Comparison of Continuous and Discontinuous Treadmill Protocols for Elicitation of Maximum Oxygen Uptake in Prepubescent Females

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COMPARISON OF CONTINUOUS AND DISCONTINUOUS TREADMILL PROTOCOLS FOR ELICITATION OF MAXIMUM OXYGEN UPTAKE IN PREPUBESCENT FEMALES

BY

MONICA JEAN SEVERSON

A thesis submitted in partial fulfillment of the requirements for the degree Master of Science
Major in Health, Physical Education, and Recreation
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1988
COMPARISON OF CONTINUOUS AND DISCONTINUOUS TREADMILL
PROTOCOLS FOR ELICITATION OF MAXIMUM OXYGEN
UPTAKE IN PREPUBESCENT FEMALES

This thesis is approved as a creditable and
independent investigation by a candidate for the degree,
Master of Science, and is acceptable for meeting the thesis
requirements for this degree. Acceptance of this thesis
does not imply that the conclusions reached by the candi-
date are necessarily the conclusions of the major depart-
ment.

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DEDICATION

This thesis is dedicated to my husband Scott for all his love, support, and patience during my year in graduate school. Without him it would have been more difficult and less enjoyable.
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The author would like to thank Dr. Jack Ewing for all his time and effort during the writing of this thesis. A special thanks to Wally Cantrell for his help and guidance during the data collection. Thanks to Dr. Jim Lidstone for initiating my interest in research. The author would like to acknowledge her parents for their continuing support of her as she furthers her education.
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A continuous and discontinuous treadmill test was utilized for the elicitation of VO$_2$max in 14 females ages 8, 9, and 10 years. The first visit to the lab was a familiarization session with equipment and procedures explained and a continuous treadmill test completed. The order of the next two sessions was randomly assigned and was either a continuous or discontinuous treadmill protocol. Both tests were run at 4.5 mph and began with a 0% grade. A grade increase of 2.5% occurred for each workload until the subject indicated she could no longer continue. The duration of each workload was 2 minutes on the continuous protocol and 3 minutes on the discontinuous. A five minute rest followed each three minute workload in the discontinuous protocol. From a correlated groups T-test it was determined that a significant difference existed in VO$_2$max in both liters per minute and milliliters per kilogram per minute obtained from continuous and discontinuous treadmill protocols. The mean VO$_2$max of the continuous test was $1.23 \pm .16$ liters per minute and $40.7 \pm 5.42$ milliliters per kilogram per minute and the discontinuous test was $1.43 \pm .2$ liters per minute and $47.3 \pm 7.11$ milliliters per kilogram per minute.
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While America has been involved in a so-called fitness "boom" for over a decade many of America's children have not been reaping the benefits. In the 1960's only about 24% of all adults exercised, but recent figures show about 50% to 60% of adults are now exercising (Corbin & Lindsey, 1988). Although a majority of adults feel exercise is important for good health they are not motivating their children to be physically active. According to the National Children and Youth Fitness Study more than one-half of school age children are not considered physically fit and do not exercise enough (Ross, Dotson, Gilbert, & Katz, 1985).

The fitness "boom", along with our increased knowledge of the importance of regular exercise, has had an impact on, but has not prevented, cardiovascular disease. Heart disease is still the leading cause of death in the United States (Corbin & Lindsey, 1988). The risk factors of cardiovascular disease in children have been shown to include obesity, hypertension, elevated serum cholesterol and triglycerides, and physical inactivity (Gilliam, Katch, Thorland, & Weltman, 1977). Gilliam et al., (1977) found 19.1% of the 47 children they studied were obese, 10% had
elevated serum cholesterol; 18% had elevated triglycerides, and 11% had low work capacities. While identification of risk factors has been heavily stressed in adults, it is apparent that these risk factors are being identified during adolescence or even childhood. If these risks factors are prevalent in children there is justified concern for how unhealthy the adult population may be in the future.

It is believed that physical activity is a protection against cardiovascular disease and regular exercise is very beneficial (Pollock, Wilmore, & Fox, 1978). These benefits include increased work capacity, cardiorespiratory fitness, and muscular strength and endurance, all of which can decrease the risk of disease. In addition, physical activity can help regulate blood pressure, reduce and control weight, regulate metabolism, and prevent loss of bone mass. Physical activity can also provide an outlet for tension and mental fatigue, improvements in posture and self-image, and a sense of "feeling good" (Pollock et al., 1978; Corbin & Lindsey, 1988).

Physical fitness is the ability of the heart, blood vessels, lungs, and muscles to work their best to meet the challenges of life (Corbin & Lindsey, 1988). These challenges could range from shoveling snow, to touching one's toes, to running a marathon. The major components of physical fitness are body composition, flexibility,
strength, muscular endurance, and cardiovascular endurance (Pollock et al., 1978). Cardiovascular endurance is frequently considered the most important aspect of physical fitness because those who possess it are likely to decrease their risk of coronary heart disease. Cardiovascular endurance is the ability of the heart, blood vessels, blood, and respiratory system to supply oxygen to the muscles during sustained exercise (Corbin & Lindsey, 1988). If a person has good cardiovascular endurance, they can persist in physical activity for relatively long periods of time without undue stress.

To determine a person's cardiovascular endurance, the maximum amount of oxygen that a person is capable of using during strenuous exercise is measured ($V_{O2max}$). $V_{O2max}$ is considered to be the best indicator of aerobic work capacity and is limited by the capacity of the cardiorespiratory systems to deliver oxygen to the tissues (Miyamura & Honda, 1972). To measure maximum oxygen uptake, researchers have used modes of exercise in which the workload can be controlled. The motor-driven treadmill and the bicycle ergometer are two commonly used modes. Controlling the workload involves regulating the speed and grade of the treadmill or the resistance and cadence of the bicycle ergometer. $V_{O2max}$ is attained when the workload is so high that the subject can no longer continue.

Individuals of all ages and both sexes have been
tested for VO₂max. Optimal procedures for determining VO₂max have been identified but most of the research has been carried out with college-age males as subjects. Studies examining the measurement of maximum oxygen uptake in children have been completed (Wilmore & Sigerseth, 1966; Skinner, Bar-Or, Bergsteinova, Bell, Royer, & Buskirk, 1971; Nagle, Hagberg, & Kamei, 1977; Cunningham, Van-Waterschoot, Paterson, Lefcoe, & Sangal, 1977; Krahenbuhl, Pangrazi, Petersen, Burkett, & Schneider, 1978; Paterson, Cunningham, & Donner, 1981; Ferrar, 1985; Sheehan, Rowland, & Burke, 1987) although there is still some question as to the most appropriate protocol (Skinner et al., 1971; Shephard, 1971; Paterson et al., 1981).

Questions encountered in the assessment of VO₂max in children may be related to unrealistic VO₂max attainment criteria, inappropriate test protocols, physiological and psychological differences in exercise responses of children compared to adults, and the identification of a maximal effort in children (Paterson et al., 1981). In order to determine whether maximum oxygen uptake has been attained during a test the normal criteria is the establishment of a plateau or leveling off in oxygen uptake with an increase in workload. A true plateau has been difficult to observe on a regular basis in children. Only 2 of the 13 subjects met the criterion for a plateau during the continuous test in Ferrar's (1985) study. Also using a continuous test,
Paterson et al. (1981) had only 24 of the 72 tests administered result in a plateau in VO$_2$. Cunningham et al. (1977) found a plateau in only 38% of their subjects using a continuous test. However, Krahenbuhl et al. (1978) used a continuous protocol and observed that 83 of the 117 subjects or 71% attained a plateau in oxygen consumption. When a plateau is not attained it may be more appropriate to use the term peak VO$_2$.

Commonly used treadmill protocols have been designed for adults and may not be appropriate for use with children. The physiological and psychological differences between adults and children may require a modification of the testing protocol for elicitation of VO$_2$max in children. Many researchers have been concerned with the reliability of the results from using the same protocols on children that are used to test adults (Skinner et al., 1971; Paterson et al., 1981; Shephard, 1984). Since children may not be highly motivated to give a maximal effort it may be more difficult to measure their maximum oxygen uptake.

The bicycle ergometer and the treadmill are the most often used modes for the assessment of VO$_2$max. The treadmill appears to elicit the highest VO$_2$max values (Hermansen & Saltin, 1969; Miyamura & Honda, 1972; McArdle, Katch, & Pechar, 1973). A variety of treadmill protocols exist with the two main classifications being continuous or discontinuous. A treadmill test is continuous when there
is a gradual transition from low intensity to maximal work capacity with no rest periods. A treadmill test is discontinuous when there is a gradual transition from low intensity to maximal work capacity that alternates work and rest periods. Therefore, the major difference between the protocols is that the continuous test has no rest periods and the discontinuous test has a rest period after each workload.

Deciding whether to use a continuous or a discontinuous protocol can be a concern for the researcher. The continuous protocol has advantages as does the discontinuous protocol. Although the continuous protocol needs less time to complete, a plateau in oxygen consumption is not always attained. Discontinuous protocols require more time to complete, but subjects may not need as much motivation to reach their maximal capacity. During a discontinuous test the subject can be encouraged during the rest periods and while on the treadmill, whereas during a continuous test they can only be encouraged while on the treadmill. It takes a highly motivated subject to give a maximal effort on a continuous test. In many studies using adults no significant differences in VO$_2$max have been observed when elicited by continuous and discontinuous protocols (Maksud & Coutts, 1971; Skinner et al., 1971; McArdle et al., 1973, Fardy & Hellerstein, 1978). The same results have been found with boys as subjects by Sheehan et
al. (1987). However, Ferrar (1985) did find a significant difference in VO$_2$max values obtained from continuous and discontinuous protocols using 8, 9, and 10 year old females as subjects. While the results of this study were thought to be reliable, due to a constant error in the measurement system there is concern about the validity of the results and it, therefore, should be replicated.

Testing for maximum oxygen uptake is needed to assess the physical fitness of our children. While treadmill protocols which accurately determine VO$_2$max have been designed, assessed, and validated for adults (Maksud & Coutts, 1971; McArdle et al., 1973; Frolicher et al., 1974; McKay & Banister, 1976; Fardy & Hellerstein, 1978) there is still some question regarding which maximum oxygen test is best used for children. More research needs to be completed utilizing children as subjects to develop the most appropriate protocol for eliciting VO$_2$max. Therefore, this study, which is a replication of the Ferrar (1985) study, was undertaken to further examine VO$_2$max testing in children.

Statement of the Problem

The purpose of this study was to compare continuous and discontinuous treadmill protocols for the elicitation of maximum oxygen uptake in 8, 9, and 10 year old females.
Hypotheses

The research hypotheses tested were:

1. The maximum oxygen uptake of prepubescent females in liters per minute measured during a continuous treadmill protocol is not different from those values obtained from a discontinuous treadmill protocol.

2. The maximum oxygen uptake of prepubescent females in milliliters per kilograms per minute measured during a continuous treadmill protocol is not different from those values measured during a discontinuous treadmill protocol.

3. The respiratory exchange ratio of prepubescent females at VO$_2$max measured during a continuous treadmill protocol is not different from those values measured during a discontinuous treadmill protocol.

4. The volume expired of prepubescent females at VO$_2$max measured during a continuous treadmill protocol is not different from those values measured during a discontinuous treadmill protocol.

Definition of Terms

Continuous Treadmill Test: A protocol for the elicitation of VO$_2$max with progressively increasing workloads with no rest periods (Lamb, 1978).
**Discontinuous Treadmill Test**: A protocol for the elicitation of VO\(_2\)max with progressively increasing workloads allowing sufficient time for recovery between increments of work (Taylor, Buskirk, & Henschel, 1955).

**Maximum Oxygen Uptake (VO\(_2\)max)**: The greatest volume of oxygen a person can utilize during maximal physical work. It is a measure of the person's maximal capacity to transport oxygen to the tissues of the body and the tissues ability to utilize the oxygen (Mitchell, Sproule, & Chapman, 1957).

**Maximal Effort**: When an individual exercises to exhaustion. If an individual attains a plateau in VO\(_2\) with increasing workloads and has a RER over 1.00 it is a good indication the individual has given a maximal effort (Paterson et al., 1981).

**Maximal Heart Rate**: The maximum number of times the heart can contract in one minute (Lamb, 1978).

**Plateau**: A plateau in VO\(_2\) occurs when two consecutive measurements differ by 2.1 milliliters per kilogram per minute or less following a 2.5% increase in grade (Taylor, Buskirk, & Henschel, 1955).

**Respiratory Exchange Ratio (RER)**: The volume of carbon dioxide produced divided by the amount of oxygen produced. This variable reflects the intensity of the exercise and the type of fuel being used (Issekutz, Birkhead, & Rodahl, 1961).
Peak VO₂: The highest oxygen consumption achieved by the subject on a test to exhaustion. VO₂ max will equal or exceed peak VO₂. A subject may achieve a peak value, but may not meet the criterion for VO₂ max. Without a plateau in VO₂ there is no assurance that VO₂ max has been attained, therefore in these cases peak VO₂ is the more appropriate term (Krahenbuhl, Skinner, & Kohrt, 1985).

Open Circuit Method: Subject breathes in unlimited amounts of ambient air that is made up of a constant composition of oxygen, carbon dioxide, and nitrogen instead of breathing in the expired air again (McArdle, Katch, & Katch, 1986).

Assumptions

The following assumptions have been made for the purpose of this study:

1. All females ages 8, 9, and 10 years can give a maximal effort on a graded exercise treadmill test.

2. The minor environmental fluctuations in the Human Performance Lab did not affect the results of the study.

3. The different levels of maturation of females 8, 9, and 10 years did not affect the physiological response to the graded exercise test.
4. The highest oxygen uptake attained during a test (peak VO$_2$) is equal to VO$_2$max.

Limitations

This study incorporated a repeated measures design with each subject completing a continuous and discontinuous treadmill test. There are both advantages and disadvantages to repeated measures designs. While the subjects may have experienced a learning effect following the first test with resultant improvement in second test values, this limitation was controlled for by randomly assigning the order of the tests.

Scope of the Study

Subjects were 8, 9, and 10 year old females from Colman, South Dakota. The subjects made three visits to the Human Performance Lab in the Stanley J. Marshall Health, Physical Education, and Recreation Center on the campus of South Dakota State University. Each testing session lasted approximately 30 minutes. The first visit was a familiarization session to acquaint the subjects to the treadmill and lab procedures. At each testing session four electrodes were placed on the torso of the subject and then connected to the heart rate monitor. The mouthpiece, headgear, and nose clip were then placed on the subject and
the hoses from the gas meter and to the mixing chamber were connected to the mouthpiece valves. All protocols were carried out until the subject indicated she could no longer continue. The second and third visits consisted of the subjects completing either a continuous or discontinuous treadmill test. The order of the tests were randomly assigned. The testing was completed between March 7 and March 25, 1988, between 4:00 and 6:30 pm. At least 48 hours separated each test.

Significance of the Study

Most researchers consider maximum oxygen uptake as the best indicator of cardiovascular endurance, the most important component of physical fitness. Today, fitness is of great importance, therefore, we need an accurate method of measuring VO$_2$max. Maximal exercise testing has been studied extensively, however, most of the work has been done on college-age males (Maksud & Coutts, 1971; Miyamura & Honda, 1972; McArdle et al., 1973; Keren et al., 1980). More research on maximal exercise testing in children needs to be completed since it is necessary to identify protocols that accurately measure VO$_2$max. A major goal of physical education programs is to improve the physical fitness of our children. It is important to be able to measure these improvements using either VO$_2$max tests or tests which predict VO$_2$max. More research focusing on the actual
measurement of VO₂max needs to be completed so that accurate predictive measurements can be established for physical educators to utilize with children. Accurate assessments of VO₂max have been established for adults and postpubescent boys. However, no clear identification of the best VO₂max protocol for prepubescent girls has been established. With the current emphasis on fitness, and particularly children's fitness, it is critical that appropriate measurement techniques be utilized. Therefore, this study tested prepubescent girls on continuous and discontinuous protocols to help establish appropriate measurement techniques.
CHAPTER II

REVIEW OF LITERATURE

The research literature that is pertinent to this study on maximum oxygen uptake testing in prepubescent females is presented in this chapter. It has been organized into four major sections and the chapter concludes with a summary of the review of literature.

Maximum Oxygen Uptake

Over the last 30 years hundreds of studies have been completed examining maximal oxygen uptake (VO₂ max). Presented in this section are several of the classic studies establishing VO₂ max as the single best indicator of cardiovascular function.

In one of classical studies of maximum oxygen uptake, Taylor, Buskirk, and Henschel (1955) described the technique of measuring VO₂ max along with its limitations and usefulness. Forty-six male volunteers between the ages of 18 and 35 years came to the lab a minimum of three days and some as many as five to establish workload that would elicit VO₂ max. On the first visit the subjects performed the treadmill version of the Harvard Fitness Test. From this test the grade that would produce VO₂ max was es-
timated. The second visit to the lab involved a treadmill test with a warmup at 3.5 miles per hour and 10% grade. Within five minutes of completing the warmup, subjects ran at seven miles per hour for three minutes at the grade which had previously been determined. On the third trip to the lab, subjects followed the same protocol as on the second visit except they ran at a 2.5% higher grade. If the two oxygen intakes were different by less than 150 cubic centimeters per minute or 2.1 cubic centimeters kilograms per minute the authors determined that a VO$_{2\text{max}}$ had been reached. If a larger difference was found, another test was performed on a subsequent day with a 2.5% grade increase. This was continued until two consecutive tests elicited an oxygen intake that met the criterion. Another method of attaining VO$_{2\text{max}}$ was also examined. On successive days the subjects ran for three minutes with the grade set at zero percent while the speed was increased each day until a plateau using the previously described criteria had been reached. Nine of the thirteen subjects using the increasing speed method showed a plateau in VO$_2$. When using the method of increasing grade instead of speed it was found that only 7 subjects out of 115 did not reach a plateau. The authors concluded that if two consecutive measurements separated by a 2.5% grade increase differ by less than 150 cubic centimeters per minute or 2.1 cubic
centimeters per kilogram per minute, a plateau has been attained.

As a follow-up to the Taylor et al., (1955) study, Mitchell, Sproule, and Chapman (1957) attempted to determine the physiological meaning of the maximum oxygen uptake test. Sixty-five men aged 20 years or over completed a testing protocol similar to Taylor et al., (1955) except rather than allowing 24 hours between runs on the treadmill only 10 minutes of rest was given. The subjects warmed up for 10 minutes at 3 miles per hour and 10% grade followed by a 10 minute rest. The first 3 minute workload was at 6 miles per hour and 0% grade followed by a 10 minute rest. The grade was increased by 2.5% in each subsequent workload while the speed remained constant. The test continued until increases in oxygen uptake leveled off following the same criteria as Taylor et al., (1955). On a subset of 15 subjects cardiac output and A-VO₂ difference were determined at rest and during three workloads of the test. To facilitate these measures a catheter was placed in the left brachial artery and the brachial and femoral veins. The authors determined that maximum oxygen uptake was limited by cardiac output and A-VO₂ difference and that increased cardiac output may be more important than increased A-VO₂ difference. Also a 10 minute rest between workloads was found to be sufficient time rather than using Taylor's et al., (1955) rest period of 24 hours.
A study finding slightly different results than Taylor et al. (1955) was completed by Wyndham, Strydom, Maritz, Morrison, Peter, and Potgieter (1959). They examined the relationship between heart rate and VO₂max as well as the criteria for attaining VO₂max. Four highly trained men were the subjects. The training involved a 10 minute warm up with 3000 feet per pound per minute. Then for 30 minutes they worked at 70 revolutions per minute and a resistance of 7500 feet per pound per minute. After the 30 minute workload, subjects pedaled at 9000 to 11000 feet per pound per minute until exhaustion. After the subjects were trained they then worked for 4 months at workloads ranging from 2500 to 11000 feet per pound per minute. On Mondays the workload was always 7500 feet per pound per minute to test the variability of heart rate and oxygen consumption while on other days the workload was randomly assigned. Gases were collected at the second and tenth minutes at workloads below 8000 feet per pound per minute and only at the second minute when above 8000 feet per pound per minute. The oxygen intake and heart rate curves were linear until maximum heart rate was attained. A shift of the curve was observed towards higher values of oxygen intake than would be expected if plotted along the maximum heart rate curve. The authors suggest that predicting VO₂max from maximum heart rates values could result in underestimating VO₂max. In conflict with Taylor's et al.,
(1955) criteria for establishing VO₂max, this study found at the three highest workloads there was no significant difference in VO₂ from the mean VO₂ of those minutes. The authors pointed out that there is such a slow rise in oxygen intake to the asymptote when plotted against work rate that Taylor's et al., (1955) criteria may underesti­mate VO₂max.

