need to further clarify these relationships.

Cardiac Adaptations To Training In Children

Research Utilizing Trained Subjects

There appears to be significant evidence that central cardiac changes accompany improvements in maximal oxygen consumption. Geenen et al. (1982) studied seventy-nine children between the ages of 6 and 7 years who were divided into an exercise group (n=38) and a control group (n=41). Skinfold measures, height, weight, activity levels, resting heart rate and echocardiographic measures were obtained. No significant differences were found between the groups for any of the above measures. The exercise group then performed aerobic exercise consisting of running games and dance for 20 minutes at an intensity of 150-185 beats per minute. This exercise was performed four days per week for eight months. After the eight months of training the pre-exercise testing was repeated. Investigators discovered no significant changes in left ventricular end-systolic or diastolic dimensions, cardiac shortening fraction or resting heart rate. Significant increases were found for the exercise group in left ventricular posterior wall thickness and left ventricular mass. Authors concluded that aerobic exercise of this type will lead to increased left ventricular posterior wall thickness and left ventricular mass without an increase in left ventricular chamber size or a decrease in resting heart rate (Geenen et al., 1982).

A study by Shepherd (1987) attempted to clarify the effect of prolonged endurance training on cardiac size and dimensions in children. Thirteen highly trained prepubescent boys (ages 5-12 years) underwent echocardiographic measurements to determine cardiac dimensions. These runners trained between 30-60 miles per week and had been training for at least 12 months. An age and body size matched control group was utilized. Echocardiographic measurements were taken at rest and during supine leg exercise at a heart rate of 110 beats per minute. Results showed a significantly larger left ventricular posterior wall during diastole for the trained group. No differences were found however in left ventricular diameter during diastole between the two groups, but a smaller ratio was discovered between the left ventricular internal diameter relative to the left ventricular posterior wall thickness. The author concluded that this pattern of cardiac adaptation with endurance training was different for children as compared to adults.

Research Utilizing Untrained Subjects

A study conducted by Blimkie et al. (1980) attempted to correlate VO_2max measures with various cardiac functions and dimensions. Investigators recruited 117 untrained males between the ages of 10 and 14 years. VO_2max ($L \bullet min^{-1}$) was measured for all subjects. The subjects were then divided into groups by age (10-11, 12-13, 14-15 years) and these groups were divided again based upon either a high or low absolute VO_2max measurement. Body weight, fat free weight, height and activity levels were determined and cardiac size, dimension and function were measured echocardiographically. The groups with a higher VO_2max were significantly taller and heavier. Body weight and fat free weight had the highest correlation with VO_2max within each age category. Stroke volume, left ventricular mass and left ventricular end-diastolic diameter were also highly correlated with VO_2max. Left ventricular end-systolic diameter was moderately correlated and posterior wall thickness was poorly correlated with VO_2max. Left ventricular end-diastolic diameter, left ventricular end-diastolic volume, stroke volume, posterior wall thickness, septal thickness and left ventricular mass were significantly larger in the high VO_2max ($L \bullet min^{-1}$) group compared to the low VO_2max group independent of age category. There were no significant differences in resting heart rate between high and low VO_2max groups. It was concluded that the lower resting heart rate permitted more complete diastolic filling and larger end diastolic volumes thus improving left ventricular efficiency. The increased preload associated with larger end-diastolic volumes most likely explains the increased stroke volumes in the high VO_2max group and is the primary factor that differentiates stroke volumes between the high and low VO_2max groups. A possible larger blood volume was attributed to the increased preload in the larger subjects. It was concluded that fat free weight was the primary determinant of VO_2max and the larger cardiac dimensions were mainly ascribed to influence of body size (Blimkie et al., 1980).

These studies seem to provide tangible evidence that endurance exercise and high fitness levels are associated with cardiac changes in children. This would agree with the results seen in adults (Adams, 1978; Demaria et al., 1978; Ehsani et al., 1978; Gilbert et al., 1977; McArdle et al., 1994, p.366). The pattern of these differences, however, does not appear to be the same as adults (Shepherd et al., 1988). There is evidence that the variation may be due to differences in body size (i.e. amount of lean body mass) (Blimkie et al., 1980), not training level. The lack of a significant difference in resting heart rate between fitness levels seen in the two previously mentioned studies (Blimkie et al., 1980; Geenen et al., 1982) appears to be at variance with the conclusions of other authors (Bar-Or, 1983, p.49; Blessing et al., 1995; Diamant et al., 1989, p.27). These results are also in disagreement with those seen in adults (American College of Sports Medicine, 1990; Andrew et al., 1966; Astrand & Rodahl, 1977, p.394; Katona et al., 1982; McArdle et al., 1994, p.366; Scheuer & Tipton, 1977).

Correlation of VO_2max and Cardiac Function In Untrained Children

Only one other study was located that studied the ability to predict VO_2max based upon it's component measures. This experiment lends some credence to the predictive relationship between oxygen consumption and cardiac function in children.

Foster (1972) recruited six boys to perform four testing sessions on a bicycle ergometer. Each session measured heart & respiratory rate and pulmonary ventilation as well as oxygen consumption. Resistance was preset and the subjects were allowed to self pace the exercise. Tests were stopped after a predetermined distance had been reached per the ergometers odometer. Cardiac and respiratory measures were then correlated with the oxygen consumption measure. Significant correlations were discovered for heart rate and oxygen consumption as well as for pulmonary ventilation and respiratory rate and oxygen consumption. There were no differences in the predictive power between these variables however.

This study would appear to present evidence supporting a direct correlation between heart rate and oxygen consumption. A few aspects of the study leave some doubt however. These would be the small sample size as well as the fact that maximal oxygen consumption was not attained due to the self-paced nature of the exercise. The factors of body size (i.e. height, weight, lean body mass and body fat %) were also not addressed.

This lack of consensus concerning the relationships between VO_2max and it's components; stroke volume, a-vO_2 difference and heart rate suggest the need for further study concerning this interesting aspect of fitness in children.

Measurement of Cardiac Output

The most accurate methods of assessing cardiac output during exercise have traditionally involved invasive procedures and substantial experience and equipment, thus making it difficult if not impractical to perform (Bar-Or et al., 1971; Driscoll et al., 1989; Wilmore et al., 1982). Noninvasive techniques for the measurement of cardiac output however have been shown to be valid and reliable alternatives (Driscoll et al., 1989). One of the most common is the equilibration CO_2 rebreathing technique. This technique utilizes the Fick equation and measures all components in the gas phase and is also known as the "indirect" method (Driscoll et al., 1989). The reliability of such tests had been questioned, but with the advent of automated metabolic measurement devices the desire to vaidate this technique gained renewed attention (Bar-Or et al., 1971). Wilmore has attempted to document the validity and reliability of the CO_2 rebreathing technique to measure cardiac output during exercise.

Wilmore et al. (1982) studied six male subjects with a mean age of 28.2 years and VO_2max of 62.3 ml• kg^{-1}• min^{-1}. Eleven subjects (average age 60 years) were utilized as controls to validate the procedure. The subjects performed the CO_2 rebreathing technique for cardiac output measurement while resting upright on a cycle ergometer. Three separate measurements were made in this position. The subjects then began pedaling at 50 rpm with a continous resistance of one kp. This resulted in a workload of 49 watts or 300 kpm• min^{-1}. At the attainment of steady state VO_2 three separate determinations of cardiac output were made. The workload was then increased to 98 watts or 600 kpm• min^{-1}. After steady state was achieved at this intensity, three seperate cardiac output measurements were made. The eleven control subjects, who were scheduled to undergo cardiac catheterization, underwent a standard thermodilution technique to determine cardiac output. This procedure was then used to validate the results of the CO_2 rebreathing technique. The correlation of the rebreathing technique possessed excellent agreement within subjects with correlations varying between $r=0.985$ and $r=0.999$ for each of the individual subjects. The correlation between the two techniques was $r=0.87$ and the correlation between VO_2 and cardiac output was $r=0.90$. The authors concluded that the automated CO_2 rebreathing technique that they utilized is a valid and reliable method to measure cardiac output in the exercising subject and that it essential to evaluate individual cardiac output values relative to the matching VO_2 value (Wilmore et al., 1982).

Gender Differences in Cardiovascular Responses to Exercise in Children

A recent study has attempted to measure submaximal cardiovascular response to exercise in children and how these responses may differ between gender and exercise modality. This study presents evidence that there are few gender differences in cardiovascular responses to submaximal exercise in untrained children.

Turley & Wilmore (1997) studied 24 seven to nine year old children (12 males and 12 females). These subjects then performed two maximal exercise sessions to determine VO_2max. Exercise modalities were randomly chosen and consisted of a motorized treadmill and a cycle ergometer. On seperate occasions the subjects then performed four submaximal exercise bouts. Treadmill exercise consisted of walking or jogging at 3.0, 4.0 and 5.0 mph. Cycle exercise consisted of pedaling at 65 ±5 rpm at 20, 40 and 60 watts. Subjects exercised at each intensity until a steady-state was achieved. Once acheived, cardiac output (utilizing the CO_2 rebreathing method), VO_2, heart rate and blood pressure were measured. These measures were then used to calculate stroke volume, a-v O_2 difference, mean blood pressure and total peripheral resistance. Measures were duplicated at each exercise intensity and utilizing both exercise modalities. Height, weight, body fat % and leg volume were also measured for each subject. Left ventricular dimension, septal wall thickness, left ventricular internal diameter, left ventricular posterior wall thickness were measured echocardiographically. Shortening fraction and left ventricular mass were then calculated from these measures. Lastly hemoglobin concentrations were measured for each subject.

Results showed there were no significant differences between gender and physical characteristics. No significant differences were observed in left ventricular measurements between gender with the exception of left ventricular mass, which was greater in the males. No significant differences were found for the males and females for any of the maximal exercise data for both exercise modalities. Submaximal exercise testing showed no significant differences in RER or oxygen consumption between genders for both exercise modalities. The only submaximal exercise measurements that showed significant differences between genders was the mean blood pressure. Mean blood pressure of male subjects was higher with all cycle ergometer intensities and at 5.0 mph on the treadmill. Heart rate for the males was significantly lower at 4.0 mph on the treadmill. Although not significant, stroke volume and mean blood pressure were consistently higher in the males compared to the females. Heart rate was also consistently lower in the males compared to the females. The relationships between cardiac output, stroke volume, heart rate, total peripheral resistance and a-v O_2 difference and a given VO_2 value were also not significantly different for males and females. The authors concluded that when utilizing children in the 7 to 9 year age group that submaximal cardiovascular measures must be determined to not be significantly different before these data sets can be grouped together.

