THE RELIABILITY AND REPRODUCIBILITY
OF MAXIMAL OXYGEN CONSUMPTION
IN YOUNG FEMALES, AGED 10-13

A Thesis Presented

to

The Graduate Faculty

University of Wisconsin - La Crosse

In Partial Fulfillment
of the Requirements for the
Masters of Science Degree

by

Anne Herbert

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ABSTRACT


Forty-one female Ss, aged 10-13, volunteered to undergo underwater weighing and to perform a maximal treadmill exercise test (T1). Forty Ss also completed a maximal bicycle ergometer test (T2). Comparison of physical characteristics (ht, wt, % fat, LBW) between age groups, as well as the peak cardiorespiratory responses to the treadmill exercise (L·min⁻¹, ml·kg⁻¹·min⁻¹, ml·kgLBW⁻¹·min⁻¹, HR, Ve, time, RER) was done. A one-way ANOVA was used to determine the sig between age groups and a Scheffe post-hoc test showed where the sig occurred. Sig diff (P<.05) in ht was found between 10 and 12 yr old Ss and 10 and 13 yr old Ss; in wt between 10 and 13 yr old Ss and 11 and 13 yr old Ss; in LBW between 10 and 13 yr old Ss and 11 and 13 yr old Ss. Peak L·min⁻¹ differed (P<.05) between 10 and 13 yr old Ss and 11 and 13 yr old Ss. Peak Ve was found to differ sig (P<.05) between 10 and 13 yr old Ss. No other variable differed (P>.05) between ages. Eighteen of these Ss volunteered to perform a retest (T2), 9 on the treadmill, 9 on the bicycle ergometer. A Pearson Product Moment r was employed to compare each variable for T1 and T2. Sig r (P<.05) were seen in L·min⁻¹ for treadmill exercise and in L·min⁻¹, ml·kg⁻¹·min⁻¹, ml·kgLBW⁻¹·min⁻¹ and Ve for bicycle ergometry. Dependent "t" tests showed no sig diff (P>.05) in mean values between T1 and T2 in ml·kg⁻¹·min⁻¹ and HR for peak treadmill exercise. For bicycle exercise, no sig diff (P>.05) was observed in Ve and performance time. It was concluded that difficulty in the attainment of maximal exercise in children due to a lack of motivation to reach that level of effort makes the reliability and reproducibility of peak cardiorespiratory responses questionable.
Candidate:  Anne Herbert

We recommend acceptance of this thesis in partial fulfillment of this candidate's requirements for the Master of Science degree in Adult Fitness/Cardiac Rehabilitation. The candidate has completed her oral report.

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CHAPTER I
INTRODUCTION

Background

The large number of studies investigating the physical work capacities of adults have presented valuable information regarding the benefits that can be derived from a regular fitness regimen. The findings of this research have helped in establishing a new awareness in many individuals regarding their health and physical condition. Unfortunately, little research has been done regarding work capacity of children. Not only does this paucity leave many unanswered questions concerning the physical capabilities that exist at specific stages of a child's development, but it also may indicate a dangerous oversight regarding the physical state of children.

Enos, Holmes and Beyers (1953) found that 77.3% of 300 American men killed in the Korean War showed gross evidence of arteriosclerosis in the heart vessels. The average age in 200 of these men was 22.1 years. Astrand (1967) projected that such findings could be due to a lack of physical activity.

Numerous studies have found that obesity in children can be linked to inactivity (Bruch, 1940; Bronstein, Wexler, Brown & Halperin, 1942; Bullen, Reed & Mayer, 1964; Durnin, 1971; Johnson, Burke & Mayer, 1956; Stefanik, Heald & Mayer, 1959). Bronstein et al. (1942)
and Durin (1971) found that this inactivity seemed to be related to a sedentary lifestyle, while Bullen et al. (1964) found that fat children were less active, for longer periods of time while participating in games, than were thin children. It has been shown that inactivity is of greater importance than overeating in the development of obesity, since the caloric intakes of non-obese girls were larger than that of obese subjects (Johnson et al., 1956).

Cumming (1967) reported a poor performance by a large group of Canadian children on a battery of physical fitness tests and projected that the low scores may have been caused by an inadequacy of school physical education programs and a general lack of leadership from parents to lead active, healthy lives. Since lack of physical activity has such a detrimental effect on the total physical condition of an individual, these findings indicate that a serious health problem may exist in children and young adults.

**Statement of the Problem**

Maximal oxygen uptake (max VO$_2$) is defined by Astrand and Rodahl (1977) as the highest oxygen uptake an individual can attain during physical work while breathing air at sea level. Astrand (1956) said that the capacity for oxygen is decisive in determining one's state of fitness and it has since become the most widely used measurement of aerobic capacity. Gilliam, Sady, Thorland & Weltmen (1977) chose to use the term "peak" as opposed to "maximal" for VO$_2$ and for other physiological variables measured, to indicate the highest obtained value recorded.
Peak was considered a more appropriate term because of the difficulty in obtaining maximal values in children.

When measuring peak $\text{VO}_2$ in children a controversy exists concerning which parameter of body size best indicates maximal aerobic capacity. According to Kemper and Verschuur (1980) aerobic power must be measured in relative expressions in order to give information about functional work capacity. It has been found that peak $\text{VO}_2$ increases with age (Anderson, Seliger, Rutenfranz & Mocellin, 1974; Astrand, 1967; Daniels, Oldridge, Nagle & White, 1978; Davies, Barnes & Godfrey, 1972; Gilliam et al., 1977; Kemper & Verschuur, 1980). But Gilliam et al. (1977) and Daniels et al. (1978) found no significant difference between age groups of children in max $\text{VO}_2$ expressed relative to body weight. Other researchers have commented that max $\text{VO}_2$ is best indicated through measurements that neglect the inactive adipose tissue (Burmeister, Rutenfranz, Sbresny & Radny, 1972; Davies, 1971; Davies et al., 1972; Sloan, Koeslag & Bredell, 1973; von Dobeln, 1956). Several other studies have shown that peak $\text{VO}_2$ can easily be related to body surface area (Anderson et al., 1974a; James, Kaplan, Glueck, Tsay, Knight & Sarwan, 1980).

Cunningham, Goode and Critz (1975), Mitchell, Sproule and Chapman (1958), Magel and Faulkner (1967) and Taylor, Buskirk and Henschell (1955) found that peak $\text{VO}_2$ measurements were reliable and reproducible in adults. Shephard (1971) however, has questioned the reproducibility of peak $\text{VO}_2$ measurements in children.
Purpose

The fundamental intention of this study was to continue certain longitudinal research being done to study the developmental changes in the maximal work capacity of young females.

An objective of this specific research was to compare cardiorespiratory responses to maximal work to specific physical characteristics of female children, aged 10-13 years. Another objective was to test for reproducibility and reliability of peak Vo2 measurements from the treadmill and the bicycle ergometer in this population of children.

A secondary purpose of this study was to provide information to each subject on her circulatory capacity. The annual retesting nature of this research presents an evaluation of the individual's progress regarding her health status. The presentation of this knowledge may also help to provide the proper motivation to the child, and/or her parents to continue with or establish a regular fitness regimen, one that will lead to a healthy, daily pattern of living.

Need for the Study

Disagreement on how peak Vo2 should be expressed and the lack of confidence in the reproducibility and reliability of such measurements in children creates a need for this study. An additional need is created due to a lack of longitudinal studies concerning the developmental changes of cardiorespiratory capacities in children. Also, the possible lack of concern in parents and children on the matter of daily physical activity is of interest to health professionals. Therefore, this study
was needed to investigate this possibility, so that appropriate action can be taken to rectify the problem.

**Hypotheses**

It was hypothesized that no significant differences would be found in height, weight, percent body fat and lean body weight when comparing females, 10-13 years of age.

It was hypothesized that there would be no significant differences in peak $V_0_2$ and other cardiorespiratory responses in females, aged 10-13 years, measured by volitional maximal treadmill tests.

It was hypothesized that there would be no significant differences in comparative measures of peak $V_0_2$ relevant to body size.

It was hypothesized that there would be no significant differences between physiological variables recorded from the pre and post tests on both the treadmill and the bicycle ergometer.

**Assumptions**

It was assumed that no physical restrictions to exercise were present in the subjects prior to testing that would hinder their performance.

It was also assumed that after one practice session the subjects were adequately acquainted with treadmill running and stationary bicycle riding, thus alleviating any fear or anxiety that the subjects may have felt.

It was assumed that no significant changes in fitness levels took place in the time period between the first and second test.
It was assumed that the subjects worked hard, using all of the energy they had, during all of the exercise tests and that they had achieved their physiological maximum.

**Limitations**

A random sample was not used for this study, thus it did not represent a true cross section of the population.

The attainment of peak physical exercise is often largely dependent on psychological incentives that vary between individuals and from time to time within the same individual. Those lacking high levels of motivation may not have reached their physiological limit.

Maximal cardiorespiratory responses are a function of the individual's activity level. Since fitness levels were not determined prior to testing, it is not known how the results would be affected by this condition.

**Delimitation**

The sample for this study was comprised of a group of 41 volunteer female subjects that were taking part in an ongoing long term study at the University of Wisconsin - La Crosse, La Crosse, Wisconsin.

**Definition of Terms**

Beckman Metabolic Cart - an instrument used to measure and record inspired volumes of air, O₂ consumed, CO₂ produced and respiratory quotient, during rest and/or during physical activity.
**Bruce Treadmill Protocol** - a process of increasing the speed of a treadmill in three minute increments, in order to increase the work intensity during an exercise test (Bruce, Kusumi & Hosmer, 1973, p.549).

**Borg Scale of Perceived Exertion** - a device developed by Borg (1970, p. 93) to indicate an individual's perception of physical stress during physical exertion.

**Maximal Oxygen Consumption (max VO₂)** - the maximal amount of oxygen that can be ingested, transported and utilized by the body, determined through volitional maximal effort and expressed in units of L·min⁻¹, ml·kg⁻¹·min⁻¹, or ml·kgLBW⁻¹·min⁻¹.

**Peak Oxygen Consumption (peak VO₂)** - the highest recorded value of O₂ consumed during an exercise test.

**Percent Fat (% fat)** - the percentage of the total body weight that is adipose tissue, determined by means of hydrostatic weighing.

**Volitional Maximal Exercise Test** - an exercise test, done on a treadmill or a bicycle ergometer, in which the subject being tested determines when her maximal exertion has been reached.
CHAPTER II
REVIEW OF RELATED LITERATURE

Introduction

Until recently, few studies have investigated the exercise responses of children, especially females. Unfortunately, many of the results of these studies are inconsistent. A difference of opinion exists as to which parameter of body size, if any, should be used to express maximal oxygen uptake, as well as the modality that is best suited for maximally testing children. The question has also been raised regarding the reliability and reproducibility of maximal exercise testing in children. This chapter reviews the literature on the following subjects: cardiorespiratory responses to exercise; reliability and reproducibility of exercise testing; and, the differences between treadmill and bicycle testing in children.

Cardiorespiratory Responses to Maximal Exercise in Children

Maximal Oxygen Consumption (max VO₂)

Astrand and Rodahl (1977) have defined maximal oxygen consumption as the highest oxygen uptake an individual can attain during physical work while breathing air at sea level (p. 318). The literature refers to several possible body parameters from which max VO₂ can be measured and compared in children. Among these parameters are body weight.
(ml·kg\(^{-1}\)·min\(^{-1}\)), lean body weight (ml·kgLBW\(^{-1}\)·min\(^{-1}\)), body surface area (BSA), and leg volume. Attention also should be paid to the modality employed by each study, either the treadmill or the bicycle ergometer.

\[ \text{LITERS\cdot MINUTE}^{-1} (L\cdot MIN^{-1}) \] It has been found the max \( \dot{V}O_2 \), when expressed in the absolute terms of \( L\cdot MIN^{-1} \), increases in children with increases in age (Anderson et al., 1974a; Astrand, 1967; Daniels et al., 1978; Davies et al., 1972; Gilliam et al., 1977; Kemper & Verschuur, 1980; Schoenleber, 1981). Utilizing the bicycle ergometer, Anderson and others (1974a) found the correlation between \( L\cdot MIN^{-1} \) and age to be positive, but not in a linear fashion. With the same mode, Astrand (1967) reported that the increase in \( L\cdot MIN^{-1} \) with age was only significant prior to the age of 12 or 13 years in females.