Astrand and Saltin (1961) used one female and four males as subjects to examine oxygen uptake, heart rate, pulmonary ventilation, and lactic acid concentration during heavy exercise. The exercise was performed on a bicycle ergometer at 50 revolutions per minute. A 10 minute warm up was completed at about 55% of VO₂max followed by a workload which was designed to increase to a level that would produce exhaustion within two to eight minutes. When the workload could be maintained for 6.5 minutes the VO₂ after 1 minute of exercise was 84% of the 1 minute value from workloads that could be maintained only 2 minutes. The time for establishment of a plateau, therefore, depends on the workload. The authors felt that a 10 minute warm up followed by 2 minutes of very heavy exercise will produce maximal oxygen uptake and heart rate. The acceleration of heart rates was higher, (177 beats per minute) after the first minute of exercise in the 2 minute workload than in the 6.5 minute workload (164 beats per minute). The VE for the 6.5 minute exercise was 137.3 liters and 155.8 liters
for the 2 minute workload. The heavier the workload the higher the VE and the increase was more rapid. The authors concluded that in order to establish a steady state VO₂ the workload should be at least five minutes for lighter exercise, however, if the exercise was heavy measurements could be taken after one minute of exercise.

In 1971, Mitchell and Blomqvist wrote a comprehensive review of the work completed on maximum oxygen uptake. They indicated that when a person is subjected to progressively increasing workloads there is a linear relationship between workload and oxygen uptake until VO₂max is attained. Many times more work can be accomplished beyond the workload which elicits VO₂max. While VO₂max depends on maximal cardiac output and A-VO₂ difference, maximal cardiac output seems to be more important. A number of variables have been shown to influence VO₂max including body size, age, sex, and activity level. When VO₂max is expressed in liters per minute it reflects the total volume of oxygen the body is capable of using but is inappropriate to use for comparing individuals due to differences in muscle mass. When VO₂max is expressed in milliliters per kilogram per minute it reflects the relative volume of oxygen the body is capable of using and should be used when comparing the VO₂max of two or more individuals. VO₂max appears to decrease with age and males tend to have a higher VO₂max than females. More active individuals tend
to have a higher VO$_2$max than their sedentary counterparts. And finally, maximum oxygen uptake has been well-established as the best indicator of cardiovascular fitness.

Modes of Testing

Although there are various modes of measuring VO$_2$max, the treadmill and the bicycle ergometer are used most often and elicit the highest VO$_2$max values because of the large muscle groups being used (Mitchell & Blomqvist, 1971). Studies have been conducted which compared VO$_2$max elicited on the treadmill with that elicited on the bicycle ergometer. Maximal oxygen uptake has been found to be consistently higher on the treadmill than on the bicycle ergometer (Glassford, Baycroft, Sedgwick, & MacNab, 1964; Hermansen & Saltin, 1969; McArdle & Magel, 1970; Miyamura & Honda, 1972; McKay & Banister, 1976; Keren, Magazanik, & Epstein, 1980).

Glassford, Baycroft, Sedgwick, & MacNab (1964) used four different methods for determination of VO$_2$max. The subjects were 24 in number and ranged in age from 17 to 33 years. One test was the Taylor Buskirk, and Henschel (1955) test, the specifics of which have been described previously in this review. This protocol has the subjects returning on subsequent days for the next higher workload until a plateau in VO$_2$ has occurred. The Mitchell, Sproule, & Chapman (1957) test was also administered, the
specifics of which have also been described in the previous section. This protocol is similar to the Taylor et al., (1955) protocol with the replacement of 24 hour rest periods by 10 minute rest periods. The Astrand bike test was also used which involves pedaling at 50 revolutions per minute and 600 kiloponds meters per minute of resistance for 6 minutes which was followed with a 5 minute rest. The resistance was then increased by 300 kiloponds per minute each workload until a plateau in VO₂ was reached (increase of 80 milliliters or less). The Astrand-Rhyming predictive test on the bike also involved riding at 600 kilogram meters per minute and 50 revolutions per minute. Heart rates were recorded the last 30 seconds of each minute. The duration of each workload was determined by having reached a steady state in heart rate. Criteria for having attained a steady state was when two consecutive heart rate values which were separated by a minute did not differ more than ±5 beats. The subject pedalled at least five minutes before this criteria was applicable. The two heart rate values were averaged and used in the Astrand-Rhyming nomogram to predict VO₂ max. Results included: Taylor, Buskirk, and Henschel test - 50.2 ± 4.43 milliliters per kilogram per minute; Mitchell, Sproule, and Chapman test - 49.86 ± 5.65 milliliters per kilogram per minute; Astrand test - 46.31 ± 4.67 milliliters; and Astrand-Rhyming prediction - 49.3 ± 10.72 milliliters per kilogram per minute. The mean from
the Astrand test was significantly lower than the means of the other three tests. The means of the two treadmill tests were significantly higher than the mean of the Astrand bike test. These results indicate that the treadmill elicits higher VO\textsubscript{2}max values than the bicycle ergometer.

Keren, Magazanik, and Epstein (1980), like Glassford et al., (1964), used three direct measurements (treadmill test, bicycle ergometer test, and step test) and one indirect measurement (Astrand-Rhyming Nomogram) to determine VO\textsubscript{2}max. Fifteen males with a mean age of 20.2 ± 0.17 years completed all 4 tests. The Bruce protocol was utilized for the treadmill test. The test was initiated at 1.7 miles per hour and 10% grade. Every three minutes the grade was increased two% and speed increased every three minutes as follows: 1.7, 2.5, 3.4, 4.2, 5.0, 5.5, and 6.0 miles per hour. The test was terminated when the subject was unable to continue. The bicycle ergometer test consisted of pedaling at 600 kilogram meters per minute for 3 minute workloads with an increase of 300 kilogram meters per minute each workload. This continued until subject was unable to maintain the cadence. A bench with a height of 32.5 centimeters was used for the step test. The stepping pace started at 24 steps per min and increased continuously each minute to between 40 to 60 steps per min. With the Astrand-Rhyming Nomogram the subjects pedaled at 50
revolutions per minute for three successive workloads of 600, 900, and 1200 kiloponds meters per minute each lasting five minutes. Heart rates were monitored and used in the nomogram to predict VO₂max. The mean VO₂max values were: treadmill test - 63.8 ± 1.3 milliliters per kilogram per minute; bicycle ergometer test - 60.2 ± 1.45 milliliters per kilogram per minute; step test - 59.6 ± 1.35 milliliters per kilogram per minute; and predicted bicycle ergometer test - 59.9 ± 1.4 milliliters per kilogram per minute. No significant differences were found between VO₂max determined by the bicycle ergometer, the step test, and the Astrand-Rhyming nomogram. The treadmill test elicited significantly greater VO₂max values of about six percent when compared to the other methods.

In 1969 Hermansen and Saltin also found significantly higher maximum oxygen uptake values from a treadmill protocol compared to values from a bicycle ergometer protocol. The subjects were 55 males ages 19 to 69 years. Both tests were discontinuous in nature. A constant grade of 5.25% was used for the treadmill test. The speed was increased by two kilometer per hour every three minutes until a plateau in VO₂ was observed. The Astrand and Saltin protocol for the bicycle ergometer was used. The pedal rate was 50 revolutions per minute and the workload was increased by 200 kiloponds meters per minute after each successive 10 minute stage until VO₂max was
achieved. A significant difference was found between the mean VO$_2$max values with the treadmill protocol eliciting 4.18 liters per minute and the bicycle protocol 3.9 liters per minute. Forty-seven of the 55 subjects showed higher VO$_2$max values on the treadmill test than the bicycle ergometer test.

McArdle and Magle (1970) also used a treadmill and a bicycle ergometer for elicitation of VO$_2$max from 23 male college students. The treadmill test was begun with the subjects walking at 0% grade and a speed of 3.4 miles per hour for the first 2 minutes. Grade was increased by one percent every minute until the subject was unable to continue. On the bicycle ergometer test the subject pedaled at 60 revolutions per minute. An increase of 180 kilograms per minute every two minutes was administered until the subject was unable to continue. The mean VO$_2$max values were significantly higher on the treadmill compared to the bicycle ergometer (42.7 milliliters per kilogram per minute and 38.5 milliliters per kilogram per minute, respectively).

Using 17 college-age males, Miyamura and Honda (1972) compared the VO$_2$max values obtained from a constant loading and a stepwise incremental loading treadmill and bicycle ergometer test. The treadmill speed and the bicycle ergometer load were such that maximal efforts would be reached in four to eight minutes. The treadmill
constant loading test consisted of a speed of 180 to 200 meters per minute and 8.6% grade. The incremental loading treadmill test utilized a two minute warmup at 150 to 170 meters per minute at 8.6% grade. After the warmup, the speed was increased 10 meters per minute each minute until exhaustion. The constant loading bicycle test involved pedaling at 60 revolutions per minute and the workload varied from 1260 to 1620 kilograms per minute depending on the subject's level of fitness. The incremental loading bicycle test began with a two minute warmup at 60 revolutions per minute and a load of 900 to 1200 kilograms per minute. The workload was increased by 180 kilograms per minute each minute until exhaustion after the warmup period. The mean VO₂max values for the treadmill tests were not significantly different between the incremental loading (3.95 liters per minute) and the constant loading technique (3.89 liters per minute). For the bicycle ergometer test, the VO₂max value on the incremental loading was 3.37 liters per minute and for the constant loading 3.58 liters per minute; a significant difference. A significant difference was also found between VO₂max values from the treadmill compared to the bicycle ergometer with the treadmill eliciting higher values. Therefore, it is best to use the treadmill for elicitation of VO₂max values. Significantly higher VO₂max values from a treadmill test versus a bicycle ergometer test were also found by
McKay and Banister (1976). Five males with a mean age of 24.8 ± 2.5 years were tested on 4 maximal treadmill tests and 4 maximal bicycle ergometer tests. The differences between the tests were in the pedaling rate and the treadmill speed. Subjects pedaled at 60, 80, 100, and 120 revolutions per minute on the Monark bicycle ergometer for the four bicycle tests. The workload began at 900 kilograms per minute and increased by 300 kilograms per minute every 2 minutes. Subjects continued until they could not maintain the desired pedaling rate. The treadmill test consisted of subjects running at 6, 6.5, 7, and 7.5 miles per hour. The test was begun at 0% grade and increased by 2.5% each minute until the subject could no longer continue. The treadmill test elicited higher maximum oxygen uptake values versus the bicycle ergometer values (63.28 ± 1.72 milliliters per kilogram per minute and 58.7 ± 1.83 milliliters per kilogram per minute, respectively). The speed of the treadmill appears to have little effect on VO₂max when increasing grade is used as a loading effect since there was no significant difference in values obtained from the four different treadmill speeds. On the bicycle ergometer significant differences were only found between pedaling rates of 60 revolutions per minute and 80 revolutions per minute and 80 revolutions per minute and 120 revolutions per minute.
All of the literature reviewed in this section revealed significantly higher VO$_2$max values from treadmill tests compared to bicycle ergometer tests. Is the treadmill a better mode to use for determination of maximum oxygen uptake than the bicycle ergometer? Both the treadmill and bicycle ergometer have advantages and disadvantages. Some advantages of the bicycle are it is inexpensive, portable, and easily calibrated. Whereas, the treadmill is expensive, not portable, and is more difficult to calibrate (Krahenbuhl, Skinner, & Kohrt, 1985). The bike has the advantage of the subjects' head being held reasonably still so direct breath analyzers can be used easily and not affect the test. On the treadmill, the hoses connect the mouthpiece valves to the analyzers and this can possibly limit the natural upper body movement (Cardus, 1978). The treadmill uses a larger muscle mass, whereas, the bicycle ergometer uses a smaller muscle mass which can cause local fatigue and end the test before reaching VO$_2$max. The bicycle ergometer is difficult for children to use since they need to maintain cadence for proper workload. However, the treadmill is suited for children with no modifications (Krahenbuhl et al. 1985). Also, Shephard (1984) pointed out that the treadmill is used most often for VO$_2$max testing, therefore, there are more norms to which the results can be compared.
Continuous and Discontinuous Testing

To obtain an accurate measurement of VO₂ max a test that exercises the subject to exhaustion is necessary. A number of different protocols have been designed to do this. The two most common protocols are the continuous and discontinuous. A continuous protocol involves progressively increasing workloads with no rest periods. A discontinuous protocol also involves progressively increasing workloads but alternates rest periods and work periods. A number of studies have been completed examining continuous and discontinuous treadmill protocols.

Using continuous and discontinuous protocols, Maksud and Coutts (1971) compared the maximum oxygen uptake of 20 males ages 17 to 30 years. The continuous test began with a 10 minute warmup at 3.5 miles per hour and 0% grade followed by a 5 minute rest. The test continued with the subjects running at zero percent grade and seven miles per hour. The grade was increased by 2.5% each minute until exhaustion. The discontinuous test also utilized a 10 minute warmup at 3.5 miles per hour, but with 10% grade. Following a short rest, subjects ran at one of six grades (2.5%, 5%, 7.5%, 10%, 12.5%, and 15%) which were randomly assigned. The speed of the treadmill was maintained at seven miles per hour and the subject worked for three minute periods. The remaining workloads were completed on succeeding days until a difference of less than 150 cubic
centimeters per minute in VO_{2max} were found between consecutive treadmill grade increases. The continuous protocol produced a mean VO_{2max} of 55.6 ± 7.7 milliliters per kilogram per minute and the discontinuous protocol produced a mean VO_{2max} of 55.2 ± 6.8 milliliters per kilogram per minute. The difference was not significant.

No significant difference in VO_{2max} from continuous and discontinuous protocols was also found by McArdle, Katch, and Pechar (1973). Fifteen male college students were the subjects who performed six test protocols. The first test was a continuous bicycle test. Subjects pedaled at 60 revolutions per minute with an increase of 180 kilograms per minute every two minutes until subjects' pedal rate dropped below 47 to 50 revolutions per minute. On the discontinuous bicycle test subjects pedaled at 60 revolutions per minute with 2 kilograms of resistance for a 5 minute warmup followed by a 10 minute rest. The resistance was increased to three kilograms for the next five minute workload and thereafter was increased a half a kilogram for each workload. The test was terminated when the subject was unable to continue. The continuous Balke treadmill test was carried out at a constant speed of 3.4 miles per hour and began at 0% grade. The grade was increased by one percent each minute until the subject could not continue. The Mitchell, Sproule, and Chapman (1957) discontinuous treadmill test was also utilized and has been described.
previously in this review. Another continuous treadmill test consisted of the subject running at a constant speed of six miles per hour and a starting grade of zero percent for two minutes. The grade was increased 2.5% every 2 minutes until the subject could no longer continue.

Another discontinuous treadmill test consisted of running at 6 miles per hour at 2.5% grade for 5 minutes as a warmup. Five minute work stages, 2.5% higher than the previous one were alternated with 10 minute rest intervals until the subject could no longer continue. The VO\textsubscript{2max} values obtained were as follows: discontinuous bicycle test - 50 ± 6.9 milliliters per kilogram per minute; continuous bicycle test - 49.9 ± 7 milliliters per kilogram per minute; Mitchell, Sproule, and Chapman test - 56.6 ± 7.3 milliliters per kilogram per minute; Balke test - 53.7 ± 7.5 milliliters per kilogram per minute; discontinuous treadmill test - 56.6 ± 7.6 milliliters per kilogram per minute; and continuous treadmill test - 55.5 ± 6.8 milliliters per kilogram per minute. The bicycle ergometer VO\textsubscript{2max} values were significantly lower than the treadmill values. No significant differences were found between the discontinuous treadmill test, the continuous treadmill tests, and the Mitchell, Sproule, and Chapman test.

In 1978, Fardy and Hellerstein also studied VO\textsubscript{2max} elicited from discontinuous and continuous treadmill protocols. Twelve male subjects (42.3 ± 9.9 years) were
tested three times with the order of the tests randomly assigned. The first test was for familiarization. For the continuous protocol, subjects walked at two miles per hour and zero percent grade the grade was increased every three minutes as follows: 3.5%, 7%, 10.5%, 14%, 17.5%, 12.5%, 15%, 17.5%, and 20%. The speed remained at two miles per hour until the seventh three minute stage when it was increased to three miles per hour. The discontinuous protocol followed the same procedure as the continuous protocol with the inclusion of a three minute rest between each stage. The continuous test produced a mean VO\textsubscript{2}max of 40.7 milliliters per kilogram per minute and the discontinuous test 39.5 milliliters per kilogram per minute. The differences was not significant.

Conflicting results were reported by, Froelicher, Brammel, Davis, Noguera, Stewart, and Lancaster (1974) who did find a significant difference between discontinuous and continuous protocols. The subjects were 15 males with a mean age of 32 years. The subjects performed the Bruce protocol, the Balke protocol, and a modified Taylor protocol three times each over a nine week period. The continuous Bruce protocol has been described previously in this review. Also continuous in nature, the Balke protocol consisted of a constant speed of 3.3 miles per hour beginning at 1% grade. The grade was increased one percent every minute until exhaustion. The modified Taylor
protocol consisted of a speed of seven miles per hour beginning at a grade of zero percent. The grade was increased every 3 minutes by 2.5% until subject could not continue. A five minute rest period followed each workload. The mean VO₂max values were 44.3 ± 5.9 milliliters per kilogram per minute for the Bruce protocol, 42.8 ± 5.2 milliliters per kilogram per minute for the Balke protocol, and 47.4 ± 6.1 milliliters per kilogram per minute for the Taylor protocol. The Taylor protocol, which was discontinuous, elicited significantly higher VO₂max values than either the Bruce or Balke protocols which are continuous. A plateau was demonstrated in 33% of the Taylor protocol tests while only 17% on the Balke protocol and 7% on the Bruce protocol.

Maximum Oxygen Uptake in Children

As has been identified in the previous sections VO₂max can be measured in a variety of ways in adults but many questions have been raised about the reliability of measuring VO₂max in children. Measuring VO₂max in children is more difficult than in adults because of the unfamiliarity of children with maximal efforts. Identification of a plateau in VO₂ with increasing workloads has been the criteria for VO₂max in many studies. The evidence of a plateau has been seen less in children than in adults (Paterson, Cunningham, & Donner, 1981). Many factors can
account for the failure to attain a plateau including lack of effort by the child, poor definition of the appropriate criteria for a plateau or possibly another factor not yet identified. Despite these problems a number of studies have been carried out examining VO\textsubscript{2}max in children.