These results provide evidence that submaximal cardiovascular measures of males and females can be utilized together, provided they are not significantly different.

METHODS

Subjects

Thirty-two (32) physical education students from western and central West Virginia (17 males and 15 females), ages 11 to 15 years, agreed to serve as experimental subjects. Each child had been previously cleared to participate in all physical education class activities and signed, informed consent was obtained from the parents or legal guardians.

The literatute has clearly shown the equivocal relationship between habitual physical activity and aerobic fitness in children (Rowland, 1996, p.101). Therefore, habitual activity level of the subjects was not controlled in this study. Approval was obtained for all of the procedures employed in this investigation from the Institutional Review Board of Marshall University.

Laboratory Procedures

Testing was conducted on one day and began with recording of the subjects age, height, weight and body fat percentage. Body fat percentage was estimated using skinfold calipers and two site skinfold measurement. The fat percentage was estimated using the following equations according to Lohman (1992):

Triceps plus calf skinfold (**ΣSF**)
Boys $\%\text{fat}=0.735(\Sigma SF)+1.0$, all ages
Girls $\%\text{fat}=0.610(\Sigma SF)+5.0$, all ages

and then utilized to determine lean body mass (LBM). Two EKG electrodes were applied to the subject's trunk (CM5 placement) to assess heart rate using a wireless EKG monitor (SpaceLab 900, Redmond, WA). An additional wireless EKG monitor comprising a chest placed strap and wrist-watch style monitor (Polar USA, Stamford, CT) was utilized as a secondary means to monitor heart rate. Subjects were then placed in a quiet, dark room and instructed to rest quietly in a supine position for approximately 20 minutes. Heart rates were monitored throughout the rest period. Resting heart rate (RHR) was determined by the lowest sustained heart rate during this period. Subjects were oriented to the testing protocol and testing equipment. This included the treadmill (Quinton MedTrack ST 65, Bothell, WA), cycle ergometer (SensorMedics Ergo-metrics 800s, Yorba Linda, CA), metabolic cart (SensorMedics 2900, Yorba Linda, CA) and mask (Hans-Rudolph 8592 Series 2-way NRBV Pediatric Valve and 8950 Series Pediatric Mask, Kansas City, MO) used with the metabolic cart. Maximal, incremental exercise testing protocol(s) used to determine VO_2max were then explained to the subject (Tables 1 and 2). Subjects performed either the walking or running protocol according to personal preference, the SensorMedics metabolic cart being calibrated before each exercise test (SensorMedics, 1991). Achievement of VO_2max included attainment of at least two of the following criteria: (1) achievement of a heart rate $\geq$195 bpm; (2) a leveling off of VO_2 ($\leq$2.0 ml• kg^{-1}• min^{-1}) despite an increase in workload; or (3) an RER value >1.10 (Bar-Or, 1983, p.333). All subjects achieved at least two of these criteria.

Table 1

Progressive Treadmill Exercise Protocol #1

Running Protocol

Stage	Duration (min:sec)	Speed (mph)	Grade (%)
1	1:15	2.0	0
2	1:15	3.0	0
3	1:15	4.0	0
4	1:15	5.0	0
5	1:15	5.0	2
6	1:15	5.0	4
7	1:15	5.0	6
8	1:15	5.0	8
9	1:15	5.0	10
10	1:15	5.0	12
11	1:15	5.0	14
12	1:15	5.0	16
13	1:15	5.0	18
14	1:15	5.0	20
15	1:15	5.0	22
16	1:15	5.0	22.5

Table 2

Progressive Treadmill Exercise Protocol #2

Walking Protocol

Stage	Duration (min:sec)	Speed (mph)	Grade (%)
1	1:00	2.0	0
2	1:00	3.0	0
3	1:00	3.0	2
4	1:00	3.0	4
5	1:00	3.0	6
6	1:00	3.0	8
7	1:00	3.0	10
8	1:00	3.0	12
9	1:00	3.0	14
10	1:00	3.0	16
11	1:00	3.0	18
12	1:00	3.0	20
13	1:00	3.0	22
14	1:00	3.0	22
15	1:00	3.0	22.5
16	1:00	3.0	22.5

The next phase of testing consisted of measuring resting and exercise cardiac output (Q). Testing was initiated with at least a 90 minute span between the maximal exercise test and the cardiac output determination. An automated CO_2 rebreathing technique implementing the equilibration method was used to measure cardiac output (Wilmore et al., 1982). The CO_2 rebreathing method with equilibration has been reported as an acceptable method of measuring cardiac output in children (Driscoll et al., 1989). A Hans-Rudolf 2700 Series 2-way NRBV valve and 8200 Series CO_2 rebreathing setup with 3-way directional inflatable balloon (Hans-Rudolph, Kansas City, MO.) and mouthpiece were connected to a rubber anaesthesia bag. The bag was connected to a tank containing CO_2 at a concentration of 10% in O_2 which provided the gas used for rebreathing. The bag was filled to a volume of approximately 5.0L for each cardiac output measurement. Measurements of inspired and expired gases were made with the SensorMedics metabolic cart for determining cardiac output, with the metabolic cart being calibrated before each subject was tested (SensorMedics, 1991). The internal computer program utilized the following equations to determine cardiac output (SensorMedics, 1991):

$$PaCO_2 = 5.5 + 0.9(PETCO_2) - 0.0021(TV)$$

$$PvCO_2 = 0.76(PeqCO_2) + 11$$

$$Cv\text{-}aCO_2 \text{ diff} = 11.08(PvCO_2{}^{0.396} - PaCO_2{}^{0.396})$$

$$Q = VCO_2/Cv\text{-}aCO_2 \text{ diff}$$

where $PaCO_2$ is the partial pressure of CO_2 in arterial blood; $PETCO_2$ is the partial pressure of end tidal CO_2; TV is the tidal volume; $PvCO_2$ is the partial pressure of

CO_2 in mixed venous blood; $PeqCO_2$ is the partial pressure of CO_2 at equilibration; $Cv\text{-}aCO_2$ diff. is the CO_2 content difference between mixed venous and arterial blood; and VCO_2 is the volume of CO_2 produced per minute. The first determination of cardiac output was made while the subject was resting in an upright position on the cycle ergometer, the SensorMedics Ergo-metrics 800s (SensorMedics, Yorba Linda, CA). Seat height was adjusted according to Adams (1994, p. 114-115). Heart rate was monitored utilizing the Polar Vantage XL Heart Rate Monitor (Polar USA, Stamford, CT). Testing began with the subject breathing room air through the mouthpiece until a steady state VO_2 was achieved. Steady state was considered to be achieved when two consecutive VO_2 measurements were within ± 100 ml/min and the RER was <1.0. When steady state was achieved the control bladder was deflated to allow the subject to breath from the anaesthesia bag for approximately 20 seconds so that equilibration could be achieved between the subject and the rebreathing bag. Subjects were encouraged to maintain the same depth of respiration as when breathing room air, but to double the respiration rate throughout the maneuver. Heart rate (HR) was recorded at the initiation of the maneuver to be used for calculation of stroke volume (SV). The rebreathing bag was then flushed with CO_2 and refilled to the previously mentioned volume. Subjects began pedaling on the cycle ergometer at a rate of 60 rpm while breathing room air. Resistance of the electrically-braked cycle ergometer was increased until a steady state of approximately 50% of the previously determined VO_2max was reached. Steady state was defined as mentioned previously. The CO_2 rebreathing maneuver was then repeated. The identical maneuver was then repeated at the same exercise intensity. The test-retest reliability correlation for the cardiac output measurements at 50% of VO_2max was r=0.863.

These data permitted calculation of arterio-venous O_2 difference at rest and the submaximal exercise intensity as VO_2/Q. Stroke volume at rest and during exercise was calculated as Q/HR. Pearson product moment correlation coefficients were calculated to determine the relationship between the VO_2max measures and the measures of it's components. Regression analysis was conducted to provide prediction equations for relationships between VO_2max measures and the other variables measured. Regression equations were calculated for relationships with correlations >r=0.60. All statistical measures were calculated with Lotus1-2-3 Release 5 (Lotus Development Corp.).

RESULTS

Table 4 presents a summary of the group means for age, height, weight , % body fat, lean body mass and resting heart rate. The means and standard deviations for the group of 15 females and 17 males for these measures were as follows: age 12.9 years ±1.1, height 164 cm ±9.64, weight 56.3 kg ±14.24, % body fat 24 ±0.09 and lean body mass 42 kg ±8.8. The group means for VO_2max were 2341.49 ml• min^{-1} ±450.74, 42.89 ml•kg^{-1}• min^{-1} ±8.40 and 56.34 ml• $kgLBM^{-1}$• min^{-1} ±9.91. The mean maximum heart rate for the group was 202.22 bpm ±7.74 and the mean resting heart rate was 72.9 bpm ±9.18. These results are summarized in Table 5 and compared to two studies utilizing similar groups of subjects (Blessing et al., 1995; Mahon & Vaccaro, 1994).

Based upon the recommendations of Turley & Wilmore (1997) the measurements of VO_2max, cardiac output, stroke volume, arterio-venous O_2 difference, heart rate and VO_2 at $VO2_{50\%}$ were equated by gender and analyzed to ensure that no significant differences were present. Means of these measures were then compared using a Students t-test for independent variables. A two-tailed test with an $\propto$ level of 0.05 was used to determine significance. No significant differences were found for these measures when sorted by gender (see Table 3). Thusly the subjects were grouped together for further analysis.