Daniels et al. (1978) related the increase in max \( \dot{V}O_2 \), recorded from treadmill exercise, with increases in body weight, which normally increases with age. Using the same modality and finding similar results, Schoenleber (1981) also attributed the increase in \( L\cdot MIN^{-1} \) to body size, including height, body weight, and/or lean body weight.

\[ \text{MILLILITERS\cdot KILOGRAM}^{-1}\cdot \text{MINUTE}^{-1} (ml\cdot kg^{-1}\cdot min^{-1}) \] Shephard (1971) stated that when measuring max \( \dot{V}O_2 \) in children of differing body size, weight is the only standardization that is adequate. When expressed on the basis of the body weight of the subject no significant differences in various age groups of children were found by Gilliam et al. (1977), Daniels et al. (1978), and Schoenleber (1981) in maximal work capacity measured with either the treadmill or the bicycle ergometer. With a stationary bicycle, Anderson et al. (1974a) reported a somewhat irregular decrease in the ability to utilize oxygen with an increase in age,
in both girls and boys between the ages of 8 and 16, when max \( \text{VO}_2 \) was corrected for body weight. Astrand (1952) found a similar decrease in girls at the age of 10 years. This decrease was regarded as an effect of sexual maturity, for example, increases in height, weight, and percent body fat.

Astrand (1952) found a similar decrease in girls at the age of 10 years. This decrease was regarded as an effect of sexual maturity, for example, increases in height, weight, and percent body fat.

\[ \text{Milliliters} \cdot \text{kilogram lean body weight}^{-1} \cdot \text{minute}^{-1} (\text{ml} \cdot \text{kg} \cdot \text{LBW}^{-1} \cdot \text{min}^{-1}) \]

Anderson et al. (1974a), Burmeister et al. (1972), Buskirk and Taylor (1957), Cureton, Boileau, Lohman and Misner (1967), Sloan et al. (1973), and von Dobeln (1956) believed that max \( \text{VO}_2 \) measured as \( \text{ml} \cdot \text{kg} \cdot \text{LBW}^{-1} \cdot \text{min}^{-1} \) is the most appropriate interpretation of aerobic capacity, since "fat is metabolically inactive" (Anderson et al., 1974a, p. 162). von Dobeln (1956) recommended the use of a parameter that does not contain the amount of fat in the body, but rather contains the cellular matter of the adipose tissue. A ratio of this value to the percentage of pure fat in the tissue was calculated for maximal oxygen intake, in order to approximate the percentage of the cellular matter and body fluid that is present in the bone marrow. von Dobeln (1956) did not find a linear relationship between body size and max \( \text{VO}_2 \) with this parameter.

The wide variability of body size during growth caused Burmeister et al. (1972) to use cell mass, or more specifically potassium content, rather than LBW as a parameter to evaluate physical performance capacity because the metabolic values of LBW can be calculated from the potassium content of the cell.

Anderson and others (1974a) found that max \( \text{VO}_2 \) values are nearly equal in children when recorded on the basis of body weight \( (\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}) \) and lean body weight \( (\text{ml} \cdot \text{kg} \cdot \text{LBW}^{-1} \cdot \text{min}^{-1}) \). According to Anderson et al.
(1974a) this suggests the max \( \dot{V}O_2 \) is dependent on the development of muscle mass, and they projected that "muscle mass must deteriorate with age in girls" (Anderson et al., 1974a, p. 193). When comparing the sexes, Astrand (1952) suggested the use of maximal oxygen uptake per kg of muscular tissue.

**Leg Volume.** Davies (1971) related max \( \dot{V}O_2 \) in children to the amount of muscle involved in the activity. When max \( \dot{V}O_2 \) is related to the leg volume, variations in sex and age between subjects tested on the bicycle is reduced significantly (Davies, 1971; Davies et al., 1972). Leg volume accounted for more than 80% of the total variance of max \( \dot{V}O_2 \) in the 116 boys and girls, aged 6-16, that were tested on the bicycle ergometer (Davies, 1971).

Both of these studies suggested that cardiorespiratory performance can only be determined after max \( \dot{V}O_2 \) is compared appropriately to leg size and composition and then standardized accordingly.

Using the bicycle ergometer, James et al. (1980) found that body size, expressed by height, was the major determinant of physical work in children. Increases in leg length and leg muscle mass were associated with increases in height, which was found to be related to increases in aerobic power as measured in ml·kg\(^{-1}\)·min\(^{-1}\).

**Body Surface.** Anderson et al. (1974a) studied max \( \dot{V}O_2 \) values, obtained from bicycle testing, of male and female children aged 8 to 16, and found that work capacity increases with body surface area, specifically between the ages of 10 and 16 years of age. Astrand (1952) found nonlinear relationships of max \( \dot{V}O_2 \) related to body surface area (BSA).
In 149 children and young adults, "height accounted for up to 67% of the variation for total work" (James et al., 1980, p. 909). When body surface area was less than one square meter in children, and greater than or equal to 1.2 squared meters in young adults, James and associates (1980) found that age was less of a factor than height in total work capacity. At a BSA of 1.2 M² total work values in females were significantly lower than their male counterparts, but at smaller body sizes, no sex difference in max VO₂ was seen.

Maximal Heart Rate (max HR)

Gilliam et al. (1977) performed maximal exercise tests on children grouped by age into three categories: 6-8 years of age, 9-10 years of age, and 11-13 years of age. They found no significant difference in max HR reached between the three groups during bicycle work. The average max HR of all the subjects was 193 beats per minute (bpm).

In agreement with Gilliam et al. (1977), Cumming, Everatt and Hastman (1978) found no significant difference in heart rates between age groups of children of both sexes, between the ages of 4 and 18 years, maximally tested on a treadmill. They did, however, find the highest max HR in the youngest age group. The lowest range of max HR by age group recorded in the females was 180-193 bpm, for the group of 13-15 year olds, and the highest range in the females was 203-220 bpm, in the 4-5 year olds.

Contrary to the findings of Godfrey, Davies, Wozniak and Barnes (1971), Anderson, Seliger, Rutenfranz and Bernst (1974) and Astrand (1952) found that maximal heart rate is independent of age and sex during pubertal growth. The highest mean max HR that was found by
Anderson et al. (1974b) was 203 bpm and the lowest was 192 bpm, but it was reported that these means varied unsystematically. Earlier, Astrand (1952) reported mean max HR values for male and female subjects between the ages of 4 and 20 years that were slightly higher than those reported by Anderson et al. (1974).

It was found by Wirth, Traeger, Scheele, Mayer, Diehm, Reischl, and Weicher (1978) that max HR decreases with age. Among female children grouped as either prepubertal, pubertal, or postpubertal, Wirth et al. (1978) found max HRs of 192, 186 and 178 bpm, respectively, during maximal bicycle tests.

Maximal Ventilation (max \( V_E \)).

Ventilation has been defined as the volume of air expired per minute (Astrand & Rodahl, 1977). Tidal volume and respiratory rate are determinants of \( V_E \), and as tidal volume and respiratory frequency increase, as with increases in work intensity, \( V_E \) increases also.

Max \( V_E \) has been found to increase with age in children of both sexes (Astrand, 1956; Gilliam et al., 1977; Godfrey et al., 1977; Robinson, 1952; Schoenleber, 1981). Significant differences were reported between 8 and 12 year olds (Schoenleber, 1981), between 6-8 year olds, 9-10 year olds, and 11-13 year olds (Gilliam et al., 1977), and between 6, 10 and 14 year olds (Robinson, 1952). These differences were credited to increases in growth and changes in lung volumes.
Performance Time

The performance time of exercise tests in children may be indicative of several things. Cummings et al. (1978) found when using the Bruce protocol, the performance time on the treadmill was positively related to max VO$_2$ in 327 children of both sexes with a normal heart murmur. A correlation coefficient of 0.88 was found between endurance time and max VO$_2$. Following a suggestion of Katch (1973), Gutin, Fogle and Stewart (1976) computed a correlation between max VO$_2$ in L·min$^{-1}$ and running performance with weight held constant to remove any influence of body weight. Slightly lower correlations between max VO$_2$ and performance time were observed when max VO$_2$ was expressed in L·min$^{-1}$ than when expressed as ml·kg$^{-1}$·min$^{-1}$.

Cummings and Hnatiuk (1980), Cureton et al. (1977), and Gutin, Trinidad, Norton, Giles, Giles and Stewart (1978) concluded that body composition may be a factor in performance time. In 33 female volunteer subjects of ages 11 and 12, high positive correlations were found between run time on the treadmill and body weight, percent body fat, and the sum of skinfolds. Since a positive correlation was also found between mean weight and percent body fat, Gutin et al. (1978) concluded that fat rather than weight was perhaps more of a determining factor in endurance time.

Parizkora (1961) found that puberty in females brings about a sudden increase in adipose tissue. This finding may explain the decrease with age in mean endurance time that has been seen by Cummings et al. (1978). A steady increase in performance time was observed from the
ages of four through 12 years (Cumming et al., 1978). A decrease was seen beginning at age 13 and the mean run time continued to decrease as age increased in their female subjects. Cumming and Hnatiuk (1980) observed a decrease in run time with an increase in weight and a greater body build.

It has also been suggested that perhaps social maturation may have as much influence as physical maturation in performance time. Gutin et al. (1978) speculated that social maturity may lead to a reduction in the vigorous activity in the lives of many females causing the observed decrease in performance time with increasing age. Cumming et al. (1978) also suggested that the motivation level of the child, as well as the ability of the technician to induce a true maximal effort, are also major determinants of the endurance time achieved.

**Respiratory Exchange Ratio**

Respiratory exchange ratio (RER), as defined by Astrand and Rodahl (1977, p. 488), is the ratio between the volume of carbon dioxide produced and the volume of oxygen utilized. It has been determined that RER increases as work intensity increases (Issekutz & Rodahl, 1961; Issekutz, Birkhead & Rodahl, 1962). This increase has been correlated with increases in blood lactate levels and is thought to be representative of the anaerobic breakdown of glycogen for energy to be utilized during exercise.

Issekutz et al. (1962) reported that an RER value of greater than 1.1 can accurately predict aerobic capacity in adult populations.
The RER should approach or exceed one (1.0) for a correct measurement of maximal cardiorespiratory endurance. It is assumed that the higher the RER, the more accurate the prediction of aerobic capacity (Issekutz et al., 1962).

In studies involving children (Macek & Vavra, 1971; Godfrey et al., 1971), it has been found that RER increased with increasing workloads on the bicycle ergometer. Godfrey et al. (1971) observed no change in the respiratory exchange ratio at the first workload, but reported a significant increase with the addition of resistance at higher workloads.

No significant differences between the sexes were found in RER by Gilliam et al. (1977) and Godfrey et al. (1971) with maximal exertion. Macek and Vavra (1971) reported no difference in RER between boys and girls at lower workloads, but observed significantly greater increases in the RER in girls as the work intensity increased. No significant differences in RER were found among three groups of children, maximally tested on the bicycle ergometer, aged 6-8, 9-10 and 11-13 years of age (Gilliam et al., 1977). The RER values recorded were 0.92, 0.92 and 0.94, respectively, for the three age groups (Gilliam et al., 1977).