The bicycle ergometer was the mode of exercise used by Wilmore and Sigerseth (1967) to determine if any physiological differences exist among girls ages 7 to 13 years based on their maximum oxygen uptake values. Three testing sessions were conducted with the first one used as a familiarization. During the last two sessions, a work capacity test on a bicycle ergometer was performed. The test consisted of a starting workload of 0 kilogram meters per minute per minute and pedaling rate of 50 revolutions per minute with 150 kilogram meters per minute increases in workloads every minute until exhaustion. The mean VO\textsubscript{2}max values for the 7 to 9 year old subjects was 53.5 ± 6.5 milliliters per kilogram per minute; 10 to 11 year old subjects 50.7 ± 5.9 milliliters per kilogram per minute; and 12 to 13 year old subjects 48.7 ± 8.7 milliliters per kilogram per minute. When VO\textsubscript{2}max was expressed in liters per minute it was inversely related to age and independent of work capacity. As girls reach puberty their body weight and lean body mass ratio decreases and the authors suggest that this could cause lower VO\textsubscript{2}max in milliliters per kilogram per minute in the older girls.
Nagle, Hagberg, and Kamei (1977) also used the bicycle ergometer along with the treadmill to determine VO₂ max of girls as well as boys. The subjects were 120 boys and 120 girls 14 to 17 years of age. Subjects completed a 5 minute ride on the bicycle ergometer at submaximal workloads of 450 kilogram meters per minute for girls and 600 kilogram meters per minute for boys. In the fifth minute, heart rates were taken for 15 seconds and used in the Astrand-Rhyming Nomogram to predict VO₂ max. The treadmill protocol consisted of a constant speed of five, six, or seven miles per hour. The speed was established from the predicted VO₂ max on the submaximal bicycle ergometer ride. Grade was increased by two percent every minute with girls starting at zero percent and boys at two percent. This procedure continued until the subject was exhausted. The mean VO₂ max for the girls was 40.8 ± 4.0 milliliters per kilogram per minute and for the boys was 54.7 ± 5.6 milliliters per kilogram per minute. This difference was significant.

Gilliam, Katch, Thorland, and Weltman (1977) used a bike ergometer to measure VO₂ max in 47 boys and girls. They also examined cardiovascular risk factors in the 7 to 12 year old children by doing a complete medical and physical evaluation. A blood sample was taken for determination of serum cholesterol, triglycerides, and blood lipids. Each child participated in hydrostatic weighing to
assess percent body fat and lean body mass. A bicycle
ergometer test was completed to determine peak VO_2_. The
test started at zero load and every three minutes was
increased one-half kilopond with the pedaling rate main-
tained at 60 revolutions per minute. The subjects con-
tinued until exhaustion. During each minute of the test
oxygen uptake was measured by the open circuit spirometry
method. The 7 to 8 year old subjects had a mean peak VO_2
of 34.4 milliliters per kilogram per minute, the 9 to 10
year olds 38.2 milliliters per kilogram per minute, and the
11 to 12 year olds 43.3 milliliters per kilogram per
minute. Eleven percent of the children were classified as
having low work capacities. Nineteen percent of the
children were greater than 20% body fat and 10.6% were
greater than 25% body fat. Elevated cholesterol levels (> 200mg percent/100milliliters) were observed in 10.5% of the
children and elevated triglycerides (> 100mg percent/100milliliters) were found in 18% of the children.
Twenty-five percent of the children had a family history of
cardiovascular disease.

Krahnenbuhl, Pangrazi, Petersen, Burkett, and
Schneider (1978) examined the relationship between VO_2_max
values obtained from a treadmill test and timed distance
runs of 800, 1200, and 1600 meters. The purpose was to
determine the validity of using the runs to predict
cardiorespiratory fitness. Subjects were 69 male and 48
female first, second, and third grade children. The order of the tests was randomly assigned to the subjects and they completed one run each week. The treadmill test consisted of a speed set at 115 meters per minute with the grade at 0% for the first four minutes. The grade was increased by two percent every minute thereafter until subject was unable to continue. The 1600 meter run was the best predictor of VO2max. The mean VO2max for males was 45.2 ± 6.4 milliliters per kilogram per minute and for females was 41.2 ± 6.5 milliliters per kilogram per minute. The difference was significant. Plateaus were observed in 71% of the males and 70.8% of the females.

Plateaus were not observed at such a high percentage when Cunningham, VanWaterschoot, Paterson, Lefcoe, and Sangel (1977) attempted to determine if a true plateau could be attained in young boys. The subjects were 10 year old hockey players (n=66). The boys were tested during midseason (T1) and postseason (T2). The treadmill test was begun at a speed of 4.1 miles per hour and 0% grade. The grade was increased by 2.5% every 2 minutes until exhaustion. After testing the subjects were grouped according to whether or not a plateau in VO2 had been attained. The groups were: no plateau, plateau in T1 or T2, and plateau in T1 and T2. It was observed that only 38% of the subjects reached a plateau. There were no significant differences in any of the groups' mean VO2max
values at either testing time. This reflects that the attainment of a plateau in boys of this age is not necessary for establishment of VO2max.

The subjects utilized by Skinner, Bar-Or, Bergsteinova, Bell, Royer, and Buskirk (1971) were 83 boys and 61 girls ages 6 to 15 years. Each subject was randomly assigned to perform one of the three treadmill tests for elicitation of VO2max. All tests included a three minute warmup at 7.5% grade and 3.5 miles per hour. Test A was begun at 10% grade and 3.5 miles per hour. There was a 2.5% increase in grade every 2 minutes until exhaustion. Test B was the same as Test A except grade increased 2.5% every 3 minutes instead of every 2 minutes. Test C consisted of the subjects walking for 4 minutes at 15% grade and 3.5 miles per hour then rest followed by a rest for 10 minutes. Every 4 minutes the grade was increased by 2.5% with speed maintained at 3.5 miles per hour until exhaustion. The girls' VO2max values were: Test A - 43.0 ± 6.9 milliliters per kilogram per minute; Test B - 45.7 ± 5.1 milliliters per kilogram per minute; and Test C - 44.8 ± 6.2 milliliters per kilogram per minute. The boys' VO2max values were: Test A - 51.6 ± 7.0 milliliters per kilogram per minute; Test B - 50.0 ± 5.5 milliliters per kilogram per minute; and Test C - 53.0 ± 4.3 milliliters per kilogram per minute. Four age groups were established between 6 and 15 years and similar VO2max values were found
in all groups for the 3 tests. From the data, the authors identified that a speed of 3.4 miles per hour requires 6 to 8 year old children to walk inefficiently and suggest that possibly a 3 miles per hour speed would be better.

Paterson, Cunningham, and Donner (1981) were also concerned about the speed of the treadmill when studying VO$_2$max in 8 boys 10 to 12 years old. They examined at attainment of a plateau in oxygen uptake using three different treadmill speeds. Each subject completed nine maximal tests, three for each protocol. All protocols were continuous with an initial grade of 0% and increases of 2.5% every 2 minutes, but using different speeds. The treadmill speeds were 3.4 miles per hour walking, 4.1 miles per hour jogging, and 4.9 miles per hour running. The results revealed the walking test elicited a mean VO$_2$max of 55.5 ± 5.0 milliliters per kilogram per minute, the jogging test a mean of 57.9 ± 4.4 milliliters per kilogram per minute, and the running test a mean of 59.5 ± 5.4 milliliters per kilogram per minute. The differences were only significant between the walk and run protocols. Maximal values were not elicited during the walk test, therefore, it may not be appropriate to use it to measure VO$_2$max in children. In nine walking tests, five jogging tests, and seven running tests plateaus in oxygen uptake were attained. The authors suggest that a discontinuous test may be more reliable than a continuous test in
determining maximum oxygen uptake in children since a plateau is apparent in a greater proportion of subjects using a discontinuous protocol. They did indicate that the highest VO₂ measured (peak VO₂) using the jogging or running protocol was as consistent as the VO₂max measurement observed in adult groups. It appears that the motivation of young boys for maximal exercise is stable and VO₂max can be assumed without need for a plateau in oxygen consumption.

Interest in the criteria for the achievement of VO₂max lead Sheehan, Rowland, and Burke (1978) to utilize four different treadmill protocols for elicitation of VO₂max in 16 boys ages 10 to 12 years. They were tested on the treadmill on four different occasions with 7 to 10 days between tests. The continuous walking test involved subjects walking at three miles per hour and six percent grade. Grade was increased two percent every three minutes and speed remained constant. For the continuous running protocol, speed was constant at five miles per hour and grade started at zero percent. Grade was increased two percent every three minutes. In the intermittent running test, subjects ran at a constant speed of five miles per hour at two percent grade with a two percent grade increase every three minutes. The subjects walked at 2.5 miles per hour for the 3 minute rest period. The continuous running while holding handrails protocol consisted of a constant
speed five miles per hour and four percent grade with a grade increase of two percent every minutes. The three running tests elicited significantly higher VO₂max values compared with the continuous walking protocol, but did not differ significantly from each other. A plateau in VO₂ was obtained more often in the running protocols with the intermittent running protocol having 69% of the subjects reaching a plateau compared to 56% of the subjects in the continuous test. The mean VO₂max values were: continuous walk - 43.1 ± 6.1 milliliters per kilogram per minute; continuous run - 47.8 ± 4.2 milliliters per kilogram per minute; intermittent run - 48.8 ± 5.0 milliliters per kilogram per minute; and the handrail run - 46.7 ± 4.3 milliliters per kilogram per minute. The differences were not significant.

Ferrar (1985) found a significant difference between VO₂max values elicited from continuous and discontinuous treadmill protocols in the lab where the present study was completed. Thirteen females with a mean age of 8.88 ± .82 years were tested on both a continuous and discontinuous treadmill protocol. The continuous test utilized a constant speed of 4.1 miles per hour and began with a grade of 0% with a 2.5% increase every 3 minutes until exhaustion. The discontinuous test also utilized a constant speed of 4.1 miles per hour and began at 0% grade. A five minute rest period followed each three minute
workload. The grade was increased by 2.5% every 3 minutes. This was continued until subject was exhausted or a plateau (2.1 milliliters per kilogram per minute increase in VO₂ or less) between consecutive workloads was attained. The mean VO₂max for the continuous protocol was 47.49 ± 5.74 milliliters per kilogram per minute and for the discontinuous protocol was 51.76 ± 6.22 milliliters per kilogram per minute. The difference was significant. Plateaus in VO₂ were observed in only 2 of the 13 during the continuous test, whereas, 11 of the 13 subjects reached a plateau during the discontinuous test. The current study is a replication of this study since there was a constant error built into the metabolic measurement system resulting in inflated VO₂max values and reduced respiratory exchange ratios.

Summary

Maximal oxygen uptake or VO₂max is attained when two consecutive measurements separated by a 2.5% grade increase differ by 2.1 milliliters per kilogram per minute or less are observed (Taylor et al. 1955). Both cardiac output and A-VO₂ difference limit VO₂max with cardiac output probably being the most important. It was found that after maximum heart rate is attained it appears oxygen uptake continues to rise. The prediction of VO₂max from maximum heart rates can therefore underestimate VO₂max
(Mitchell et al. 1957). The time for establishment of a plateau in VO\textsubscript{2} depends on the workload. For lighter exercise the workload should last at least five minutes while heavier exercise could result in maximum values after one minute of exercise (Astrand & Saltin 1961).

The bicycle ergometer and the treadmill have been utilized most extensively when measuring VO\textsubscript{2}max. Consistently, VO\textsubscript{2}max obtained from treadmill tests are higher than those obtained from the bicycle ergometer tests (Glassford et al., 1964; Hermansen & Saltin, 1969; McArdle & Magel, 1970; Miyamura & Honda, 1972; McKay & Banister, 1976; Keren et al., 1980).

The two main categories of protocols used for elicitation of VO\textsubscript{2}max are continuous or discontinuous. The Froelicher et al. (1974) study was the only one reviewed that found significant differences in VO\textsubscript{2}max values obtained from a continuous and discontinuous protocols using adults. When using children as subjects, Ferrar (1985) found significantly higher VO\textsubscript{2}max values from the discontinuous compared to the continuous test. Ferrar (1985) was the only study reviewed that used young girls as subjects.

The criteria for attaining maximal oxygen uptake is a plateau in VO\textsubscript{2} with increasing workloads is seen less in children than in adults. Cunningham et al. (1977) had only 38% of his subject attain plateaus. Paterson et al. (1981)
felt that the discontinuous test was better for attaining a plateau in VO₂, but also felt it may be unrealistic for children to attain a plateau. This was in agreement with Ferrar (1985) since only 2 of the 13 subjects on the continuous attained a plateau and 11 of the 13 subjects on the discontinuous attained a plateau.
CHAPTER III

METHODS AND PROCEDURES

Information regarding the subjects, facilities, equipment, testing procedures and the statistical analyses are presented in this chapter.

Subjects

The subjects were 14 prepubescent females ages 8, 9, or 10 years from Colman, South Dakota. The subjects were recruited by the researcher to take part in a study that compared VO₂max values elicited from continuous and discontinuous treadmill protocols. The researcher taught in the Colman School during the previous two years and had the subjects in her physical education classes. The researcher went to the Colman School and asked for volunteers to participate in the study. A meeting was held with the parents of the subjects before the testing began to explain procedures, sign the informed consent form (Appendix A), set up testing times, and make transportation arrangements. The mean weight of the subjects was 30.6 ± 4.7 kilograms with a range of 23.2 to 41.5 kilograms. The mean height was 134.2 ± 4.8 centimeters with a range of 121.0 to 142.0 centimeters. The mean age of the subjects
was 8.9 ± .44 years with a range of 8.3 to 10.0 years. These descriptive statistics are presented in Table 1.

Facilities

The Human Performance Lab, located in the Stanley J. Marshall Health, Physical Education, and Recreation Center at South Dakota State University, was the site of all the testing for the elicitation of maximum oxygen uptake. The air temperature in the lab was maintained at a constant 21 degrees Centigrade. The barometric pressure ranged from 707 to 725 millimeters of mercury. The relative humidity ranged from 38% to 50%. These variations were taken into account for all calculations of VO2max and should not have affected the results of this study.

Equipment

All testing was completed on a motor-driven treadmill with maximal oxygen uptake determined using the open circuit method. The treadmill was a Quinton Q65 treadmill with a 645 controller which facilitated the pre-programming of testing protocols. A Hans-Rudolph two-way
TABLE 1

Descriptive Statistics of Subjects

<table>
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<th>Variable</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Range</th>
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</thead>
<tbody>
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<td>Weight (kg)</td>
<td>30.6</td>
<td>4.7</td>
<td>23.2 - 41.5</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>134.2</td>
<td>4.8</td>
<td>121.0 - 142.0</td>
</tr>
<tr>
<td>Age (years)</td>
<td>8.9</td>
<td>0.44</td>
<td>8.3 - 10.0</td>
</tr>
</tbody>
</table>

Instruments were seven liter mixing chamber with samples drawn at a flow rate of 500 milliliters per minute. An Ametek CD-2A carbon dioxide analyzer and an exact 8-3A oxygen analyzer were used for determination of the composition of the expired air. The temperature was read from a thermocouple placed in the nasal cavity. The relative humidity was determined from a sling psychrometer from the University of Pittsburgh, Pennsylvania. The thermocouples were calibrated before and after each test with known concentrations of the certified by the manufacturer. In addition, four electrodes were placed on the nasolabial and auricular areas. Heart rate and systolic blood pressure were monitored on lead II using a Hewlett-Packard 700 Monitor, Series 1011. All physiological data were reduced using the Hewlett-Packard Analytical System (500-5) on a digital computer. The carbon dioxide concentration of the inspired air was generated, and the expired gas carbon dioxide concentration was determined by using the equations of all mathematical models.
valve model 2700 with a headgear support and mouthpiece was used to facilitate expired gas collection. A spring-type nose clip was used to ensure respiration through the valve system. Inspired air was measured by a Rayfield RAM-9200 air flow meter. Expired air passed through a Physio-Dyne Instruments seven liter mixing chamber with samples drawn through oxygen and carbon dioxide analyzers at a flow rate of 500 milliliters per minute. An Amatek CD-3A carbon dioxide analyzer and an Amatek S-3A oxygen analyzer were used for determination of the composition of the expired air. The barometric pressure was measured on a Nova barometer made by Princo of Southampton, Pennsylvania and the temperature was read from the thermometer on this same instrument. The relative humidity was determined from a sling psychrometer from Bacharach of Pittsburgh, Pennsylvania. The analyzers were calibrated before and after each test with known concentrations of gas certified by Scotts Specialty Gases, Toledo, Ohio. Four electrodes were placed on the subjects before each test using standard exercise limb lead locations. Heart rates were monitored on lead III using a Marquette Electronics ECG Monitor, Series 4000. All metabolic measurement data were reduced using the Rayfield Data Acquisition System (REP 200-C) on a Apple II+ micro computer. As this system receives constant input from the gas meter, and the oxygen and carbon dioxide analyzers during the testing calculations of all metabolic
measurement variables occur on an on-going basis. The fixed variables of barometric pressure, temperature, and relative humidity were entered into the computer prior to each test.

Testing Procedures

Familiarization Session

Prior to testing the temperature (degrees Centigrade), barometric pressure (millimeters of mercury), and relative humidity (percent) were determined and recorded and the oxygen and carbon dioxide analyzers were calibrated. The two-way valve, mouthpiece, and nose clip were sterilized prior to each test.

When the subject arrived her weight and age were recorded. The testing procedures were carefully explained and the subject was given the opportunity to ask any questions. The subject had a chance to walk on the treadmill for a several minutes in order to become acquainted with the task before testing.

Heart rate was monitored using standard limb lead exercise electrode locations. The arm electrodes were placed in the infraclavicular fossa and the leg electrodes at the level of the iliac crest on the mid-clavicular line. Each site was first wiped with rubbing alcohol and lightly abraded with fine sand paper prior to electrode placement.

When ready the subject stepped onto the treadmill
with her feet to the side of the belt. The mouthpiece, two-way valve, headgear, and nose clip were placed on the subject and adjusted. The treadmill belt was started at 1.3 miles per hour. Holding onto the rails the subject stepped onto the belt. When she could walk normally and remove her hands from the rails the test was initiated by pressing the "start exercise" button on the treadmill controller.

The familiarization test utilized the same protocol as the continuous test which employed a constant speed of 4.5 miles per hour and was begun at 0% grade. The test proceeded with a 2.5% grade increase every 2 minutes until the subject indicated she could continue no longer. Throughout the test the metabolic variables of VO₂max in liters per minute and milliliters per kilogram per minute, minute ventilation, respiratory exchange ratio, and heart rate were calculated and recorded every 60 seconds. When the subject finished the test the mouthpiece, two-way valve, headgear, and nose clip were removed. The subject walked on the treadmill for several minutes to cool down after the testing. Electrodes were removed after the cool down.

During all testing at least two investigators were always present. One investigator weighed the subject, placed electrodes, mouthpiece, two-way valve, headgear, and nose clip on the subject prior to the start of the testing.
During the test this investigator stood beside the treadmill and was responsible for monitoring the subject's progress and encouraging her. The other investigator was responsible for monitoring the equipment and recording data from the computer.

**Continuous and Discontinuous Testing Sessions**

The continuous session followed exactly the same procedures as the familiarization session. The discontinuous session was similar to the continuous session using the same speed and the same grade changes, but was different in regards to test duration. During the discontinuous test each workload (change in grade) was three minutes in duration and was followed by a five minute rest period. The workloads were continued until a plateau was reached or the subject indicated she was no longer able to continue. In order to control for a learning effect the order of the tests was randomly assigned.
Statistical Analyses

A correlated groups t-test was utilized for the determination of significant differences between VO₂max (liters per minute and milliliters per kilogram per minute), respiratory exchange ratio, and minute ventilation on the continuous and discontinuous protocols. No analysis was carried out on the heart rate data as the quality of the recording was not consistent enough to ensure accurate readings at all times. The statistical analyses were carried out following the formulae presented in Statistics for the Behavioral Sciences (pages 203-204, Jaccard, 1983). The .05 level of significance was used. The independent variable was the protocol (continuous or discontinuous) while VO₂max, RER, and VE were the dependent variables.
CHAPTER IV

RESULTS AND DISCUSSION

The information presented in this chapter are the results of continuous and discontinuous treadmill protocols used for elicitation of maximal oxygen uptake in prepubescent females. A discussion of the results will follow.