Results of the cardiovascular measures at rest in the upright position are summarized in Table 6. Group means for VO_2 were 301.64 ml• min^{-1} ±53.21, 5.82 ml• kg^{-1}• min^{-1} ±1.24 and 7.40 ml• $kgLBM^{-1}$• min^{-1} ±1.51. Mean heart rate for the

Table 3 Gender Comparisons for VO_2 and Cardiovascular Measures

Variable	Males (n=17) M	Males (n=17) SD	Females (n=15) M	Females (n=15) SD	*t* Value
VO_2max ($ml \bullet kg^{-1} \bullet min^{-1}$)	41.6	8.8	44.3	7.9	0.89
Cardiac Output ($L \bullet min^{-1}$)^a	11.6	2.2	11.5	2.0	0.10
Stroke Volume (ml)^a	79.2	16.3	77.2	14.8	0.37
a-v O_2 diff ($ml \bullet L^{-1}$)^a	93.6	8.7	100.4	15.0	1.54
Heart Rate (bpm)^a	146.6	7.6	149.7	14.5	0.75
VO_2 ($ml \bullet min^{-1}$)^a	1071.6	194.1	1133.1	166.9	0.97

Note. * $= P < 0.05$

df =30

a =at $VO2_{50\%}$

Table 4 Means of Physical Characteristics of Subjects

Variable	Present Study[b]	Mahon & Vaccaro (1994)[c]	Blessing et al. (1995)[d]
Age (yrs)	12.9	10.6	14.5
Height (cm)	164	141.5	154.3
Weight (kg)	56.3	33.0	51.3
Body Fat (%)	24	------	------
Lean Body Mass (kg)	42	------	------
Resting Heart Rate[a] (bpm)	72.9	------	77.6

Note. a =resting heart rate in a supine position

b =*n* =32

c =n =13

d =n=25

Table 5 **Means of Cardiovascular Responses at VO_2max**

Variable	Present Study[a]	Mahon & Vaccaro (1994)[b]	Rowland & Boyajian (1995)[c]
VO_2 ($ml \bullet min^{-1}$)	2341.49	1470	1960
VO_2 ($ml \bullet kg^{-1} \bullet min^{-1}$)	42.89	44.2	44.3
VO_2 ($ml \bullet min^{-1} \bullet kgLBM^{-1}$)	56.34	------	------
Heart rate (bpm)	202.22	205.1	201

Note. a = n = 32

b = n = 13

c = n = 37

Table 6 **Means and Standard Deviations of Cardiovascular Responses at Rest**[a]

Variable	Mean	SD
VO$_2$ (ml• min^{-1})	301.64	53.21
VO$_2$ (ml• kg^{-1}• min^{-1})	5.82	1.24
VO$_2$ (ml• min^{-1}• kgLBM^{-1})	7.40	1.51
Heart Rate[a] (bpm)	104.4	11.52
Stroke Volume (ml)	36.39	12.11
Cardiac Output (L• min^{-1})	3.76	1.16
a-vO$_2$ difference (ml• L^{-1})	85.39	21.34

Note. *n* =32

a =at rest in upright sitting position on cycle ergometer group was 104.4 bpm +11.52, while mean cardiac output at rest was 3.76 L• min-1 +1.16, stroke volume was 36.39 ml +12.11 and a-v O2 difference was 85.39 ml• L^{-1} ±21.34. All of the preceding values were measured while resting in the upright position.

Means and standard deviations of the cardiovascular measures at 50% of VO_2max ($VO2_{50\%}$) are summarized in Table 7. The actual mean VO_2 was 47% ±4.19 of the previously determined VO_2max. The group means for VO_2 were 1100.41 ml• min^{-1} ±181.65, 20.29 ml• kg^{-1}• min^{-1} ±4.25 and 26.72 ml• kgLBM^{-1}• min^{-1} ±5.43. Mean heart rate for the group was 148.08 bpm ±11.25. Mean cardiac output was measured at 11.53 L• min^{-1} ±2.09, stroke volume was 78.27 ml ±15.40 and arterio-venous O_2 difference was 96.77 ml• L^{-1} ±12.35.

Pearson Product Moment Correlations for all variables measured are given in Tables 8 and 9. Strong positive correlations were discovered between the variables of cardiac output at $VO2_{50\%}$ (r =0.75), stroke volume at $VO2_{50\%}$ (r =0.67), height (r = 0.78) and lean body mass (r =0.65) and absolute VO_2max (ml• min^{-1}). A moderate positive correlation (r =0.55) was determined between body weight and absolute VO_2max (ml• min^{-1}). Low positive correlations (r =0.02 - 0.12) were determined for a-vO_2 diff at $VO2_{50\%}$, heart rate at $VO2_{50\%}$ and body fat % and absolute VO_2max (ml• min^{-1}). A low negative correlation (r =-0.21) was discovered between supine resting heart rate and absolute VO_2max (ml• min^{-1}). A strong negative correlation (r =-0.63) was observed between body weight and relative VO_2max (ml• kg^{-1}• min^{-1}). Moderate

Table 7 **Means and Standard Deviations of Cardiovascular Responses at $VO2_{50\%}$**

Variable	Mean	SD
VO_2 (ml• min^{-1})	1100.41	181.65
VO_2 (ml• kg^{-1}• min^{-1})	20.29	4.25
VO_2 (ml• min^{-1}• kgLBM^{-1})	26.72	5.43
Heart rate (bpm)	148.08	11.25
Stroke Volume (ml)	78.27	15.40
Cardiac Output (L• min^{-1})	11.53	2.09
a-vO_2 difference (ml• L^{-1})	96.77	12.35

Note. *n* =32

Table 8 Pearson Product Moment Correlations Between Anthropometric and Cardiovascular Measures and VO_2max

Variable	VO_2max ($ml \bullet min^{-1}$)	VO_2max ($ml \bullet kg^{-1} \bullet min^{-1}$)
Resting Heart Rate	-0.207	-0.26
Cardiac output at $VO2_{50\%}$	0.751*	0.183
Stroke Volume at $VO2_{50\%}$	0.673*	0.069
$a\text{-}vO_2$ difference at $VO2_{50\%}$	0.025	-0.012
Heart Rate at $VO2_{50\%}$	0.118	0.309
Height	0.784*	-0.026
Weight	0.553*	-0.629*
Lean Body Mass	0.652*	-0.402
Body Fat %	0.019	-0.502*

Note. $n = 32$

* $= P < 0.01$

$df = 30$

Table 9 Pearson Product Moment Correlations Between Anthropometric Measures and Cardiovascular Response at 50% of VO2max

Variable	Cardiac Output	Stroke Volume	a-vO2 diff	Heart Rate
Height	0.607*	0.606*	-0.036	-0.036
Weight	0.462*	0.482*	0.019	-0.145
Lean Body Mass	0.512*	0.596*	-0.054	-0.261
Body Fat %	0.065	-0.011	0.136	0.105
Heart rate at 50% of VO2max	0.003	-0.356	0.244	1.00

Note. n = 32
df = 30
* = P<0.01

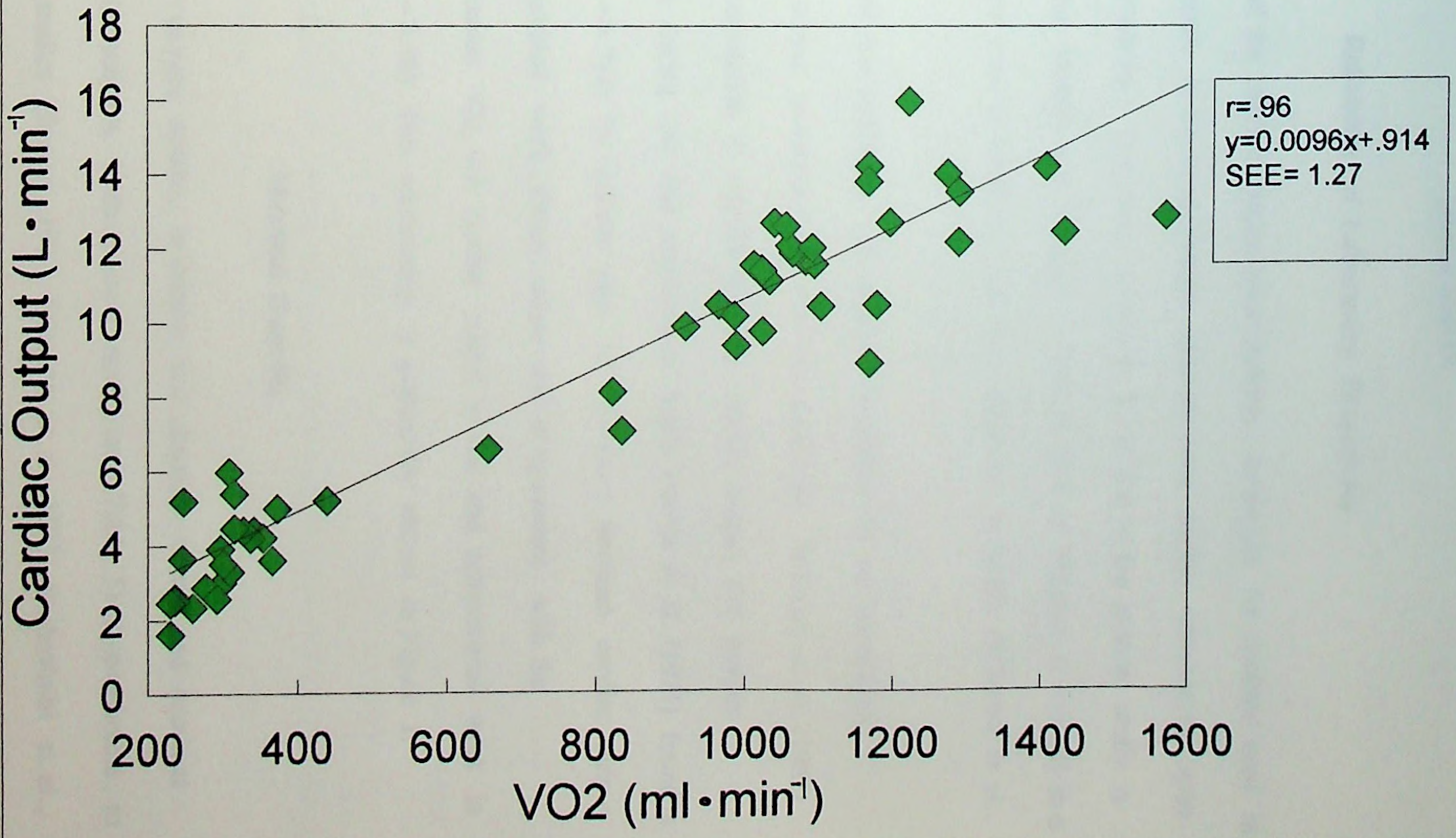
negative correlations were determined for lean body mass (r =-0.40) and body fat % (r =-0.50) and relative VO_2max (ml• kg^{-1}• min^{-1}). A low negative correlation (r =-0.26) was revealed between supine resting heart rate and relative VO_2max (ml• kg^{-1}• min^{-1}). There was no correlation between VO_2max (ml• kg^{-1}• min^{-1}) and a-vO_2 diff. at $VO2_{50\%}$ (r =0.01) and height (r =-0.03). No correlation was determined between heart rate at $VO2_{50\%}$ and relative VO_2max (ml• kg^{-1}• min^{-1}). No correlations were discovered between relative VO_2max and cardiac output at $VO2_{50\%}$ (r=0.18) and stroke volume at $VO2_{50\%}$ (r =0.07).