**Reliability and Reproducibility**

Measurements of maximal oxygen uptake have been found to be both reliable and reproducible in adult populations with various testing modes (Cunningham et al., 1975; Magel & Faulkner, 1967; Mitchell et al., 1958; Taylor et al., 1955). Taylor et al. (1955) obtained a correlation coefficient of 0.95 in 69 test-retest max VO₂ determinations in
adult men. One year follow-up tests in these men whose activity levels did not vary much found very similar results. In 15 subjects, Mitchell and others (1958) found a mean max \( \dot{V}O_2 \) expressed in L\cdot min\(^{-1}\) to be 3.06 liters, and a very slight increase to 3.07 liters in a reliability re-test situation. This finding lead Mitchell et al. (1958) to conclude that max \( \dot{V}O_2 \) testing can be very repeatable if rigid criteria for the attainment of maximal effort can be established.

In studies involving children, the reliability measures have not been quite as successful. In 66 ten year old boys, Cunningham, Van Waterschoot, MacFarlane, Paterson, Lefcoe and Sangal (1977) found a correlation coefficient of 0.74 in those subjects that reached a plateau of 2.1 ml\cdot kg\(^{-1}\)\cdot min\(^{-1}\) of max \( \dot{V}O_2 \) during both tests of a mid-to-post season max \( \dot{V}O_2 \) treadmill test study of young ice hockey players. Results were found to be less reliable in those subjects that did not reach a plateau. Although a four to five month time period intervened between tests, Cunningham et al. (1977) concluded that the attainment of a oxygen uptake plateau was more critical in reference to reproducibility than the time interval between tests. In the same group of boys that reached a plateau of \( \dot{V}O_2 \) on both tests, correlation coefficients of max HR and max \( \dot{V}E \) were 0.92 and 0.72, respectively.

Cumming et al. (1978) found that endurance time was highly reproducible in 20 normal children, aged 7-13 years, in two treadmill tests, three to ten days apart. Using the Bruce protocol, a correlation coefficient of 0.94 was obtained for endurance time. These researchers did not report the reliability of physiological data.
Cunningham, Teleford and Swart (1976) tested 15, nine and ten year old boys on a bicycle ergometer. A retest within 48 hours of the first test found moderately high correlations in the variables measured. Correlation coefficients were calculated for max \( \dot{V}O_2 \) on the basis of both \( L\cdot\text{min}^{-1} \) and \( \text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1} \), with the former having an r value of 0.81, while the r for the latter was slightly lower at 0.76. The r values for max \( \dot{V}_E \) and max HR were 0.60 and 0.62, respectively.

Patterson, Cunningham and Donner (1981) studied the effects of different treadmill speeds on the reliability of maximal measurements of \( \dot{V}O_2 \), HR, RER, and \( \dot{V}_E \) on eight boys aged 10-12 years of age. The data reported showed that the reliability of the measurements was higher when jogging and running protocols were used, as when compared with walking protocols. Correlation coefficients for \( L\cdot\text{min}^{-1} \) were 0.91 and 0.90, respectively, for the jog and run tests, as compared to 0.56 for the walk, and were 0.87, 0.95 and 0.47 for \( \text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1} \), on the jog, run and walk tests, respectively. Correlation coefficients were high on all tests for max HR, but were higher for RER when the running protocol was used (0.17 to 0.75, comparing walking to running) and for max \( \dot{V}_E \) with the jogging protocol (0.57 to 0.95, comparing walking to jogging). It was concluded that although the achievement of a plateau in \( \dot{V}O_2 \) is difficult and probably not realistic in children, jog and run treadmill protocols yield reliable and reproducible max \( \dot{V}O_2 \) measurements which are as consistent as those that have been reported in adult populations.
Bicycle Ergometry

Astrand (1971) has stated that exercise testing with a stationary bicycle ergometer produces a five to eight percent lower oxygen uptake on the average as compared to uphill running on a treadmill. A similar statement was made by the World Health Organization (1971) who indicated that treadmill running produces a 10% higher max \( \text{VO}_2 \).

Kemper and Verschuur (1978) admitted that the results they obtained with 13 and 14 year old boys and girls, could not be accurately compared with other studies because of the differences in methods of exercising. Gilliam et al. (1977) acknowledged that their results were lower than the other literature suggests, on max HR, because the testing mode they utilized was the bicycle ergometer.

Anderson et al. (1974b) have criticized the bicycle ergometer as a testing modality because "the highest values obtained in bicycling can hardly be considered as true maximal values, because working with arms and legs together brings about higher heart rates than when only leg exercises are used" (Anderson et al., 1974b, p. 204).

Astrand (1971) was concerned that maximal values may be difficult to obtain on the bicycle because of a feeling of local fatigue and a sensation of pain in the thighs or knees that often occurs. It has also been suggested (Gilliam et al., 1977) that factors such as general discomfort, nervousness and deficient leg strength make the attainment of true maximal effort difficult in children subjects. Cumming and Friesen (1967) found that it was extremely difficult to obtain a true plateau in oxygen uptake by exercising untrained children on the bicycle ergometer.
According to Cumming et al. (1978) it is very difficult for children to reach metabolic loads on the bicycle ergometer that are equivalent to stage five on the Bruce protocol, the stage that was attained by the majority of the male children they tested. The equivalent ergometer metabolic load for stage five of the Bruce protocol is approximately 26 kilopond-meters·min⁻¹·kg of body weight⁻¹, a load too difficult for most children to obtain, therefore leading to the conclusion that children cannot reach the true maximum of their oxygen transport systems on the bicycle ergometer.

Indirect Measurements of Aerobic Capacity in Children

Questions have been raised regarding the practicality of routinely measuring oxygen uptake in children. Other problems exist with direct measurements, such as an unwillingness in some children to endure the strenuous effort that is required for a direct max VO₂ measurement, and a child's short attention span for long, monotonous activities.

Woynarowska (1980) used the Astrand and Ryhming nomogram, that has been found to accurately predict maximal aerobic endurance in adults, to calculate max VO₂ in 11 and 12 year old children. It was found that this technique underestimated the max VO₂ measurements that were obtained in bicycle ergometer testing. These findings lead Woynarowska (1980) to conclude that direct measurements of cardiorespiratory capacity should be used unless accurate individual values are not required.

An investigation was done to determine the accuracy of timed distance runs as predictors of maximal aerobic capacity in eight year old children (Krahenbuhl, Pangrazi, Burkett, Schneider & Peterson, 1977).
Of the three distances used, 600 yards, 3/4 mile and one mile, it was found that the one mile run was the best indication of max VO$_2$, as compared to treadmill results, in males, but that none of the runs were acceptable for females. The reason for the sex difference was unknown and it was also questioned whether the one mile was accurate enough, even in boys.

**Summary**

From the review of the related literature it is evident that a paucity of research exists in the area of exercise responses in children. The results of the available research are inconsistent, as are the methods and modes that have been used to collect them. Standardization of the actual responses, as well as the type of measurements to employ when reporting data in children, is definitely needed. Research done to test the reliability and reproducibility of the data in children, especially females, is very limited and that which is available has not been as successful as that reported for adults. A need exists for more research in this area to determine accurate testing procedures. An additional lack of information is present in the changes that may take place during growth and development in the physical capacity of children.
CHAPTER III

METHODS

Subject Selection

The study was conducted with a group of 41 volunteer female subjects, aged 10-13 years of age, who were participating in an on-going study at the University of Wisconsin - La Crosse, La Crosse, Wisconsin.

Prior to the start of the study, the parents of the subjects were informed of the testing by mail. A letter of invitation to participate in the study (see Appendix A), as well as informed consent and medical release forms (see Appendix B), were sent to the parent(s) of each girl. All testing procedures and potential risks were explained. It was required that these forms be signed by the parent before the potential subject could participate in any phase of the project.

Upon receiving the signed informed consent, each parent was contacted by phone in order to arrange a date to begin the testing. All of the testing was done at the convenience and availability of the parent and the child.

General Procedure

Participation in the study required three visits to the Human Performance Laboratory at the University of Wisconsin - La Crosse, La Crosse, Wisconsin. The initial visit consisted of measurements of height, weight, residual volume and percent body fat, by means of
hydrostatic weighing, as well as practice submaximal treadmill and bicycle tests. The remaining two visits were devoted to two maximal exercise tests on both a treadmill and a stationary bicycle, which were scheduled at least one week a part. It was arbitrarily decided which test the subject would perform first. Only a small portion of the data from the bicycle testing, along with the complete treadmill test results, will be reported in this paper.

In order to determine the test reliability and to compare the reliability of the two modalities, ten subjects were asked to repeat the treadmill test and ten were asked to repeat the bicycle test.

**Body Composition**

**Residual Volume Determination**

The residual volume determination was done using a modified version of the closed-circuit oxygen-dilution technique (Wilmore, 1969). The method was modified in order to reduce the amount of dead space, and consequently the total volume within the system, enabling a faster attainment of an equilibrium which would have otherwise been difficult to accomplish in smaller children (Jensen, 1979).

Residual volume was measured while the subject was seated in front of the nitrogen analyzer head, outside of the hydrostatic weighing tank. A Collin's Nitrogen Analyzer Head was used to continuously analyze inspired and expired air throughout the test.

Before the actual measurement began, the testing procedures were thoroughly explained to each subject. The subject was then told to
position the mouthpiece within her mouth. With a noseclip securely fastened over her nose, the subject was instructed to inhale deeply following an expiration and then to exhale maximally and to tap the technician on the hand at the completion of the maximal expiration. Initial alveolar nitrogen concentration ($AN_2$) was recorded at this time. The valve to room air was then closed, connecting the subject to the $O_2$ bag. The concentration of $N_2$ in the original $O_2$ ($IN_2$) was recorded at the moment of inspiration. This value was the impurity of the oxygen. The rebreathing continued until an equilibrium was reached between the air remaining in the lungs and the $O_2$ in the bag. Another inspiration followed by a maximal expiration was then performed. The final $N_2$ concentration ($FN_2$) was recorded and the subject reconnected to room air. The equilibrium value ($EN_2$) was then calculated as the midpoint of the equilibrium range. A second trial was done after two minutes of normal breathing, and if a difference of more than 30 ml existed between the trials, a third trial was performed. The mean of the lowest two trials was used. The following equation was used to calculate residual volume (Wilmore, 1969, p.98):

$VO_2 \cdot \frac{EN_2 - IN_2}{(AN_2 - FN_2)} - DS \times BTPS \text{ factor}$

where: $RV =$ residual volume  
$VO_2 =$ original volume of $O_2$ in the system  
$IN_2 =$ percent $N_2$ at equilibrium  
$IN_2 =$ impurity of $N_2$ in the original volume of $O_2$  
$AN_2 =$ percent $N_2$ initially in alveolar air  
$FN_2 =$ percent $N_2$ in alveolar air at the end of the test  
$DS =$ dead space
The residual volume correction from ATPS to BTPS was made by multiplying the residual volume by 1.1.

Underwater Weighing

A modification of the standard underwater weighing procedure, as designed by Jensen (1979), was used. Jensen (1979) developed a modification that allows an inspiration of one liter of air following a maximal expiration prior to submersion. This modification was an attempt to alleviate some of the difficulty in the underwater weighing procedure for young subjects, specifically submerging with only the residual volume in the lungs.

The one liter of air was inspired from a rubber breathing bag measured using a six liter Collin's Vitameter, just after a maximal expiration. The subject then submerged and the underwater weight recorded to the nearest 25 grams. This procedure was repeated until reproducible trials were obtained. The heaviest weight recorded twice was used as the underwater weight.