Results

Table 2 contains the means, standard deviations, and standard errors of the means for maximum oxygen uptake (liters per minute and milliliters per kilograms per minute), respiratory exchange ratio (RER), and minute ventilation (VE) for the continuous and discontinuous treadmill protocols.

Maximum oxygen uptake was expressed in both liters per minute (liters per minute) and milliliters per kilogram per minute (milliliters per kilograms per minute). It is most appropriate to use the units of liters per minute when making intraindividual comparisons and to use the units of milliliters per kilograms per minute when making interindividal comparisons. The primary purpose of this study was to look at changes within individuals and therefore more emphasis will be placed on the measure in liters per minute.
minute. Since the weight of the subjects was not different for the two tests the results are the same for both units. On the continuous protocol a mean VO$_2$max of 1.23 liters per minute was determined with a standard deviation of .16. On the discontinuous protocol a mean VO$_2$max of 1.43 liters per minute was determined with a standard deviation of .20. A significant difference at the .05 level was found between the two protocols. When expressed in milliliters per kilograms per minute the continuous protocol mean VO$_2$max was 40.7 with a standard deviation of 5.42. On the discontinuous test the mean VO$_2$max was 47.3 milliliters per kilogram per minute and a standard deviation of 7.11. This difference was also significant at the .05 level. This is shown in Table 3.

The mean respiratory exchange ratio for the continuous protocol was .99 with a standard deviation of .06. The mean respiratory exchange ratio for the discontinuous protocol was 1.01 with a standard deviation of .06. These results are presented in Table 2. At the .05 level of significance no significant difference in RER was found between the continuous and discontinuous protocols using a correlated groups t-test as shown in Table 3.

As shown in Table 2 the mean minute ventilation for the continuous test was 36.01 liters per minute with a standard deviation of 4.0 liters per minute. On the discontinuous test the mean minute ventilation was 41.1
liters per minute and a standard deviation of 6.06 liters per minute. Table 3 shows that at the .05 level there was a significant difference in VE obtained from a continuous and discontinuous treadmill tests.

Discussion

The discontinuous treadmill protocol elicited higher VO₂max values than the continuous treadmill protocol when utilizing prepubescent females as subjects in this study in both liters per minute and milliliters per kilogram per minute. The present study found a mean VO₂max of 1.23 liters per minute or 40.7 milliliters per kilograms per minute on the continuous protocol and 1.43 liters per minute or 47.3 milliliters per kilograms per minute on the discontinuous protocol. These differences were significant. This supports the findings of Ferrar (1985) who also found a significant difference in VO₂max values of prepubescent females obtained from continuous and discontinuous protocols. Ferrar (1985) reported mean VO₂max of 1.43 liters per minute and 47.49 milliliters per kilograms per minute on the continuous test and 1.55 liters per minute and 51.76 milliliters per kilograms per minute on the discontinuous test. Ferrar (1985) reported that her VO₂max values may be somewhat inflated due to a constant error in the metabolic measurement system. This could explain the differences in values between the present study
TABLE 2

Results

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*Significant at the .05 level.
and hers. Certainly both studies reflect that discontinuous testing in prepubescent females elicits higher VO₂ max values than continuous testing.

Froelicher et al. (1974) also reported results in agreement with the present study as they found that a discontinuous protocol elicited significantly higher VO₂ max values than a continuous protocol. However, Froelicher et al. (1974) used adult males as subjects. Three protocols were used to test the male adults with the Balke test (a continuous protocol) eliciting a mean VO₂ max of 42.8 milliliters per kilograms per minute, the Bruce test (a continuous protocol) a mean VO₂ max of 44.3 milliliters per kilograms per minute, and the discontinuous protocol of Taylor a mean VO₂ max of 47.4 milliliters per kilograms per minute.

Even though Ferrar (1985) and Froelicher et al. (1974) have found results similar to the present study that discontinuous protocols elicit significantly higher VO₂ max values than continuous protocols there are a number of studies which do not support this (Skinner et al., 1971; Sheehan et al., 1987; Maksud & Coutts, 1971; McArdle et al., 1973; Fardy & Hellerstein, 1978). Skinner et al. (1971) found no significant difference in VO₂ max values from two continuous protocols and one discontinuous protocol. The subjects were boys and girls ages 6 to 15.5
years. Since the present project studied girls only the 
VO₂max values for the girls will be reviewed. The two 
continuous test produced mean VO₂max values of 43.0 
milliliters per kilograms per minute and 45.7 milliliters 
per kilograms per minute. The discontinuous test VO₂max 
mean value was 44.8 milliliters per kilograms per minute. 
The present study examined girls ages 8, 9, and 10 years 
while Skinner et al. (1971) looked at a wider age range of 
girls. The results of Sheehan et al. (1987) are also not 
in support of the present study's findings. The elicited 
mean VO₂max values of 10 to 12 year old boys were 1.61 
liters per minute and 43.1 milliliters per kilograms per 
minute on the continuous walk test, 1.8 liters per minute 
and 47.7 milliliters per kilograms per minute on the 
continuous run test, and 1.83 liters per minute and 48.7 
milliliters per kilograms per minute on the intermittent 
run test. Although there were no significant differences 
in VO₂max found among the tests, the intermittent or 
discontinuous test did elicit the highest values. The 
differences between the present project and that of 
Sheehan's et al. (1987) are that boys ages 10 to 12 years 
were used by Sheehan et al. (1987) while prepubescent girls 
were utilized in the present study. It is possible that 
the response of boys and girls in this age range are 
different.
The results of the present study also do not support the findings of Maksud and Coutts (1971), McArdle et al. (1973), and Fardy and Hellerstein (1978) who found no significant differences in VO$_2$max values obtained from continuous and discontinuous protocols. An explanation for the difference in the results could be that adults were used as subjects in the above studies and the present study utilized prepubescent girls.

Normally, to assure attainment of VO$_2$max a plateau or leveling off, of VO$_2$ with an increase in grade of 2.5% needs to be observed. A 2.1 milliliters per kilograms per minute or less increase in VO$_2$ following an increase in the workload is the normal criteria for a plateau. On the continuous test in this study 8 of the 14 subjects or 57% attained a plateau according to the above criteria. This finding was not expected and is in conflict with a number of studies (Froelicher et al., 1974; Cunningham et al., 1977; Krahentbuhl et al., 1978; Paterson et al., 1981; Ferrar, 1985).

Froelicher et al. (1974) found only 17% achieving a plateau on the Balke continuous test and 7% on the Bruce continuous test. Adult males were used as subjects in the study as well as different protocols compared to the present study. These could be the reasons for the conflicting results.
Cunningham et al. (1977) observed a greater percentage of subjects attaining plateaus in continuous tests than Froelicher et al. (1974), but not as great a percentage as the present study. Thirty-eight percent of the 66 boys who were 10 years old demonstrated the criteria for a plateau in VO₂. The present study used 8, 9, and 10 year girls. Except for a faster speed in the present study (4.5 mph versus 4.1 mph) the protocols of the two studies were the same.

The results from Paterson et al. (1981) are also in opposition with those of this study. Plateaus were observed in 9 of 24 continuous walk tests or 38%, 5 of 24 continuous jog tests or 21%, and 7 of 24 run tests or 29%. All of these percentages were lower than the present study. The protocols differed in speed only as the grade and increases in grade were identical. The walk (3.4 miles per hour) and the jog (4.1 miles per hour) tests were slower than the present study and the run test (4.9 miles per hour) was faster. The subjects were also different as Paterson et al. (1981) used 10 to 12 year old boys and the present study used 8 to 10 year old girls. Ferrar (1985) reported 2 of 13 subjects or 15% attaining a plateau on the continuous test which is a much lower percentage than the present study. The reasons for this conflict is unclear since the same protocol was used except for an increase of speed to 4.5 miles per hour instead of 4.1 miles per hour.
used by Ferrar (1985). Of the four studies in conflict with the percentage of plateaus attained on a continuous test Krahenbuhl et al. (1978) was the only one to find a higher percentage of plateaus on a continuous test. A different protocol was used compared to the present study and utilized 6 to 9 year old boys and girls as subjects. Krahenbuhl et al. (1978) used a speed of 115 meters per minute and 0% grade for 4 minutes then increased the grade by 2.5% per minute while the speed remained constant. It was observed that 49 of 69 boys or 71% attained a plateau and 34 of 48 girls or 71% attained a plateau. This is in conflict with the present study as only 57% reached a plateau. While these results appear to be somewhat higher than those of the present study they also reinforce the present study's finding by showing that with young children it is possible to see a plateau in more than half of the subjects on a continuous test.

In the present study the discontinuous protocol elicited only 5 plateaus of the 14 subjects or 36%. This was clearly not expected and does not support the findings of Ferrar (1985) who had 11 of 13 subjects attain a plateau on the discontinuous protocol. It is unclear why this conflict exists since the protocols were the same except for a small increase in speed (4.5 miles per hour) for the present study. Froelicher et al. (1974) who used adults as subjects are also not in agreement with this result. It
was observed by Froelicher et al. (1974) that a greater percentage (33%) of the subjects demonstrated a plateau during the discontinuous Taylor protocol, whereas, only 17% during the continuous Balke test and 7% during the continuous Bruce test met the criteria for a plateau.

The intermittent run produced the highest percentage of plateaus in the Sheehan et al. (1987) study. It was observed that 68.7%, which was a greater percentage than for the other three continuous protocols, reached a plateau on the intermittent run test. The discontinuous test of the present study and Sheehan's et al. (1987) do differ. The Sheehan et al. (1987) study utilized a speed of 5 miles per hour and 2% grade increases every three minutes, whereas, this study used 4.5 miles per hour for the speed and 2.5% grade increase every 3 minutes. The rest periods for the protocols differed also. The rest periods consisted of walking on the treadmill at 2.5 miles per hour for 3 minutes. The present study had the subjects rest for five minutes with no exercise. Both of these differences could have caused the difference in the test results.

The continuous test of the present study elicited maximal oxygen uptake values ranging from .9 to 1.4 liters per minute and 27.6 to 47.4 milliliters per kilograms per minute. The mean $\text{VO}_2\text{max}$ was $1.23 \pm 0.16$ liters per minute and $40.7 \pm 5.42$ milliliters per kilograms per minute. The
present study's discontinuous test elicited maximal oxygen uptake values of 1.0 to 1.7 liters per minute and 30.3 to 58.5 milliliters per kilograms per minute. The mean VO$_2$\textsubscript{max} for the discontinuous test was $1.43 \pm 0.2$ liters per minute and $47.3 \pm 7.11$ milliliters per kilograms per minute.

These maximal oxygen uptake values are similar to those found in several studies using a similar population (Skinner et al., 1971; Krahenbuhl et al., 1978). Skinner et al. (1971) reported a range of 43.0 to 45.7 milliliters per kilograms per minute on the continuous test which is higher than the present study's range. Although Skinner's et al. (1971) values were higher than the present they are still very close. On the discontinuous test Skinner's et al. (1971) results were lower ($44.8 \pm 4.3$ milliliters per kilograms per minute) than the present study's results ($47.3 \pm 7.1$ milliliters per kilograms per minute), but are actually very similar. The age range for the girls in Skinner's et al. (1971) study (6 to 15.5 years) was larger than the present study (8 to 10 years).

Also in support of the results of this study is Krahenbuhl et al. (1978) who reported a mean VO$_2$\textsubscript{max} value of $41.2 \pm 6.5$ milliliters per kilograms per minute for 6 to 9 year old girls. This is very comparable to the results of the present study of $40.7 \pm 5.42$ milliliters per kilograms per minute.
A couple of studies whose results conflict with the present study are Wilmore and Sigerseth (1966) and Ferrar (1985). Wilmore and Sigerseth (1966) used a bicycle ergometer as the mode of testing and their VO$_2$max values were higher than the present study's results. They found VO$_2$max values of $1.73 \pm 0.07$ liters per minute for 7 to 9 year old girls and $1.68 \pm 0.1$ liters per minute for 10 to 11 year old girls. This is difficult to explain as normally the bicycle ergometer will elicit lower VO$_2$max values than the treadmill.

There is also conflict with the present study and the study it is replicating (Ferrar, 1985). The values from the Ferrar (1985) study may be somewhat inflated since the laboratory equipment was not functioning properly. On the continuous test Ferrar's (1985) results ranged from 40.6 to 56.33 milliliters per kilogram per minute with a mean of $47.49 \pm 5.74$ milliliters per kilogram per minute which are higher than those for the present study. The discontinuous test of Ferrar's (1985) elicited results ranging from 40.32 to 60.47 milliliters per kilogram per minute with a mean of $51.76 \pm 6.22$ milliliters per kilogram per minute which are also higher than the present study's findings.

The respiratory exchange ratios of the present study were not significantly different when obtained from the continuous or discontinuous protocol. The continuous
test RER was .99 ± .06 and the discontinuous test RER was 1.01 ± .06. Ferrar's (1985) RER values are thought to be somewhat deflated. The RER for the continuous test was .82 ± .04 and the discontinuous test .81 ± .04 for the Ferrar (1985). However, two other studies (Krahenbuhl et al. 1978 and Paterson et al. 1981) had results that were comparable to the RER values of this study. For a continuous test administered to 6 to 9 year girls, Krahenbuhl et al. (1978) recorded a mean RER of 1.06 ± .05, whereas, the present study's RER was .99 ± .06 for the continuous test. Although Paterson et al. (1981) used 10 to 12 year old boys, they found similar results for RER compared to the present study's results. The RER values included .98 ± .07 for the continuous walk, 1.00 ± .02 for the continuous jog, which is what the present study used, and .99 ± .07 for the continuous run. The present study's RER of .99 ± .06 is essentially the same as the continuous jog value of 1.00 ± .02.

The minute ventilation values from this study were significantly different on the continuous and discontinuous protocols. The continuous protocol elicited a mean VE of 36.01 ± 4 liters per minute and the discontinuous test 41.1 ± 6.06 liters per minute. Krahenbuhl et al. (1978) used girls of similar ages (6 to 9 years) and observed a similar
VE of 40.5 ± 10 on a continuous test. This was the only study reviewed that used similar aged girls and reported VE.

In this study the discontinuous protocol elicited significantly higher VO₂max values in both milliliters per kilogram per minute and liters per minute than the continuous protocol. The RER values demonstrate that the subjects were working at maximum effort as their RERs were close to 1.00 or over. The discontinuous protocol elicited significantly higher VE values than the continuous protocol.

During the familiarization session, the subject was informed about the equipment and procedures utilized during the testing. Also during this session the subject completed a continuous treadmill test. The order of the continuous and discontinuous tests were randomly assigned. Before either the continuous or discontinuous tests were performed procedures were explained and questions answered.

The continuous test was administered at a constant speed of 6.3 mph. The initial grade was 0% with 0.1% increase every 3 minutes. This procedure continued until the subject could no longer continue. A constant speed of 6.3 mph was also used for the discontinuous test. The initial grade was 0% and increased by 1.5% every 3 minutes. A five minute rest period followed each work phase. This procedure was continued until the subject
CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The purpose of this study was to compare continuous versus discontinuous treadmill protocols for the elicitation of maximum oxygen uptake in 14 prepubescent females. Each subject participated in a familiarization session as well as continuous and discontinuous testing sessions. During the familiarization session, the subject was informed about the equipment and procedures utilized during the testing. Also during this session the subject completed a continuous treadmill test. The order of the continuous and discontinuous tests were randomly assigned. Before either the continuous or discontinuous tests were performed procedures were explained and questions answered.

The continuous test was administered at a constant speed of 4.5 mph. The initial grade was 0% with 2.5% increase every 2 minutes. This procedure continued until the subject could no longer continue. A constant speed of 4.5 mph was also used for the discontinuous test. The initial grade was 0% and increased by 2.5% every 3 minutes. A five minute rest period followed each three minute work period. This procedure was continued until the subject
could no longer continue or until a plateau in VO2 was attained.

All three testing sessions were completed on a motor-driven treadmill. A two-way valve with headgear and mouthpiece facilitated expired gas collection. Inspired air was measured by an air flow meter. Expired gases passed through a mixing chamber and were sampled through carbon dioxide and oxygen analyzers. All metabolic measures were calculated using a computerized measurement system.

The statistical analysis used for determination of significant differences was a correlated groups t-test. The correlated groups t-test was completed on the dependent variables of VO2max in liters per minute and milliliters per kilogram per minute, respiratory exchanged ratio, and minute ventilation. The .05 level of significance was utilized to determine significance of the results. The discontinuous test exhibited significantly higher VO2max values in both liters per minute and milliliters per kilogram per minute. There was no significant difference in respiratory exchange ratio between the continuous and discontinuous protocols. A significant difference was observed in minute ventilation between the two protocols with the discontinuous test eliciting the higher values.

Conclusions
A discontinuous protocol elicited significantly higher maximum oxygen uptake values in this study than the continuous protocol. This study supports that children are capable of a maximum effort as their RER's approached 1.00, the value commonly used in adult studies as indicative of a maximal effort. Using traditional criteria there were more plateaus attained in the continuous test than in the discontinuous test. This was not anticipated and may be indicative that these may not be appropriate for children.

Recommendations for Further Study

It is recommended that the present study be repeated adding boys as subjects and have four testing groups (continuous protocol boys and girls and discontinuous protocol boys and girls) to determine if boys and girls respond in a similar manner to VO2max testing. To determine if cardiovascular risk factors are developing in our children. Each child would complete a medical and physical evaluation to assess the prevalence of cardiovascular risk factors. The items to be used for assessment would be a blood test for serum cholesterol and triglycerides, a work capacity test, body composition, and a family history questionnaire.
Bibliography


Stamford, B. (1984). Exercise and longevity. The Physician and Sportsmedicine, 10(8), 75-8


Appendix A

INFORMED CONSENT FORM

Dear Parents,

My name is Monica Severson and I am currently a master's degree student in the Department of Health, Physical Education, and Recreation at South Dakota State University. I am attempting to recruit 30 boys and girls ages 8, 10, and 12 years to participate in a study of maximal oxygen uptake measurement procedures. Since I am familiar with the students and parents of the Colman School, I have decided that it would be beneficial to do my study on these children. As a participant in the study you and your child can expect to find out his/her current cardiovascular fitness level.

Maximal oxygen uptake is the best measure of cardiovascular fitness. Each child will run on a motor-driven treadmill during three testing sessions. Each session will be approximately 1 hour in length and will be completed at least 48 hours apart. During the first session the child will become familiarized with the equipment, procedures, and how to run on the treadmill. During the second and third sessions, each child will perform two different maximal exercise test protocols for the determination of maximal oxygen uptake.

During one of the maximal exercise testing
sessions, each child will warm-up for 5 minutes and will have a 10 minute rest period afterwards. After the rest period, each child will run at a set speed for three, 3 minute period with each period being separated by a 10 minute rest. The grade of the treadmill will be increased each period. During the other maximal exercise testing session, each child will run at a comfortable speed which will remain constant throughout the test. The grade of the treadmill will be increased every 3 minutes (as if the child is running uphill). Each child's heart rate will be monitored throughout the testing and there will be constant supervision and encouragement. Dr. Jack Ewing, an exercise physiologist at SDSU, will be supervising each testing session.

