CANADIAN THESES

THÈSES CANADIENNES

THE UNIVERSITY OF ALBERTA

A Study of Appropriate Measures of Anaerobic Power and Capacity for Upper Body Activities

by

DONALD J. CLARK

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

AND RESEARCH IN PARTIAL FULFILMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

DEPARTMENT OF PHYSICAL EDUCATION AND

SPORT STUDIES

EDMONTON, ALBERTA

FALL 1986

ISBN 0-315-32607-7

THE UNIVERSITY OF ALBERTA

RELEASE FORM

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TITLE OF THESIS: A Study of Appropriate Measures of Anaerobic Power and Capacity for Upper Body Activities

DEGREE: DOCTOR OF PHILOSOPHY

YEAR THIS DEGREE GRANTED: 1986

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Date: September 19, 1986

ABSTRACT

The majority of tests of anaerobic power and capacity involve the musculature of the lower extremities. Many athletes and coaches have questioned the appropriateness of these tests to determine anaerobic power and capacity in athletes participating in events where upper body musculature plays a major role in the performance of the activity. The purpose of this study is to determine appropriate measures of anaerobic power and capacity for those activities where it is generally assumed that upper body musculature plays a major role in the performance of the activity. Thirty six subjects (12 elite wrestlers, 11 novice wrestlers, 13 university hockey players) completed eight tests over a two week mid-season testing period. The tests were: Vertical Jump; Arm Pull; Modified Arm Pull (specifically designed for this study); Leg Bicycle Ergometer Anaerobic Power; Leg Bicycle Ergometer Anaerobic Capacity; Arm Bicycle Ergometer Anaerobic Power; Arm Bicycle Ergometer Anaerobic Capacity; and the Margaria-Kalamen Power Test (Stair Climb). Results relative to body weight were determined for the ergometer tests and the Margaria-Kalamen Test. All subjects completed a standardized warmup prior to the testing sessions which were conducted at the same time each testing day. Leg anaerobic power (6 seconds) and anaerobic capacity (30 seconds) values (watts) were: elite wrestlers 850.35 w and 3146.45 w; novice wrestlers 735.30 w and 2814.19 w; and university hockey players 943.36 w and 3617.06 w. Arm anaerobic power (6 seconds) and anaerobic capacity (30

seconds) values (watts) were: elite wrestlers 423.13 w and 1675.78 w; novice wrestlers 367.54 w and 1493.35 w; and university hockey players 484.51 w and 1969.90 w. A oneway analysis of variance and subsequent Tukey range test revealed the university hockey players differed significantly (.05 level) from the novice wrestlers for all tests except for weight and vertical jump. The university hockey players and elite wrestlers differed significantly (.05 level) from the novice wrestlers for each of the relative tests. The university hockey players and elite wrestlers results did not differ significantly on the arm pull and modified arm pull tests. Based on the results it was concluded the tests utilized in this study are not more appropriate for measuring anaerobic power and capacity for those activities where upper body musculature plays a major role in the performance of the activity. It was suggested that an explanation for the tests utilized in this study for not discriminating between arm and leg anaerobic power and capacity for the study groups was the nature of the training programs and activities in which the groups were participating. It was suggested there is a generality of expression of anaerobic power and capacity by either the upper or lower body musculature.

ACKNOWLEDGEMENTS

I would like to express my appreciation to the members of my committee: Dr. S. Mendryk (Supervisor); Dr. A. Quinney; Dr. M. Singh; Dr. R. Hodges; and Dr. J. Alexander (External Examiner) for their advice and guidance in the completion of this thesis.

I would also like to acknowledge the direction and encouragement provided by Dr. R. Macnab throughout the preparation of this thesis.

I would like to thank the subjects who participated in this study for their cooperation and maximum effort during the testing sessions.

I would like to thank the Laboratory Assistants in the Dr. Paul Schwann Centre, University of Regina for their assistance during the testing sessions.

I would like to acknowledge the encouragement and support provided by my colleagues in the Faculty of Physical Activity Studies, University of Regina during the completion of this thesis.

A special acknowledgement must be made for the contribution by my wife Ann for her ever present support throughout the completion of this thesis.

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CHAPTER I

INTRODUCTION

A meaningful study of the physiological factors affecting the performance of an activity is based on a sound knowledge of the overall nature of the activity (Astrand and Rodahl 1977, Fox 1984, MacDougall and Wenger 1982, Tesch 1984). When the nature of the activity is clearly understood, energy demands, energy sources, and the relationship of the activity to the energy continuum can be determined (Fox 1984, Jensen and Fisher 1979). This knowledge of the activity must include realistic values for the intensity, frequency, and duration of muscular contractions required in the performance of the activity. Within the same activity the energy requirements may be continually changing. Physical performance limits are determined by the ability to produce energy. Energy production for physical activity can be divided into two components, aerobic and anaerobic. When the contribution of aerobic and anaerobic energy production necessary for maximum performance of the activity can be determined then the benefit of measuring each in relation to predicting performance and designing appropriate training programs is understood. Considerably greater emphasis has been placed on understanding and assessing the aerobic component. This is surprising since a large number of competitive athletic activities utilize a greater anaerobic than aerobic energy component. Wrestling and gymnastic performance involving high intensity, short duration effort are considered to be primarily anaerobic activities. In these activities the energy contribution is 75-90 percent from anaerobic sources and 10-25 percent from aerobic sources.

The immediate source of muscular energy is adenosine triphosphate (ATP). ATP can be supplied by anaerobic or aerobic energy systems (Fox 1984, Green 1982, Katch and Weltman 1979). In high intensity, short duration activities energy is primarily supplied by the anaerobic system. The relationship between the nature of the activity and the energy source establish the energy continuum. The most direct source of energy is the anaerobic metabolism of stored high energy organic phosphate compounds (phosphagens), primarily ATP and phosphocreatine (PC). This source precedes all other exergonic processes and is limited in the absence of resynthesis by oxidation, the myokinase reaction (condensation of ADP to ATP), or glycolysis. It is estimated that muscular contraction can continue for approximately 6 seconds via this energy system (Bergstrom 1971, Karlsson and Saltin 1970, Margaria et al 1964). The potential of this system is expressed as a rate per unit of time. This measure is termed anaerobic power (Di Prampero 1971, Margaria et al 1964, Margaria et al 1966). A second source of anaerobic energy is the glycolytic production of ATP where glycogen or glucose is metabolised to lactic acid.

Maximum involvement of this system is achieved when a rate of work requiring an energy load greater than an individual's maximum oxygen uptake is performed until exhaustion. Energy supplied by this system can support muscle contraction over a time period ranging from 30-40 seconds to 2-4 minutes (Bouchard et al 1982, Cunningham and Faulkner 1969, Margaria et al 1964, Margaria et al 1966). The potential of this system is expressed as a total capacity or maximal lactate or pyruvate production. This measure is termed anaerobic capacity (Katch and Weltman 1979).

These two anaerobic systems can be related to the first two areas of the energy continuum. The first area includes activities of less than 30 seconds duration and the energy source is primarily the phosphagens. The second area includes activities ranging in duration from 30 seconds to approximately one and a half minutes and the source of energy is primarily glycolytic producion of ATP. The nature of a particular activity will determine the contribution from each area of the energy continuum (Fox 1984).

Tests, based on biochemical, histological, and performance factors, have been developed to measure anaerobic power and capacity. The biochemical factors have included: changes in blood lactate; determination of oxygen debt; muscle concentrations of ATP, PC, and glycogen; and assays for enzyme activities. Muscle fiber type and size are the primary histological factors examined. The performance factors have included: vertical jump; standing broad jump; running (sprint) time; squat weight lifts; throwing of weighted objects; vertical arm pull; muscular force; muscular power; vertical velocity; leg power output during stair climbing and bicycle ergometer tests; arm power output; and performance on isokinetic devices. The relationships between these three factors have been investigated by Katch and Weltman (1979), Komi et al (1977), and McCafferty and Horvath (1977), Tesch (1984) and Tharp et al (1985).

Statement of the Problem

The primary purpose of this study is to determine appropriate measures of anaerobic power and capacity for those activities where it is generally assumed that upper body musculature plays a major role in the performance of the activity.