Strong positive correlations were established between height and cardiac output at $VO2_{50\%}$ (r =0.61) and stroke volume at $VO2_{50\%}$ (r =0.61). Moderate positive correlations were revealed between lean body mass and cardiac output at $VO2_{50\%}$ (r =0.51) and stroke volume at $VO2_{50\%}$ (r =0.596). Moderate positive correlations were also determined for body weight and cardiac output at $VO2_{50\%}$ (r =0.46) and stroke volume at $VO2_{50\%}$ (r =0.48). A low positive correlation was discovered for heart rate at $VO2_{50\%}$ and a-vO_2difference at $VO2_{50\%}$ (r =0.24). No correlations were established between cardiac output at $VO2_{50\%}$ and body fat % (r =0.07) and heart rate at $VO2_{50\%}$ (r =0.003). No correlations were also revealed between a-vO_2 diff at $VO2_{50\%}$ and body weight (r =0.02) and body fat % (r =0.14). No correlation was determined between heart rate at $VO2_{50\%}$ and body fat % (r =0.11). A low negative correlation was discovered between stroke volume at $VO2_{50\%}$ and heart rate at $VO2_{50\%}$ (r =-0.36). A low negative correlation was also established between lean body mass and heart rate at 47% of VO_2max (r =-0.26). No correlation was revealed between stroke volume at $VO2_{50\%}$ and body fat % (r =-0.01). No correlations were determined for a-vO_2 diff at $VO2_{50\%}$ and height (r =-0.04) and lean body mass (r =-0.05). No correlations were discovered for heart rate at $VO2_{50\%}$ and height (r =-0.04) and body weight (r =-0.15).

The values for cardiac output at rest and at $VO2_{50\%}$ were strongly correlated (r =0.96) to the VO_2 values at rest and at $VO2_{50\%}$ (see Figure 1). The test-retest reliability correlation for the cardiac output measures at $VO2_{50\%}$ also showed a strong relationship (r =0.86).

Figure 1

Relationship of VO2 & Cardiac Output



DISCUSSION

Reliability of Laboratory Procedures

The reliability of the cardiac output measurement technique for children used in the present study appears to be in agreement with previous studies utilizing the same technique of CO_2 rebreathing. Test-retest reliability (r =0.86) in the present study is similar to that found by Mahon and Vaccaro (1994) at 50% of VO_2max (r =0.88) in a similar age group. This level of reliability was also observed in adults (Wilmore et al., 1982).

The reliability of this technique can also be examined by the correlation between the cardiac output measures and the VO_2 measures. Wilmore et al. (1982) found a very strong correlation (r =0.90) between cardiac output and oxygen consumption in adults during rest and submaximal work. Bar-Or et al. (1971) found a strong correlation (r =0.714) for children ages 10 - 13 years between cardiac output and VO_2 during submaximal work. These values are in agreement with the relationship found between VO_2 and cardiac output at rest and submaximal work in the present study (r =0.96). This relationship is graphically shown in Figure 1.

Maximal Exercise

Mean maximal oxygen uptake, in relative and absolute terms, and maximal heart rate found for the subjects in the present study (see Table 5) is comparable to those found in other studies (Brown, 1972; Eriksson et al., 1973; Krahenbuhl et al., 1985; Lussier et al., 1977, Mahon et al., 1994, Mercier et al., 1987, Rowland et al., 1995; Soong, 1993) and in published normative values (Bar-Or, 1983, p.303-304).

Anthropometric Measures

Body size (i.e. height, weight, lean body mass, body fat %) means for the subjects of the present study (see Table 4) are in agreement with other studies utilizing a similar age group (Bar-Or et al., 1971; Bar-Or & Zwiren, 1973; Blessing et al, 1995; Brown et al., 1972; Eriksson & Koch, 1973; Foster, 1972; Gatch & Byrd, 1979; Lussier & Buskirk, 1977; Mahon & Vaccaro, 1994; Mercier et al., 1987; Rowland & Boyajian, 1995; Soong, 1993). Mean resting heart rate (supine position) for the subjects in the present study (see Table 4) is comparable to that found in other studies utilizing subjects of similar age and body size (Blessing et al., 1995; Blimkie et al., 1980; Geenen et al., 1982).

Submaximal Exercise

Oxygen consumption (relative and absolute), heart rate, cardiac output, stroke volume and a-vO_2 diff means at $VO2_{50\%}$ found in this study compared favorably to those found in other studies with similar subjects anthropometrically and at a similar exercise intensity (Eriksson & Koch, 1973; Gatch & Byrd, 1979; Lussier & Buskirk, 1977; Mahon & Vaccaro, 1994). These results are also in agreement with published normative values for the measure of cardiac output (Bar-Or, 1983, p.20). The mean % of maximum heart rate at $VO2_{50\%}$ was 73%.

Correlations of Cardiovascular Measures and VO_2max

Studies Utilizing Untrained Subjects

The low correlation between resting heart rate and VO_2max level, expressed in relative and absolute terms, found in this study (see Table 8) seems to agree with the results found by Blimkie et al. (1980) with untrained subjects. There is not a concrete relationship between fitness level as expressed by VO_2max and resting heart rate. The strong correlations shown between stroke volume and cardiac output and absolute VO_2max ($L \bullet min^{-1}$) agree with the correlation found by Blimkie et al. (1980) that showed a strong relationship between stroke volume and cardiovascular efficiency as expressed by VO_2max ($L \bullet min^{-1}$) in untrained children.

Studies Utilizing Trained Subjects

The low correlation between relative and absolute VO_2max and resting heart rate found in this study (See Table 8) is in agreement with the results of Geenen et al. (1982) with trained subjects. These results are in direct disagreement, however, with results of other studies (Blessing et al., 1995) and the consensus in the literature (Bar-Or, 1983, p.49; Diamant et al., 1989, p.27) that a resting bradycardia is strongly linked to and predictive of, a high fitness level in children following endurance training. This is an indication that cardiovascular efficiency may not be the sole indicator of fitness level in children.

Strong correlations between stroke volume and cardiac output with absolute VO_2max ($ml \bullet min^{-1}$) (see Table 8 & Figures 2 & 3) agree with the results found with studies that show a relationship between improved VO_2max and stroke volume and/or