The child will be encouraged to give a maximal effort (run as long as possible), however, the child may stop at any time. The risk of injury in this type of testing is minimal and all precautions to prevent injury will be taken. The child may withdraw from the study at any time. It will be important that the child abstain from eating for 2 hours prior to the testing. The testing will be completed at the Human Performance Lab at SDSU.

Signature of the Parent ________________________________
Signature of the Investigator ____________________________
Date ________________________________
## Appendix B

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Note. Dis=Discontinuous Test; Con=Continuous Test; V02(ml)=VO2max in ml/kg/min; V02(l)=VO2max in 1/min; RER=Respiratory Exchange Ratio; VE=Minute Ventilation in 1/min
COMPARISON OF CONTINUOUS AND DISCONTINUOUS TREADMILL PROTOCOLS FOR ELICITATION OF MAXIMUM OXYGEN UPTAKE IN PREPUBESCENT FEMALES

BY

MONICA JEAN SEVERSON

A thesis submitted in partial fulfillment of the requirements for the degree Master of Science
Major in Health, Physical Education, and Recreation
South Dakota State University
1988
COMPARISON OF CONTINUOUS AND DISCONTINUOUS TREADMILL PROTOCOLS FOR ELICITATION OF MAXIMUM OXYGEN UPTAKE IN PREPUBESCENT FEMALES

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Dr. Jack Ewing, Associate Professor, Thesis Advisor and HPER Graduate Coordinator

Dr. James E. Lidstone, Associate Professor, HPER Research Coordinator

Dr. Harry Forsyth, Professor and Head, Department of HPER
DEDICATION

This thesis is dedicated to my husband Scott for all his love, support, and patience during my year in graduate school. Without him it would have been more difficult and less enjoyable.
ACKNOWLEDGEMENTS

The author would like to thank Dr. Jack Ewing for all his time and effort during the writing of this thesis. A special thanks to Wally Cantrell for his help and guidance during the data collection. Thanks to Dr. Jim Lidstone for initiating my interest in research. The author would like to acknowledge her parents for their continuing support of her as she furthers her education.
Severson, M. J. *Comparison of continuous and discontinuous treadmill protocols for elicitation of maximum oxygen uptake in prepubescent females*. Master of Science, 1988, 85 p. (J.L. Ewing)

A continuous and discontinuous treadmill test was utilized for the elicitation of VO\textsubscript{2max} in 14 females ages 8, 9, and 10 years. The first visit to the lab was a familiarization session with equipment and procedures explained and a continuous treadmill test completed. The order of the next two sessions was randomly assigned and was either a continuous or discontinuous treadmill protocol. Both tests were run at 4.5 mph and began with a 0% grade. A grade increase of 2.5% occurred for each workload until the subject indicated she could no longer continue. The duration of each workload was 2 minutes on the continuous protocol and 3 minutes on the discontinuous. A five minute rest followed each three minute workload in the discontinuous protocol. From a correlated groups T-test it was determined that a significant difference existed in VO\textsubscript{2max} in both liters per minute and milliliters per kilogram per minute obtained from continuous and discontinuous treadmill protocols. The mean VO\textsubscript{2max} of the continuous test was $1.23 \pm 0.16$ liters per minute and $40.7 \pm 5.42$ milliliters per kilogram per minute and the discontinuous test was $1.43 \pm 0.2$ liters per minute and $47.3 \pm 7.11$ milliliters per kilogram per minute.
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CHAPTER I

INTRODUCTION

While America has been involved in a so-called fitness "boom" for over a decade many of America's children have not been reaping the benefits. In the 1960's only about 24% of all adults exercised, but recent figures show about 50% to 60% of adults are now exercising (Corbin & Lindsey, 1988). Although a majority of adults feel exercise is important for good health they are not motivating their children to be physically active. According to the National Children and Youth Fitness Study more than one-half of school age children are not considered physically fit and do not exercise enough (Ross, Dotson, Gilbert, & Katz, 1985).

The fitness "boom", along with our increased knowledge of the importance of regular exercise, has had an impact on, but has not prevented, cardiovascular disease. Heart disease is still the leading cause of death in the United States (Corbin & Lindsey, 1988). The risk factors of cardiovascular disease in children have been shown to include obesity, hypertension, elevated serum cholesterol and triglycerides, and physical inactivity (Gilliam, Katch, Thorland, & Weltman, 1977). Gilliam et al., (1977) found 19.1% of the 47 children they studied were obese, 10% had
elevated serum cholesterol; 18% had elevated triglycerides, and 11% had low work capacities. While identification of risk factors has been heavily stressed in adults, it is apparent that these risk factors are being identified during adolescence or even childhood. If these risks factors are prevalent in children there is justified concern for how unhealthy the adult population may be in the future.

It is believed that physical activity is a protection against cardiovascular disease and regular exercise is very beneficial (Pollock, Wilmore, & Fox, 1978). These benefits include increased work capacity, cardiorespiratory fitness, and muscular strength and endurance, all of which can decrease the risk of disease. In addition, physical activity can help regulate blood pressure, reduce and control weight, regulate metabolism, and prevent loss of bone mass. Physical activity can also provide an outlet for tension and mental fatigue, improvements in posture and self-image, and a sense of "feeling good" (Pollock et al., 1978; Corbin & Lindsey, 1988).

Physical fitness is the ability of the heart, blood vessels, lungs, and muscles to work their best to meet the challenges of life (Corbin & Lindsey, 1988). These challenges could range from shoveling snow, to touching one's toes, to running a marathon. The major components of physical fitness are body composition, flexibility,
strength, muscular endurance, and cardiovascular endurance (Pollock et al., 1978). Cardiovascular endurance is frequently considered the most important aspect of physical fitness because those who possess it are likely to decrease their risk of coronary heart disease. Cardiovascular endurance is the ability of the heart, blood vessels, blood, and respiratory system to supply oxygen to the muscles during sustained exercise (Corbin & Lindsey, 1988). If a person has good cardiovascular endurance, they can persist in physical activity for relatively long periods of time without undue stress.

To determine a person's cardiovascular endurance, the maximum amount of oxygen that a person is capable of using during strenuous exercise is measured (VO2max). VO2max is considered to be the best indicator of aerobic work capacity and is limited by the capacity of the cardiorespiratory systems to deliver oxygen to the tissues (Miyamura & Honda, 1972). To measure maximum oxygen uptake, researchers have used modes of exercise in which the workload can be controlled. The motor-driven treadmill and the bicycle ergometer are two commonly used modes. Controlling the workload involves regulating the speed and grade of the treadmill or the resistance and cadence of the bicycle ergometer. VO2max is attained when the workload is so high that the subject can no longer continue.

Individuals of all ages and both sexes have been
tested for VO₂ max. Optimal procedures for determining VO₂ max have been identified but most of the research has been carried out with college-age males as subjects. Studies examining the measurement of maximum oxygen uptake in children have been completed (Wilmore & Sigerseth, 1966; Skinner, Bar-Or, Bergsteinova, Bell, Royer, & Buskirk, 1971; Nagle, Hagberg, & Kamei, 1977; Cunningham, Van-Waterschoot, Paterson, Lefcoe, & Sangal, 1977; Krahenbuhl, Pangrazi, Petersen, Burkett, & Schneider, 1978; Paterson, Cunningham, & Donner, 1981; Ferrar, 1985; Sheehan, Rowland, & Burke, 1987) although there is still some question as to the most appropriate protocol (Skinner et al., 1971; Shephard, 1971; Paterson et al., 1981).

Questions encountered in the assessment of VO₂ max in children may be related to unrealistic VO₂ max attainment criteria, inappropriate test protocols, physiological and psychological differences in exercise responses of children compared to adults, and the identification of a maximal effort in children (Paterson et al., 1981). In order to determine whether maximum oxygen uptake has been attained during a test the normal criteria is the establishment of a plateau or leveling off in oxygen uptake with an increase in workload. A true plateau has been difficult to observe on a regular basis in children. Only 2 of the 13 subjects met the criterion for a plateau during the continuous test in Ferrar's (1985) study. Also using a continuous test,
Paterson et al. (1981) had only 24 of the 72 tests administered result in a plateau in VO$_2$. Cunningham et al. (1977) found a plateau in only 38% of their subjects using a continuous test. However, Krahenbuhl et al. (1978) used a continuous protocol and observed that 83 of the 117 subjects or 71% attained a plateau in oxygen consumption. When a plateau is not attained it may be more appropriate to use the term peak VO$_2$.

Commonly used treadmill protocols have been designed for adults and may not be appropriate for use with children. The physiological and psychological differences between adults and children may require a modification of the testing protocol for elicitation of VO$_2$max in children. Many researchers have been concerned with the reliability of the results from using the same protocols on children that are used to test adults (Skinner et al., 1971; Paterson et al., 1981; Shephard, 1984). Since children may not be highly motivated to give a maximal effort it may be more difficult to measure their maximum oxygen uptake.

The bicycle ergometer and the treadmill are the most often used modes for the assessment of VO$_2$max. The treadmill appears to elicit the highest VO$_2$max values (Hermansen & Saltin, 1969; Miyamura & Honda, 1972; McArdle, Katch, & Pechar, 1973). A variety of treadmill protocols exist with the two main classifications being continuous or discontinuous. A treadmill test is continuous when there
is a gradual transition from low intensity to maximal work capacity with no rest periods. A treadmill test is discontinuous when there is a gradual transition from low intensity to maximal work capacity that alternates work and rest periods. Therefore, the major difference between the protocols is that the continuous test has no rest periods and the discontinuous test has a rest period after each workload.

Deciding whether to use a continuous or a discontinuous protocol can be a concern for the researcher. The continuous protocol has advantages as does the discontinuous protocol. Although the continuous protocol needs less time to complete, a plateau in oxygen consumption is not always attained. Discontinuous protocols require more time to complete, but subjects may not need as much motivation to reach their maximal capacity. During a discontinuous test the subject can be encouraged during the rest periods and while on the treadmill, whereas during a continuous test they can only be encouraged while on the treadmill. It takes a highly motivated subject to give a maximal effort on a continuous test. In many studies using adults no significant differences in VO₂max have been observed when elicited by continuous and discontinuous protocols (Maksud & Coutts, 1971; Skinner et al., 1971; McArdle et al., 1973, Fardy & Hellerstein, 1978). The same results have been found with boys as subjects by Sheehan et
al. (1987). However, Ferrar (1985) did find a significant difference in VO$_2$max values obtained from continuous and discontinuous protocols using 8, 9, and 10 year old females as subjects. While the results of this study were thought to be reliable, due to a constant error in the measurement system there is concern about the validity of the results and it, therefore, should be replicated.

Testing for maximum oxygen uptake is needed to assess the physical fitness of our children. While treadmill protocols which accurately determine VO$_2$max have been designed, assessed, and validated for adults (Maksud & Coutts, 1971; McArdle et al., 1973; Frolicher et al., 1974; McKay & Banister, 1976; Fardy & Hellerstein, 1978) there is still some question regarding which maximum oxygen test is best used for children. More research needs to be completed utilizing children as subjects to develop the most appropriate protocol for eliciting VO$_2$max. Therefore, this study, which is a replication of the Ferrar (1985) study, was undertaken to further examine VO$_2$max testing in children.

Statement of the Problem

The purpose of this study was to compare continuous and discontinuous treadmill protocols for the elicitation of maximum oxygen uptake in 8, 9, and 10 year old females.
Hypotheses

The research hypotheses tested were:

1. The maximum oxygen uptake of prepubescent females in liters per minute measured during a continuous treadmill protocol is not different from those values obtained from a discontinuous treadmill protocol.

2. The maximum oxygen uptake of prepubescent females in milliliters per kilograms per minute measured during a continuous treadmill protocol is not different from those values measured during a discontinuous treadmill protocol.

3. The respiratory exchange ratio of prepubescent females at VO_{2}max measured during a continuous treadmill protocol is not different from those values measured during a discontinuous treadmill protocol.

4. The volume expired of prepubescent females at VO_{2}max measured during a continuous treadmill protocol is not different from those values measured during a discontinuous treadmill protocol.

Definition of Terms

Continuous Treadmill Test: A protocol for the elicitation of VO_{2}max with progressively increasing workloads with no rest periods (Lamb, 1978).
**Discontinuous Treadmill Test:** A protocol for the elicitation of VO\(_2\)\text{max} with progressively increasing workloads allowing sufficient time for recovery between increments of work (Taylor, Buskirk, & Henschel, 1955).

**Maximum Oxygen Uptake (VO\(_2\)\text{max}):** The greatest volume of oxygen a person can utilize during maximal physical work. It is a measure of the person's maximal capacity to transport oxygen to the tissues of the body and the tissues ability to utilize the oxygen (Mitchell, Sproule, & Chapman, 1957).

**Maximal Effort:** When an individual exercises to exhaustion. If an individual attains a plateau in VO\(_2\) with increasing workloads and has a RER over 1.00 it is a good indication the individual has given a maximal effort (Paterson et al., 1981).

**Maximal Heart Rate:** The maximum number of times the heart can contract in one minute (Lamb, 1978).

**Plateau:** A plateau in VO\(_2\) occurs when two consecutive measurements differ by 2.1 milliliters per kilogram per minute or less following a 2.5% increase in grade (Taylor, Buskirk, & Henschel, 1955).

**Respiratory Exchange Ratio (RER):** The volume of carbon dioxide produced divided by the amount of oxygen produced. This variable reflects the intensity of the exercise and the type of fuel being used (Issekutz, Birkhead, & Rodahl, 1961).
Peak VO₂: The highest oxygen consumption achieved by the subject on a test to exhaustion. VO₂max will equal or exceed peak VO₂. A subject may achieve a peak value, but may not meet the criterion for VO₂max. Without a plateau in VO₂ there is no assurance that VO₂max has been attained, therefore in these cases peak VO₂ is the more appropriate term (Krahenbuhl, Skinner, & Kohrt, 1985).

Open Circuit Method: Subject breathes in unlimited amounts of ambient air that is made up of a constant composition of oxygen, carbon dioxide, and nitrogen instead of breathing in the expired air again (McArdle, Katch, & Katch, 1986).

Assumptions

The following assumptions have been made for the purpose of this study:

1. All females ages 8, 9, and 10 years can give a maximal effort on a graded exercise treadmill test.

2. The minor environmental fluctuations in the Human Performance Lab did not affect the results of the study.

3. The different levels of maturation of females 8, 9, and 10 years did not affect the physiological response to the graded exercise test.
4. The highest oxygen uptake attained during a test (peak VO₂) is equal to VO₂max.

Limitations

This study incorporated a repeated measures design with each subject completing a continuous and discontinuous treadmill test. There are both advantages and disadvantages to repeated measures designs. While the subjects may have experienced a learning effect following the first test with resultant improvement in second test values, this limitation was controlled for by randomly assigning the order of the tests.

Scope of the Study

Subjects were 8, 9, and 10 year old females from Colman, South Dakota. The subjects made three visits to the Human Performance Lab in the Stanley J. Marshall Health, Physical Education, and Recreation Center on the campus of South Dakota State University. Each testing session lasted approximately 30 minutes. The first visit was a familiarization session to acquaint the subjects to the treadmill and lab procedures. At each testing session four electrodes were placed on the torso of the subject and then connected to the heart rate monitor. The mouthpiece, headgear, and nose clip were then placed on the subject and
the hoses from the gas meter and to the mixing chamber were connected to the mouthpiece valves. All protocols were carried out until the subject indicated she could no longer continue. The second and third visits consisted of the subjects completing either a continuous or discontinuous treadmill test. The order of the tests were randomly assigned. The testing was completed between March 7 and March 25, 1988, between 4:00 and 6:30 pm. At least 48 hours separated each test.

**Significance of the Study**

Most researchers consider maximum oxygen uptake as the best indicator of cardiovascular endurance, the most important component of physical fitness. Today, fitness is of great importance, therefore, we need an accurate method of measuring VO$_2$max. Maximal exercise testing has been studied extensively, however, most of the work has been done on college-age males (Maksud & Coutts, 1971; Miyamura & Honda, 1972; McArdle et al., 1973; Keren et al., 1980). More research on maximal exercise testing in children needs to be completed since it is necessary to identify protocols that accurately measure VO$_2$max. A major goal of physical education programs is to improve the physical fitness of our children. It is important to be able to measure these improvements using either VO$_2$max tests or tests which predict VO$_2$max. More research focusing on the actual
measurement of VO_{2}\text{max} needs to be completed so that accurate predictive measurements can be established for physical educators to utilize with children. Accurate assessments of VO_{2}\text{max} have been established for adults and postpubescent boys. However, no clear identification of the best VO_{2}\text{max} protocol for prepubescent girls has been established. With the current emphasis on fitness, and particularly children's fitness, it is critical that appropriate measurement techniques be utilized. Therefore, this study tested prepubescent girls on continuous and discontinuous protocols to help establish appropriate measurement techniques.
CHAPTER II

REVIEW OF LITERATURE

The research literature that is pertinent to this study on maximum oxygen uptake testing in prepubescent females is presented in this chapter. It has been organized into four major sections and the chapter concludes with a summary of the review of literature.

Maximum Oxygen Uptake

Over the last 30 years hundreds of studies have been completed examining maximal oxygen uptake (VO$_2$max). Presented in this section are several of the classic studies establishing VO$_2$max as the single best indicator of cardiovascular function.

In one of classical studies of maximum oxygen uptake, Taylor, Buskirk, and Henschel (1955) described the technique of measuring VO$_2$max along with its limitations and usefulness. Forty-six male volunteers between the ages of 18 and 35 years came to the lab a minimum of three days and some as many as five to establish workload that would elicit VO$_2$max. On the first visit the subjects performed the treadmill version of the Harvard Fitness Test. From this test the grade that would produce VO$_2$max was es-
timed. The second visit to the lab involved a treadmill test with a warmup at 3.5 miles per hour and 10% grade. Within five minutes of completing the warmup, subjects ran at seven miles per hour for three minutes at the grade which had previously been determined. On the third trip to the lab, subjects followed the same protocol as on the second visit except they ran at a 2.5% higher grade. If the two oxygen intakes were different by less than 150 cubic centimeters per minute or 2.1 cubic centimeters kilograms per minute the authors determined that a VO₂max had been reached. If a larger difference was found, another test was performed on a subsequent day with a 2.5% grade increase. This was continued until two consecutive tests elicited an oxygen intake that met the criterion. Another method of attaining VO₂max was also examined. On successive days the subjects ran for three minutes with the grade set at zero percent while the speed was increased each day until a plateau using the previously described criteria had been reached. Nine of the thirteen subjects using the increasing speed method showed a plateau in VO₂.

When using the method of increasing grade instead of speed it was found that only 7 subjects out of 115 did not reach a plateau. The authors concluded that if two consecutive measurements separated by a 2.5% grade increase differ by less than 150 cubic centimeters per minute or 2.1 cubic
centimeters per kilogram per minute, a plateau has been attained.