A secondary purpose is to determine the relationships between measures of anaerobic power and capacity utilized in this study in order to comment on their specific applicability to a variety of sport testing situations.

Justification for the Study

The majority of tests designed to measure anaerobic power and capacity have involved the musculature of the lower extremities. The appropriateness of these tests for activities where the upper body musculature plays a major role in performance has been questioned. An example of this case is wrestling and gymnastics. This has lead coaches and exercise physiologists to examine the type of tests frequently utilized to measure anaerobic power and capacity. Recently this concern has resulted in sport governing bodies attempting to develop sport specific measures of anaerobic power and capacity (C.A.W.A. 1980, Danielson 1980). This study emphasizes the practical aspects of measuring anaerobic power and capacity. This study is an attempt to examine anaerobic power and capacity tests involving both upper and lower body musculature and to determine their appropriateness for activities involving upper body musculature. The upper body tests selected involve the musculature used in technique associated with skilled, successful performance in the activity. The tests selected include, what can be described as, both "field" and "laboratory" measures of anaerobic power and capacity. The field tests were included in an attempt to determine their appropriateness for measuring anaerobic power and capacity for a specific sport and to include tests that could be easily utilized by large numbers of athletes (Tharp et al 1984). This emphasis will enhance the application of the results of this study to practical situations such as determining field tests and actual coaching decisions.

Delimitations

The delimitations of the study are:

1. The study is concerned with the measurement of anaerobic power and capacity in 3 groups of individuals. The first group consists of elite wrestlers. The second group consists of novice wrestlers. The third group consists of university hockey players. The members of all three groups are of similar age and body weight.
2. The study is concerned with differences in anaerobic power and capacity as a result of participating in specific physical activities.
3. The study is concerned with differences in anaerobic power and capacity as a result of utilizing different measuring techniques.
4. The study is concerned with the appropriateness of these measures of anaerobic power and capacity for athletes participating in activities where upper body musculature plays a major role in the performance of the activity.
5. The study is concerned with commenting on the applicability of specific measures of anaerobic power and capacity to a variety of sports.

Limitations

The limitations of the study are:

1. The number of subjects selected and the method of selection.
2. The members of the elite wrestlers group may not be representative of the most elite level competitors in this activity, since 5 of the 12 athletes are not participating in a complete year round training and competitive program.
3. The members of the novice wrestlers group included athletes who had limited wrestling experience, but who were participating in regular cardiovascular and weight training programs.
4. The members of the university hockey players group were in addition to regular hockey practises, participating in a regular weight training program.
5. The subjective performance rating of the members of the elite wrestlers group was based on their performance in four competitions prior to testing.
6. The methods and techniques selected for the measurement of anaerobic power and capacity.
7. The statistical methods and procedures selected.

Definition of Terms

<u>Anaerobic Power</u> - the power output during a high intensity, short duration activity (all out effort for 6

seconds or less). Indicative of the anaerobic metabolism of stored high energy organic phosphate compounds (ATP-PC).

Anaerobic Capacity - the power output during a high intensity, short duration activity (all out effort for 30 seconds). Indicative of the rate of anaerobic glycolysis and maximum lactate production.

Vertical Jump - the difference between the standing reach height and the height achieved in a vertical jump, recorded in centimeters. Indicative of the anaerobic metabolism of stored high energy organic phosphate compounds (ATP-PC).

Anaerobic Power Output - (a) Margaria Kalamen Power Test - the power output during an all out stair climbing effort, calculated from the subject's weight, vertical rise and time, recorded in watts (1 watt = 6.118 kg-m x min^{-1}), (b) Bicycle Ergometer Power Test - the power output by the arms or legs during the initial 6 seconds of a 30-second all out effort on a bicycle ergometer, recorded in watts.

Anaerobic Power Output Per Kilogram Body Weight - the anaerobic power output divided by body weight.

Anaerobic Capacity Output - the power output by the arms or legs during a 30 second all out effort on a bicycle ergometer, recorded in watts.

Anaerobic Capacity Output Per Kilogram Body Weight - the anaerobic capacity output divided by body weight.

Arm Pull - the work output during a vertical rope pull, calculated from distance of pull and subjects weight, recorded in joules. Indicative of the anaerobic metabolism of stored high energy organic phosphate compounds (ATP-PC).

Modified Arm Pull - the number of arm pull repetitions completed before the subject could not pull beyond one half of the maximum arm pull distance. Indicative of the rate of anaerobic glycolysis and maximum lactate production.

Body Weight - the subject's weight while dressed in gymnasium t-shirt and shorts, recorded in kilograms.

Subjective Performance Rating - a subjective rating of the individual's performance ability in a specific activity, based on a scale of 1-10, a 10 being the highest performance rating.

The units the measures are recorded in are based on the recommendations of the World Health Organization 1977 review of units in physiology (W.H.O. 1977) and the Canadian Association of Sport Sciences (MacDougall, Wenger and Green 1982).

CHAPTER II

REVIEW OF RELATED LITERATURE

This review of literature focuses on two areas related to the study of anaerobic power and capacity. The first area reviews the physiological, biochemical and histological factors. The second area includes an investigation of the types of tests utilized to measure anaerobic power and capacity. The nature of this study results in the emphasis being placed on the latter area. The primary purpose of this study relates to determining appropriate measures of anaerobic power and capacity for a range of activities and the review includes: relationships between laboratory and field tests; and comments on the practicality and applicability of tests in field testing or coaching situations.

Anaerobic Power and Capacity and Physical Performance

The relationship between anaerobic power and capacity and physical performance has been indicated from laboratory data (Karlsson 1971, Katch and Weltman 1979, Margaria et al 1964, McCafferty and Horvath 1977, and Tharp et al 1985). This relationship has been elucidated in a variety of methods. Several researchers have undertaken to investigate biochemical and histological factors related to the production of anaerobic power and capacity during physical performance (Haekkinen et al 1984).

Cunningham and Faulkner (1969) suggest the amount of energy obtained by anaerobic processes can be approximated by measuring the amount metabolism is inceased above resting values following exercise and by measuring the difference between resting blood lactate and the highest value observed during or after exercise. Oxygen debt and blood lactate concentration provide estimates of different aspects of the energy obtained from anaerobic sources. Oxygen debt provides an indication of the amount of phosphocreatine that is resynthesized following work. Blood lactate does not provide a direct estimate of the activity of glycolysis, but it does reflect the difference in the amount of pyruvate that is produced by glycolysis compared to the amount of pyruvate that is metabolized by the citric acid cycle. Both can be employed as gross indicators of anaerobic sources of energy and when applied to the same subjects performing on the same test they may be used to assess relative changes in these sources.

The relationship between fatigue and muscle concentrations of lactate, ATP and PC in man during exhaustive exercise was investigated by Karlsson and Saltin (1970). The muscle metabolite determinations indicated that the phosphagens were depleted after 2 to 3 minutes and lactate production increased until exhaustion. Two enzymes were indicated as having key positions in glycolysis. Phosphorylase activity was greater as the intensity of the exercise increased. Phosphofructokinase (PFK) which is inactivated by high concentrations of ATP was activated in anaerobic conditions, resulting from high intensity work.

Klausen et al (1975) undertook to analyze the relation between muscle glycogen, lactate accumulation and work capacity. Bouts of supermaximal exercise were altered with submaximal exercise. The inability to maintain high intensity performance was attributed to a lack of substrate (glycogen), a decrease in enzyme velocity due to low substrate concentration or a combination of these two factors.

The effects of high intensity intermittent sprint training on skeletal muscle in man was the focus of the work of Thorstensson et al (1975). Muscle concentrations of ATP and PC did not change with training. However, as a result of increased muscle mass the activity of high energy phosphate transfering enzymes, ATPase, phosphokinase and myokinase, did increase. Similar parameters were investigated by Thorstensson et al (1976) following participation in a progressive strength training program. The activities of creatine phosphokinase, myokinase and PFK as indicators of the ATP resynthesizing pathways were examined. The only significant change with the strength training program was an increase in myokinase activity. This increase could imply enhanced potential of the muscle to replenish ATP since myokinase catalyzes the formation of ATP from ADP.