The following formula (Jensen, 1979) was used to calculate body density:

\[
DB = \frac{MA}{\frac{MA - MW}{DW} - RV - 1 \text{ liter}}
\]

where:  
\(DB\) = body density  
\(MA\) = mass in air  
\(MW\) = mass of the water displaced  
\(DW\) = density of the water at the time of weighing  
\(RV\) = residual volume  
1 liter = amount of air inspired prior to submersion.
Percent fat was calculated from the following equation (Brozek, Grande, Anderson & Keys, 1963):

\[
\% \text{ fat} = \frac{4.570}{D_B - 4.142} \times 100
\]

(equation 3)

Exercise Tests

Practice Sessions

On the date that the underwater weighing was done, a practice submaximal treadmill and stationary bicycle test were administered to each girl. A general overview of the testing procedures was explained to each subject. Then, while wearing the head gear, mouthpiece, and noseclip, each girl practiced walking and running at various grades and speeds on the treadmill and practiced pedaling at a pedaling frequency of 60 revolutions per minute (rpm) at various levels of resistance on the Monark Bicycle Ergometer. All of the subjects were taught: how to get on and off the treadmill properly; how to monitor the speed of bicycle pedaling by listening to a metronome; several hand signals that were to be used during the testing; and, the use of the Borg Scale of ratings of perceived exertion (RPE). The Borg Scale, developed by Borg (1970) (see Appendix C), is a tool that is used to indicate the subject's perception of physical stress. It is a scale that consists of 15 RPE values, that range from 6, which corresponds to very, very light work, to 20, which corresponds to very, very hard work (Borg, 1970, p. 93).
Treadmill Test Description

The subjects arrived at the laboratory and were instructed to change into exercise clothing and shoes. Each was then weighed, without shoes, to the nearest ¼ pound, and prepared for an electrocardiograph with a limb-lead electrode arrangement.

The IMC treadmill was used for all treadmill tests, as was the Bruce Treadmill Protocol (Bruce et al., 1973, p. 549). This protocol calls for three minute stages of increasing speed and percent grade of the treadmill. Specific speeds, grades and the corresponding metabolic equivalent (METS) for each stage are presented in Table 1 (Bruce et al., 1973, p. 549).

<table>
<thead>
<tr>
<th>Stage</th>
<th>Speed (mph)</th>
<th>Grade (%)</th>
<th>METS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.5</td>
<td>10</td>
<td>4.0</td>
</tr>
<tr>
<td>2</td>
<td>2.5</td>
<td>12</td>
<td>6.6</td>
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<tr>
<td>3</td>
<td>3.4</td>
<td>14</td>
<td>9.9</td>
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<tr>
<td>4</td>
<td>4.2</td>
<td>16</td>
<td>13.3</td>
</tr>
<tr>
<td>5</td>
<td>5.0</td>
<td>18</td>
<td>17.2</td>
</tr>
</tbody>
</table>

Prior to each test, a review of the testing procedures was given to each child, as well as how to get on the treadmill, the Borg Scale of perceived exertion and several hand signals that were to be used during the test for communication between the subjects and the technicians. The subject was instructed to run on the treadmill for as long as she possibly could. As an incentive to reach maximal exertion, a tee-shirt was to be awarded to the child who ran for the longest time. This information was presented to the subject at this time.
Before the test began, resting heart rate values were recorded from an electrocardiogram, using the Quinton Cardiotachometer Model 611. Heart rates were obtained by counting the number of R waves in a six second electrocardiogram and multiplying that number by ten.

Each child was verbally encouraged to continue running until completely exhausted. The test was termed completed when the subject requested, through the use of the hand signals, to quit exercising, or when she refused to continue, which was manifested by her jumping off the treadmill, or by falling limp into the arms of a technician. A technician, positioned as close as possible behind the subject on the treadmill, was always available to the child for encouragement and support. Immediately upon termination of the test, the treadmill was returned to a 0% grade level and a speed of 1.5 mph for an exercise cool down. The subject continued to walk until her heart rate returned to near her resting value. Heart rates were determined by counting the number of R waves in a six second electrocardiogram, recorded with a Quinton Cardiotachometer Model 611, and then multiplying that number by ten. No girl was allowed to leave the laboratory with higher than normal heart rates or any abnormal symptoms that may have been precipitated by the exercise test. Only on one occasion were any such symptoms observed. One child was dizzy and nauseous upon completion of her treadmill test, but her distress subsided with rest.

The Beckman Metabolic Cart (MMC) was used to measure and record inspired volumes of air, respiratory frequency, temperature and barometric pressure. Samples of expired oxygen and carbon dioxide were collected in a mixing chamber and then analyzed by the Bechman OM-11
oxygen analyzer and the Bechman LB-2 Medical Gas analyzer, respectively. Using previously Scholandered gases, the gas analyzers were calibrated immediately prior to and upon completion of each test. Running calculations for the inspired volume, \( O_2 \) consumed, \( CO_2 \) produced and respiratory quotient were made by the MMC. Printouts recording such measurements were given at 60 second intervals, at the end of the ongoing breath.

Due to mechanical difficulties, it was necessary for the researcher to record the measurements from the MMC and gas analyzers manually for approximately one half of the testing sessions. Fractions of \( O_2 \) and \( CO_2 \) were recorded in the last five seconds of each minute of exercise, after which volumes of inspired air, respiratory frequency, temperature and barometric pressure were recorded from the MMC. The same procedure was repeated at peak exercise. Calculations of \( VO_2 \), RER and \( V_E \) were done using a computerized program for inspired \( VO_2 \). If 30 seconds of exercise were completed into the final minute of exercise, the values obtained were interpolated to 60 seconds. Otherwise, values obtained at the last full minute of exercise were used in the computations.

It was assumed that the accuracy of the manual recordings was equal to that of the computerized system of the MMC and that no differences would be observed in the two different modes of data collection.

Using the Quinton Cardiotachometer Model 611, electrocardiograms were recorded at the end of each minute of exercise and at peak exercise. Heart rates were obtained by counting the number of R waves in a six second electrocardiogram and multiplying that number by ten. Heart rates continued to be monitored during cool down, until they returned to resting levels.
Ratings of perceived exertion were recorded at the end of each stage of the protocol. The subjects were asked to point to the number on the chart that corresponded best to their own subjective feeling of stress.

**Bicycle Test Description**

Of the 41 girls who completed the treadmill test, 40 also participated in the maximal bicycle exercise testing. Prior to each test the subjects were weighed and then prepared for an electrocardiograph with a limb-lead electrode arrangement.

The testing was done on the Monark Bicycle Ergometer. The protocol used called for an increase in resistance of \( \frac{1}{2} \) kilopond every three minutes. The subjects were instructed to continue pedaling at 60 rpm throughout the test, the speed being monitored by a metronome. The test continued until the subject refused to continue or until she could no longer maintain the necessary pedaling frequency. At that time, the resistance was removed and the child was asked to continue pedaling for an exercise cool down. This was continued until heart rates were returned to near resting values. All procedures for data collection were the same as were used for the treadmill tests.

**Reproducibility and Reliability Test Description**

Twenty subjects were requested by the researcher to repeat either the treadmill or the bicycle ergometer test for reproducibility and reliability of the testing methods. Those selected were those that the researcher thought would be more willing to return for an additional test.
The subjects were allowed to choose between the two exercise modalities until ten had chosen one mode over the other. All of the re-testing was done between one and four months of the first test. It was assumed that no significant changes in fitness level took place in the time period between the first and second tests. The testing procedures were the same as was used for the first test.

**Statistical Interpretation of the Data**

The highest values obtained were used in all calculations. Standard descriptive statistics were calculated according to age for all variables. A one-way analysis of variance was employed to determine if a significant difference existed between age groups. The Scheffe post-hoc test was used to determine where the differences occurred. A dependent "t" test and a Pearson Product Moment correlation were used to determine the test-retest reliability of the treadmill and bicycle tests.
CHAPTER IV
RESULTS AND DISCUSSION

Age Group Comparison

Introduction

A one-way analysis of variance, according to age, was used to analyze the difference between groups of 41 female subjects aged 10-13, who performed a maximal treadmill test using the Bruce Protocol (Bruce et al., 1973). The following variables were analyzed in the age group comparison: height, weight, percent body fat, lean body weight, L·min⁻¹, ml·kg⁻¹·min⁻¹, ml·kgLBW⁻¹·min⁻¹, heart rate, performance time, respiratory quotient and ventilation. Significance at the .05 level of confidence was indicated with a critical "F" ratio of 8.58. A Pearson Product Moment correlation was calculated to determine the correlation between variables. An "r" of 0.3044 was needed for the .05 level of significance.

Physical Characteristics

The physical characteristics of height, weight, percent body fat and lean body weight were compared between age groups. Means and standard deviations for the characteristics according to age are presented in Table 2.

Height. When height was compared between 10, 11, 12 and 13 year olds, significant differences (p<.05) were found between the 10 and 12
Table 2. Means, standard deviations and ranges for the physical characteristics of subjects according to age.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Age</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
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<tbody>
<tr>
<td>Height (cm)</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>8</td>
<td>143.4</td>
<td>7.5</td>
<td>134 - 157</td>
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<tr>
<td></td>
<td>11</td>
<td>19</td>
<td>149.9</td>
<td>5.4</td>
<td>137 - 158</td>
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<td>12</td>
<td>7</td>
<td>156.3</td>
<td>5.2</td>
<td>147 - 160</td>
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<td>13</td>
<td>7</td>
<td>157.2</td>
<td>7.4</td>
<td>151 - 167</td>
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<tr>
<td>Weight (kg)</td>
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<tr>
<td></td>
<td>10</td>
<td>8</td>
<td>34.5</td>
<td>4.9</td>
<td>30.5 - 43.4</td>
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<tr>
<td></td>
<td>11</td>
<td>19</td>
<td>38.9</td>
<td>6.0</td>
<td>30.9 - 56.4</td>
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<td></td>
<td>12</td>
<td>7</td>
<td>41.6</td>
<td>3.9</td>
<td>36.3 - 48.5</td>
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<td>13</td>
<td>7</td>
<td>47.3</td>
<td>4.4</td>
<td>41.7 - 52.8</td>
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<tr>
<td>% fat</td>
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<td></td>
<td>10</td>
<td>8</td>
<td>21.1</td>
<td>7.2</td>
<td>11.8 - 30.4</td>
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<td>19</td>
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<td>4.8</td>
<td>12.3 - 32.2</td>
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<td>20.5</td>
<td>7.3</td>
<td>11.0 - 34.5</td>
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<td>LBW (kg)</td>
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<td></td>
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<td>8</td>
<td>27.1</td>
<td>3.2</td>
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<td>33.1</td>
<td>3.7</td>
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<td>7</td>
<td>37.8</td>
<td>5.2</td>
<td>32.1 - 43.1</td>
</tr>
</tbody>
</table>
year old groups and between the 10 and 13 year old groups. Height correlated significantly (p<.05) with age (r=0.63). The mean heights in centimeters for the subjects according to age were 143.4, 150.0, 156.3 and 157.2 for the 10, 11, 12 and 13 year olds, respectively.

The results of the present study are comparable to those found by Anderson et al. (1974a), Gilliam et al. (1977) and Schoenleber (1981), who also reported increases in height with increases in age. Significant differences between age groups were reported by Schoenleber (1981) in the heights of females aged 8-12. The values for the 10, 11 and 12 year old groups of her study were 143.7, 146.1 and 149.7 cm., respectively. The increase in height with age was attributed to the pubescent growth spurt (Schoenleber, 1981). This growth spurt would explain the significant differences in 10 and 12, and 10 and 13 year olds found in the present study.

The results reported by Gilliam et al. (1977) were similar to those of the present study. Significant differences in height were found in males and females between three age groups: 6-8 years, 9-10 years and 11-13 years of age (Gilliam et al., 1977). For those three groups of children, the mean heights were 130.4, 140.3 and 150.7 cm., respectively.