Figure 2

Correlation of Cardiac Output & VO2max

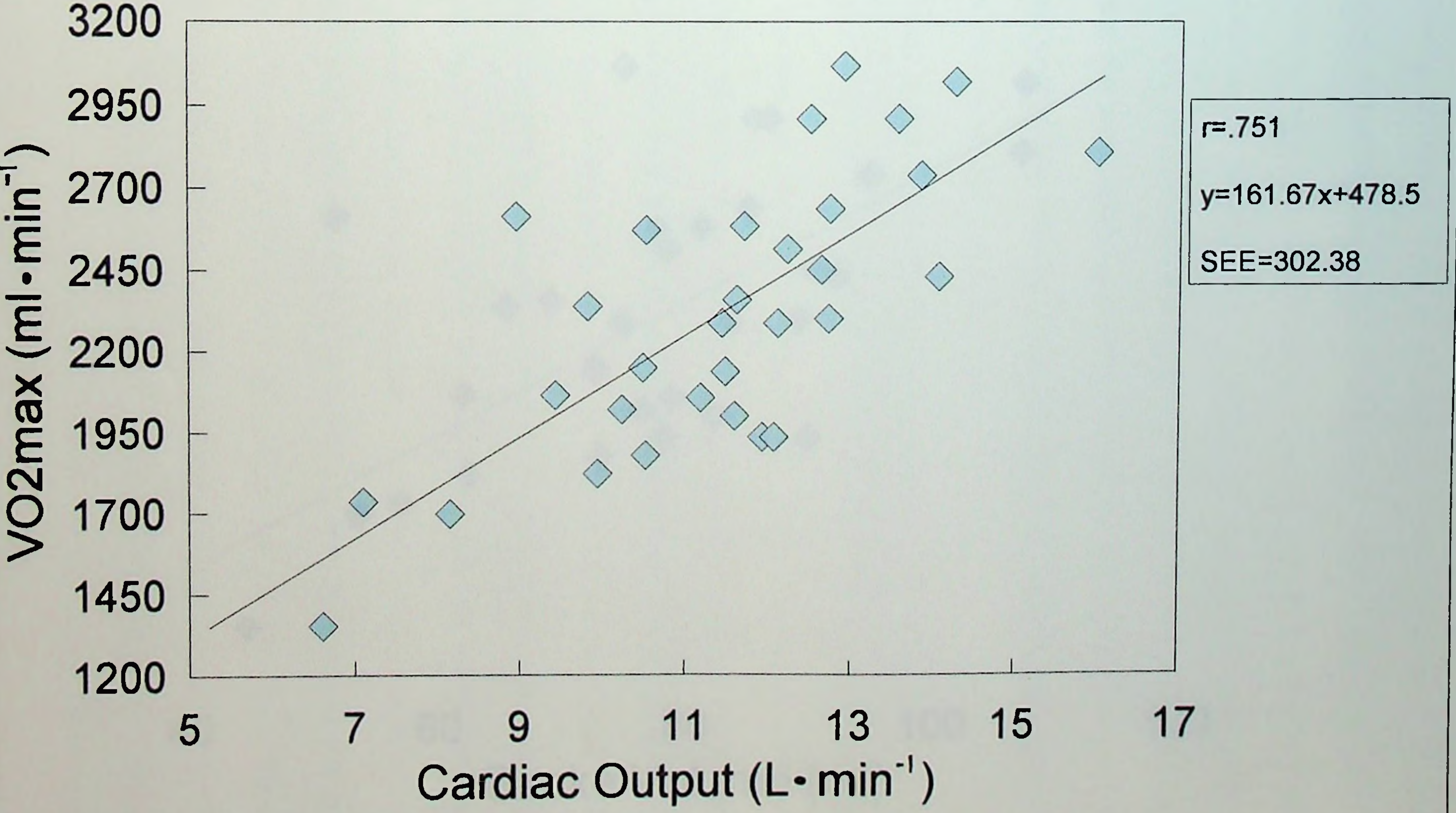
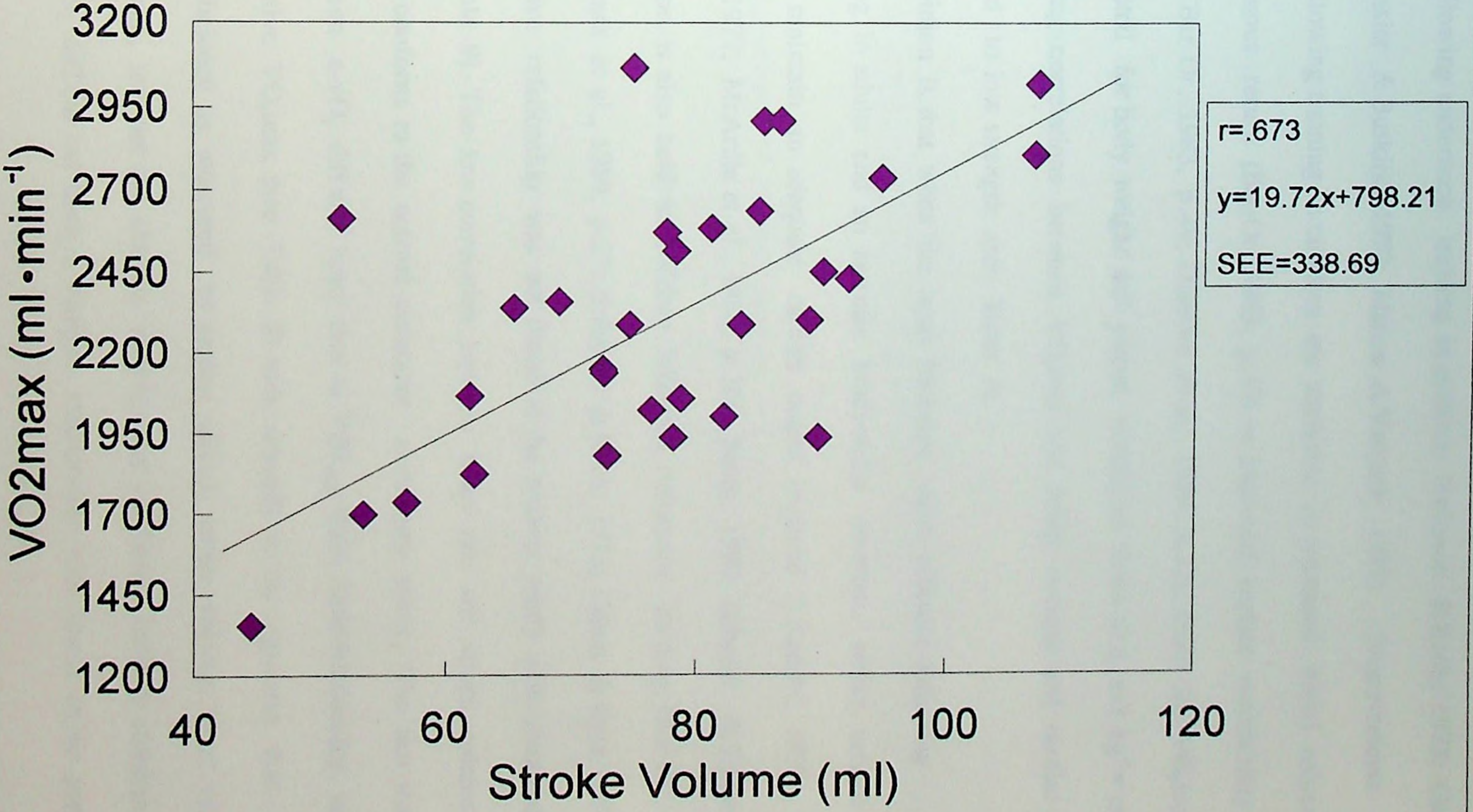


Figure 3

Correlation of Stroke Volume & VO2max



cardiac output following endurance training in children (Eriksson & Koch, 1973; Gatch & Byrd, 1979; Lussier & Buskirk, 1977; Mahon & Vaccaro, 1994). Improvements in stroke volume following training in children are attributed to increased blood volume and increased venous return (Bar-Or, 1983, p.49) or improved cardiac contractility and/or effciency (Bar-Or, 1983, p.49; Diamant et al., 1989, p.27). Once the VO_2max measure is corrected for body weight and placed in relative terms (i.e. $ml \bullet kg^{-1} \bullet min^{-1}$) however, the strong correlations between VO_2max and stroke volume and cardiac output are reduced to low strength (see Table 8).

Current opinion is that when the heart becomes more efficient following endurance training in adults and an exercise bradycardia develops, stroke volume must increase to maintain an adequate cardiac output (Astrand & Rodahl, 1977, p.394; Clausen, 1977; McArdle et al., 1994, p.366; Saltin, 1990; Scheuer & Tipton, 1977). This opinion is also held for children following endurance training (Bar-Or, 1983, p.49; Diamant et al., 1989, p.27; Eriksson & Koch, 1973; Gatch & Byrd, 1979). This strong negative relationship was not found in the present study with untrained subjects (see Table 9). The low correlation between heart rate and stroke volume at $VO2_{50\%}$ does not conform to the normal occurance mentioned above. The fact that correlations between $a\text{-}vO_2$ diff and heart rate at $VO2_{50\%}$ show little relationship with absolute and relative VO_2max (see Table 8) adds strength to the argument that cardiovascular efficiency as measured by cardiac output, stroke volume, heart rate and $a\text{-}vO_2$ difference, are not the clearest determinants of fitness level in children. The fact that $a\text{-}vO_2$ diff did not have a stronger relationship with fitness in the present study also differs from results seen in one study (Mahon & Vaccaro, 1994) following endurance training, but is in agreement with other studies (Gatch & Byrd, 1979; Lussier & Buskirk, 1977) that showed no contribution to improved fitness by improved a-vO_2 diff following endurance training. This lack of contribution may be due to the already wide a-vO_2 diff seen in trained and untrained children (Bar-Or, 1983, p.50; Diamant et al., 1989, p.27; Gatch & Byrd, 1979). These results do not reflect current opinion of the relationship between VO_2max and its' components in adults following training (American College of Sports Medicine, 1990; Andrew et al., 1966; Astrand & Rodahl, 1977, p.394; Clausen, 1977; Pollock, 1973; Saltin, 1990; Scheuer & Tipton, 1977).

Correlations of Anthropometric Measures and VO_2max

The strong positive correlation between subject height and absolute VO_2max ($ml \bullet min^{-1}$) in the present study (see Table 8 & Figure 6) is in agreement with other authors (Blimkie et al., 1980; Davies, 1972; Krahenbuhl et al., 1985), but is reduced to a very low negative correlation once VO_2max is expressed relative to body weight. A moderate positive correlation was found between body weight (mass) and absolute VO_2max which is in agreement with other sources (Blimkie et al., 1980; Krahenbuhl et al., 1985). A strong negative correlation was found between body weight and relative VO_2max (See Figure 8).

Some authors have questioned the idea of utilizing body weight or height exclusively as predictors of oxygen consumption. The current opinion suggests