Wenger and Reed (1976) proposed a model to describe metabolic factors which could lead to muscular fatigue and hence would limit the performance capacity in high intensity, anaerobic type of work. The fast twitch glycolytic motor units will be heavily recruited for this type of work and metabolic factors which affect this type of muscle and its energy supply will limit the capacity to perform. The limiting factors in this model include: stores of ATP and PC; production of lactate; depletion of muscle glycogen; delay in the activation of the phosphorylase enzyme; insufficient hydride ion acceptor (NAD); and insufficient amounts of the lactate dehydrogenase enzyme.

An examination of muscle fiber composition and selected oxidative and glycolytic enzymes in male and female athletes participating in running, jumping, and throwing events was completed by Costill et al (1976). The fiber distributions within the various events suggest that a larger percentage of fast twitch fibers are found in those athletes who participate in sprint, throwing, and jumping events. Succinate dehydrogenase activity was lowest in the athletes participating in throwing events. Lactate dehydrogenase (LDH) activity was greatest in those athletes who possessed a high percentage of fast twitch fibers. Phosphorylase activity appeared to be a function of high intensity anaerobic training. The phosphorylase activity of sprinters was double that of distance runners.

Komi et al (1977) studied anaerobic power and capacity in skeletal muscles of athletes participating in sport events of differing need for muscular force, speed and endurance. Vertical velocity was highest in athletes participating in power events. Muscular power was lowest in endurance athletes. Total and relative leg forces were highest among power athletes, canoeists, ice hockey players, ski jumpers, and alpine skiers. Power athletes, 800m runners, canoeists and alpine skiers had the highest blood lactate concentrations following a maximal treadmill run. Muscle fiber distribution expressed as percentage fast twitch fibers revealed the highest percentage (63%) in power athletes as compared to the lowest percentage (22%) in long distance runners. The activities of LDH and CPK were highest among alpine skiers and lowest in the endurance athletes. Intercorrelations revealed statistically significant positive relationships between: total leg force and body weight; percent fast twitch fibers and relative force, vertical velocity, LDH, peak blood lactate; vertical velocity and LDH and CPK.

The influence of skeletal muscle fiber composition on the force time curve in bilateral leg extension was investigated by Viitasalo and Komi (1978). The form of the force time curve is influenced by the relative proportion and absolute area of fast twitch fibers. The correlation coefficient between fiber composition and rise time was greatest when the rate of force development was highest.

Coyle et al (1979) established the functional significance of different muscle fiber compositions in the generation of peak leg extension power through a range of velocities. Subjects with greater than 50 percent fast twitch muscle fibers were able to produce 11, 16, 23 and 47 percent greater percent torque than those subjects with less than 50 percent fast twitch muscle fibers at velocities of 115, 200, 287 and 400 degrees per second. Combining the subjects resulted in the correlation between percent fast twitch muscle fibers and percent torque increasing as the velocity was increased.

Muscle fiber type and activity of selected enzymes involved in energy supply in elite performers involved in a type of physical activity where both aerobic and anaerobic systems are utilized was investigated by Green et al (1979). The effects of participating in high intensity exercise on fiber type and size appears to be transitory and restricted to the fast twitch fibers. Fast twitch a and b fibers were both larger at post season. An increase in the percentage of fast twitch a fibers was observed, while there was a decline in the percentage of fast twitch b fibers. The enzymes of glycolysis (phosphorylase, PFK and LDH) were similar between the preseason group and a control group, however in post season the values for phosphorylase and PFK were significantly lower for the athlete group. This difference was attributed to the fact that carbohydrate utilization is considerably accelerated during ice hockey performance and that glycolysis represents a significant pathway for energy metabolism but does not appear to be a criterion for stimulation of the glycolytic enzymes studied.

Gregor et al (1979) examined the relationship between fast twitch versus slow twitch cross sectional area of the vastus lateralis muscle and the "in vivo" torque velocity relationship in female track athletes. The results indicated that the relative cross sectional areas of slow twitch muscle fibers in sprinters and distance runners fall on opposing ends of the spectrum. When the group was divided on the basis of greater than or less than 50 percent slow twitch fiber population a difference in maximal torque and power were found at the higher speeds (96, 192, 288 degrees per second). It was concluded that the effect of fiber types or torque production becomes evident at a relatively slow speed.

Mechanical factors related to the production of anaerobic power during physical performance were considered by Margaria et al (1966). The power developed in a very short exercise of no more than 4-5 seconds may be indicative of the phosphagen splitting mechanism of work production alone. Running up a staircase at top speed, provided the effort is maximal, enables the attainment of constant speed in 1-2 seconds, which is constant up to the fifth second. This exercise is a very convenient ergometric procedure as it appears that the energy requirement for speed maintenance in running a given distance is independent of speed. Provided that the effort is maximal, for a given incline of steps, the energy requirement depends only on the mechanical work as calculated from the body lift. The vertical component of the speed in meters per second gives the mechanical power output expressed in kilogram meters per second. The efficiency of this type of exercise approaches 25 percent; in fact, running at an incline exceeding about 30 percent, the external work is given practically by the body lift alone, all other factors, such as the speed changes at each step and the impact of the body on the ground in the last phase being negligible. The energy requirement is therefore easily calculated.

The influence of specificity of training on anaerobic power and physical performance was studied by Clausen et al (1973). The data for submaximal and maximal exercise with the arms or legs after either arm training or leg training indicated that training is not an absolute event that affects only central circulation, but it also causes peripheral circulation variations. The peripheral as well as central circulatory changes were both most conspicuous during arm exercise. This was interpreted as an indication that arm muscles have generally a greater potentiality for local improvement and that central circulatory changes occur in proportion to the muscle mass used during training. However, cardiovascular adjustment is different during exercise with small muscle groups than with large muscle groups. Therefore, it is possible that peripheral and central circulatory adaptations show greater manifestations during arm exercise than during leg exercise.

Ayalon, Inbar, and Bar-Or (1974) assessed the degree of relationship among several measures of explosive strength and anaerobic power. A correlation of $r = .81$ was found between arm and leg pedaling tests. This relationship lead to the assumption that there is some kind of generality in the anaerobic capacity of man.

The task specific changes in maximal oxygen uptake resulting from arm versus leg training were studied by Stamford et al (1978). Groups of subjects were arm trained and leg trained. The arm trained group increased oxygen uptake 19 percent on an arm cranking test and less than 1 percent on a bicycling test. The leg trained group increased oxygen uptake 15 percent on the bicycling test and less than 1 percent on the arm cranking test. These results indicate task specific training effects. This adds support to the concept of peripheral versus central factors as being causative in terms of a training effect.

Lesmes et al (1978) further studied specificity of training in their work to compare strength and power gains achieved as a result of isokinetic (180 degrees per second) strength training. One leg of each subject was trained with 6 second bouts (6 seconds x 10, with 114 seconds of rest between each work bout), the other leg was trained with 30 second bouts (repeated until the total work performed equaled the total work completed by the 6 second leg, with 20 minutes of relief between each work bout). The results indicated significant differences in power output during a 30 second work bout following the training. During a 60 second fatigue test both legs were able to perform significantly more work after training. The 6 second trained leg increased its total work output by 15 percent which was not significantly different than the 19 percent increase observed in the 30 second trained leg. However, during the final 10 seconds the 30 second trained legs displayed a significantly greater mean work output. It was proposed that the 30 second trained leg, stressing mainly the glycolytic pathway, adapted to its specific energy producing system and thus reduced its fatiguability in the prolonged task.

Weltman, Moffatt and Stamford (1978) investigated the effects of anaerobic training and detraining on aerobic power and performance estimates of anaerobic power output and anaerobic capacity. It was found that 6 weeks of anaerobic training resulted in a significant increase in aerobic power and anaerobic capacity. Six weeks of detraining resulted in completely extinguishing improvements in aerobic power. However, performance estimates of anaerobic power output and anaerobic capacity remained significantly elevated after detraining.

The relationship between anaerobic power and capacity and physical performance can be examined in a variety of methods. It appears this relationship may in part be dependent on specificity of training and the different means of measuring anaerobic power and capacity.