Weight. As with height, increases in age produced increases in weight. The correlation coefficient of 0.62 found between age and weight was significant (p<.05). Height and weight were also positively and significantly (p<.05) correlated (r=0.76). The mean weights for the age groups of girls were 34.5, 39.0, 41.6 and 47.3 kg for the 10, 11, 12 and 13 year olds, respectively. This increase was significant between the 10 and 13 year olds and between the 11 and 13 year olds (p<.05).
Similar results were obtained by Schoenleber (1981) who found significance in the weight differences of 8 year old females with 9, 10, 11 and 12 year old groups and between the 9 and 12 year old groups. Mean weight values for the combined groups were comparable to those of the present study. Schoenleber (1981) attributed the increase in body weight with the pubescent growth spurt, since height was positively correlated with weight. The same positive correlation between height and weight \( r=0.76 \) found in the present study helps to support this justification.

Gilliam et al. (1977) also reported increases in weight with age between the age groups compared (6-8 years, 9-10 years and 11-13 years). Their group means were comparable with those of the present study. Increases in weight were reported by Anderson et al. (1974a) from the age of eight years up to the age of 14 years. A slight decrease, from 55.1 kg to 54.7 kg., was observed between 14 and 16 year olds (Anderson et al., 1974a), indicating that the pubescent growth spurt was completed in females at about 14 years of age.

**Percent Body Fat.** The percentage of body fat measured by hydrostatic weighing did not differ significantly between any of the age groups compared. The mean values for 10, 11, 12 and 13 year olds were 21.12, 20.92, 20.45 and 20.32%. This finding is in agreement with the findings of Schoenleber (1981) who also found no significant differences between females aged 8-12 when age group comparisons were made.

The values of the present study are slightly lower than those reported by Anderson et al. (1974a) who found a range of 23.4 - 27.0% for body fat of girls aged 8-14 years. The lower percentages of body
fat found in the present group may be attributed to the fact that the subjects were volunteers and may have been more physically active.

In females, accumulation of adipose tissue generally occurs after puberty (Parizkova, 1961). Puberty, as the onset of menarche, was determined in the present study through the personal communication with the subjects or their parents. Of the 41 subjects, only six were menstruating, three of which were 13 years old, the other three being 11 years old. The fact that so few of the subjects had reached puberty could have attributed to the lack of significance in body fat between the ages, since the pubertal accumulation of body fat had not yet begun.

**Lean Body Weight.** Lean body weight (LBW), the total body weight minus the weight of the adipose tissue, refers to the weight of bone and muscle mass. Significant correlations (p<.05) were found in the present study between LBW and height (r=0.83), LBW and weight (r=0.90) and LBW and age (r=0.63). Mean values for LBW were 27.06, 30.74, 33.05 and 37.75 kg., respectively, for the age groups 10 to 13. This demonstrates an increase in LBW with age, which would logically occur since height and weight, both of which are associated with bone and muscle mass, increased and correlated significantly (p<.05) with age. Anderson et al. (1974a) and Schoenleber (1981) also found increases in LBW with age in young females.

Significant differences were found in LBW between the 10 and 13 year old and between the 11 and 13 year old groups. Since significant differences were found in weight between these same age groups, gains in LBW are probably responsible for the differences in weight between the groups. It is more plausible to suggest significant changes in muscle
mass are occurred in these groups, more than changes in height, as the said groups did not differ significantly in height.

For females aged 8-12, Schoenleber (1981) found significant differences in LBW between 8 and 11 year olds, 8 and 12 year olds, 9 and 12 year olds and 11 and 12 year olds. Similar values for LBW were observed (Schoenleber, 1981).

**Peak Oxygen Consumption**

The peak oxygen consumption expressed as L·min⁻¹, ml·kg⁻¹·min⁻¹, and ml·kgLBW⁻¹·min⁻¹ were compared between age groups. Means and standard deviations for the measurements according to age are presented in Table 3.

Liters·minute⁻¹ (L·min⁻¹). Measurements of peak VO₂ expressed as L·min⁻¹, increased with increases in age. Mean values for each age group are displayed in Table 3. These data are in agreement with the findings of Anderson et al. (1974a), Astrand (1976), Daniels et al. (1978) and Schoenleber (1981) who also found increasing values of L·min⁻¹ with age in children.

The 10 and 13 year old age groups and the 11 and 13 year old age groups were found to differ significantly (p<05) in L·min⁻¹. In agreement with this, significant differences were reported in peak VO₂ (L·min⁻¹) between age groups of young females aged 6-8, 9-10 and 11-13 years (Gilliam et al., 1977). Schoenleber found similar differences (p<05) between groups of girls aged 8 and 10 years, 8 and 11 years, 8 and 12 years and 9 and 12 years.
Table 3. Means, standard deviations and ranges for the peak cardiorespiratory values of subjects according to age.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Age</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
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<tr>
<td>Peak VO$_2$</td>
<td>10</td>
<td>8</td>
<td>1.599</td>
<td>.217</td>
<td>1.183 - 1.813</td>
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<tr>
<td></td>
<td>11</td>
<td>19</td>
<td>1.940</td>
<td>.286</td>
<td>1.454 - 2.419</td>
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<tr>
<td>(L·min$^{-1}$)</td>
<td>12</td>
<td>7</td>
<td>1.968</td>
<td>.380</td>
<td>1.400 - 2.449</td>
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<tr>
<td></td>
<td>13</td>
<td>7</td>
<td>2.355</td>
<td>.423</td>
<td>1.660 - 2.790</td>
</tr>
<tr>
<td>Peak VO$_2$</td>
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<td>8</td>
<td>46.5</td>
<td>8.3</td>
<td>35.6 - 57.2</td>
</tr>
<tr>
<td>(ml·kg$^{-1}·min^{-1}$)</td>
<td>11</td>
<td>19</td>
<td>49.8</td>
<td>6.8</td>
<td>39.0 - 63.3</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>7</td>
<td>47.3</td>
<td>7.3</td>
<td>34.1 - 58.9</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>7</td>
<td>47.3</td>
<td>6.9</td>
<td>39.6 - 54.8</td>
</tr>
<tr>
<td>Peak VO$_2$</td>
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<td>8</td>
<td>59.3</td>
<td>7.1</td>
<td>47.7 - 67.1</td>
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<td>(ml·kg·LBW$^{-1}·min^{-1}$)</td>
<td>11</td>
<td>19</td>
<td>63.3</td>
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<td>50.9 - 77.0</td>
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<tr>
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<td>12</td>
<td>7</td>
<td>59.2</td>
<td>6.6</td>
<td>49.3 - 70.5</td>
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<td>13</td>
<td>7</td>
<td>62.5</td>
<td>9.4</td>
<td>51.8 - 81.5</td>
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</tr>
<tr>
<td>(bpm)</td>
<td>11</td>
<td>19</td>
<td>207.0</td>
<td>8.2</td>
<td>195 - 220</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>7</td>
<td>206.7</td>
<td>9.1</td>
<td>192 - 220</td>
</tr>
<tr>
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<td>13</td>
<td>7</td>
<td>203.4</td>
<td>9.6</td>
<td>188 - 215</td>
</tr>
<tr>
<td>Peak V$_E$</td>
<td>10</td>
<td>8</td>
<td>51.4</td>
<td>8.7</td>
<td>32.5 - 60.7</td>
</tr>
<tr>
<td>(L·min$^{-1}$)</td>
<td>11</td>
<td>19</td>
<td>64.1</td>
<td>11.4</td>
<td>44.2 - 84.1</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>7</td>
<td>60.8</td>
<td>9.1</td>
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<tr>
<td></td>
<td>13</td>
<td>7</td>
<td>71.2</td>
<td>13.4</td>
<td>46.2 - 86.1</td>
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<tr>
<td>RER</td>
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<td>.13</td>
<td>0.93 - 1.33</td>
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<tr>
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<td>19</td>
<td>1.19</td>
<td>.09</td>
<td>1.02 - 1.42</td>
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<tr>
<td></td>
<td>12</td>
<td>7</td>
<td>1.19</td>
<td>.15</td>
<td>0.95 - 1.40</td>
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<tr>
<td></td>
<td>13</td>
<td>7</td>
<td>1.18</td>
<td>.08</td>
<td>1.03 - 1.30</td>
</tr>
<tr>
<td>time</td>
<td>10</td>
<td>8</td>
<td>703.6</td>
<td>101.4</td>
<td>490 - 805</td>
</tr>
<tr>
<td>(seconds)</td>
<td>11</td>
<td>19</td>
<td>749.6</td>
<td>101.0</td>
<td>582 - 907</td>
</tr>
<tr>
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<td>12</td>
<td>7</td>
<td>756.3</td>
<td>101.7</td>
<td>620 - 885</td>
</tr>
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<td>13</td>
<td>7</td>
<td>750.7</td>
<td>107.2</td>
<td>615 - 917</td>
</tr>
</tbody>
</table>
It was found that $L\cdot\text{min}^{-1}$ correlated significantly with height ($r=0.76$), weight ($r=0.65$) and LBW ($r=0.79$), a logical discovery since height, weight, LBW and $L\cdot\text{min}^{-1}$ all increased with age in the subject population. Astrand (1976) has said that increases in body size, particularly muscle mass, has a great influence in the increase in oxygen consumption in the non-obese child. Thus, the changes in physical characteristics that were observed with age may explain the significant differences found between the 10 and 13, and 11 and 13 year old subjects in $L\cdot\text{min}^{-1}$, particularly weight and LBW, since the significance found in these variables was in the same age groups where significant differences were found in $L\cdot\text{min}^{-1}$. It might be assumed that height should have the same influence, but the significant differences observed in mean heights was between the 10 and 13 year olds and 10 and 12 year olds, and not between the 11 and 13 year olds. Two subjects of the 13 year old group (n=7) were somewhat shorter in height than the rest of their age group. This may have skewed the data, leading to the non-significant finding in height between 11 and 13 year old subjects.

$\text{Milliliters\cdot kilogram body weight}^{-1}\cdot\text{minute}^{-1}$ $(\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1})$. Although the 11 year old group scored the highest when peak $\text{VO}_2$ was related to body weight $(\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1})$, none of the scores between age groups were significant at the .05 level. For the respective age groups, 10-13 years, the mean scores for $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ were 46.53, 49.80, 47.34 and 47.33. The lack of significance between the ages that has similarly been reported in children by Daniels et al. (1978), Gilliam et al. (1977) and Schoenleber (1981), could be attributed to the similar percentages of LBW that were observed between groups. Since $\text{VO}_2$ is probably related
to the muscle mass involved in the exercise test (Kemper & Verschuur, 1980), similar proportional amounts of LBW should result in similar peak VO₂ values, if related to body size.

Gillian et al. (1977) also found no significant differences in ml·kg⁻¹·min⁻¹ between age groups of young children. Values of 49.1, 43.6 and 44.7 mls. were observed in groups of females aged 6-8, 9-10 and 11-13 years of age, respectively.

Contrary to the findings of the present study, Anderson et al. (1974a) found significant irregular decreases in max VO₂ with age. The observed values for ml·kg⁻¹·min⁻¹ for 8, 10, 12, 14 and 16 year old girls were 47.4, 41.6, 41.9, 36.9 and 38.4, respectively (Anderson et al., 1974a). This decrease in aerobic capacity seen in subjects from 10 and 12 years to eight years of age, and from 14 and 16 years to 10 and 12 years of age caused Anderson and others (1974a) to speculate that a deterioration in the quality of muscle mass occurs in girls as they increase in age, probably due to a less active lifestyle.

The measurements of 46.53, 49.80, 47.34 and 47.33 ml·kg⁻¹·min⁻¹ observed in the present study are comparatively higher than those reported by Anderson et al. (1974a) and Gilliam et al (1977). The lower values reported in these two related studies may be attributed to the use of the bicycle ergometer as a testing mode. The World Health Organization (1967) has indicated that oxygen consumption measurements made with the bicycle ergometer differ by 10 ml·kg⁻¹·min⁻¹, when compared to uphill treadmill running.
Milliliters·kilogram lean body weight\(^{-1}\)·minute\(^{-1}\) (ml·kgLBW\(^{-1}\)·min\(^{-1}\)).