Figure 6

Correlation of Height & VO2max

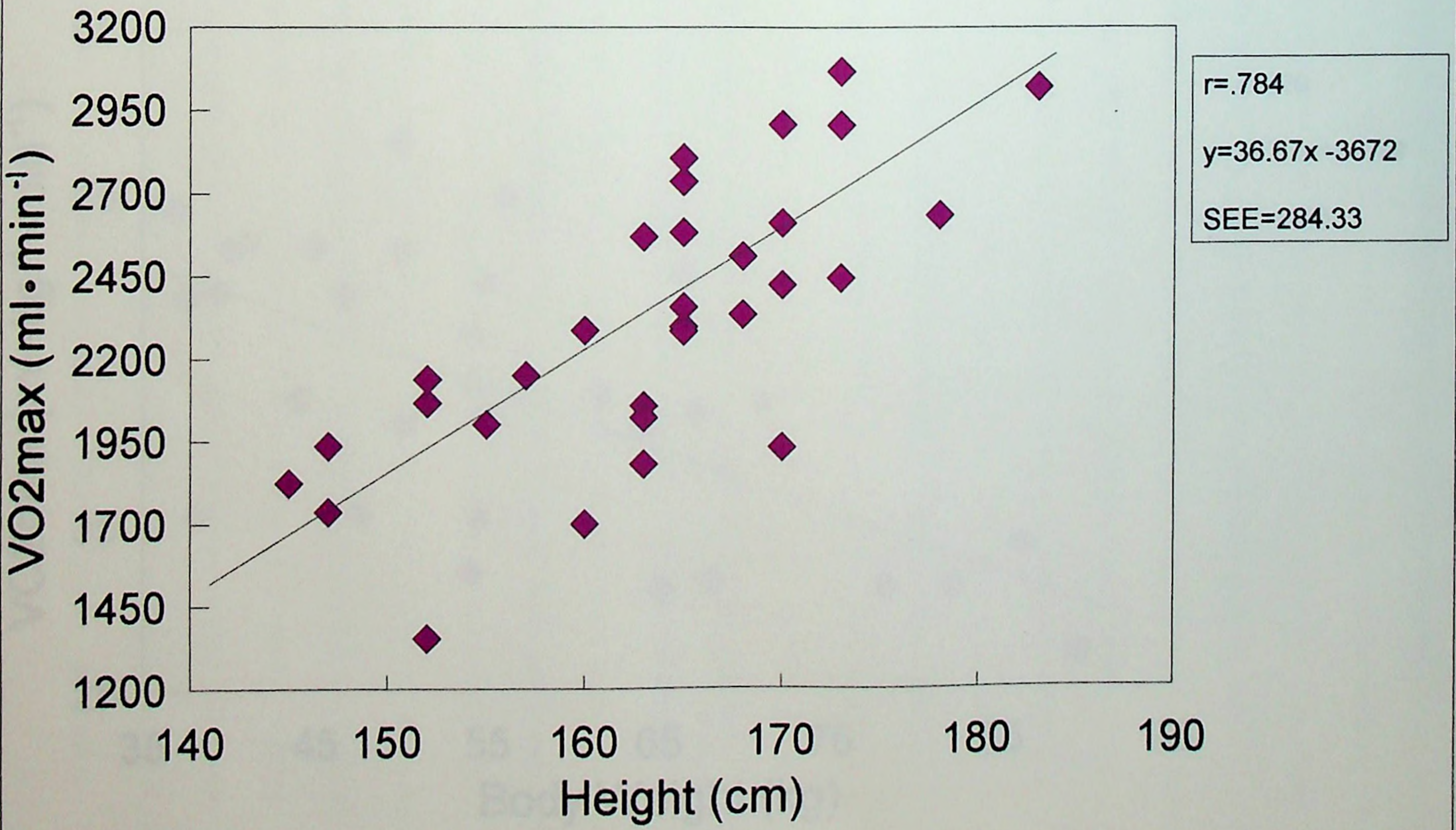
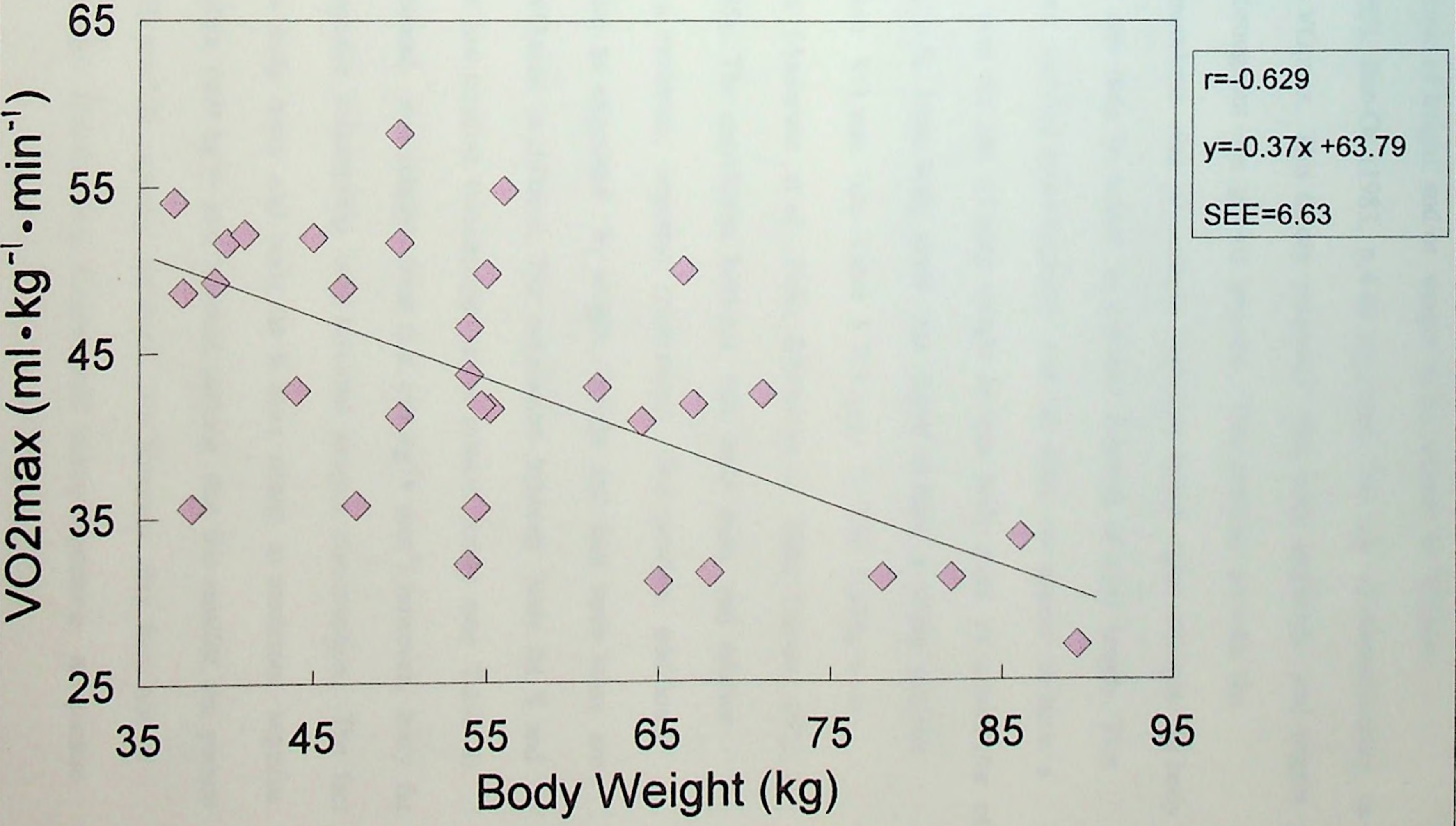


Figure 8

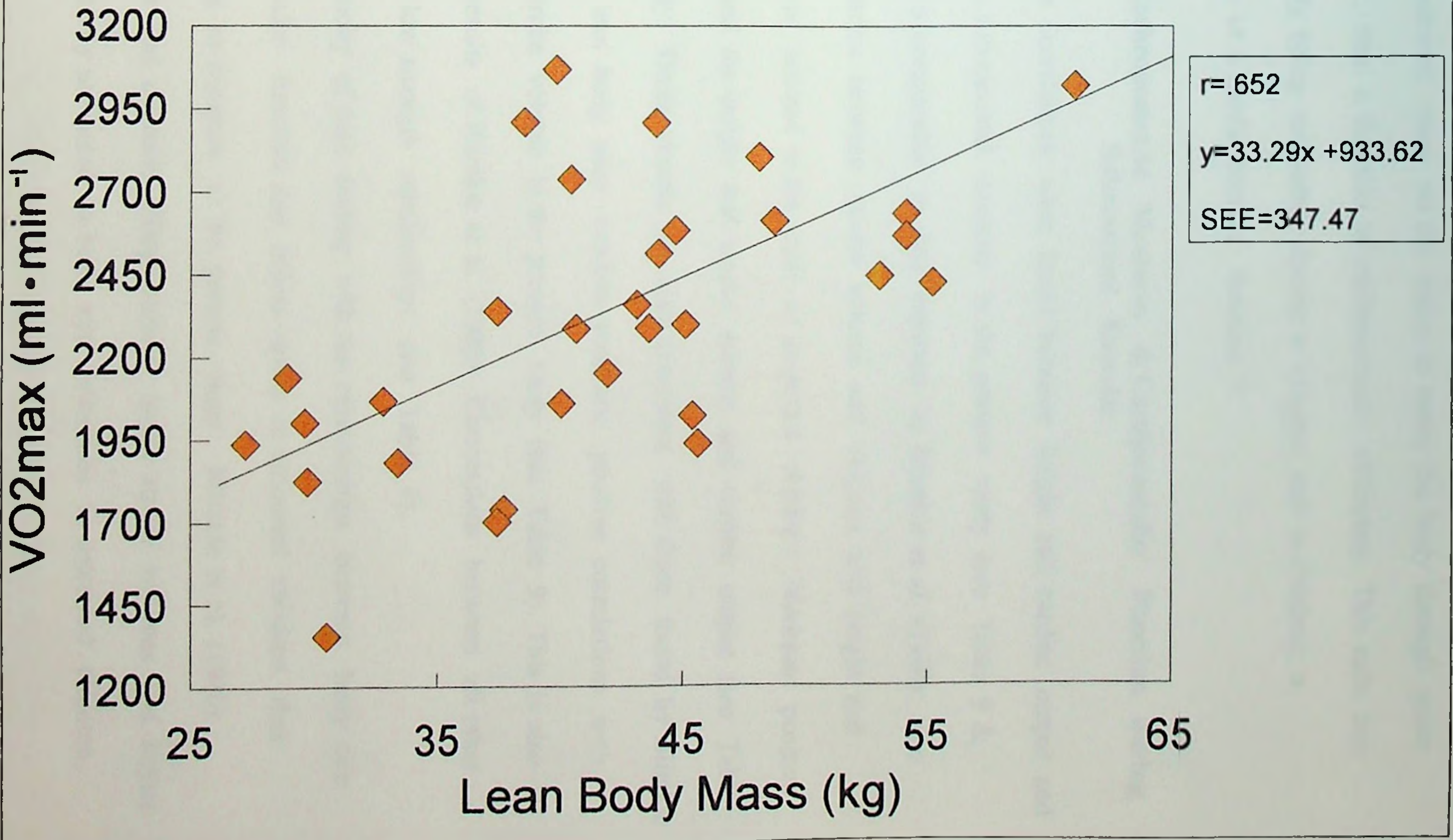
Correlation of Body Weight & VO2max



utilizing a power function of height and/or weight to be related to VO_2max (Krahenbuhlet al., 1985). Bar-Or (1983, p.4-6) suggested the use of dimensionality to relate body length to VO_2max. This theory presumes that body segments and organs remain proportional throughout the growth process. This premise permits the prediction of body dimensions and physiologic functions based upon changes in body length. These factors can then be scaled to a power function of body length. This technique has not been verified experimentally and not does not appear to have a functional advantage over the use of body weight or lean body mass as a predictor of fitness (Bar-Or, 1983, p.6). Lean body mass was found to have a strong positive correlation with absolute VO_2max (see Table 8 & Figure 7). This finding is in agreement with others (Anderson et al., 1980; Blimkie et al., 1980; Davies, 1972; Krahenbuhl et al, 1985). The correlation between lean body mass and relative VO_2max however, is a moderate, negative relationship. This provides additional evidence that body size as expressed by weight, height and lean body mass are strong predictors of VO_2max in children. The correlation between body fat % and absolute VO_2max is a low positive relationship in the present study (see Table 8). Once VO_2max is expressed in a relative form (i.e. $ml \bullet kg^{-1} \bullet min^{-1}$) however, body fat % has a moderate negative relationship with maximal oxygen consumption. The fact that body weight, lean body mass and body fat % have strong to moderate negative correlations with VO_2max ($ml \bullet kg^{-1} \bullet min^{-1}$) would indicate that the smaller the person is, the higher their VO_2 level or capacity for work. This however may may not be indicative of cardiovascular fitness. Thus fitness level (when expressed as relative

Figure 7

Correlation of Lean Body Mass & VO2max



VO_2max) may be predicated more on the ability to move the body through space during a specific task, than a function of cardiovascualr efficiency. This calls into question what is really being measured during a VO_2max test in children; a performance function or a cardiovascular function ?