Vertical Jump Tests

The application of various vertical jump tests to the measurement of power has been examined in several studies. McClements (1966) found significant relationships between leg strength and vertical jump ($r = .52$ for flexors and $r = .65$ for extensors). Berger and Henderson (1966) in a similar study found dynamic and static leg strength related to leg power. In both these studies the vertical jump was initiated from a near full squat position. Costill et al (1968) when studying the relationship among selected tests of explosive leg strength and power had the subjects assume a comfortable balanced crouch position prior to the maximum jump effort. Considine and Sullivan (1973) when examining similar relationships utilized a comparable vertical jump. They had their subjects place both toes on a prescribed starting line before assuming the crouched position.

Stair Climbing Power Tests

Margaria, Aghemo, and Rovelli (1966) developed a test for maximum anaerobic power. Subjects run at top speed up ordinary stairs. The time employed to cover an even number of steps was measured with an electronic clock sensitive to a hundredth of a second, driven by two photoelectric cells. The reason for an even number of steps was to have the subject intercept the beam of light while in the same position and in the same phase of movement. The vertical component of the speed was easily calculated by knowing the vertical and horizontal dimensions of the steps. For the measurement of power the time taken from the fourth to the sixth step was recorded. The power output was calculated as kilogram meters per second or kilogram meters per kilogram per second. This test was modified by Kalamen (1968). The Margaria-Kalamen modification resulted in greater power output than the original test. The subjects start 6 meters in front of the staircase. At their pleasure they run up the stairs as rapidly as possible, taking three at a time. An electronic switchmat is placed on the third and ninth step. An electronic timer starts as the person steps on the first switchmat and stops when they step on the second switchmat. Time is recorded to a hundredth of a second. The subject is allowed several trials and the best time is recorded for computation of power output. The power output is computed using the weight of the person, vertical height between third and ninth stair and the time required to travel from the third to the ninth stair. The power output is calculated as kilogram meters per second.

Margaria, Aghemo, and Rovelli (1966) suggested their power test had the following advantages: it measures a well defined character, power output; it requires no particular knowledge or skill; no expensive equipment is required; the test does not lead to exhaustion; the exercise involves a large portion of the muscular mass of the body; and it can be applied to studies involving large numbers of subjects.

Leg Bicycle Ergometer Power Tests

Ayalon, Inbar, and Bar-Or (1974) in attempting to relate measurements of explosive strength and anaerobic power developed tests of absolute and relative explosive power, and total power output. The absolute explosive power test measured the power exerted by the leg in the propulsive phase of pedaling on a Fleisch bicycle ergometer against a constant force of 2.90 kilograms. Subjects were instructed to perform one all out effort over 150 degrees of motion. Two microswitches operated a stop clock that measured the time involved in moving the pedal through 120 degrees to one hundredth of a second. The relative explosive power test was similar, with the difference that the load given to each subject was relative to body weight. The power output tests were performed on a Fleisch bicycle ergometer utilizing leg and arm pedaling. The leg pedaling test involved pedaling at maximal speed for 30 seconds. The load applied was 40 grams per kilogram body weight. The number of revolutions completed every 5 seconds was recorded. The total power output for the 30 second period was computed, as was the power output for the fastest 5 second period.

Katch et al (1977) conducted two experiments to ascertain the optimum protocol for a maximum anaerobic work output test on the bicycle ergometer. This work indicated the optimum characteristics for a bicycle ergometer anaerobic test to be a duration of approximately 40 seconds, a resistance of 5 to 6 kiloponds, and an all out pedal frequency. Support for this protocol measuring anaerobic power and capacity was based on the small contribution to total energy production by aerobic means during a test of this duration and workload resistance. In addition, the data on glycogen depletion and recruitment pattern of fast twitch anaerobic muscle fibers at the initiation of rapid high intensity exercise support the fact that this test is dependent on anaerobic functioning.

A short supramaximal test, aimed to estimate maximal anaerobic power and capacity was developed by Bar-Or et al (1977). The test consists of 30 second all-out bicycle pedaling against resistance corresponding to body weight. The optimal load to bring about maximal power output was .075 kiloponds per kilogram body weight. Mechanical output is monitored each 5 seconds to determine peak, as well as cumulative power output.

In order to examine the effects of anaerobic training and detraining on aerobic power and performance estimates of anaerobic power output and anaerobic capacity Weltman, Moffatt and Stamford (1978) had subjects complete an all out pedaling task on a mechanically braked bicycle ergometer against 4 kilograms frictional resistance for 40 seconds duration. Total work output on the 40 second test was used to estimate anaerobic capacity. Anaerobic power output was estimated using the highest 4 second by 4 second score. This always occurred within the first 8 seconds and was speculated to be indicative of the rate of ATP-PC splitting.

Katch and Weltman (1979) in a study to examine the relationship between performance estimates of anaerobic capability and aerobic power utilized the following tests: anaerobic capacity was measured by an all out bicycle ergometer ride for 120 seconds at a frictional resistance of 5.6 kiloponds; anaerobic power was measured from the same test utilizing the power output during the initial 6 seconds of the test.

The studies completed by Katch et al (1977), Weltman, Moffatt and Stamford (1978), and Katch and Weltman (1979) indicate the maximum power output occurs in the first 4-8 seconds.

The determination of optimal resistance settings for anaerobic power testing was investigated by Evans and Quinney (1981). Two practical and accurate predictor formulae for the resistance setting to derive true maximal power output were developed. The first utilized power output at a frictional resistance of 5 kiloponds during an all out 30 second bicycle ergometer test (optimal resistance setting = -9.0166 + 0.0291 power output at 5 kiloponds). The second formula utilized body weight and leg volume (optimal resistance setting = -0.4914 - 0.2151 body weight + 2.1124 leg volume).

Tharp, Johnson and Thorland (1984) in a study of elite young track athletes using the Wingate (Bar-Or) protocol concluded that the test differentiated between sprint and running ability. Their findings indicated that more sensitive results were realized when anaerobic power and capacity were expressed relative to body weight.

Arm Pull Power Tests

Johnson (1969) developed an arm pull test of power to predict potential or indicate ability for activities such as gymnastic apparatus work and pole vaulting. The test was a vertical arm pull test that was practical to score and correlated with an identical test scored in power units. The study used motion photography to determine the time factor for use with distance and weight in computing power scores. The tests were conducted on a standard climbing rope and consisted of a two arm pull from a sitting position with one hand releasing and then regrasping for as great a distance as possible up the rope. The test results indicated sufficient validity may be obtained for power measurement when scoring in work units. The correlation between arm length and pull distance was not significant. The correlation between body weight and test scores approached significance, indicating heavier subjects were not unduly handicapped when scored in work units.

Arm Bicycle Ergometer Power Tests

The leg bicycle ergometer power tests have posed several problems. Margaria, Aghemo, and Rovelli (1966) suggested their test measured primarily leg and lower trunk muscle power production. Several investigators have included arm bicycle ergometer cranking as a method of determining human performance. Clausen et al (1973) utilized standing arm cranking at workloads to give heart rates of 130 and 170 beats per minute. The subjects exercised for 15 minutes on each of these workloads and rested for 30 minutes between each exercise period. The workloads to elicit these heart rates were considered submaximal for arm exercise.

Ayalon, Inbar, and Bar-Or (1974) developed tests of power output using an arm bicycle ergometer. The test involved pedaling from a sitting position at an all out frequency for 30 seconds. The workload applied was 0.033 kiloponds per kilogram body weight. The number of revolutions completed every 5 seconds was recorded. The total power output for the 30 seconds was computed, as was the power output for the fastest 5 second period of the performance. Bar-Or and Zwiren (1975) devised a continuous all out arm test on the bicycle ergometer. This test involved pedaling from a sitting position at 50 revolutions per minute. The height of the axis connecting the pedals was at shoulder level. To keep the total time of exertion within 5-7 minutes, the initial workload was decided upon according to the heart rate response of each individual to a submaximal test comprised of three 2 minute stages which preceded the all out test by 20-30 minutes. Thus, an initial load of 450, 600 or 750 kilogram-meters per minute was selected. The workloads were subsequently increased every 2 minutes by 150 kilogram-meters per minute, until subjects could no longer keep up the pace.