As a follow-up to the Taylor et al. (1955) study, Mitchell, Sproule, and Chapman (1957) attempted to determine the physiological meaning of the maximum oxygen uptake test. Sixty-five men aged 20 years or over completed a testing protocol similar to Taylor et al. (1955) except rather than allowing 24 hours between runs on the treadmill only 10 minutes of rest was given. The subjects warmed up for 10 minutes at 3 miles per hour and 10% grade followed by a 10 minute rest. The first 3 minute workload was at 6 miles per hour and 0% grade followed by a 10 minute rest. The grade was increased by 2.5% in each subsequent workload while the speed remained constant. The test continued until increases in oxygen uptake leveled off following the same criteria as Taylor et al., (1955). On a subset of 15 subjects cardiac output and A-VO$_2$ difference were determined at rest and during three workloads of the test. To facilitate these measures a catheter was placed in the left brachial artery and the brachial and femoral veins. The authors determined that maximum oxygen uptake was limited by cardiac output and A-VO$_2$ difference and that increased cardiac output may be more important than increased A-VO$_2$ difference. Also a 10 minute rest between workloads was found to be sufficient time rather than using Taylor's et al., (1955) rest period of 24 hours.
A study finding slightly different results than Taylor et al. (1955) was completed by Wyndham, Strydom, Maritz, Morrison, Peter, and Potgieter (1959). They examined the relationship between heart rate and VO2max as well as the criteria for attaining VO2max. Four highly trained men were the subjects. The training involved a 10 minute warm up with 3000 feet per pound per minute. Then for 30 minutes they worked at 70 revolutions per minute and a resistance of 7500 feet per pound per minute. After the 30 minute workload, subjects pedaled at 9000 to 11000 feet per pound per minute until exhaustion. After the subjects were trained they then worked for 4 months at workloads ranging from 2500 to 11000 feet per pound per minute. On Mondays the workload was always 7500 feet per pound per minute to test the variability of heart rate and oxygen consumption while on other days the workload was randomly assigned. Gases were collected at the second and tenth minutes at workloads below 8000 feet per pound per minute and only at the second minute when above 8000 feet per pound per minute. The oxygen intake and heart rate curves were linear until maximum heart rate was attained. A shift of the curve was observed towards higher values of oxygen intake than would be expected if plotted along the maximum heart rate curve. The authors suggest that predicting VO2max from maximum heart rates values could result in underestimating VO2max. In conflict with Taylor's et al.,
(1955) criteria for establishing VO_2max, this study found at the three highest workloads there was no significant difference in VO_2 from the mean VO_2 of those minutes. The authors pointed out that there is such a slow rise in oxygen intake to the asymptote when plotted against work rate that Taylor's et al., (1955) criteria may underes-
timate VO_2max.

Astrand and Saltin (1961) used one female and four males as subjects to examine oxygen uptake, heart rate, pulmonary ventilation, and lactic acid concentration during heavy exercise. The exercise was performed on a bicycle ergometer at 50 revolutions per minute. A 10 minute warm up was completed at about 55% of VO_2max followed by a workload which was designed to increase to a level that would produce exhaustion within two to eight minutes. When the workload could be maintained for 6.5 minutes the VO_2 after 1 minute of exercise was 84% of the 1 minute value from workloads that could be maintained only 2 minutes. The time for establishment of a plateau, therefore, depends on the workload. The authors felt that a 10 minute warm up followed by 2 minutes of very heavy exercise will produce maximal oxygen uptake and heart rate. The acceleration of heart rates was higher, (177 beats per minute) after the first minute of exercise in the 2 minute workload than in the 6.5 minute workload (164 beats per minute). The VE for the 6.5 minute exercise was 137.3 liters and 155.8 liters
for the 2 minute workload. The heavier the workload the higher the VE and the increase was more rapid. The authors concluded that in order to establish a steady state VO₂ the workload should be at least five minutes for lighter exercise, however, if the exercise was heavy measurements could be taken after one minute of exercise.

In 1971, Mitchell and Blomqvist wrote a comprehensive review of the work completed on maximum oxygen uptake. They indicated that when a person is subjected to progressively increasing workloads there is a linear relationship between workload and oxygen uptake until VO₂ max is attained. Many times more work can be accomplished beyond the workload which elicits VO₂ max. While VO₂ max depends on maximal cardiac output and A-VO₂ difference, maximal cardiac output seems to be more important. A number of variables have been shown to influence VO₂ max including body size, age, sex, and activity level. When VO₂ max is expressed in liters per minute it reflects the total volume of oxygen the body is capable of using but is inappropriate to use for comparing individuals due to differences in muscle mass. When VO₂ max is expressed in milliliters per kilogram per minute it reflects the relative volume of oxygen the body is capable of using and should be used when comparing the VO₂ max of two or more individuals. VO₂ max appears to decrease with age and males tend to have a higher VO₂ max than females. More active individuals tend
to have a higher VO2max than their sedentary counterparts. And finally, maximum oxygen uptake has been well-established as the best indicator of cardiovascular fitness.

Modes of Testing

Although there are various modes of measuring VO2max, the treadmill and the bicycle ergometer are used most often and elicit the highest VO2max values because of the large muscle groups being used (Mitchell & Blomqvist, 1971). Studies have been conducted which compared VO2max elicited on the treadmill with that elicited on the bicycle ergometer. Maximal oxygen uptake has been found to be consistently higher on the treadmill than on the bicycle ergometer (Glassford, Baycroft, Sedgwick, & MacNab, 1964; Hermansen & Saltin, 1969; McArdle & Magel, 1970; Miyamura & Honda, 1972; McKay & Banister, 1976; Keren, Magazanik, & Epstein, 1980).

Glassford, Baycroft, Sedgwick, & MacNab (1964) used four different methods for determination of VO2max. The subjects were 24 in number and ranged in age from 17 to 33 years. One test was the Taylor Buskirk, and Henschel (1955) test, the specifics of which have been described previously in this review. This protocol has the subjects returning on subsequent days for the next higher workload until a plateau in VO2 has occurred. The Mitchell, Sproule, & Chapman (1957) test was also administered, the
specifics of which have also been described in the previous section. This protocol is similar to the Taylor et al., (1955) protocol with the replacement of 24 hour rest periods by 10 minute rest periods. The Astrand bike test was also used which involves pedaling at 50 revolutions per minute and 600 kiloponds meters per minute of resistance for 6 minutes which was followed with a 5 minute rest. The resistance was then increased by 300 kiloponds per min each workload until a plateau in VO₂ was reached (increase of 80 milliliters or less). The Astrand-Rhyming predictive test on the bike also involved riding at 600 kilogram meters per minute and 50 revolutions per minute. Heart rates were recorded the last 30 seconds of each minute. The duration of each workload was determined by having reached a steady state in heart rate. Criteria for having attained a steady state was when two consecutive heart rate values which were separated by a minute did not differ more than ± 5 beats. The subject pedalled at least five minutes before this criteria was applicable. The two heart rate values were averaged and used in the Astrand-Rhyming nomogram to predict VO₂max. Results included: Taylor, Buskirk, and Henschel test - 50.2 ± 4.43 milliliters per kilogram per minute; Mitchell, Sproule, and Chapman test - 49.86 ± 5.65 milliliters per kilogram per minute; Astrand test - 46.31 ± 4.67 milliliters; and Astrand-Rhyming prediction - 49.3 ± 10.72 milliliters per kilogram per minute. The mean from
the Astrand test was significantly lower than the means of the other three tests. The means of the two treadmill tests were significantly higher than the mean of the Astrand bike test. These results indicate that the treadmill elicits higher VO₂max values than the bicycle ergometer.

Keren, Magazanik, and Epstein (1980), like Glassford et al., (1964), used three direct measurements (treadmill test, bicycle ergometer test, and step test) and one indirect measurement (Astrand-Rhyming Nomogram) to determine VO₂max. Fifteen males with a mean age of 20.2 ± .17 years completed all 4 tests. The Bruce protocol was utilized for the treadmill test. The test was initiated at 1.7 miles per hour and 10% grade. Every three minutes the grade was increased two% and speed increased every three minutes as follows: 1.7, 2.5, 3.4, 4.2, 5.0, 5.5, and 6.0 miles per hour. The test was terminated when the subject was unable to continue. The bicycle ergometer test consisted of pedaling at 600 kilogram meters per minute for 3 minute workloads with an increase of 300 kilogram meters per minute each workload. This continued until subject was unable to maintain the cadence. A bench with a height of 32.5 centimeters was used for the step test. The stepping pace started at 24 steps per min and increased continuously each minute to between 40 to 60 steps per min. With the Astrand-Rhyming Nomogram the subjects pedaled at 50
revolutions per minute for three successive workloads of 600, 900, and 1200 kiloponds meters per minute each lasting five minutes. Heart rates were monitored and used in the nomogram to predict VO$_2$\text{max}. The mean VO$_2$\text{max} values were: treadmill test - 63.8 ± 1.3 milliliters per kilogram per minute; bicycle ergometer test - 60.2 ± 1.45 milliliters per kilogram per minute; step test - 59.6 ± 1.35 milliliters per kilogram per minute; and predicted bicycle ergometer test - 59.9 ± 1.4 milliliters per kilogram per minute. No significant differences were found between VO$_2$\text{max} determined by the bicycle ergometer, the step test, and the Astrand-Rhyming nomogram. The treadmill test elicited significantly greater VO$_2$\text{max} values of about six percent when compared to the other methods.

In 1969 Hermansen and Saltin also found significantly higher maximum oxygen uptake values from a treadmill protocol compared to values from a bicycle ergometer protocol. The subjects were 55 males ages 19 to 69 years. Both tests were discontinuous in nature. A constant grade of 5.25% was used for the treadmill test. The speed was increased by two kilometer per hour every three minutes until a plateau in VO$_2$ was observed. The Astrand and Saltin protocol for the bicycle ergometer was used. The pedal rate was 50 revolutions per minute and the workload was increased by 200 kiloponds meters per minute after each successive 10 minute stage until VO$_2$\text{max} was
achieved. A significant difference was found between the mean VO$_2$ max values with the treadmill protocol eliciting 4.18 liters per minute and the bicycle protocol 3.9 liters per minute. Forty-seven of the 55 subjects showed higher VO$_2$ max values on the treadmill test than the bicycle ergometer test.

McArdle and Magle (1970) also used a treadmill and a bicycle ergometer for elicitation of VO$_2$ max from 23 male college students. The treadmill test was begun with the subjects walking at 0% grade and a speed of 3.4 miles per hour for the first 2 minutes. Grade was increased by one percent every minute until the subject was unable to continue. On the bicycle ergometer test the subject pedaled at 60 revolutions per minute. An increase of 180 kilograms per minute every two minutes was administered until the subject was unable to continue. The mean VO$_2$ max values were significantly higher on the treadmill compared to the bicycle ergometer (42.7 milliliters per kilogram per minute and 38.5 milliliters per kilogram per minute, respectively).

Using 17 college-age males, Miyamura and Honda (1972) compared the VO$_2$ max values obtained from a constant loading and a stepwise incremental loading treadmill and bicycle ergometer test. The treadmill speed and the bicycle ergometer load were such that maximal efforts would be reached in four to eight minutes. The treadmill
constant loading test consisted of a speed of 180 to 200 meters per minute and 8.6% grade. The incremental loading treadmill test utilized a two minute warmup at 150 to 170 meters per minute at 8.6% grade. After the warmup, the speed was increased 10 meters per minute each minute until exhaustion. The constant loading bicycle test involved pedaling at 60 revolutions per minute and the workload varied from 1260 to 1620 kilograms per minute depending on the subject's level of fitness. The incremental loading bicycle test began with a two minute warmup at 60 revolutions per minute and a load of 900 to 1200 kilograms per minute. The workload was increased by 180 kilograms per minute each minute until exhaustion after the warmup period. The mean VO2max values for the treadmill tests were not significantly different between the incremental loading (3.95 liters per minute) and the constant loading technique (3.89 liters per minute). For the bicycle ergometer test, the VO2max value on the incremental loading was 3.37 liters per minute and for the constant loading 3.58 liters per minute; a significant difference. A significant difference was also found between VO2max values from the treadmill compared to the bicycle ergometer with the treadmill eliciting higher values. Therefore, it is best to use the treadmill for elicitation of VO2max values. Significantly higher VO2max values from a treadmill test versus a bicycle ergometer test were also found by
McKay and Banister (1976). Five males with a mean age of 24.8 ± 2.5 years were tested on 4 maximal treadmill tests and 4 maximal bicycle ergometer tests. The differences between the tests were in the pedaling rate and the treadmill speed. Subjects pedaled at 60, 80, 100, and 120 revolutions per minute on the Monark bicycle ergometer for the four bicycle tests. The workload began at 900 kilograms per minute and increased by 300 kilograms per minute every 2 minutes. Subjects continued until they could not maintain the desired pedaling rate. The treadmill test consisted of subjects running at 6, 6.5, 7, and 7.5 miles per hour. The test was begun at 0% grade and increased by 2.5% each minute until the subject could no longer continue. The treadmill test elicited higher maximum oxygen uptake values versus the bicycle ergometer values (63.28 ± 1.72 milliliters per kilogram per minute and 58.7 ± 1.83 milliliters per kilogram per minute, respectively). The speed of the treadmill appears to have little effect on \( \text{VO}_2\text{max} \) when increasing grade is used as a loading effect since there was no significant difference in values obtained from the four different treadmill speeds. On the bicycle ergometer significant differences were only found between pedaling rates of 60 revolutions per minute and 80 revolutions per minute and 80 revolutions per minute and 120 revolutions per minute.
All of the literature reviewed in this section revealed significantly higher VO$_2$max values from treadmill tests compared to bicycle ergometer tests. Is the treadmill a better mode to use for determination of maximum oxygen uptake than the bicycle ergometer? Both the treadmill and bicycle ergometer have advantages and disadvantages. Some advantages of the bicycle are it is inexpensive, portable, and easily calibrated. Whereas, the treadmill is expensive, not portable, and is more difficult to calibrate (Krahenbuhl, Skinner, & Kohrt, 1985). The bike has the advantage of the subjects' head being held reasonably still so direct breath analyzers can be used easily and not affect the test. On the treadmill, the hoses connect the mouthpiece valves to the analyzers and this can possibly limit the natural upper body movement (Cardus, 1978). The treadmill uses a larger muscle mass, whereas, the bicycle ergometer uses a smaller muscle mass which can cause local fatigue and end the test before reaching VO$_2$max. The bicycle ergometer is difficult for children to use since they need to maintain cadence for proper workload. However, the treadmill is suited for children with no modifications (Krahenbuhl et al. (1985). Also, Shephard (1984) pointed out that the treadmill is used most often for VO$_2$max testing, therefore, there are more norms to which the results can be compared.
Continuous and Discontinuous Testing

To obtain an accurate measurement of VO$_2$max a test that exercises the subject to exhaustion is necessary. A number of different protocols have been designed to do this. The two most common protocols are the continuous and discontinuous. A continuous protocol involves progressively increasing workloads with no rest periods. A discontinuous protocol also involves progressively increasing workloads but alternates rest periods and work periods. A number of studies have been completed examining continuous and discontinuous treadmill protocols.

Using continuous and discontinuous protocols, Maksud and Coutts (1971) compared the maximum oxygen uptake of 20 males ages 17 to 30 years. The continuous test began with a 10 minute warmup at 3.5 miles per hour and 0% grade followed by a 5 minute rest. The test continued with the subjects running at zero percent grade and seven miles per hour. The grade was increased by 2.5% each minute until exhaustion. The discontinuous test also utilized a 10 minute warmup at 3.5 miles per hour, but with 10% grade. Following a short rest, subjects ran at one of six grades (2.5%, 5%, 7.5%, 10%, 12.5%, and 15%) which were randomly assigned. The speed of the treadmill was maintained at seven miles per hour and the subject worked for three minute periods. The remaining workloads were completed on succeeding days until a difference of less than 150 cubic
centimeters per minute in VO$_2$max were found between consecutive treadmill grade increases. The continuous protocol produced a mean VO$_2$max of $55.6 \pm 7.7$ milliliters per kilogram per minute and the discontinuous protocol produced a mean VO$_2$max of $55.2 \pm 6.8$ milliliters per kilogram per minute. The difference was not significant. No significant difference in VO$_2$max from continuous and discontinuous protocols was also found by McArdle, Katch, and Pechar (1973). Fifteen male college students were the subjects who performed six test protocols. The first test was a continuous bicycle test. Subjects pedaled at 60 revolutions per minute with an increase of 180 kilograms per minute every two minutes until subjects' pedal rate dropped below 47 to 50 revolutions per minute. On the discontinuous bicycle test subjects pedaled at 60 revolutions per minute with 2 kilograms of resistance for a 5 minute warmup followed by a 10 minute rest. The resistance was increased to three kilograms for the next five minute workload and thereafter was increased a half a kilogram for each workload. The test was terminated when the subject was unable to continue. The continuous Balke treadmill test was carried out at a constant speed of 3.4 miles per hour and began at 0% grade. The grade was increased by one percent each minute until the subject could not continue. The Mitchell, Sproule, and Chapman (1957) discontinuous treadmill test was also utilized and has been described
previously in this review. Another continuous treadmill test consisted of the subject running at a constant speed of six miles per hour and a starting grade of zero percent for two minutes. The grade was increased 2.5% every 2 minutes until the subject could no longer continue. Another discontinuous treadmill test consisted of running at 6 miles per hour at 2.5% grade for 5 minutes as a warmup. Five minute work stages, 2.5% higher than the previous one were alternated with 10 minute rest intervals until the subject could no longer continue. The VO₂max values obtained were as follows: discontinuous bicycle test - 50 ± 6.9 milliliters per kilogram per minute; continuous bicycle test - 49.9 ± 7 milliliters per kilogram per minute; Mitchell, Sproule, and Chapman test - 56.6 ± 7.3 milliliters per kilogram per minute; Balke test - 53.7 ± 7.5 milliliters per kilogram per minute; discontinuous treadmill test - 56.6 ± 7.6 milliliters per kilogram per minute; and continuous treadmill test - 55.5 ± 6.8 milliliters per kilogram per minute. The bicycle ergometer VO₂max values were significantly lower than the treadmill values. No significant differences were found between the discontinuous treadmill test, the continuous treadmill tests, and the Mitchell, Sproule, and Chapman test.

In 1978, Fardy and Hellerstein also studied VO₂max elicited from discontinuous and continuous treadmill protocols. Twelve male subjects (42.3 ± 9.9 years) were
tested three times with the order of the tests randomly assigned. The first test was for familiarization. For the continuous protocol, subjects walked at two miles per hour and zero percent grade the grade was increased every three minutes as follows: 3.5%, 7%, 10.5%, 14%, 17.5%, 12.5%, 15%, 17.5%, and 20%. The speed remained at two miles per hour until the seventh three minute stage when it was increased to three miles per hour. The discontinuous protocol followed the same procedure as the continuous protocol with the inclusion of a three minute rest between each stage. The continuous test produced a mean VO₂max of 40.7 milliliters per kilogram per minute and the discontinuous test 39.5 milliliters per kilogram per minute. The differences was not significant.

Conflicting results were reported by, Froelicher, Brammel, Davis, Noguera, Stewart, and Lancaster (1974) who did find a significant difference between discontinuous and continuous protocols. The subjects were 15 males with a mean age of 32 years. The subjects performed the Bruce protocol, the Balke protocol, and a modified Taylor protocol three times each over a nine week period. The continuous Bruce protocol has been described previously in this review. Also continuous in nature, the Balke protocol consisted of a constant speed of 3.3 miles per hour beginning at 1% grade. The grade was increased one percent every minute until exhaustion. The modified Taylor
protocol consisted of a speed of seven miles per hour beginning at a grade of zero percent. The grade was increased every 3 minutes by 2.5% until subject could not continue. A five minute rest period followed each workload. The mean VO$_2$max values were 44.3 ± 5.9 milliliters per kilogram per minute for the Bruce protocol, 42.8 ± 5.2 milliliters per kilogram per minute for the Balke protocol, and 47.4 ± 6.1 milliliters per kilogram per minute for the Taylor protocol. The Taylor protocol, which was discontinuous, elicited significantly higher VO$_2$max values than either the Bruce or Balke protocols which are continuous. A plateau was demonstrated in 33% of the Taylor protocol tests while only 17% on the Balke protocol and 7% on the Bruce protocol.