The means and standard deviations, according to age, of ml·kgLBW\(^{-1}\)·min\(^{-1}\) are displayed in Table 3. When related to the fat-free mass of the body, peak VO\(_2\) measurements did not statistically (p>.05) differ between any of the age groups of subjects.

Anderson et al. (1974a) has suggested that oxygen uptake depends on muscle mass development during growth, therefore measurements relative to lean body weight should be nearly the same during growth. However, in a group of children of both sexes, Anderson and others (1974a) found this to be true only in the male subjects. In the females, aged 8-14, an irregular decrease in ml·kgLBW\(^{-1}\)·min\(^{-1}\) was observed. It was not reported whether the decline in aerobic capacity, on the basis of lean body mass, was significantly different among the age groups in these groups of young females; but it led Anderson et al. (1974a) to suggest that "the quality of the muscle mass must deteriorate with age in girls, while it is unchanged in boys" (Anderson et al., 1974a, p.193). This difference in the sexes was attributed to a more active lifestyle in boys from the ages 8-14.

This attribution would explain the observed lack of significance between the ages 10-13 years in females of the present study, if it could be shown that the subjects lead active lifestyles. Since the group was composed of volunteer subjects, it is likely that they may have been interested in physical activity and therefore did in fact lead physically active lives. Therefore, muscle mass development must have been similar in all subjects, leading to similar measurements of oxygen consumption relative to lean body weight.
Other Maximal Cardiorespiratory Responses

The cardiorespiratory responses of peak heart rate (HR), peak ventilation ($V_E$) and respiratory quotient (RER) were compared between age groups. Means and standard deviations for the characteristics according to age are presented in Table 3.

Peak HR. The mean peak HRs achieved for the age groups 10-13 were 200.5, 207.0, 206.7 and 203.4 bpm. No significant differences ($p > 0.05$) were found between any of the groups. Schoenleber (1981) observed similar results in females aged 8-12, attributing the lack of significance to the narrow, 5 year age span that existed between the oldest and youngest subjects. It was thought that a larger range between extreme ages was needed in order for differences in peak HR to likely occur (Schoenleber, 1981). The same justification is logical in the present study.

Cumming et al. (1978) observed small and nonsignificant age differences in max HR, ranging from 193-206 bpm, in children aged 4-18, who completed a maximal treadmill test. In comparison, Godfrey et al. (1970) reported 190 bpm as the highest heart rate achieved in a group of females aged 6-16, which was similar to the heart rates of 192.8, 193.1 and 192.8 bpm for the age groups 6-8 years, 9-10 years and 11-13 years of age that were reported by Gilliam et al. (1977). Both of the previous reports were done using a bicycle ergometer, which may be responsible for the lower values. Gilliam et al. (1977) admitted to the problem of obtaining true maximal values on the bicycle ergometer in younger children.
In a range of 192-203 bpm for max HR among boys and girls aged 8-16, Anderson et al. (1974b) found unsystemical variations in values. Confirmation of Robinson's and Astrand's statements that "maximal heart rate is independent of age...during puberty growth" (Anderson et al., 1974b, p. 200) was therefore made (Anderson et al., 1974b).

**Peak \( \dot{V}_E \).** A large range of peak \( \dot{V}_E \) measurements was seen between the ages 10-13 years (32.50 through 86.14 L·min\(^{-1}\)), but age group means yeilded significant differences (p<.05) between only the 10 and 13 year age groups. The means and standard deviations for each group are presented in Table 3. Although it was nonlinear and non-significant (p>.05), peak \( \dot{V}_E \) tended to increase with age.

Other researchers have observed similar increases in peak \( \dot{V}_E \) with age, attributing the increases to greater body size, more specically lung volume (Gilliam et al., 1977; Godfrey et al., 1971; Schoenleber, 1981). Gilliam et al. (1977) reported peak \( \dot{V}_E \) values of 50.8, 58.1 and 62.3 L·min\(^{-1}\) for three groups of young children, aged 6-8, 9-10 and 11-13 years, respectively. These means were found to be significantly different between all groups. The peak \( \dot{V}_E \) measurements of girls, 8-12 years, were found to be significantly different only between 8 and 12 year olds (Schoenleber, 1981), due to increases in tidal volumes. Although tidal volume was not determined in the present study, it was assumed that increases in such resulted with the increases in height that were significant in the groups being considered. These increases in tidal volume, could have likewise resulted in the differences in peak \( \dot{V}_E \) measurements.
Respiratory Quotient. No significant differences (p > 0.05) on the basis of age were found between any groups of subjects in RER measurements. The mean values for each age, 10-13 years were as follows: 1.13, 1.19, 1.19 and 1.18.

Of the 41 subjects, only three failed to reach an RER value greater than 1.00, which according to Issekutz, Birkhead and Rodahl (1962) indicates a true maximal effort. The higher the RER, the closer the effort is to a maximal level (Issekutz et al., 1962). The difficulty that children have in attaining this level of exertion and the difficulty that technicians have in motivating that type of performance has already been mentioned and is a plausible explanation for the three low scores in RER. The lack of significance between groups in RER could be attributed to the fact that the majority of the subjects must have been at a maximal or near maximal level and to a similar use of the anaerobic pathway for energy in the subject population.

The lack of significance in RER between the ages in the present study is in agreement with the findings of Gilliam et al. (1977) who found a similar lack of significance between three groups of children aged 6-8, 9-10 and 11-13 years in RER. The mean scores for the groups of that study were somewhat lower, being 0.92, 0.92 and 0.94 for the groups, respectively. Again, these lower scores could be attributed to the exercise modality that was utilized, the bicycle ergometer. The problem of attaining a maximal effort on the bicycle ergometer in children may have lead to the RER scores lower than 1.00.
Performance Time

All subjects were verbally encouraged to perform as long as possible. Without lactate determinations, it is difficult to determine if a subject truly performed maximally. This research allowed the subjects to decide when they had reached this point and unfortunately, in children the lack of motivation is a definite problem in exercising to a maximal effort. With consistent levels of external sources of motivation, internal motivation will be significant in performance time. All of the children in the present study made what appeared to be a maximal or near maximal effort.

For the respective age groups, 10-13 years, the mean times on the treadmill were 11:44, 12:30, 12:36 and 12:31. When these group means of performance time were compared between ages, no significant differences (p>0.05) were found.

As time on the treadmill increased, so did peak VO$_2$. When related to peak VO$_2$ measurements, performance time correlated significantly (p<.05) with L·min$^{-1}$ (r=0.57), ml·kg$^{-1}$·min$^{-1}$ (r=0.70) and ml·kgLBW$^{-1}$·min$^{-1}$ (r=0.57).

Using the Bruce protocol, Cumming et al. (1978) found a 0.88 correlation coefficient between ml·kg$^{-1}$·min$^{-1}$ and endurance time in girls aged 4-18. The lower significant correlation found in the present study may be due to the fact that the subjects in that group represented a more uniform age group. The positive resemblance between time and peak VO$_2$ lead Cumming et al. (1978) to conclude that endurance time on a treadmill, with the Bruce protocol, could be used to roughly predict maximal oxygen consumption.
As percent fat increased, exercise time on the treadmill decreased. Between the two variables, a low but significant negative correlation \( r=-0.32 \) occurred. A similar correlation was found in young girls by Cumming et al. (1978) and Gutin et al. (1978). Cumming et al. (1978) found negative correlations between % fat and endurance time, especially in those subjects under the age of 12 years. In 11 and 12 year old girls, the correlation between the sum of five skinfolds and exercise time was 0.92 (Gutin et al., 1977). The lack of significant differences between age groups in % fat may have therefore led to the similar lack of significance in exercise times found in the present study.

Cumming et al. (1978) projected that age differences in mechanical efficiency would cause differing abilities to perform on the treadmill. Perhaps the age difference in the subjects of the present study, between 10 and 13 years, was not significant enough to produce differences in mechanical efficiency, indicative of different exercise times.

Schoenleber (1981) found a similar lack of significance in females, 8-12 years, but reported lower group means: 10.2, 10.0, 10.5, 10.5 and 11.0 minutes, respectively. This particular subject population also exhibited higher percentages of body fat than the subjects of the present study, which may have caused the lower performance times.

Reliability and Reproducibility

Introduction

The following peak cardiorespiratory responses were compared between T1 and T2, with both the treadmill and the bicycle ergometer: L min\(^{-1}\),
ml·kg⁻¹·min⁻¹, ml·kgLBW⁻¹·min⁻¹, HR, Vₑ and RER. Performance time was also included in the test-retest comparison, that was done with 18 volunteer subjects. Means and standard deviations for the selected variables, for both T₁ and T₂, on the treadmill and bicycle ergometer were calculated and are presented in Table 4 and Table 5, respectively.

The reliability of the exercise testing procedure was measured with a Pearson Product Moment correlation to determine if a significant correlation existed between the data recorded for each variable between T₁ and T₂. A correlation of .6319 was needed for significance at the 95% level of confidence. A dependent "t" test was employed to determine if a significant difference existed between the means for any variable between T₁ and T₂. Differences between means were considered significant at the .05 level of confidence.

Subjects

Of the 41 subjects who completed the original treadmill and bicycle test, 19 were asked to repeat either of the tests. One child agreed to repeat both. The subjects were given a choice of either modality, until half of them had chosen the bicycle. After that time, volunteers were asked to run on the treadmill. Ten subjects repeated each test, using the same procedure as the original test. All testing was done within one to four months after the first test. It was obvious that one subject did not reach peak exercise on the treadmill retest and that one did not reach peak exercise on the original bicycle test. Therefore, these subjects were eliminated from the test-retest study.
Table 4. Means and standard deviations for the test-retest comparison on the treadmill.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Test 1</th>
<th>Test 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Peak $\dot{V}O_2$ (L.min$^{-1}$)</td>
<td>1.924$^a$</td>
<td>2.073</td>
</tr>
<tr>
<td></td>
<td>0.295$^b$</td>
<td>0.190</td>
</tr>
<tr>
<td>Peak $\dot{V}O_2$ (mL.kg$^{-1}$.min$^{-1}$)</td>
<td>53.4</td>
<td>55.7</td>
</tr>
<tr>
<td></td>
<td>5.5</td>
<td>3.3</td>
</tr>
<tr>
<td>*Peak $\dot{V}O_2$ (mL.kgL$^{-1}$.min$^{-1}$)</td>
<td>66.4</td>
<td>72.1</td>
</tr>
<tr>
<td></td>
<td>8.0</td>
<td>6.4</td>
</tr>
<tr>
<td>*Peak $\dot{V}E$ (L.min$^{-1}$)</td>
<td>60.8</td>
<td>68.8</td>
</tr>
<tr>
<td></td>
<td>10.8</td>
<td>8.3</td>
</tr>
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<td>Peak HR (bpm)</td>
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<td>209.1</td>
</tr>
<tr>
<td></td>
<td>7.5</td>
<td>7.4</td>
</tr>
<tr>
<td>*RER</td>
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<tr>
<td></td>
<td>111.1</td>
<td>76.4</td>
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</table>

*a=mean  
b=standard deviation  
* Dependent "t" test found significant differences between $T_1$ and $T_2$ (p<.05).
Table 5. Means and standard deviations for the test-retest comparison on the bicycle ergometer (n=9).