Davis et al (1976) in a study to determine anaerobic threshold had the subjects perform an arm cranking test. The subject was seated behind the ergometer in such a manner that the axis of the cranking arm formed a 60-70 degree with the perpendicular. The test was initiated against 0 kiloponds frictional resistance at 50 revolutions per minute during the first 4 minutes of the test. Thereafter, the pedal frequency was maintained at 50 revolutions per minute and the frictional resistance was increased 0.25 kiloponds each minute until the subject was fatigued. The level of the crank with reference to the subject appears to be critical for arm cranking anaerobic threshold measurement. A pilot study demonstrated that when the crank was at shoulder level a lower work rate was found to elicit the anaerobic threshold.

A 30 second all out bicycle ergometer test was developed by Bar-Or, Dotan, and Inbar (1977) to measure anaerobic power and capacity. The test was completed from a sitting position at a frictional resistance of 0.05 kiloponds per kilogram body weight. Verbal encouragement was given throughout the test. Anaerobic power was based on the power output at the fastest 5 seconds, and anaerobic capacity was based on the power output for the 30 second period. A 10 minute intermittent warmup (30 seconds exercise, 30 seconds rest) on the ergometer, such that heart rate reaches 160 beats per minute was best suited to optimal performance. Approximately 5 minutes was allowed to elapse between the warmup period and the start of the test.

Stamford et al (1978) utilized a standing arm cranking test to evaluate task specific changes in maximal oxygen uptake resulting from arm versus leg training. Arm cranking in the standing position was used to permit assistance from trunk muscles thus equalizing to a significant degree the amount of muscle mass utilized in lower body tests. The subjects pedaled at 60 revolutions per minute for 5 minute work bouts with 10 minute rest periods between each work bout. The initial frictional resistance was 1.5 kiloponds and 0.5 kiloponds were added for each subsequent work bout until the subject could no longer keep the cadence.

Oldridge, Heigenhauser, and Jones (1979) investigated cardiorespiratory response to arm cranking and treadmill walking in female swimmers. The arm cranking test was carried out in a sitting position using a mechanically braked bicycle ergometer. The initial workload was carried out at 0 kiloponds resistance with increments of 75 kilogram-meters per minute each minute until a cranking rate of 60 revolutions per minute could not be maintained.

Practical Considerations

MacDougall, Wenger and Green (1982) advocated the need to examine the practical aspects and relationships of physiological testing. They propose that testing, and in particular 'laboratory' testing, should supplement other sources of information, such as, actual performances or program should be one where: the variables tested are relevant to that sport; the tests which are selected are valid and reliable; the test protocols are as sport specific as possible; test administration is rigidly controlled; the athletes human rights are respected; the testing is repeated at regular intervals; and results are interpreted to the coach and athlete directly.

Reed (1982) suggested that field tests should complement those tests traditionally conducted in laboratories. He indicated field tests are most practical when they are used to compare results of the same individual on repeated tests. He stated the validation of field tests must be established. This validation is completed by ensuring: the simulation of actual performance in the test; and the selection of the physiological variables which contribute to performance.

Semeniuk (1984) outlined field anaerobic power and capacity tests. The tests were categorized on the basis of duration and repetition of performance. He suggested tests should be: reliable; simple to administer; appealing to competetive instincts of subjects; contributing to the physical development of subjects; and valid.

Sharratt (1984) indicated that an integrated approach must be utilized in assessing athletes. This integration must include laboratory tests and sport specific applied in practical situations.

Rhodes, Potts and Benicky (1985) utilized laboratory and field tests (on-ice) to assess anaerobic power and capacity. Significant relationships were found between laboratory and on-ice tests for anaerobic power and capacity.

Tesch (1984) utilizing a modified arm cranking device reported a significant correlation between arm anaerobic capacity and 25m swim performance.

In a study to examine force-velocity relationships on a bicycle ergometer Nadeau, Brassard and Cuerrier (1983) indicated the importance of field testing of leg power. They indicated that certain activities required sport specific tests as a result of the individuals centre of gravity not being substantially lifted during performance.

Simoneau et al (1983) in a study to examine anaerobic alactacid and lactacid capacities indicated that it is essential to measure both variables to determine anaerobic metabolism capacity. It was recommended that test modifications should be made to accommodate individual differences in order that a high pedalling frequency could be maintained throughout the test.

Bouchard, Taylor and Dulac (1982) suggest for testing of anaerobic power and capacity in many sports the commercially available testing equipment will have to be modified, while in other sports specific equipment will have to be constructed.

This review of practical considerations related to the determination of anaerobic power and capacity supports the need for an integrated application of laboratory and sport specific field tests.

METHODOLOGY

Subjects

Elite Wrestlers. Twelve wrestlers, who were carded (receiving financial support) by either the national sport governing body or provincial sport governing body, volunteered and consented (Appendix 1) to participate in the study. The criteria for inclusion in the elite wrestler group were: training and competing in a year round program; and at least 2 years competitive wrestling experience. The selection of this group for the study was based on the assumption that training for and competing in wrestling at this level results in higher arm anaerobic power and capacity as compared to the novice wrestler and university hockey player groups. Prior to the testing for the study the members of this group participated in regular wrestling practices for a three month period. These practices were from 90-120 minutes in length 4 or 5 days per week. The number of practices was dependent on their competition schedule. In addition the members of this group were participating in a weight training program 3 times per week. During the month prior to testing the members of this group participated in four wrestling competitions. The physical characteristics of this group are shown in Table I.

Novice Wrestlers. Eleven wrestlers, who were members of a university or club wrestling team, volunteered and consented (Appendix 1) to participate in the study. The selection of this group for the study was based on the assumption that training for and competing in wrestling at this level would result in lower arm anaerobic power and capacity as compared to the elite wrestlers group. Prior to testing for the study the members of this group had participated in a three week wrestling preseason training program, followed by four weeks of regular wrestling practices. The preseason program consisted of distance running, flexibility exercises and weight training. The weight training program was continued 3 times per week in addition to the regular practices. The regular practices were from 90-120 minutes in length 4 or 5 days per week. The number of practices was dependent on the members of this group participating in wrestling competitions. During this time period only 4 of the members of this group competed in regularly scheduled wrestling competitions. The physical characteristics of this group are shown in Table I.

<u>University Hockey Players</u>. Thirteen members of the University of Regina Cougars hockey team volunteered and consented (Appendix 1) to participate in the study. The selection of this group for the study was based on the assumption that training for and competition in hockey at this level would result in higher leg anaerobic power and capacity and lower arm anaerobic power and capacity as compared to the two wrestling groups. Prior to testing for the study the members of this group had participated in

regular hockey practices for a two month period. These practices were from 60-90 minutes in length 4 or 5 days per week. The number of practices was dependent on their competitive schedule. In addition the members of this group were participating in a weight training program 3 times per week. During the month prior to testing the members of this group participated in 2 games each weekend. The physical characteristics of this group are shown in Table I.

TABLE I

PHYSICAL CHARACTERISTICS OF SUBJECTS

GROUP	N	AGE(yrs)	WEIGHT(kg)
Elite Wrestlers	12	23.0±1.6	70.58±8.12
Novice Wrestlers	11	20.8±1.2	74.81±12.96
University Hockey	13	20.8±1.2	77.30±7.53

Means ± Standard Deviations

Experimental Design

The testing for this study, for each group, was completed over 2 consecutive weeks. The first week consisted of an orientation session and one testing session. The second testing session was completed the following week. During the orientation session: the age and weight of each subject was recorded; test procedures were demonstrated; subjects were instructed on methods of palpation of heart rate (radial or carotid pulse); and consent forms were completed. Following the test demonstrations the subjects were allowed a practice session on the leg and arm ergometers. This practice session was identical to the standard warmup that was completed prior to each testing session. This warmup session consisted of 1 minute leg cranking and 1 minute arm cranking on the bicycle ergometer. Immediately following the second minute of the warmup, heart rate was recorded by palpation for a 6 second period. The subjects were instructed that heart rate should be 12-14 beats for the 6 seconds. This intensity was selected to ensure complete recovery of the ATP-PC energy system prior to the testing. In no case did the heart rate exceed 150 beats per minute during the warmup. Following the warmup on the orientation day the subjects were allowed a 5 minute rest prior to completing the vertical jump test. The tests were ordered as shown in Table II.