Correlations of Anthropometric Measures & Cardiovascular Function during Submaximal Exercise

Strong positive correlations were found between height and cardiac output and stroke volume during submaximal exercise in the present study (see Table 9 & Figures 4 & 5). This is comparable to data reported by Blimkie et al. (1980), who found a strong correlation between stroke volume and VO_2max and height and VO_2max in the subjects utilized in his study of untrained children. Moderate positive correlations were found for weight and stroke volume and cardiac output (see Table 9) in the present study. These results are also consistent with those found by Blimkie et al. (1980). Lastly, lean body mass exhibits moderate positive correlations with cardiac output and stroke volume in the present study (see Table 9). This is also in agreement with the results of Blimkie et al. (1980). Correlations between all other factors showed very low strength relationships (see Table 9).

There is a paucity of data dealing with the relationships between body size measures, cardiovascular function and fitness levels in untrained children, thus leaving very little data to compare to the present study. Blimkie et al. (1980) concluded that higher end diastolic filling volumes, larger stroke volumes and higher VO_2 levels were primarily attributed to body size influences in untrained children.

Figure 4

Correlation of Height & Cardiac Output

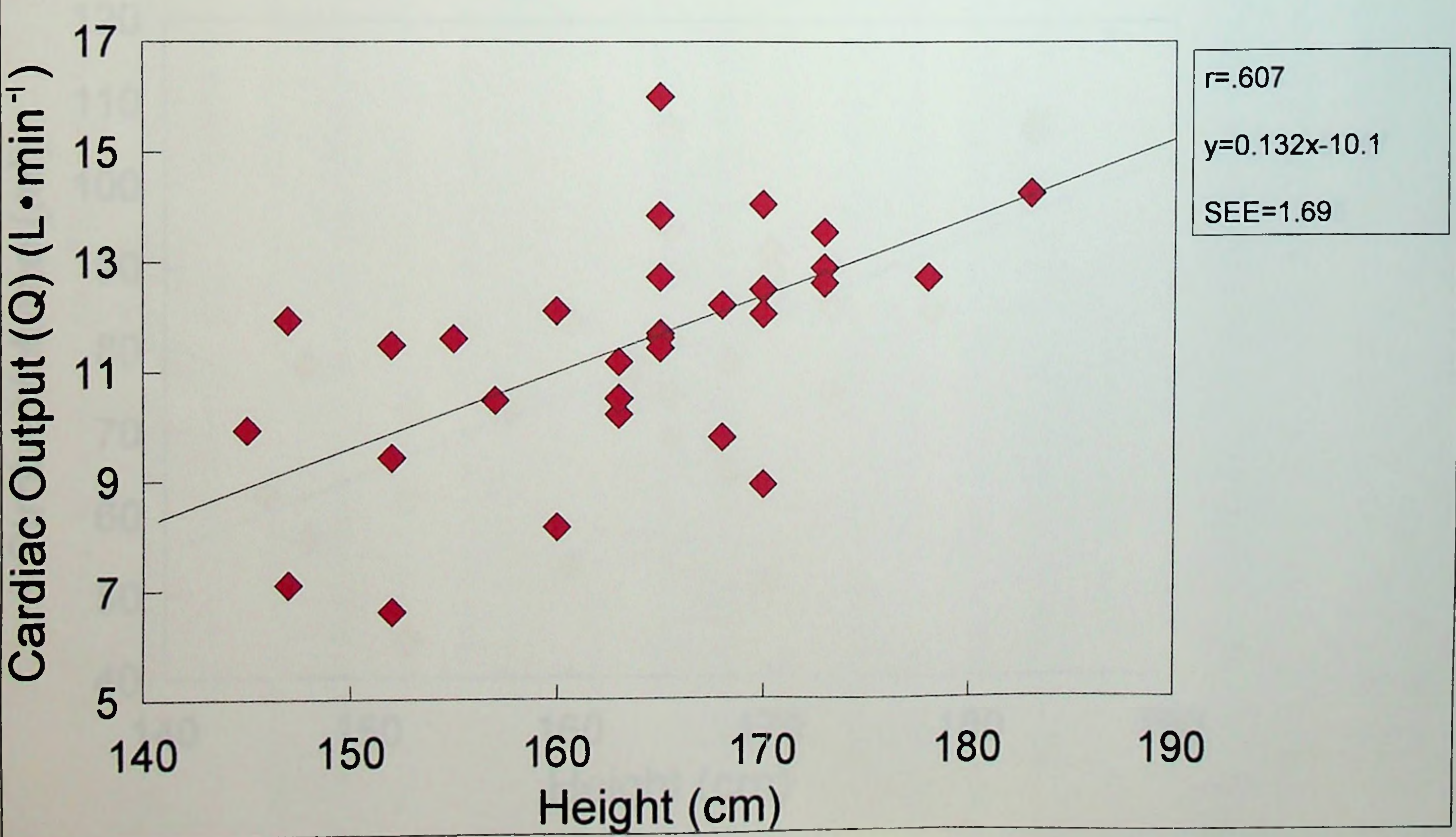
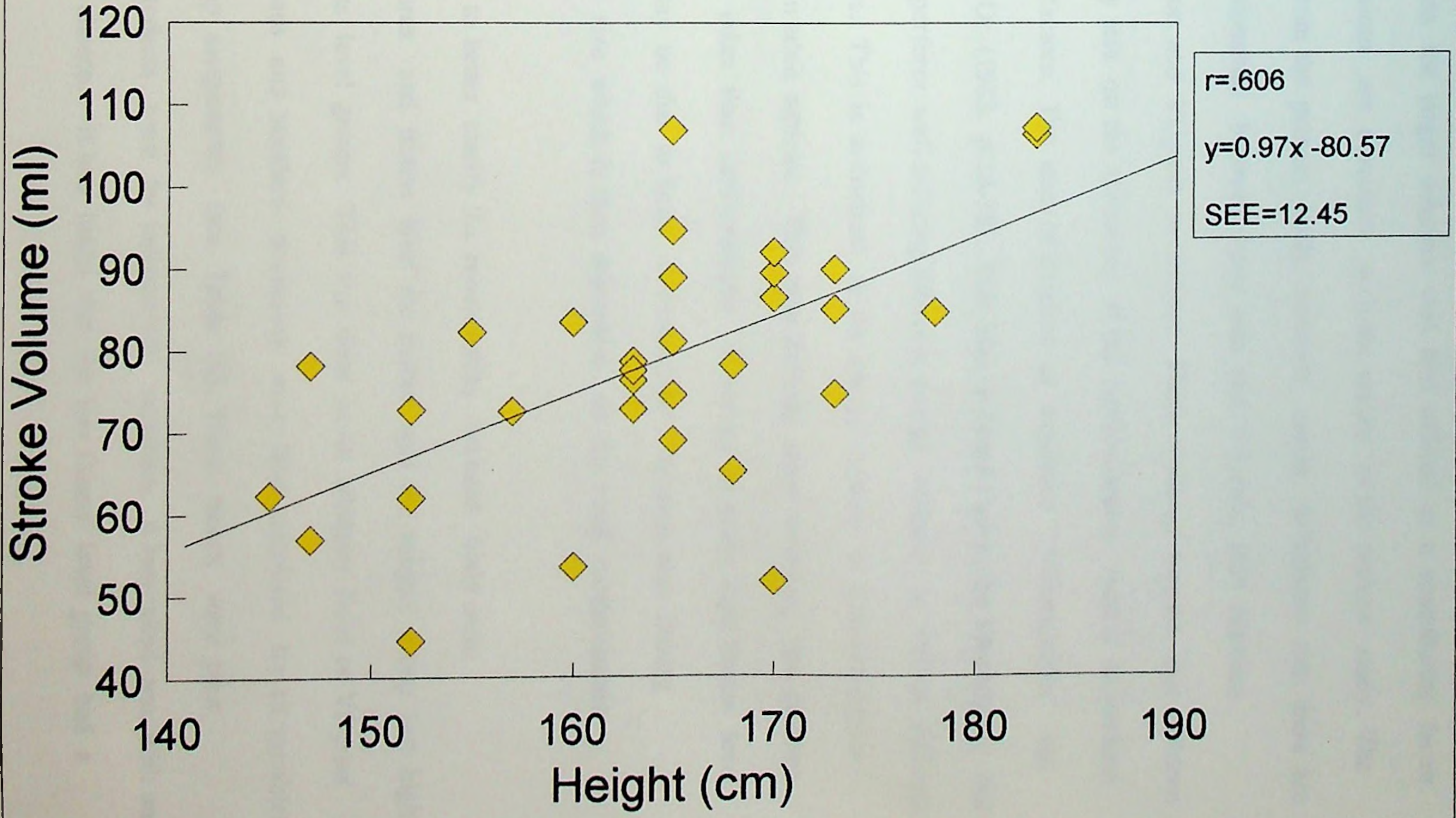


Figure 5

Correlation of Height & Stroke Volume



Larger blood volumesin the larger subjects was also offered as a contributing factor.