<table>
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<tr>
<th>Variable</th>
<th>Test 1</th>
<th>Test 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak ( \dot{V}_{O_2} ) (L·min(^{-1}))</td>
<td>1.832(^a)</td>
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</tr>
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<td></td>
<td>0.344(^b)</td>
<td>0.276</td>
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<td>Peak ( \dot{V}_{O_2} ) (ml·kg(^{-1})·min(^{-1}))</td>
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<td>41.6</td>
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<tr>
<td></td>
<td>5.3</td>
<td>5.0</td>
</tr>
<tr>
<td>Peak ( \dot{V}_{O_2} ) (ml·kgLBW(^{-1})·min(^{-1}))</td>
<td>54.3</td>
<td>57.9</td>
</tr>
<tr>
<td></td>
<td>11.6</td>
<td>8.8</td>
</tr>
<tr>
<td>Peak ( \dot{V}_{E} ) (L·min(^{-1}))</td>
<td>58.9</td>
<td>61.0</td>
</tr>
<tr>
<td></td>
<td>13.1</td>
<td>18.4</td>
</tr>
<tr>
<td>Peak HR (bpm)</td>
<td>203.8</td>
<td>190.4</td>
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<td></td>
<td>9.6</td>
<td>8.7</td>
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<tr>
<td>RER</td>
<td>1.18</td>
<td>1.07</td>
</tr>
<tr>
<td></td>
<td>0.11</td>
<td>0.05</td>
</tr>
<tr>
<td>time (seconds)</td>
<td>962.4</td>
<td>955.6</td>
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<td></td>
<td>113.4</td>
<td>115.4</td>
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</tbody>
</table>

\(a=\)mean  \\(b=\)standard deviation  
* Dependent "t" test found significant differences between \(T_1\) and \(T_2\) (\(p<.05\)).  
** \(N=8\) for ml·kgLBW\(^{-1}\)·min\(^{-1}\)
Results

**Bicycle Ergometry.** When comparing the data recorded for T1 and T2 on the bicycle ergometer, significant correlations were found in peak $V_{E}$ ($r=0.94$) and peak $VO_2$, as measured $L\cdot min^{-1}$ ($r=0.91$), $ml\cdot kg^{-1}\cdot min^{-1}$ ($r=0.83$), and $ml\cdot kgLBW^{-1}\cdot min^{-1}$ ($r=0.93$). Lower, non-significant correlations ($r=0.63$) were calculated for peak HR, RER and performance time, with the lowest $r$ value being recorded for peak HR ($r=0.35$). All correlation coefficients for the bicycle ergometer are presented in Table 6.

A dependent "t" test showed no significant differences ($p>0.05$) between T1 and T2 for the variables peak $V_{E}$ and performance time. Test-retest comparisons for all other variables revealed significant differences ($p<0.05$) between group means.

**Treadmill.** In the present study, the treadmill demonstrated less reliability as compared with the bicycle ergometer. Only one significant correlation coefficient was found, that in peak $VO_2$ as measured $L\cdot min^{-1}$ ($r=0.86$). All other variables showed non-significant correlations ($r=0.63$). The reliability of peak $V_{E}$ was found to be the lowest of all the selected variables ($r=0.30$) when measured on the treadmill.

The difference between the means for T1 and T2 was not significant for the variables peak $VO_2$ as measured $ml\cdot kg^{-1}\cdot min^{-1}$ and peak HR ($p>0.05$). Significance was seen between the group means ($p<0.05$) for all the other variables.
Table 6. Correlation coefficients for each selected variable for the test-retest comparison on both the treadmill and bicycle ergometer.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Treadmill</th>
<th>Bicycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak $\dot{V}O_2$ (L min$^{-1}$)</td>
<td>0.86*</td>
<td>0.91*</td>
</tr>
<tr>
<td>Peak $\dot{V}O_2$ (mL kg$^{-1}$ min$^{-1}$)</td>
<td>0.56</td>
<td>0.83*</td>
</tr>
<tr>
<td>Peak $\dot{V}O_2$ (mL kgLBW$^{-1}$ min$^{-1}$)</td>
<td>0.60</td>
<td>0.93*</td>
</tr>
<tr>
<td>Peak $V_E$</td>
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<td>0.94*</td>
</tr>
<tr>
<td>Peak HR</td>
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<td>0.35</td>
</tr>
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<td>RER</td>
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<tr>
<td>time</td>
<td>0.39</td>
<td>0.55</td>
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</tbody>
</table>

* Denotes significant correlation (p<0.05).
Discussion

The results of the present study indicate a problem in the reliability and reproducibility of the measurements of maximal oxygen uptake and other cardiorespiratory responses to exercise in children, supporting the statement of Shephard (1971) that results from exercise tests in children are questionable. Correlation coefficients for each variable for both modalities are found in Table 6.

The problem of identifying a maximal effort in children, by means of a plateau in $\dot{V}O_2$, has been suggested by Patterson et al. (1981) as a possible major cause of this lack of accuracy. Cunningham et al. (1977) found that the reliability of the measurement increased with the presence of a plateau of 2.1 ml·kg⁻¹·min⁻¹ or less of max $\dot{V}O_2$. The correlation coefficient of 0.60 reported by Cunningham et al. (1977) for max $\dot{V}O_2$ measured as ml·kg⁻¹·min⁻¹ in a group of 10 year old boys who reached a plateau in $\dot{V}O_2$ during either $T_1$ or $T_2$, was similar to the 0.56 found in the present study for treadmill exercise. In a group of boys who did not reach a plateau in either the test or retest, Cunningham et al. (1977) found a correlation of 0.40 in heart rate, similar to the 0.42 found for the treadmill heart rates in the present study. Correlations as high as 0.74 for ml·kg⁻¹·min⁻¹ and 0.92 for peak HR were recorded in boys who reached a plateau in both tests, and as low as 0.27 for ml·kg⁻¹·min⁻¹ were found in boys who did not reach a plateau in either test (Cunningham et al., 1977). Since the presence or absence of a plateau in peak $\dot{V}O_2$ was not determined in the present study, it is unclear what percentage of subjects reached maximal exertion, as determined by the
presence of a plateau, and what effect the attainment of such may have had on the reliability of the measurement.

Although the children were strongly encouraged verbally and through other motivational techniques to exercise until exhaustion, and many seemed to be fatigued at the conclusion of the test, the extreme difficulty in motivating children that Shephard (1971) observed, was also seen in the present study, particularly in the treadmill exercise. The subjects who volunteered for the retest portion of the study were given a choice of treadmill or bicycle exercise, and many were reluctant to choose the treadmill. The bicycle ergometer was much more popular and comments such as, "The bike is more fun", and "The treadmill is too hard" were common among the subjects. This observation, although subjective, gives probable cause to the observed increased reliability of bicycle over treadmill exercise. Although the subjects volunteered for the second test, this researcher "sensed" a feeling of a loss of cooperation among some of the subjects, especially in treadmill subjects.

As a group, the test means for the selected variables tended to increase from $T_1$ to $T_2$, indicating the possibility that a conditioning or learning response may have taken place during the intervening period between tests, which was from one to four months. Cunningham et al. (1977) found high reproducibility and moderately high reliability in 10 year old boys, retested on a treadmill, four to five months after the original test. But the subjects of that research were competitive ice hockey players and the interim period between tests fell during the hockey season, thus the activity levels were controlled. Since the activity levels were not determined or controlled in the present study,
the possibility of changes in daily activity levels may have had an effect on the results. Many of the subjects were involved in school and community athletic programs and since the testing was done in both the winter and spring months, it is likely that seasonal changes in team sports may have caused drastic changes in some of the children's regular activity regimens.

Significant differences (p<.05) were found between test means for all selected variables for treadmill exercise, excluding ml·kg⁻¹·min⁻¹, peak HR and performance time, and for all variables, excluding peak VE and performance time on the bicycle ergometer exercise. These findings are not in agreement with Cunningham et al. (1976) and Cunningham et al. (1977), who reported no significant differences between T₁ and T₂ for the variables measured. These two previous studies used young male athletes as the subject populations. Athletes generally have a great desire to perform well in physical activity and are highly motivated to do so. If a higher level of motivation was present in the males of the previous research, a more accurate measurement of max VO₂ and other cardiorespiratory variables may have been made in both or one of the tests.

Inappropriate test protocols have been suggested as a deterrent to accurate measurements of exercise responses in children (Patterson et al., 1981). When comparing walking, jogging and running protocols on a treadmill, Patterson et al. (1981) found a higher reliability and reproducibility for most variables with a jogging protocol. The Bruce protocol was used in the present study, which increases in speed every three minutes, achieving a running speed by the 12th minute of exercise. This protocol begins at a 10% incline of the treadmill and calls for
a 2% increase with every three minutes of exercise. With such a steep incline, leg fatigue may prevent subjects from reaching maximal exertion. The Bruce protocol may, therefore, be inappropriate for maximally exercising children.

Due to mechanical difficulties, the data collected for peak oxygen consumption were obtained by two methods: by the computerized system of the Beckman Metabolic Cart and by a manual recording from the MMC. The data from the latter method were then used to calculate oxygen consumption by a computerized program. It was assumed that the two methods were equally accurate, but differences in the two methods may have presented problems in accuracy, especially since different technicians were employed at different testing sessions. A precise recording with the manual method is sometimes difficult to achieve, especially if the technician is not experienced in doing it. It is reasonable to attribute some of the problems with the reproducibility data to this problem of data collection.
CHAPTER V
SUMMARY, RECOMMENDATIONS AND CONCLUSIONS

Summary

The physical characteristics and the cardiorespiratory responses to maximal exercise were compared between age groups in 41 female subjects, aged 10-13 years of age, using the Bruce protocol (1973). A reliability and reproducibility study was completed in 9 subjects with treadmill exercise and in 9 subjects with stationary bicycle ergometer exercise.

Physical Characteristics

Height was found to be significantly different between 10 and 12 year old subjects and between 10 and 13 year old subjects. Height also correlated significantly with age.

When comparing the body weights of the subjects, significant differences were found between the 10 and 13 year old groups and between the 11 and 13 year old groups. As with height, weight increased significantly with increases in age.

Lean body weight also positively correlated with age, as it differed significantly between 10 and 13 year olds and 11 and 13 year olds. Percent body fat was not found to be significantly different among any of the age groups.
Peak Oxygen Consumption

Peak oxygen consumption measured in L·min⁻¹ was found to increase with age in these young female subjects and to differ significantly between the 10 and 13 year old groups and between the 11 and 13 year old groups. Peak oxygen consumption expressed relative to size, ml·kg⁻¹·min⁻¹ and ml·kgLBW⁻¹·min⁻¹, was not found to be significantly different among any of the age groups.

Other Cardiorespiratory Responses

A probable increase in lung volume with age caused peak \( \dot{V}_E \) to be statistically different between 10 and 13 year olds. No other cardiorespiratory variables differed between the age groups.

Performance Time

All the peak VO₂ measurements were found to correlate significantly with age, but no significant differences were found between any of the age groups, 10-13 years.

Reliability and Reproducibility

Test-retest comparisons on the bicycle ergometer and the treadmill showed that the measurements of the cardiorespiratory responses to exercise were inadequately reliable and reproducible. Positive correlations between tests were found in L·min⁻¹ and RER on the treadmill, while peak \( \dot{V}_E \), L·min⁻¹, ml·kg⁻¹·min⁻¹ and ml·kgLBW⁻¹·min⁻¹ all statistically correlated between bicycle ergometer tests. No significant differences
between $T_1$ and $T_2$ were found in peak $\dot{V}_E$ on the bicycle ergometer, in $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ on the treadmill, and in peak HR and performance time on both modalities.

**Conclusions**

It was concluded that:

The physical characteristics of height, weight and lean body weight were significantly different among age groups of females, aged 10-13 years of age. Coupled with the finding that height, weight and lean body weight increased with increasing age in these females, it was concluded that the growth and development that occurs as a result of the pubescent growth spurt in children is still taking place, at least up until the age of 13 years. Percent body fat did not change significantly in this age range, probably because so few of the subjects had reached puberty and had not begun to accumulate body fat as is seen in most post-pubertal females.