Maximum Oxygen Uptake in Children

As has been identified in the previous sections VO$_2$max can be measured in a variety of ways in adults but many questions have been raised about the reliability of measuring VO$_2$max in children. Measuring VO$_2$max in children is more difficult than in adults because of the unfamiliarity of children with maximal efforts. Identification of a plateau in VO$_2$ with increasing workloads has been the criteria for VO$_2$max in many studies. The evidence of a plateau has been seen less in children than in adults (Paterson, Cunningham, & Donner, 1981). Many factors can
account for the failure to attain a plateau including lack of effort by the child, poor definition of the appropriate criteria for a plateau or possibly another factor not yet identified. Despite these problems a number of studies have been carried out examining VO\textsubscript{2}max in children.

The bicycle ergometer was the mode of exercise used by Wilmore and Sigerseth (1967) to determine if any physiological differences exist among girls ages 7 to 13 years based on their maximum oxygen uptake values. Three testing sessions were conducted with the first one used as a familiarization. During the last two sessions, a work capacity test on a bicycle ergometer was performed. The test consisted of a starting workload of 0 kilogram meters per minute per minute and pedaling rate of 50 revolutions per minute with 150 kilogram meters per minute increases in workloads every minute until exhaustion. The mean VO\textsubscript{2}max values for the 7 to 9 year old subjects was 53.5 ± 6.5 milliliters per kilogram per minute; 10 to 11 year old subjects 50.7 ± 5.9 milliliters per kilogram per minute; and 12 to 13 year old subjects 48.7 ± 8.7 milliliters per kilogram per minute. When VO\textsubscript{2}max was expressed in liters per minute it was inversely related to age and independent of work capacity. As girls reach puberty their body weight and lean body mass ratio decreases and the authors suggest that this could cause lower VO\textsubscript{2}max in milliliters per kilogram per minute in the older girls.
Nagle, Hagberg, and Kamei (1977) also used the bicycle ergometer along with the treadmill to determine VO$_2$max of girls as well as boys. The subjects were 120 boys and 120 girls 14 to 17 years of age. Subjects completed a 5 minute ride on the bicycle ergometer at submaximal workloads of 450 kilogram meters per minute for girls and 600 kilogram meters per minute for boys. In the fifth minute, heart rates were taken for 15 seconds and used in the Astrand-Rhyming Nomogram to predict VO$_2$max. The treadmill protocol consisted of a constant speed of five, six, or seven miles per hour. The speed was established from the predicted VO$_2$max on the submaximal bicycle ergometer ride. Grade was increased by two percent every minute with girls starting at zero percent and boys at two percent. This procedure continued until the subject was exhausted. The mean VO$_2$max for the girls was $40.8 \pm 4.0$ milliliters per kilogram per minute and for the boys was $54.7 \pm 5.6$ milliliters per kilogram per minute. This difference was significant.

Gilliam, Katch, Thorland, and Weltman (1977) used a bike ergometer to measure VO$_2$max in 47 boys and girls. They also examined cardiovascular risk factors in the 7 to 12 year old children by doing a complete medical and physical evaluation. A blood sample was taken for determination of serum cholesterol, triglycerides, and blood lipids. Each child participated in hydrostatic weighing to
assess percent body fat and lean body mass. A bicycle ergometer test was completed to determine peak VO₂. The test started at zero load and every three minutes was increased one-half kilopond with the pedaling rate maintained at 60 revolutions per minute. The subjects continued until exhaustion. During each minute of the test oxygen uptake was measured by the open circuit spirometry method. The 7 to 8 year old subjects had a mean peak VO₂ of 34.4 milliliters per kilogram per minute, the 9 to 10 year olds 38.2 milliliters per kilogram per minute, and the 11 to 12 year olds 43.3 milliliters per kilogram per minute. Eleven percent of the children were classified as having low work capacities. Nineteen percent of the children were greater than 20% body fat and 10.6% were greater than 25% body fat. Elevated cholesterol levels (> 200mg percent/100milliliters) were observed in 10.5% of the children and elevated triglycerides (> 100mg percent/100milliliters) were found in 18% of the children. Twenty-five percent of the children had a family history of cardiovascular disease.

Krahenbuhl, Pangrazi, Petersen, Burkett, and Schneider (1978) examined the relationship between VO₂max values obtained from a treadmill test and timed distance runs of 800, 1200, and 1600 meters. The purpose was to determine the validity of using the runs to predict cardiorespiratory fitness. Subjects were 69 male and 48
female first, second, and third grade children. The order of the tests was randomly assigned to the subjects and they completed one run each week. The treadmill test consisted of a speed set at 115 meters per minute with the grade at 0% for the first four minutes. The grade was increased by two percent every minute thereafter until subject was unable to continue. The 1600 meter run was the best predictor of VO$_2$max. The mean VO$_2$max for males was $45.2 \pm 6.4$ milliliters per kilogram per minute and for females was $41.2 \pm 6.5$ milliliters per kilogram per minute. The difference was significant. Plateaus were observed in 71% of the males and 70.8% of the females.

Plateaus were not observed at such a high percentage when Cunningham, VanWaterschoot, Paterson, Lefcoe, and Sangel (1977) attempted to determine if a true plateau could be attained in young boys. The subjects were 10 year old hockey players ($n=66$). The boys were tested during midseason (T1) and postseason (T2). The treadmill test was begun at a speed of 4.1 miles per hour and 0% grade. The grade was increased by 2.5% every 2 minutes until exhaustion. After testing the subjects were grouped according to whether or not a plateau in VO$_2$ had been attained. The groups were: no plateau, plateau in T1 or T2, and plateau in T1 and T2. It was observed that only 38% of the subjects reached a plateau. There were no significant differences in any of the groups' mean VO$_2$max.
values at either testing time. This reflects that the attainment of a plateau in boys of this age is not necessary for establishment of VO₂max.

The subjects utilized by Skinner, Bar-Or, Bergsteinova, Bell, Royer, and Buskirk (1971) were 83 boys and 61 girls ages 6 to 15 years. Each subject was randomly assigned to perform one of the three treadmill tests for elicitation of VO₂max. All tests included a three minute warmup at 7.5% grade and 3.5 miles per hour. Test A was begun at 10% grade and 3.5 miles per hour. There was a 2.5% increase in grade every 2 minutes until exhaustion. Test B was the same as Test A except grade increased 2.5% every 3 minutes instead of every 2 minutes. Test C consisted of the subjects walking for 4 minutes at 15% grade and 3.5 miles per hour then rest followed by a rest for 10 minutes. Every 4 minutes the grade was increased by 2.5% with speed maintained at 3.5 miles per hour until exhaustion. The girls' VO₂max values were: Test A - 43.0 ± 6.9 milliliters per kilogram per minute; Test B - 45.7 ± 5.1 milliliters per kilogram per minute; and Test C - 44.8 ± 6.2 milliliters per kilogram per minute. The boys' VO₂max values were: Test A - 51.6 ± 7.0 milliliters per kilogram per minute; Test B - 50.0 ± 5.5 milliliters per kilogram per minute; and Test C - 53.0 ± 4.3 milliliters per kilogram per minute. Four age groups were established between 6 and 15 years and similar VO₂max values were found
in all groups for the 3 tests. From the data, the authors identified that a speed of 3.4 miles per hour requires 6 to 8 year old children to walk inefficiently and suggest that possibly a 3 miles per hour speed would be better.

Paterson, Cunningham, and Donner (1981) were also concerned about the speed of the treadmill when studying VO$_{2\text{max}}$ in 8 boys 10 to 12 years old. They examined at attainment of a plateau in oxygen uptake using three different treadmill speeds. Each subject completed nine maximal tests, three for each protocol. All protocols were continuous with an initial grade of 0% and increases of 2.5% every 2 minutes, but using different speeds. The treadmill speeds were 3.4 miles per hour walking, 4.1 miles per hour jogging, and 4.9 miles per hour running. The results revealed the walking test elicited a mean VO$_{2\text{max}}$ of 55.5 ± 5.0 milliliters per kilogram per minute, the jogging test a mean of 57.9 ± 4.4 milliliters per kilogram per minute, and the running test a mean of 59.5 ± 5.4 milliliters per kilogram per minute. The differences were only significant between the walk and run protocols. Maximal values were not elicited during the walk test, therefore, it may not be appropriate to use it to measure VO$_{2\text{max}}$ in children. In nine walking tests, five jogging tests, and seven running tests plateaus in oxygen uptake were attained. The authors suggest that a discontinuous test may be more reliable than a continuous test in
determining maximum oxygen uptake in children since a plateau is apparent in a greater proportion of subjects using a discontinuous protocol. They did indicate that the highest VO₂ measured (peak VO₂) using the jogging or running protocol was as consistent as the VO₂ max measurement observed in adult groups. It appears that the motivation of young boys for maximal exercise is stable and VO₂ max can be assumed without need for a plateau in oxygen consumption.

Interest in the criteria for the achievement of VO₂ max lead Sheehan, Rowland, and Burke (1978) to utilize four different treadmill protocols for elicitation of VO₂ max in 16 boys ages 10 to 12 years. They were tested on the treadmill on four different occasions with 7 to 10 days between tests. The continuous walking test involved subjects walking at three miles per hour and six percent grade. Grade was increased two percent every three minutes and speed remained constant. For the continuous running protocol, speed was constant at five miles per hour and grade started at zero percent. Grade was increased two percent every three minutes. In the intermittent running test, subjects ran at a constant speed of five miles per hour at two percent grade with a two percent grade increase every three minutes. The subjects walked at 2.5 miles per hour for the 3 minute rest period. The continuous running while holding handrails protocol consisted of a constant
speed five miles per hour and four percent grade with a grade increase of two percent every minutes. The three running tests elicited significantly higher VO$_2$max values compared with the continuous walking protocol, but did not differ significantly from each other. A plateau in VO$_2$ was obtained more often in the running protocols with the intermittent running protocol having 69% of the subjects reaching a plateau compared to 56% of the subjects in the continuous test. The mean VO$_2$max values were: continuous walk - 43.1 ± 6.1 milliliters per kilogram per minute; continuous run - 47.8 ± 4.2 milliliters per kilogram per minute; intermittent run - 48.8 ± 5.0 milliliters per kilogram per minute; and the handrail run - 46.7 ± 4.3 milliliters per kilogram per minute. The differences were not significant.

Ferrar (1985) found a significant difference between VO$_2$max values elicited from continuous and discontinuous treadmill protocols in the lab where the present study was completed. Thirteen females with a mean age of 8.88 ± .82 years were tested on both a continuous and discontinuous treadmill protocol. The continuous test utilized a constant speed of 4.1 miles per hour and began with a grade of 0% with a 2.5% increase every 3 minutes until exhaustion. The discontinuous test also utilized a constant speed of 4.1 miles per hour and began at 0% grade. A five minute rest period followed each three minute.
workload. The grade was increased by 2.5% every 3 minutes. This was continued until subject was exhausted or a plateau (2.1 milliliters per kilogram per minute increase in VO₂ or less) between consecutive workloads was attained. The mean VO₂max for the continuous protocol was 47.49 ± 5.74 milliliters per kilogram per minute and for the discontinuous protocol was 51.76 ± 6.22 milliliters per kilogram per minute. The difference was significant. Plateaus in VO₂ were observed in only 2 of the 13 during the continuous test, whereas, 11 of the 13 subjects reached a plateau during the discontinuous test. The current study is a replication of this study since there was a constant error built into the metabolic measurement system resulting in inflated VO₂max values and reduced respiratory exchange ratios.

Summary

Maximal oxygen uptake or VO₂max is attained when two consecutive measurements separated by a 2.5% grade increase differ by 2.1 milliliters per kilogram per minute or less are observed (Taylor et al. 1955). Both cardiac output and A-VO₂ difference limit VO₂max with cardiac output probably being the most important. It was found that after maximum heart rate is attained it appears oxygen uptake continues to rise. The prediction of VO₂max from maximum heart rates can therefore underestimate VO₂max
(Mitchell et al. 1957). The time for establishment of a plateau in $\text{VO}_2$ depends on the workload. For lighter exercise the workload should last at least five minutes while heavier exercise could result in maximum values after one minute of exercise (Astrand & Saltin 1961).

The bicycle ergometer and the treadmill have been utilized most extensively when measuring $\text{VO}_2\text{max}$. Consistently, $\text{VO}_2\text{max}$ obtained from treadmill tests are higher than those obtained from the bicycle ergometer tests (Glassford et al., 1964; Hermansen & Saltin, 1969; McArdle & Magel, 1970; Miyamura & Honda, 1972; McKay & Banister, 1976; Keren et al., 1980).

The two main categories of protocols used for elicitation of $\text{VO}_2\text{max}$ are continuous or discontinuous. The Froelicher et al. (1974) study was the only one reviewed that found significant differences in $\text{VO}_2\text{max}$ values obtained from a continuous and discontinuous protocols using adults. When using children as subjects, Ferrar (1985) found significantly higher $\text{VO}_2\text{max}$ values from the discontinuous compared to the continuous test. Ferrar (1985) was the only study reviewed that used young girls as subjects.

The criteria for attaining maximal oxygen uptake is a plateau in $\text{VO}_2$ with increasing workloads is seen less in children than in adults. Cunningham et al. (1977) had only 38% of his subject attain plateaus. Paterson et al. (1981)
felt that the discontinuous test was better for attaining a plateau in VO₂, but also felt it may be unrealistic for children to attain a plateau. This was in agreement with Ferrar (1985) since only 2 of the 13 subjects on the continuous attained a plateau and 11 of the 13 subjects on the discontinuous attained a plateau.
CHAPTER III

METHODS AND PROCEDURES

Information regarding the subjects, facilities, equipment, testing procedures and the statistical analyses are presented in this chapter.

Subjects

The subjects were 14 prepubescent females ages 8, 9, or 10 years from Colman, South Dakota. The subjects were recruited by the researcher to take part in a study that compared VO2max values elicited from continuous and discontinuous treadmill protocols. The researcher taught in the Colman School during the previous two years and had the subjects in her physical education classes. The researcher went to the Colman School and asked for volunteers to participate in the study. A meeting was held with the parents of the subjects before the testing began to explain procedures, sign the informed consent form (Appendix A), set up testing times, and make transportation arrangements. The mean weight of the subjects was $30.6 \pm 4.7$ kilograms with a range of 23.2 to 41.5 kilograms. The mean height was $134.2 \pm 4.8$ centimeters with a range of 121.0 to 142.0 centimeters. The mean age of the subjects
was 8.9 ± .44 years with a range of 8.3 to 10.0 years. These descriptive statistics are presented in Table 1.

Facilities

The Human Performance Lab, located in the Stanley J. Marshall Health, Physical Education, and Recreation Center at South Dakota State University, was the site of all the testing for the elicitation of maximum oxygen uptake. The air temperature in the lab was maintained at a constant 21 degrees Centigrade. The barometric pressure ranged from 707 to 725 millimeters of mercury. The relative humidity ranged from 38% to 50%. These variations were taken into account for all calculations of VO₂max and should not have affected the results of this study.

Equipment

All testing was completed on a motor-driven treadmill with maximal oxygen uptake determined using the open circuit method. The treadmill was a Quinton Q65 treadmill with a 645 controller which facilitated the pre-programming of testing protocols. A Hans-Rudolph two-way
### TABLE 1

**Descriptive Statistics of Subjects**

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</table>
valve model 2700 with a headgear support and mouthpiece was used to facilitate expired gas collection. A spring-type nose clip was used to ensure respiration through the valve system. Inspired air was measured by a Rayfield RAM-9200 air flow meter. Expired air passed through a Physio-Dyne Instruments seven liter mixing chamber with samples drawn through oxygen and carbon dioxide analyzers at a flow rate of 500 milliliters per minute. An Amatek CD-3A carbon dioxide analyzer and an Amatek S-3A oxygen analyzer were used for determination of the composition of the expired air. The barometric pressure was measured on a Nova barometer made by Princo of Southampton, Pennsylvania and the temperature was read from the thermometer on this same instrument. The relative humidity was determined from a sling psychrometer from Bacharach of Pittsburgh, Pennsylvania. The analyzers were calibrated before and after each test with known concentrations of gas certified by Scotts Specialty Gases, Toledo, Ohio. Four electrodes were placed on the subjects before each test using standard exercise limb lead locations. Heart rates were monitored on lead III using a Marquette Electronics ECG Monitor, Series 4000. All metabolic measurement data were reduced using the Rayfield Data Acquisition System (REP 200-C) on a Apple II+ micro computer. As this system receives constant input from the gas meter, and the oxygen and carbon dioxide analyzers during the testing calculations of all metabolic
measurement variables occur on an on-going basis. The fixed variables of barometric pressure, temperature, and relative humidity were entered into the computer prior to each test.

Testing Procedures

Familiarization Session

Prior to testing the temperature (degrees Centigrade), barometric pressure (millimeters of mercury), and relative humidity (percent) were determined and recorded and the oxygen and carbon dioxide analyzers were calibrated. The two-way valve, mouthpiece, and nose clip were sterilized prior to each test.

When the subject arrived her weight and age were recorded. The testing procedures were carefully explained and the subject was given the opportunity to ask any questions. The subject had a chance to walk on the treadmill for a several minutes in order to become acquainted with the task before testing.

Heart rate was monitored using standard limb lead exercise electrode locations. The arm electrodes were placed in the infraclavicular fossa and the leg electrodes at the level of the iliac crest on the mid-clavicular line. Each site was first wiped with rubbing alcohol and lightly abraded with fine sand paper prior to electrode placement.

When ready the subject stepped onto the treadmill
with her feet to the side of the belt. The mouthpiece, two-way valve, headgear, and nose clip were placed on the subject and adjusted. The treadmill belt was started at 1.3 miles per hour. Holding onto the rails the subject stepped onto the belt. When she could walk normally and remove her hands from the rails the test was initiated by pressing the "start exercise" button on the treadmill controller.

The familiarization test utilized the same protocol as the continuous test which employed a constant speed of 4.5 miles per hour and was begun at 0% grade. The test proceeded with a 2.5% grade increase every 2 minutes until the subject indicated she could continue no longer. Throughout the test the metabolic variables of VO₂max in liters per minute and milliliters per kilogram per minute, minute ventilation, respiratory exchange ratio, and heart rate were calculated and recorded every 60 seconds. When the subject finished the test the mouthpiece, two-way valve, headgear, and nose clip were removed. The subject walked on the treadmill for several minutes to cool down after the testing. Electrodes were removed after the cool down.

During all testing at least two investigators were always present. One investigator weighed the subject, placed electrodes, mouthpiece, two-way valve, headgear, and nose clip on the subject prior to the start of the testing.
During the test this investigator stood beside the treadmill and was responsible for monitoring the subject's progress and encouraging her. The other investigator was responsible for monitoring the equipment and recording data from the computer.

**Continuous and Discontinuous Testing Sessions**

The continuous session followed exactly the same procedures as the familiarization session. The discontinuous session was similar to the continuous session using the same speed and the same grade changes, but was different in regards to test duration. During the discontinuous test each workload (change in grade) was three minutes in duration and was followed by a five minute rest period. The workloads were continued until a plateau was reached or the subject indicated she was no longer able to continue. In order to control for a learning effect the order of the tests was randomly assigned.
Statistical Analyses

A correlated groups t-test was utilized for the determination of significant differences between VO₂max (liters per minute and milliliters per kilogram per minute), respiratory exchange ratio, and minute ventilation on the continuous and discontinuous protocols. No analysis was carried out on the heart rate data as the quality of the recording was not consistent enough to ensure accurate readings at all times. The statistical analyses were carried out following the formulae presented in Statistics for the Behavioral Sciences (pages 203-204, Jaccard, 1983). The .05 level of significance was used. The independent variable was the protocol (continuous or discontinuous) while VO₂max, RER, and VE were the dependent variables.
RESULTS AND DISCUSSION

The information presented in this chapter are the results of continuous and discontinuous treadmill protocols used for elicitation of maximal oxygen uptake in prepubescent females. A discussion of the results will follow.