On testing days the subjects were advised to not participate in strenuous activity prior to the testing session. They were also advised to not ingest food, tea or coffee for 2 hours prior to reporting to the laboratory.

TABLE II

TEST ORDER

TEST	TEST DAY	ORDER
Vertical Jump	Orientation	1
Arm Pull/Modified Arm Pull	1	2
Leg Bicycle Ergometer	1	3
Margaria-Kalamen	2	4
Arm Bicycle Ergometer	2	5

The laboratory was available for testing from 1500 to 1900 hours daily. There was at least one day between each testing session for all subjects. A testing schedule was arranged for the subjects. Subjects were scheduled such that each subject was tested at approximately the same time of day each session.

Vertical Jump Test

The procedure for the vertical jump test (Costill et al 1966) was as follows:

1. The subject completed the standard warmup of 1 minute leg cranking and 1 minute arm cranking on the bicycle ergometer at an intensity such that the exercise heart rate did not exceed 150 beats per minute (6 second palpation rate 12-14), followed by a 5 minute rest period before testing.

2. The subject stood sideways to a vertical jump board marked in centimeters, with either arm adjacent to the board. Both the subject's toes were touching a designated starting line during the test.
3. Chalk was applied to the fingers of the arm the subject used to touch the board. The opposite arm was held behind the back with the fingers grasping the top of his shorts.
4. The subject then stood as tall as possible, keeping the heels in contact with the floor, and marked the board as high as possible. The mark was recorded to the nearest centimeter. (Appendix 3)
5. The subject, re-chalked his fingers, then assumed a comfortable, balanced crouch position and jumped marking the board with his fingers as high as possible. The mark was recorded to the nearest centimeter. The vertical jump was then determined.
6. The subject was allowed 3 trials, with a rest of approximately 30 seconds between trials. The best vertical jump was used for calculation of vertical jump work.
7. Vertical jump work was calculated as follows:

$$\frac{\text{Vertical jump (cm)} \times \text{Weight (kg)} \times 9.807}{100} = \_\_\_\_ \text{ Joules}$$

Margaria-Kalamen Power Test

The procedure for the Margaria-Kalamen Power Test

(Kalamen 1968) was as follows:

1. The subject completed the standard warmup of 1 minute leg cranking and 1 minute arm cranking on the bicycle ergometer at an intensity such that the exercise heart rate did not exceed 150 beats per minute (6 second palpation rate 12-14), followed by a 5 minute rest period before testing.
2. The subject's body weight was recorded.
3. The subject stood 6 meters in front of the staircase.
4. At his pleasure the subject ran up the stairs as fast as possible, taking 3 steps at a time. A switchmat was placed on the third and ninth stair. The electronic timer (Dekan Model 741 Automatic Performance Analyzer) started when the subject stepped on the first switchmat. The time was recorded to the nearest hundredth of a second. The subject was encouraged to run past the ninth step. The vertical rise from the third to the ninth stair was determined.
5. The subject was allowed at least 5 trials, and if the time was still decreasing additional trials were allowed. A rest of approximately 30 seconds was allowed between trials. The fastest time was used for calculation of power. (Appendix 3)
6. Margaria-Kalamen Power Test power was calculated as follows:

$$\frac{\text{Weight (kg)} \times \text{Vertical Rise (m)} \times 9.807}{\text{Time (secs)}} = \_\_\_\_\_ \text{Watts}$$

Leg Bicycle Ergometer Power Test

The procedure for the leg bicycle ergometer power test (Bar-Or, Dotan, Inbar 1977) was as follows:

1. The subject completed the standard warmup of 1 minute leg cranking and 1 minute arm cranking on the bicycle ergometer an intensity such that the exercise heart rate did not exceed 150 beats per minute (6 second palpation rate 12-14), followed by a 5 minute rest period before testing.
2. The subjects body weight was recorded. Workload resistance to the nearest .25 kilopond was determined on the basis of .066 kiloponds per kilogram body weight. The calibration of the bicycle was checked prior to the start of each daily testing session.
3. The height of the seat on the Monark bicycle ergometer (Model 868) was adjusted to allow for full leg extension. The pedals of the bicycle were equipped with toe pieces.
4. The subject was told the test would be a short duration all out effort. The subject was not made aware of the exact duration of the test in an attempt to avoid any self pacing.
5. The subject was told to begin pedaling as fast as possible, and as the resistance was set the stopwatch

and revolution counter (Layfayette Model 54517-A Clock/Counter) were started. The number of half revolutions every 6 seconds were recorded for 30 seconds. Strong verbal encouragement was given throughout the test. (Appendix 3)

6. At the completion of the 30 second test the resistance was reduced to approximately 1 kilopond and the subject was encouraged to continue to pedal for approximately 1 minute to maintain the muscle blood pump effect.

7. Anaerobic power was calculated as follows:

$$\frac{\text{Resistance(kp)} \times \text{Distance(m)} \times \text{Revolutions Per Minute}}{6.118} = \_\_\_ \text{Watts}$$

Resistance = .066 kp per kg body weight (to nearest .25 kp)

Distance = distance flywheel on Monark bicycle moves per pedal revolution (6 m)

Revolutions Per Minute = revolutions per minute based on six second period.

8. Anaerobic capacity (watts) was calculated by summing the power output for each of the five 6 second periods.

Arm Pull Test

The procedure for the arm pull test (Johnson 1969) was as follows:

1. The subject completed the standard warmup of 1 minute leg cranking and 1 minute arm cranking on the bicycle ergometer an intensity such that the exercise heart rate did not exceed 150 beats per minute (6 second palpation rate 12-14), followed by a 5 minute rest period before testing.
2. The subject's body weight was recorded.
3. The subject sat on a 45 centimeter bench at the base of a climbing rope. The climbing rope was touching the edge of the bench between the subject's legs. The rope had a measuring tape attached to it between the 1 and 2.5 meter height.
4. The subject was told to grasp as high as possible up the rope without raising the buttocks from the bench. The hand of the preferred arm should be just above the opposite hand. The height of the uppermost hand was recorded.
5. The subject was then told to pull with the preferred hand and reach as high as possible with the opposite hand. The height of the uppermost hand was recorded. The subject was encouraged to flex at the hips as he made the pull. The feet were not allowed to touch the floor during the pull. The distance of the pull was determined in centimeters. (Appendix 3)
6. The subject was allowed 3 trials, with a rest of approximately 30 seconds between trials. The largest

pull distance was used for calculation of work.

7. Arm pull test work was calculated as follows:

$$\frac{\text{Pull Distance (cm)} \times \text{Body Weight (kg)} \times 9.807}{100} = \_\_\_ \text{ Joules}$$

Modified Arm Pull Test

The procedure for the modified arm pull test was as follows:

1. Immediately following the arm pull test the one half maximum pull distance was determined and marked by tape on the rope.
2. The subject then repeated the procedure of the arm pull test until he could no longer pull beyond the one half maximum pull distance.
3. The subject was allowed to relax between each trial. The duration of the relaxation period was sufficient to allow the subject to release his grip from the rope, but was not longer than 5 seconds.
4. The maximum number of trials completed before not being able to pull the one half maximum pull distance was recorded. The 3 trials completed in the arm pull test were included in the total for the modified arm pull test. (Appendix a)
5. Modified arm pull test results were recorded as the number of pulls completed.

The procedure for the arm bicycle ergometer power test (Ayalon, Inbar, Bar-Or 1974) was as follows:

1. The subject completed the standard warmup of 1 minute leg cranking and 1 minute arm cranking on the bicycle ergometer an intensity such that the exercise heart rate did not exceed 150 beats per minute (6 second palpation rate 12-14), followed by a 5 minute rest period before testing.
2. The subject's body weight was recorded. Workload resistance to the nearest .25 kilopond was determined on the basis of .033 kiloponds per kilogram body weight. The calibration of the bicycle was checked prior to the start of each daily testing session.
3. A Monark bicycle ergometer (Model 868) was fastened to a 1 meter high bench.
4. The height of the acromion process of the shoulder of each subject was recorded using a laboratory stadiometer.
5. The subject stood behind the ergometer and the height of the ergometer was adjusted to place the axis connecting the pedals 25 centimeters below the height of the acromion process of the shoulder. The subject was told to assume a heel to toe stagger stance and firmly grasp the pedals.
6. The subject was told the test would be a short

aware of the exact duration of the test in an attempt to avoid any self pacing.