Changes in body size caused peak oxygen consumption measurements to increase and to differ significantly in young females, aged 10-13 years of age, when expressed absolutely as $\text{L} \cdot \text{min}^{-1}$. Therefore, if accurate group comparisons are needed in this age range, they should be made in $\text{L} \cdot \text{min}^{-1}$.

When expressed relative to body weight or lean body weight, volitional peak $\dot{V}O_2$ did not differ significantly in girls between the ages 10-13, due to the use of muscle mass in the attainment of maximal oxygen consumption. Accurate, functional individual comparisons made from this population of children in peak $\dot{V}O_2$ should be made relative to one
of these body parameters since percent body fat and lean body mass, which differ individually but not in groups, affect performance.

Peak ventilation measurements differed significantly between the youngest and the oldest subjects due to changes in lung volumes that occurred with growth and development.

Comparisons of maximal heart rates, respiratory quotients and performance times should not be made in children, as they did not statistically differ among female children, aged 10-13, when tested maximally on a treadmill.

The reliability and reproducibility of exercise testing on the treadmill and the bicycle ergometer with children is questionable due to problems in attaining a true maximal effort. Serious attempts should be made when maximally testing children to acquire the highest attainable degree of effort.

**Recommendations for Further Study**

As a result of this study, it is recommended that:

Criteria for maximal oxygen consumption need to be established in exercising children, especially females. It is recommended that plateaus in VO₂ be determined in a test-retest situation, in an attempt to determine its effect on the reliability and reproducibility of the cardiorespiratory measurements.

Reliability and reproducibility studies should be undertaken that will retest subjects with an intervening period between test, short enough that changes in activity levels will be eliminated.
Experimentation with motivational techniques is needed in order to identify those methods that are successful when applied to exercising children.

Internal motivational levels should be determined in young children, as well as the sources of such motivation, in order to discover its effect on exercise performance. If it can be determined that motivation is lacking in children, educational processes should be undertaken that will demonstrate the importance of greater intensities of effort, not only in exercise sessions, but in all lifetime endeavors and pursuits.

Methods of predicting maximal oxygen consumption from submaximal exercise efforts need to be established in children, due to the difficulty young children experience when attempting maximal exertions.

Changes due to puberty need to be determined in young females, both in physical characteristics and in cardiorespiratory responses to maximal exercise, so that accurate comparisons can be made.
References


Astrand, P.O. Experimental studies of physical working capacity in relation to sex and age. Ejnar Munksgaard, Copenhagen, 1952.


APPENDIX A
Dear

Approximately a year has elapsed since your daughter participated in our body composition and fitness study. Since that time you should have received her results. At present we have two consecutive years of data on more than 50 girls including your daughter.

We would like to extend an invitation to you and your daughter to participate in this project again this year. Only with your cooperation can we successfully complete the data collection for a third consecutive year. In addition to helping us you would also have your daughter's results to compare with previous years. If you are willing to again participate in this study we plan on doing the testing in January and February at your convenience.

In addition to the body composition and treadmill tests, we would like to add a bicycle exercise test. This test would be similar to the treadmill but rather than a walk/run on the treadmill it would be riding a stationary bicycle. Even with the addition of the bicycle test we anticipate only three visits to the Human Performance Laboratory will be necessary. The body composition test should take only one visit. During that day your daughter will be given an opportunity to practice walking/running on the treadmill and riding the bicycle. She will then return on two separate days for the actual exercise tests. The specific information regarding these tests are provided on the enclosed sheets.

If, after discussing this with your daughter, you are willing to participate in any or all phases of this study please indicate this on the enclosed sheet(s). Although I would encourage you to participate in all three tests you can do any combination. Regardless of your decision would you please return the enclosed green sheet in the self addressed, stamped envelope. If you have any questions pertaining to any part of this study please do not hesitate contacting me at 785-8177 or leave a message for me to return your call at 785-8586.

I hope that you will again take this opportunity to assist us in this valuable research effort. I would like to thank you in advance for your cooperation and I am looking forward to hearing from you.

Sincerely,

Nancy Kay Butts
Associate Professor

NKB/m1
PARENTAL INFORMED CONSENT
FOR BODY COMPOSITION TEST

I, the parent/guardian of __________________________, give my permission for my daughter to participate in the body composition study being conducted in the Human Performance Laboratory at the University of Wisconsin-La Crosse. I understand that participation in this study will involve one visit to the Human Performance Laboratory and at that visit my daughter will have anthropometric measurements taken, residual lung volume determined and be underwater weighed. I also understand that I may withdraw my daughter from the study at any time.

In any type of testing situation some potential risk is involved. In working in a water environment these risks include infection, accident and possible drowning. However, there has never been an accident or report of infection as a result of the hydrostatic weighing procedure at the Human Performance Laboratory.

The actual testing will be conducted by Joann McGarty, a graduate student in the Adult Fitness/Cardiac Rehabilitation program at the University of Wisconsin-La Crosse. She will be under the supervision of Nancy Kay Butts, Ph.D.

I, __________________________, parent/guardian of __________________________, approve the participation of my daughter in the body composition test at the Human Performance Laboratory at the University of Wisconsin-La Crosse. I have read the foregoing and I understand it, and any questions which may have occurred to me have been fully answered to my satisfaction. The potential risks have been explained to me and I fully understand their implications. I hereby acknowledge that no representations, warranties, guarantees, or assurances of any kind pertaining to the procedures have been made to me by the University of Wisconsin-La Crosse, the officers, administrators, employees, or by anyone acting on behalf of any of them.

Signed: __________________________ Date: __________
(parent/guardian)
PARENTAL INFORMED CONSENT
FOR MAXIMAL TREADMILL TEST

I, the parent/guardian of ________________________________, give permission for my daughter to participate in the maximal treadmill test at the Human Performance Laboratory at the University of Wisconsin-La Crosse. I understand that this test consists of walking/running to voluntary exhaustion on a motor-driven treadmill. The speed of the treadmill will be gradually increased from 1.7 mph to approximately 5 mph. The treadmill will also be inclined gradually throughout the test. During this test heart rates will be monitored continuously on an electrocardiograph (ECG). She will breathe room air through a mouthpiece so that her exhaled air can be collected. This test requires a maximal effort, however, I understand my daughter can stop the test anytime she wishes.

As with any exercise, there exists the possibility of adverse changes occurring i.e., dizziness, staggering, difficulty in breathing etc. during the test. In addition she will feel tired at the end of the exercise. If any abnormal observations are noted the test will be immediately terminated.

The actual testing will be conducted by Anne Herbert, a graduate student in the Adult Fitness/Cardiac Rehabilitation program at the University of Wisconsin-La Crosse. She will be under the supervision of Nancy Kay Butts, Ph.D.

To my knowledge my daughter is not infected with any disease or has any limiting physical conditions or disabilities, especially with respect to her heart, that would preclude such a strenuous exercise.

I, ________________________________, parent/guardian of ________________________________, approve the participation of my daughter in the maximal treadmill test at the Human Performance Laboratory at the University of Wisconsin-La Crosse. I have read the foregoing and I understand it, and any questions which may have occurred to me have been answered to my satisfaction. The potential risks have been explained to me and I fully understand their implications. I hereby acknowledge that no representations, warranties, guarantees, or assurances of any kind pertaining to the procedures have been made to me by the University of Wisconsin-La Crosse, the officers, administrators, employees, or by anyone acting on behalf of any of them.

Signed: ________________________________ Date: ________________

(parent/guardian)
I, the parent/guardian of ____________________________, give permission for my daughter to participate in the maximal bicycle test at the Human Performance Laboratory at the University of Wisconsin-La Crosse. I understand that this test consists of riding a stationary bicycle ergometer to voluntary exhaustion. The pedalling speed will be at a rate of 60 rpms against a set resistance which will be progressively increased every two minutes until she can no longer maintain the necessary pedalling rate. During this test heart rates will be monitored continuously on an electrocardiograph (ECG). She will breathe room air through a mouth piece so that her exhaled air can be collected. This test requires a maximal effort, however, I understand my daughter can stop the test anytime she wishes.

As with any exercise, there exists the possibility of adverse changes occurring i.e., dizziness, staggering, difficulty in breathing etc. during the test. In addition she will feel tired at the end of the exercise. If any abnormal observations are noted the test will be immediately terminated.

The actual testing will be conducted by Joan Zahalka, a graduate student in the Adult Fitness/Cardiac Rehabilitation program at the University of Wisconsin-La Crosse. She will be under the supervision of Nancy Kay Butts, Ph.D.

To my knowledge my daughter is not infected with any disease or has any limiting physical conditions or disabilities, especially with respect to her heart, that would preclude such a strenuous exercise.

I, ________________________________, parent/guardian of ____________________________, approve the participation of my daughter in the maximal bicycle test at the Human Performance Laboratory at the University of Wisconsin-La Crosse. I have read the foregoing and I understand it, and any questions which may have occurred to me have been fully answered to my satisfaction. The potential risks have been explained to me and I fully understand their implications. I hereby acknowledge that no representations, warranties, guarantees, or assurances of any kind pertaining to the procedures have been made to me by the University of Wisconsin-La Crosse, the officers, administrators, employees, or by anyone acting on behalf of any of them.

Signed: ________________________________ Date: ____________________
PLEASE CHECK THE APPROPRIATE BOXES

☐ I would be willing to have my daughter _____ (name) participate in:
   ☐ All three tests previously described.
      (Please read and sign the blue, yellow and pink sheets)
   ☐ The body composition test:
      (Please read and sign the blue sheet)
   ☐ The treadmill test:
      (Please read and sign the yellow sheet)
   ☐ The bicycle test:
      (Please read and sign the pink sheet)

☐ I would not be willing to have my daughter _____ (name) participate in any of these tests.

Signed: ___________________________ Date: __________

(parent/guardian)

Address: ___________________________ Phone: __________

COMMENTS:
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(Borg, 1970, p.93)
APPENDIX D
We have finally completed the analysis of this year's testing and would like to share the results with you and your daughter. A total of 46 girls between the ages of 8 and 14 participated in the various tests. An overview of the total results according to age groups are on the enclosed sheet. Your daughter's specific results for the tests she completed are:

- Height__________ inches
- Weight__________ pounds
- Percent fat______%  
- Maximum Oxygen Consumption
- Treadmill__________
- Bicycle____________

The percent body fat represents the amount of total body weight that is adipose or "fat" tissue. Although a healthy individual should have some body fat it is generally accepted that a low percent is desirable. The average for the total group this year was lower than in past years. This may be due to the fact that some of the heavier girls of the past years did not participate this time.

The results of the exercise tests are expressed in mLO/kg/min\(^{-1}\). High values on this test are associated with greater fitness levels and may indicate a potential for endurance type activities such as running, cycling, etc. Not all the girls participated in both tests but overall the values were lower on the bicycle test than on the treadmill. This is a common finding in adults so we expected it to occur in children. The reason for the lower value is due to the smaller body mass involved as well as leg fatigue.

We would like to thank you and your daughter for your time and cooperation in making this project so successful again this year. Although we realize that making the necessary arrangements to get to the Human Performance Lab often was inconvenient, we would like to invite you to participate in this project next year. If you are willing to continue to participate we will be contacting you in early January.

Again, thank you and your daughter for your cooperation and we look forward to seeing you next year.

Sincerely,

Nancy Kay Butts
Professor
### Results of girls' 1982 testing according to age groups (means & ranges)

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<tr>
<th>Age (yrs)</th>
<th>Height (in)</th>
<th>Weight (lbs)</th>
<th>% Fat</th>
<th>Bicycle (mlO\textsubscript{2}/kg/min\textsuperscript{-1})</th>
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*Only one in a group.*