These conclusions are consistent with the results of the present study. The weight of evidence from the present study, however, seems to indicate that there are far more distinct relationships between body size and VO_2max, than between cardiovascular function and VO_2max in children. These findings suggest that children in this age group rely less on the efficiency of the cardiovascular system to perform work, than on other factors. The idea of children as metabolic "nonspecialists" has been offered by Bar-Or (1983, p.16-18). This idea is based upon the observation that children are able to perform well utilizing different energy systems as well as different components of fitness. This is in contrast to the energy system or skill component specialization seen in adult athletes. This may provide some evidence that children rely on many factors other than cardiovascular efficiency to attain high fitness level performance. This may be due to basal cardiovascular function thus linking performance to body size which is then dependent on the basal cardiovascular function.

In an attempt to better clarify the relationships between body size, cardiovascular measures and fitness level the author split the subject group into high fitness and low fitness level groups. This was done at an arbitrary level of VO_2max ($ml \bullet kg^{-1} \bullet min^{-1}$). Means and standard deviations were then calculated for all variables based upon the group assignments (see Table 10). These means were then compared utilizing Students t-test for independent variables. A two-tailed test with an $\propto$ level of 0.05 was chosen. It was found that the low fitness level group had a

Table 10 Comparison of Means of Anthropometric and Maximal, Submaximal and Resting Cardiovascular Measures Between High and Low VO_2max Groups

Variable	High VO_2max ($ml \bullet kg^{-1} \bullet min^{-1}$) Group (n = 13)		Low VO_2max ($ml \bullet kg^{-1} \bullet min^{-1}$) Group (n = 19)		*t* Value
	M	SD	M	SD	
Age (years)	12.46	1.20	13.21	1.03	1.81
Height (cm)	162.2	11.13	165.26	8.56	0.85
Weight (kg)	47.53	8.77	62.29	14.29	3.64*
Body fat %	21.00	7.00	26.00	10.00	1.75
Lean Body Mass (kg)	37.81	8.50	45.35	7.84	2.46*
Resting Heart Rate (bpm)	71.00	10.40	74.16	8.29	0.91
VO_2max ($ml \bullet min^{-1}$)	2439.8	464.6	2274.2	440.72	1.01
VO_2max ($ml \bullet kg^{-1} \bullet min^{-1}$)	51.35	3.06	37.09	5.30	12.00*
Cardiac Output ($L \bullet min^{-1}$)^a	11.78	1.46	11.35	2.46	0.62
a-v O_2 difference ($ml \bullet L^{-1}$)^a	96.71	12.22	96.80	12.78	0.03
Stroke Volume (ml)^a	78.50	12.61	78.11	17.38	0.08
Exercise Heart Rate (bpm)^a	151.2	9.51	145.97	12.09	1.34
Maximum Heart Rate (bpm)	203.2	8.24	201.6	7.53	0.56

Note. * $= P < 0.05$
df = 30

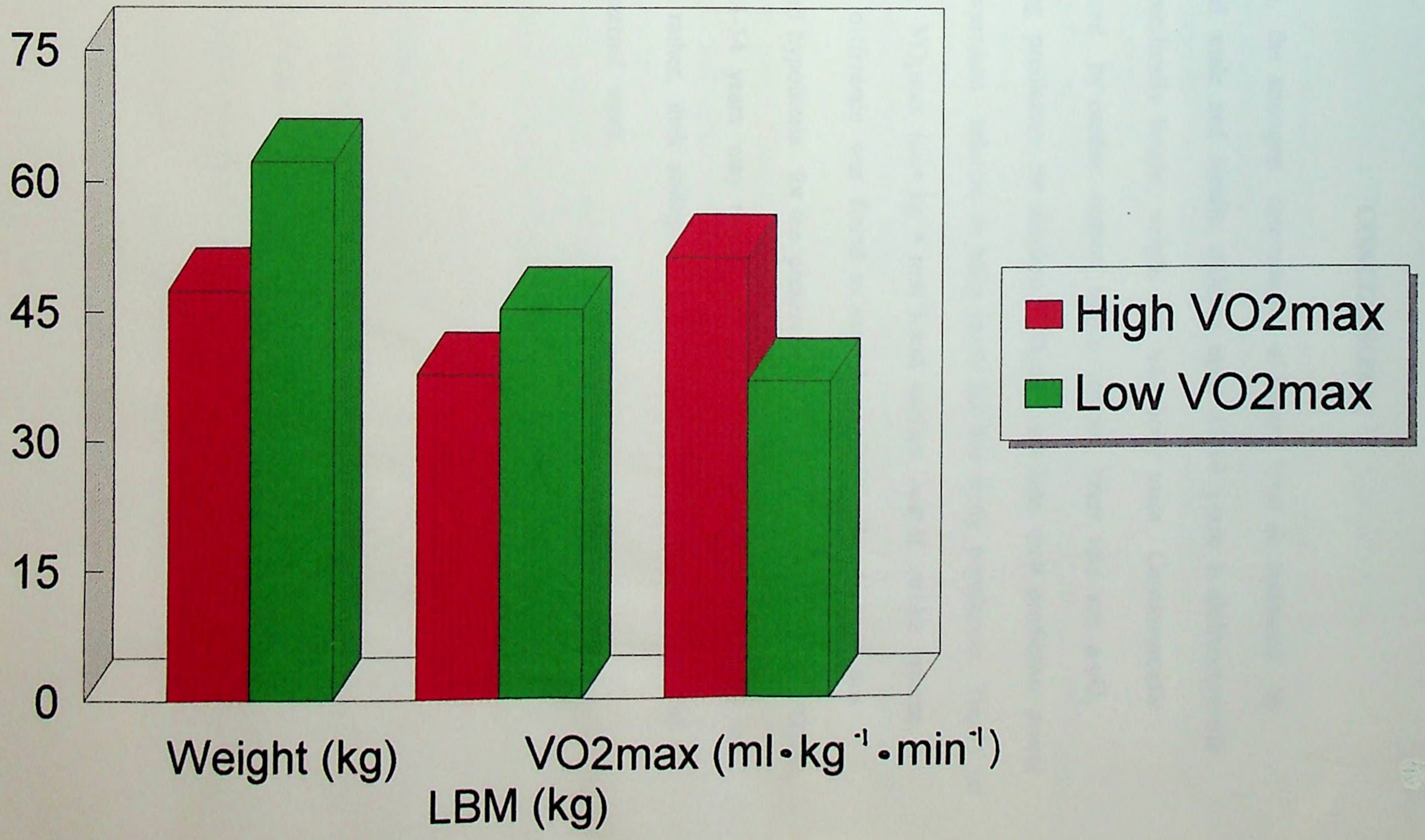
a = at $VO2_{50\%}$

significantly lower VO_2max (ml• kg^{-1}• min^{-1}), significantly higher body weight and significantly higher lean body mass than the high fitness level group (see Figure 9). Age, height, body fat %, resting heart rate, absolute VO_2max, cardiac output at $VO2_{50\%}$, heart rate at $VO2_{50\%}$, stroke volume at $VO2_{50\%}$ and a-vO_2 difference at $VO2_{50\%}$ were all non-significantly different between the two groups. This calculation lends added support to the idea that body size has a greater impact on fitness level than cardiovascular efficiency. The reasons for this are unknown. It could be that true cardiovascular efficiency is not reached or essential until the major physiological changes of puberty.

If so, the cardiovascular efficiency and peripheral O_2 extraction may be similar in untrained children regardless of their VO_2max measure. Therefore body size predominates as the variable that most influences relative O_2 uptake. There appears to be no evidence that an inherent mechanical efficiency could be a factor. This is due to the fact that children are less mechanically efficient during running and walking compared to adults (Bar-Or, 1983, p.6-9). Whatever the mechanism for this difference, it appears that body size is a strong determinant of fitness as measured by relative VO_2 in the children utilized in this study.

Figure 9

Comparison of Significant Body Size & VO2max Differences



CONCLUSION

In conclusion, the strongest determinant of fitness level as measured by VO_2max in untrained male and female children aged 11-14 years is anthropometric measures, more specifically height, weight and lean body mass. Cardiovascular efficiency as measured by cardiac output, stroke volume, heart rate and a-vO_2 difference are strong predictors for absolute VO_2max, but lose their predictive power when VO_2max is expressed relative to body mass for this study population. Thusly no correlation between VO_2max ($ml \bullet kg^{-1} \bullet min^{-1}$) and cardiac output, stroke volume, heart rate or a-vO_2 difference was found to exceed $r = 0.40$. Based upon this observation, the null hypothesis for the present study is accepted. Tests of VO_2max for children aged 11-14 years may not be measuring cardiovascular efficiency in these subjects, but rather, their ability to move his/her body through space and perform efficient external work.

RECOMMENDATIONS FOR FURTHER RESEARCH

1. Continue to attempt to clarify the roles of cardiac output, stroke volume, heart rate and a-vO_2 difference in improvements in VO_2max in children.

2. Gather concrete normative data for stroke volume and a-vO_2 difference in children at submaximal and maximal exercise levels.

3. Attempt to clarify the relationship of body size to cardiac output, stroke volume and a-vO_2 difference in children.

4. Improve the understanding of the heart rate - VO_2max relationship in children.

5. Explore the apparent differences between a-vO_2 difference in children compared to adults.

6. Compare the body size - VO_2max relationship in children and adults.

7. Examine the focus and goals of VO_2max testing in children and clarify the performance vs. physiology issue.

8. Determine if VO_2max testing of the untrained population in children is a true picture of fitness level as stated by relative VO_2max.

9. Determine why the body size - VO_2max relationship does not carry over to cardiac output and stroke volume in children.

10. Determine if the negative correlation between stroke volume and heart rate in adults is as strong in children.

11. Clarify the relationship between lean body mass and a-vO_2 difference in children.

12. Determine the cardiovascular - body size relationship in untrained adults.

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