7. The subject was told to begin cranking as fast as possible, and as the resistance was set the stopwatch and revolution counter (Lafayette Model 54517-A Clock/Counter) were started. The number of half revolutions every 6 seconds were recorded for 30 seconds. Strong verbal encouragement was given throughout the test. (Appendix 3)

8. At the completion of the 30 second test the resistance was reduced to approximately 0.5 kilopond and the subject was encouraged to continue to crank for approximately 1 minute to maintain the muscle blood pump effect.

9. Anaerobic power was calculated as follows:

$$\frac{\text{Resistance(kp)} \times \text{Distance(m)} \times \text{Revolutions Per Minute}}{6.118} = \underline{\quad} \text{ Watts}$$

10. Anaerobic capacity (watts) was calculated by summing the power output for each of the five 6 second periods.

Subjective Performance Rating

The procedure for the subjective performance rating of the members of the elite wrestlers group was as follows:

1. Each member of the elite group was rated on a scale

recent wrestling competitions by three members of the University of Regina Cougars wrestling team coaching staff. (Appendix 2)

2. The average of these three ratings, to the nearest whole number, was recorded as the subjective performance rating for each individual.

Statistical Treatment and Analysis

The results of each of the tests are included in Appendix 4. An analysis of variance (SPSSX-ONEWAY) was computed to statistically evaluate the relationships between the three study groups for each of the tests completed. This analysis included the Tukey range test to examine for significant differences between pairs of group means.

A correlation matrix (SPSSX-PEARSON CORR) was computed for the elite wrestlers group to statistically evaluate the relationships between each of the tests completed, including their performance rating.

A correlation matrix (SPSSX-PEARSON CORR) was computed to statistically evaluate the relationships between each of the tests when the test results are examined as a composite group. This statistical examination was completed in order to make further statements regarding the appropriateness of the tests utilized in the study as measures of anaerobic power and capacity in a variety of

The SAS/GRAPH GPLOT procedure was utilized to produce graphical illustrations of the study results.

divided into four sections. The first section reviews the tests selected for this study. This section will discuss practical considerations and concerns for the tests utilized. The second section examines the relationships between the three study groups for each of the tests. This section will discuss the appropriateness of the tests utilized for measuring anaerobic power and capacity in activities where upper body musculature plays a major role in the performance of the activity. The third section examines the relationships between each of the tests, including performance ranking, for the elite wrestlers group. This section will discuss which tests are related to performance rating for an activity where upper body musculature does play a major role in the performance of the activity. The fourth section examines the relationships between tests when the total sample is considered as one group. This section will discuss which of the tests utilized in the study appear to be the most appropriate for measuring anaerobic power and capacity in a variety of sport testing situations.

Study Tests

<u>Vertical Jump Test</u>. The test procedures outlined for the vertical jump test were easily followed by

the study participants. The test can accommodate large numbers in a short period of time.

Margaria-Kalamen Power Test. The test procedure followed resulted in 27 of the 36 subjects reaching their fastest time during the first five trials. This supports the suggestion that the level of fatigue while participating in this test is low (Margaria et al 1966). However, this may indicate some apprehension among subjects during the first several trials before they put forth a maximum effort. The sensitive timing equipment required to administer the Margaria-Kalamen Test may be a concern in some practical applications.

Leg Bicycle Ergometer Power and Capacity Tests. The maximum power output was recorded every six seconds in this study in an attempt to have all subjects generate their maximum power output during the first six seconds of the test. Four of the study participants did not generate their maximum power output during the first six seconds. This may be an indication of a methodological problem in applying resistance. This may suggest that increasing the duration for recording anaerobic power output as suggested by Bouchard, Taylor and Dulac (1982) should be considered for this test.

Arm Bicycle Ergometer Power and Capacity Tests. The adjusting of the height of the ergometer enabled the subjects to assume a balanced stance similar to a position they would frequently utilize in performance of either wrestling or hockey skills. This position alleviated the concerns expressed by Davis et al (1976) regarding arm cranking when the crank was above shoulder level. However, in many testing situations it may not be feasible to quickly adjust the height of the ergocycle. In this test as in the leg bicycle ergometer power and capacity test, six subjects did not generate their maximal power output during the first six seconds. This suggests that there may be a methodological problem or the duration for measuring maximum power output should also be increased for arm tests.

In both the leg and arm anaerobic power and capacity tests utilized in this study the resistance selected may result in lower anaerobic power and capacity output because of the relationship between resistance applied and pedal revolutions (Evans and Quinney 1981).

Arm Pull and Modified Arm Pull Tests. The administration of the arm pull tests posed no problems for the wrestling groups. It was necessary to complete some additional explanation and demonstration with most members of the hockey group. This may be a result of rope climbing frequently being used as a part of wrestling training programs. The thirty second rest allowed between trials in the arm pull test seemed more than adequate. Most subjects expressed readiness to complete the next trial in 10-20 seconds. The maximum five second rest allowed between trials for the modified arm pull test was sufficient. In the majority of instances the participants simply released their grip and then regrasped the rope and completed another trial. This situation replicates an actual situation that frequently occurs in wrestling. In many situations a wrestler will grasp his opponent and apply force, if the desired results are not achieved, the grip is released and applied on another portion of the opponents body. The arm pull test is appropriate for testing large numbers in a short period of time. The modified arm pull test has the increased administrative problem of calculating and marking the fifty percent pull distance. In addition there is the problem of increased time required to test each subject.

Study Groups

The means, standard deviations, and ranges for the study groups for each test are shown in Table III and IV.

TABLE III

LOWER BODY TESTS

GROUP DATA

TEST	ELITE WRESTLERS	NOVICE WRESTLERS	UNIVERSITY HOCKEY
Vertical Jump (Joules)			
Mean	320.58	309.10	347.66
Standard deviation	66.40	61.69	42.60
Range	206.73-415.13	229.48-433.00	299.40-443.66
Margaria-Kalamen (Watts)			
Mean	1511.09	1383.51	1647.73
Standard deviation	228.27	260.56	246.22
Range	1144.31-1914.87	1054.66-1783.10	1[illegible]21.73-2049.86
Margaria-Kalamen (Watts·Kg^{-1})			
Mean	21.38	18.61	21.32
Standard deviation	1.83	2.51	2.21
Range	17.86-23.07	16.52-24.60	17.30-25.75
Leg Anaerobic Power (Watts)			
Mean	850.35	735.30	943.36
Standard deviation	247.21	100.87	174.92
Range	529.58-1294.54	549.19-902.25	706.11-1353.38
Leg Anaerobic Power (Watts·Kg^{-1})			
Mean	11.97	9.96	12.14
Standard deviation	2.79	1.36	1.38
Range	7.90-15.59	7.30-11.68	9.8-15.20
Leg Anaerobic Capacity (Watts)			
Mean	3146.45	2814.19	3671.06
Standard deviation	950.52	352.91	709.74
Range	2157.56-5232.10	2392.93-3552.63	2912.71-5526.31
Leg Anaerobic Capacity (Watts·Kg^{-1})			
Mean	44.18	38.10	47.23
Standard deviation	10.25	4.56	5.44
Range	32.93-63.03	31.20-44.78	40.45-62.09

The data presented in Table III is comparable to other studies of anaerobic power and capacity (Goslin and Graham 1985, Smith et al 1982, and Lavoie et al 1984).