Results

Table 2 contains the means, standard deviations, and standard errors of the means for maximum oxygen uptake (liters per minute and milliliters per kilograms per minute), respiratory exchange ratio (RER), and minute ventilation (VE) for the continuous and discontinuous treadmill protocols.

Maximum oxygen uptake was expressed in both liters per minute (liters per minute) and milliliters per kilogram per minute (milliliters per kilograms per minute). It is most appropriate to use the units of liters per minute when making intraindividual comparisons and to use the units of milliliters per kilograms per minute when making interindividual comparisons. The primary purpose of this study was to look at changes within individuals and therefore more emphasis will be placed on the measure in liters per
minute. Since the weight of the subjects was not different for the two tests the results are the same for both units. On the continuous protocol a mean VO2max of 1.23 liters per minute was determined with a standard deviation of .16. On the discontinuous protocol a mean VO2max of 1.43 liters per minute was determined with a standard deviation of .20. A significant difference at the .05 level was found between the two protocols. When expressed in milliliters per kilograms per minute the continuous protocol mean VO2max was 40.7 with a standard deviation of 5.42. On the discontinuous test the mean VO2max was 47.3 milliliters per kilogram per minute and a standard deviation of 7.11. This difference was also significant at the .05 level. This is shown in Table 3.

The mean respiratory exchange ratio for the continuous protocol was .99 with a standard deviation of .06. The mean respiratory exchange ratio for the discontinuous protocol was 1.01 with a standard deviation of .06. These results are presented in Table 2. At the .05 level of significance no significant difference in RER was found between the continuous and discontinuous protocols using a correlated groups t-test as shown in Table 3.

As shown in Table 2 the mean minute ventilation for the continuous test was 36.01 liters per minute with a standard deviation of 4.0 liters per minute. On the discontinuous test the mean minute ventilation was 41.1
liters per minute and a standard deviation of 6.06 liters per minute. Table 3 shows that at the .05 level there was a significant difference in VE obtained from a continuous and discontinuous treadmill tests.

Discussion

The discontinuous treadmill protocol elicited higher VO$_2$max values than the continuous treadmill protocol when utilizing prepubescent females as subjects in this study in both liters per minute and milliliters per kilogram per minute. The present study found a mean VO$_2$max of 1.23 liters per minute or 40.7 milliliters per kilograms per minute on the continuous protocol and 1.43 liters per minute or 47.3 milliliters per kilograms per minute on the discontinuous protocol. These differences were significant. This supports the findings of Ferrar (1985) who also found a significant difference in VO$_2$max values of prepubescent females obtained from continuous and discontinuous protocols. Ferrar (1985) reported mean VO$_2$max of 1.43 liters per minute and 47.49 milliliters per kilograms per minute on the continuous test and 1.55 liters per minute and 51.76 milliliters per kilograms per minute on the discontinuous test. Ferrar (1985) reported that her VO$_2$max values may be somewhat inflated due to a constant error in the metabolic measurement system. This could explain the differences in values between the present study
TABLE 2

Results

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<td>t value</td>
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*Significant at the .05 level.
and hers. Certainly both studies reflect that discontinuous testing in prepubescent females elicits higher VO_{2\text{max}} values than continuous testing.

Froelicher et al. (1974) also reported results in agreement with the present study as they found that a discontinuous protocol elicited significantly higher VO_{2\text{max}} values than a continuous protocol. However, Froelicher et al. (1974) used adult males as subjects. Three protocols were used to test the male adults with the Balke test (a continuous protocol) eliciting a mean VO_{2\text{max}} of 42.8 milliliters per kilograms per minute, the Bruce test (a continuous protocol) a mean VO_{2\text{max}} of 44.3 milliliters per kilograms per minute, and the discontinuous protocol of Taylor a mean VO_{2\text{max}} of 47.4 milliliters per kilograms per minute.

Even though Ferrar (1985) and Froelicher et al. (1974) have found results similar to the present study that discontinuous protocols elicit significantly higher VO_{2\text{max}} values than continuous protocols there are a number of studies which do not support this (Skinner et al., 1971; Sheehan et al., 1987; Maksud & Coutts, 1971; McArdle et al., 1973; Fardy & Hellerstein, 1978). Skinner et al. (1971) found no significant difference in VO_{2\text{max}} values from two continuous protocols and one discontinuous protocol. The subjects were boys and girls ages 6 to 15.5
years. Since the present project studied girls only the VO2max values for the girls will be reviewed. The two continuous test produced mean VO2max values of 43.0 milliliters per kilograms per minute and 45.7 milliliters per kilograms per minute. The discontinuous test VO2max mean value was 44.8 milliliters per kilograms per minute. The present study examined girls ages 8, 9, and 10 years while Skinner et al. (1971) looked at a wider age range of girls. The results of Sheehan et al. (1987) are also not in support of the present study's findings. The elicited mean VO2max values of 10 to 12 year old boys were 1.61 liters per minute and 43.1 milliliters per kilograms per minute on the continuous walk test, 1.8 liters per minute and 47.7 milliliters per kilograms per minute on the continuous run test, and 1.83 liters per minute and 48.7 milliliters per kilograms per minute on the intermittent run test. Although there were no significant differences in VO2max found among the tests, the intermittent or discontinuous test did elicit the highest values. The differences between the present project and that of Sheehan's et al. (1987) are that boys ages 10 to 12 years were used by Sheehan et al. (1987) while prepubescent girls were utilized in the present study. It is possible that the response of boys and girls in this age range are different.
The results of the present study also do not support the findings of Maksud and Coutts (1971), McArdle et al. (1973), and Fardy and Hellerstein (1978) who found no significant differences in VO$_2$max values obtained from continuous and discontinuous protocols. An explanation for the difference in the results could be that adults were used as subjects in the above studies and the present study utilized prepubescent girls.

Normally, to assure attainment of VO$_2$max a plateau or leveling off, of VO$_2$ with an increase in grade of 2.5% needs to be observed. A 2.1 milliliters per kilograms per minute or less increase in VO$_2$ following an increase in the workload is the normal criteria for a plateau. On the continuous test in this study 8 of the 14 subjects or 57% attained a plateau according to the above criteria. This finding was not expected and is in conflict with a number of studies (Froelicher et al., 1974; Cunningham et al., 1977; Krahnenbuhl et al., 1978; Paterson et al., 1981; Ferrar, 1985).

Froelicher et al. (1974) found only 17% achieving a plateau on the Balke continuous test and 7% on the Bruce continuous test. Adult males were used as subjects in the study as well as different protocols compared to the present study. These could be the reasons for the conflicting results.
Cunningham et al. (1977) observed a greater percentage of subjects attaining plateaus in continuous tests than Froelicher et al. (1974), but not as great a percentage as the present study. Thirty-eight percent of the 66 boys who were 10 years old demonstrated the criteria for a plateau in VO₂. The present study used 8, 9, and 10 year girls. Except for a faster speed in the present study (4.5 mph versus 4.1 mph) the protocols of the two studies were the same.

The results from Paterson et al. (1981) are also in opposition with those of this study. Plateaus were observed in 9 of 24 continuous walk tests or 38%, 5 of 24 continuous jog tests or 21%, and 7 of 24 run tests or 29%. All of these percentages were lower than the present study. The protocols differed in speed only as the grade and increases in grade were identical. The walk (3.4 miles per hour) and the jog (4.1 miles per hour) tests were slower than the present study and the run test (4.9 miles per hour) was faster. The subjects were also different as Paterson et al. (1981) used 10 to 12 year old boys and the present study used 8 to 10 year old girls. Ferrar (1985) reported 2 of 13 subjects or 15% attaining a plateau on the continuous test which is a much lower percentage than the present study. The reasons for this conflict is unclear since the same protocol was used except for an increase of speed to 4.5 miles per hour instead of 4.1 miles per hour.
used by Ferrar (1985). Of the four studies in conflict with the percentage of plateaus attained on a continuous test Krahenbuhl et al. (1978) was the only one to find a higher percentage of plateaus on a continuous test. A different protocol was used compared to the present study and utilized 6 to 9 year old boys and girls as subjects. Krahenbuhl et al. (1978) used a speed of 115 meters per minute and 0% grade for 4 minutes then increased the grade by 2.5% per minute while the speed remained constant. It was observed that 49 of 69 boys or 71% attained a plateau and 34 of 48 girls or 71% attained a plateau. This is in conflict with the present study as only 57% reached a plateau. While these results appear to be somewhat higher than those of the present study they also reinforce the present study's finding by showing that with young children it is possible to see a plateau in more than half of the subjects on a continuous test.

In the present study the discontinuous protocol elicited only 5 plateaus of the 14 subjects or 36%. This was clearly not expected and does not support the findings of Ferrar (1985) who had 11 of 13 subjects attain a plateau on the discontinuous protocol. It is unclear why this conflict exists since the protocols were the same except for a small increase in speed (4.5 miles per hour) for the present study. Froelicher et al. (1974) who used adults as subjects are also not in agreement with this result. It
was observed by Froelicher et al. (1974) that a greater percentage (33%) of the subjects demonstrated a plateau during the discontinuous Taylor protocol, whereas, only 17% during the continuous Balke test and 7% during the continuous Bruce test met the criteria for a plateau.

The intermittent run produced the highest percentage of plateaus in the Sheehan et al. (1987) study. It was observed that 68.7%, which was a greater percentage than for the other three continuous protocols, reached a plateau on the intermittent run test. The discontinuous test of the present study and Sheehan's et al. (1987) do differ. The Sheehan et al. (1987) study utilized a speed of 5 miles per hour and 2% grade increases every three minutes, whereas, this study used 4.5 miles per hour for the speed and 2.5% grade increase every 3 minutes. The rest periods for the protocols differed also. The rest periods consisted of walking on the treadmill at 2.5 miles per hour for 3 minutes. The present study had the subjects rest for five minutes with no exercise. Both of these differences could have caused the difference in the test results.

The continuous test of the present study elicited maximal oxygen uptake values ranging from .9 to 1.4 liters per minute and 27.6 to 47.4 milliliters per kilograms per minute. The mean VO$_2$ max was 1.23 ± .16 liters per minute and 40.7 ± 5.42 milliliters per kilograms per minute. The
present study's discontinuous test elicited maximal oxygen uptake values of 1.0 to 1.7 liters per minute and 30.3 to 58.5 milliliters per kilograms per minute. The mean VO\textsubscript{2}max for the discontinuous test was 1.43 ± .2 liters per minute and 47.3 ± 7.11 milliliters per kilograms per minute. These maximal oxygen uptake values are similar to those found in several studies using a similar population (Skinner et al., 1971; Krahenbuhl et al., 1978). Skinner et al. (1971) reported a range of 43.0 to 45.7 milliliters per kilograms per minute on the continuous test which is higher than the present study's range. Although Skinner's et al. (1971) values were higher than the present they are still very close. On the discontinuous test Skinner's et al. (1971) results were lower (44.8 ± 4.3 milliliters per kilograms per minute) than the present study's results (47.3 ± 7.1 milliliters per kilograms per minute), but are actually very similar. The age range for the girls in Skinner's et al. (1971) study (6 to 15.5 years) was larger than the present study (8 to 10 years).

Also in support of the results of this study is Krahenbuhl et al. (1978) who reported a mean VO\textsubscript{2}max value of 41.2 ± 6.5 milliliters per kilograms per minute for 6 to 9 year old girls. This is very comparable to the results of the present study of 40.7 ± 5.42 milliliters per kilograms per minute.
A couple of studies whose results conflict with the present study are Wilmore and Sigerseth (1966) and Ferrar (1985). Wilmore and Sigerseth (1966) used a bicycle ergometer as the mode of testing and their VO₂ max values were higher than the present study's results. They found VO₂ max values of 1.73 ± .07 liters per minute for 7 to 9 year old girls and 1.68 ± .1 liters per minute for 10 to 11 year old girls. This is difficult to explain as normally the bicycle ergometer will elicit lower VO₂ max values than the treadmill.

There is also conflict with the present study and the study it is replicating (Ferrar, 1985). The values from the Ferrar (1985) study may be somewhat inflated since the laboratory equipment was not functioning properly. On the continuous test Ferrar's (1985) results ranged from 40.6 to 56.33 milliliters per kilogram per minute with a mean of 47.49 ± 5.74 milliliters per kilogram per minute which are higher than those for the present study. The discontinuous test of Ferrar's (1985) elicited results ranging from 40.32 to 60.47 milliliters per kilogram per minute with a mean of 51.76 ± 6.22 milliliters per kilogram per minute which are also higher than the present study's findings.

The respiratory exchange ratios of the present study were not significantly different when obtained from the continuous or discontinuous protocol. The continuous
test RER was $0.99 \pm 0.06$ and the discontinuous test RER was $1.01 \pm 0.06$. Ferrar's (1985) RER values are thought to be somewhat deflated. The RER for the continuous test was $0.82 \pm 0.04$ and the discontinuous test $0.81 \pm 0.04$ for the Ferrar (1985). However, two other studies (Krahenbuhl et al. 1978 and Paterson et al. 1981) had results that were comparable to the RER values of this study. For a continuous test administered to 6 to 9 year girls, Krahenbuhl et al. (1978) recorded a mean RER of $1.06 \pm 0.05$, whereas, the present study's RER was $0.99 \pm 0.06$ for the continuous test. Although Paterson et al. (1981) used 10 to 12 year old boys, they found similar results for RER compared to the present study's results. The RER values included $0.98 \pm 0.07$ for the continuous walk, $1.00 \pm 0.02$ for the continuous jog, which is what the present study used, and $0.99 \pm 0.07$ for the continuous run. The present study's RER of $0.99 \pm 0.06$ is essentially the same as the continuous jog value of $1.00 \pm 0.02$.

The minute ventilation values from this study were significantly different on the continuous and discontinuous protocols. The continuous protocol elicited a mean VE of $36.01 \pm 4$ liters per minute and the discontinuous test $41.1 \pm 6.06$ liters per minute. Krahenbuhl et al. (1978) used girls of similar ages (6 to 9 years) and observed a similar
VE of 40.5 ± 10 on a continuous test. This was the only study reviewed that used similar aged girls and reported VE.

In this study the discontinuous protocol elicited significantly higher VO₂max values in both milliliters per kilogram per minute and liters per minute than the continuous protocol. The RER values demonstrate that the subjects were working at maximum effort as their RERs were close to 1.00 or over. The discontinuous protocol elicited significantly higher VE values than the continuous protocol.

During the familiarisation session, the subject was informed about the equipment and procedures utilized during the testing. Also during this session the subject completed a continuous treadmill test. The order of the continuous and discontinuous tests were randomly assigned. Before either the continuous or discontinuous tests were performed, procedures were explained and questions answered.

The continuous test was administered at a constant speed of 4.5 mph. The initial grade was 0% with 2% increase every 2 minutes. This procedure continued until the subject could no longer continue. A constant speed of 4.1 mph was also used for the discontinuous test. The initial grade was 0% and increased by 1.5% every 3 minutes. A five minute rest period following each exercise period. This procedure was continued until the subject
CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The purpose of this study was to compare continuous versus discontinuous treadmill protocols for the elicitation of maximum oxygen uptake in 14 prepubescent females. Each subject participated in a familiarization session as well as continuous and discontinuous testing sessions. During the familiarization session, the subject was informed about the equipment and procedures utilized during the testing. Also during this session the subject completed a continuous treadmill test. The order of the continuous and discontinuous tests were randomly assigned. Before either the continuous or discontinuous tests were performed procedures were explained and questions answered.

The continuous test was administered at a constant speed of 4.5 mph. The initial grade was 0% with 2.5% increase every 2 minutes. This procedure continued until the subject could no longer continue. A constant speed of 4.5 mph was also used for the discontinuous test. The initial grade was 0% and increased by 2.5% every 3 minutes. A five minute rest period followed each three minute work period. This procedure was continued until the subject
could no longer continue or until a plateau in VO2 was attained.

All three testing sessions were completed on a motor-driven treadmill. A two-way valve with headgear and mouthpiece facilitated expired gas collection. Inspired air was measured by an air flow meter. Expired gases passed through a mixing chamber and were sampled through carbon dioxide and oxygen analyzers. All metabolic measures were calculated using a computerized measurement system.

The statistical analysis used for determination of significant differences was a correlated groups t-test. The correlated groups t-test was completed on the dependent variables of VO2max in liters per minute and milliliters per kilogram per minute, respiratory exchanged ratio, and minute ventilation. The .05 level of significance was utilized to determine significance of the results. The discontinuous test exhibited significantly higher VO2max values in both liters per minute and milliliters per kilogram per minute. There was no significant difference in respiratory exchange ratio between the continuous and discontinuous protocols. A significant difference was observed in minute ventilation between the two protocols with the discontinuous test eliciting the higher values.

Conclusions
A discontinuous protocol elicited significantly higher maximum oxygen uptake values in this study than the continuous protocol. This study supports that children are capable of a maximum effort as their RER's approached 1.00, the value commonly used in adult studies as indicative of a maximal effort. Using traditional criteria there were more plateaus attained in the continuous test than in the discontinuous test. This was not anticipated and may be indicative that these may not be appropriate for children.

Recommendations for Further Study

It is recommended that the present study be repeated adding boys as subjects and have four testing groups (continuous protocol boys and girls and discontinuous protocol boys and girls) to determine if boys and girls respond in a similar manner to VO2max testing. To determine if cardiovascular risk factors are developing in our children. Each child would complete a medical and physical evaluation to assess the prevalence of cardiovascular risk factors. The items to be used for assessment would be a blood test for serum cholesterol and triglycerides, a work capacity test, body composition, and a family history questionnaire.
Bibliography


INFORMED CONSENT FORM

Dear Parents,

My name is Monica Severson and I am currently a master's degree student in the Department of Health, Physical Education, and Recreation at South Dakota State University. I am attempting to recruit 30 boys and girls ages 8, 10, and 12 years to participate in a study of maximal oxygen uptake measurement procedures. Since I am familiar with the students and parents of the Colman School, I have decided that it would be beneficial to do my study on these children. As a participant in the study you and your child can expect to find out his/her current cardiovascular fitness level.

Maximal oxygen uptake is the best measure of cardiovascular fitness. Each child will run on a motor-driven treadmill during three testing sessions. Each session will be approximately 1 hour in length and will be completed at least 48 hours apart. During the first session the child will become familiarized with the equipment, procedures, and how to run on the treadmill. During the second and third sessions, each child will perform two different maximal exercise test protocols for the determination of maximal oxygen uptake.

During one of the maximal exercise testing
sessions, each child will warm-up for 5 minutes and will have a 10 minute rest period afterwards. After the rest period, each child will run at a set speed for three, 3 minute period with each period being separated by a 10 minute rest. The grade of the treadmill will be increased each period. During the other maximal exercise testing session, each child will run at a comfortable speed which will remain constant throughout the test. The grade of the treadmill will be increased every 3 minutes (as if the child is running uphill). Each child's heart rate will be monitored throughout the testing and there will be constant supervision and encouragement. Dr. Jack Ewing, an exercise physiologist at SDSU, will be supervising each testing session.

The child will be encouraged to give a maximal effort (run as long as possible), however, the child may stop at any time. The risk of injury in this type of testing is minimal and all precautions to prevent injury will be taken. The child may withdraw from the study at any time. It will be important that the child abstain from eating for 2 hours prior to the testing. The testing will be completed at the Human Performance Lab at SDSU.

Signature of the Parent

Signature of the Investigator

Date
## Appendix B

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*Note.* Dis=Discontinuous Test; Con=Continuous Test; VO2(ml)=VO2max in ml/kg/min; VO2(1)=VO2max in l/min; RER=Respiratory Exchange Ratio; VE=Minute Ventilation in l/min