TABLE IV

UPPER BODY TESTS

GROUP DATA

TEST	ELITE WRESTLERS	NOVICE WRESTLERS	UNIVERSITY HOCKEY
Arm Pull (Joules)			
Mean	424.34	296.65	438.17
Standard deviation	79.66	51.77	67.21
Range	300.68-561.64	223.59-387.57	341.08-576.06
Modified Arm Pull (Reps)			
Mean	21.66	13.0	19.9
Standard deviation	7.41	2.1	2.8
Range	12-36	9-16	15-25
Arm Anaerobic Power (Watts)			
Mean	423.13	367.54	484.51
Standard deviation	73.58	88.98	77.43
Range	333.44-566.36	254.98-541.84	353.05-588.42
Arm Anaerobic Power ($Watts \cdot Kg^{-1}$)			
Mean	5.96	4.89	6.24
Standard deviation	0.43	0.74	0.57
Range	5.44-6.82	4.07-6.45	4.90-6.95
Arm Anaerobic Capacity (Watts)			
Mean	1675.78	1493.35	1969.90
Standard deviation	307.69	332.40	245.88
Range	1372.99-2373.32	1147.43-2167.37	1654.95-2500.81
Arm Anaerobic Capacity ($Watts \cdot Kg^{-1}$)			
Mean	23.61	19.93	25.46
Standard deviation	2.00	2.34	1.76
Range	20.48-28.59	16.13-23.42	22.62-28.09

The anaerobic power per kilogram body weight is higher for all three study groups than reported in the study of Goslin and Graham (1985). The anaerobic power and capacity values reported by Smith et al (1982) and Lavoie et al (1984) are similar to the results of this study. The arm anaerobic power and capacity data presented in Table IV follows a similar pattern to other studies involving arm cranking to measure anaerobic power and capacity (Bar-Or, Dotan, and Inbar 1977). The Margaria-Kalamen Test results for the study groups are illustrated in Figure 1.

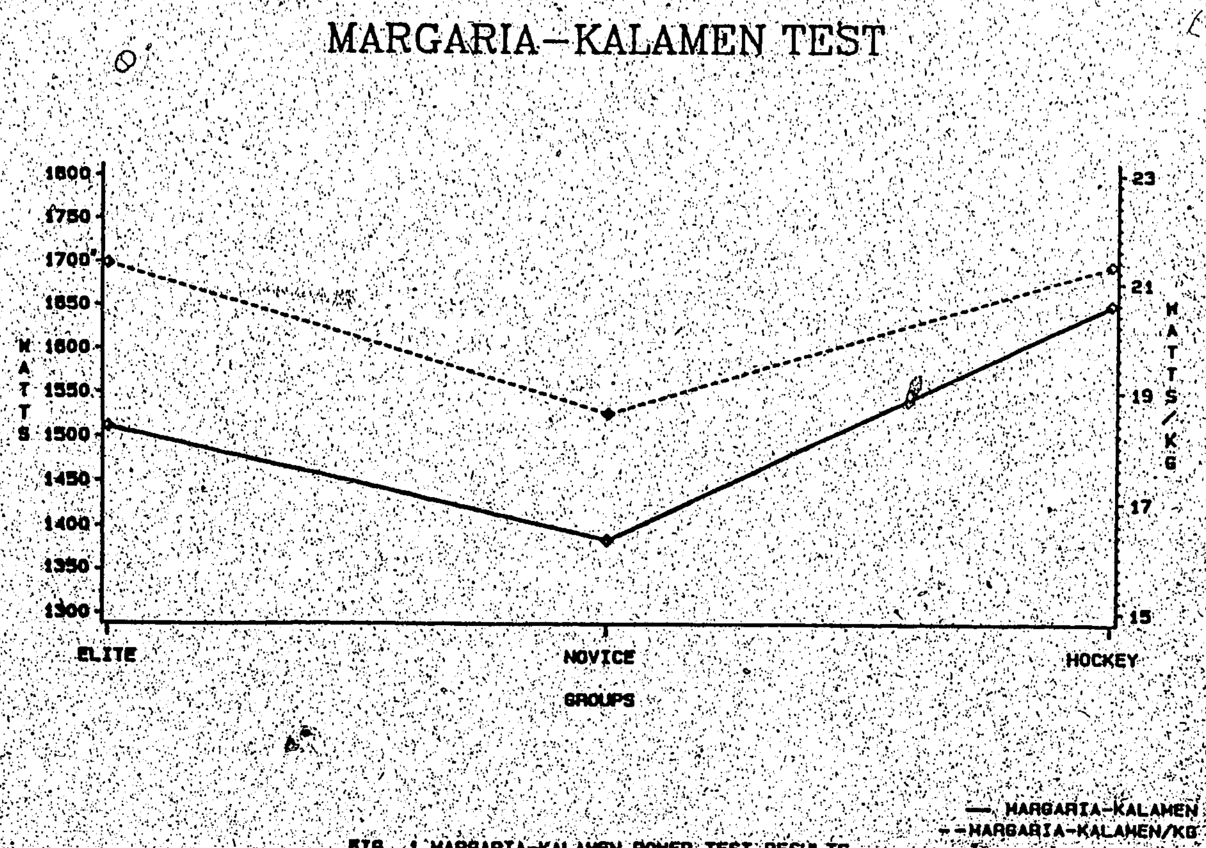

FIG. 1 MARGARIA-KALAMEN POWER TEST RESULTS FOR STUDY GROUPS

Figure 1 illustrates the relationship between the Margaria-Kalamen Power Test and the Margaria-Kalamen Test per unit body weight for each of the study groups. Figure 2 illustrates the leg anaerobic power results for the study groups.

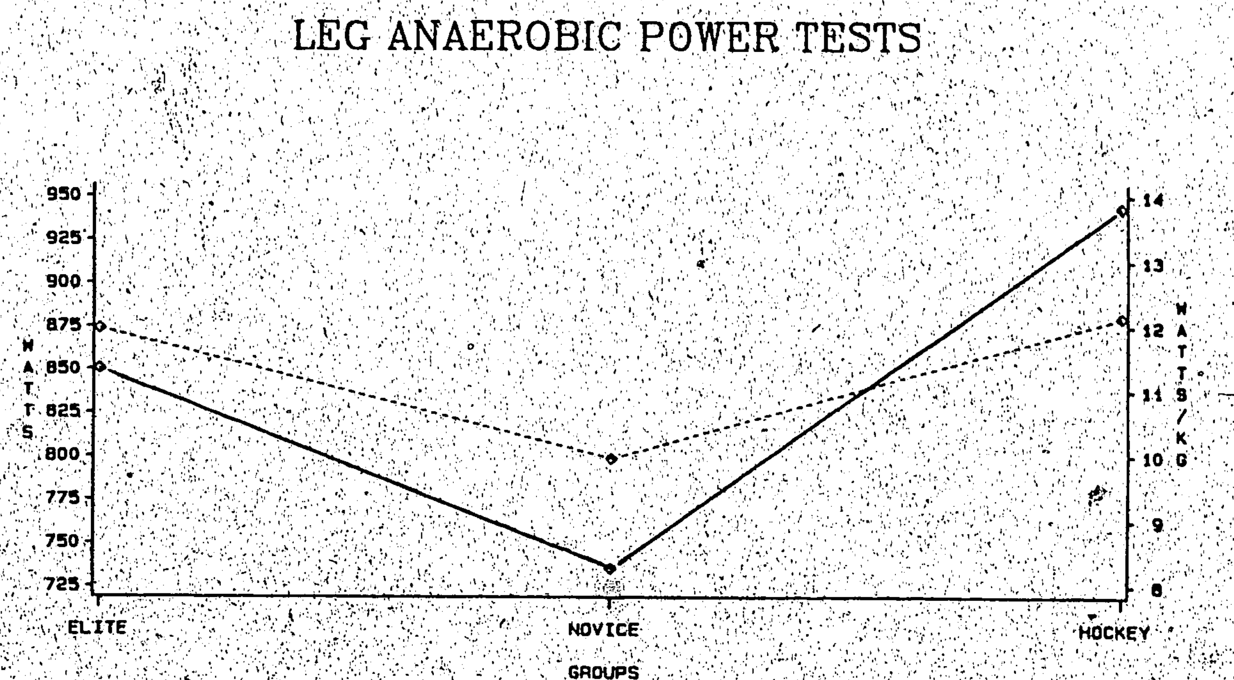

FIG. 2 LEG ANAEROBIC POWER TEST RESULTS FOR STUDY GROUPS

The results presented in Figure 2 are less than the results of Smith and Stokes (1985) for elite power athletic groups. (Range 11.8-16.2 watts$\cdot$Kg^{-1})

Figure 3 illustrates the relationship between the leg anaerobic capacity tests for the study groups.

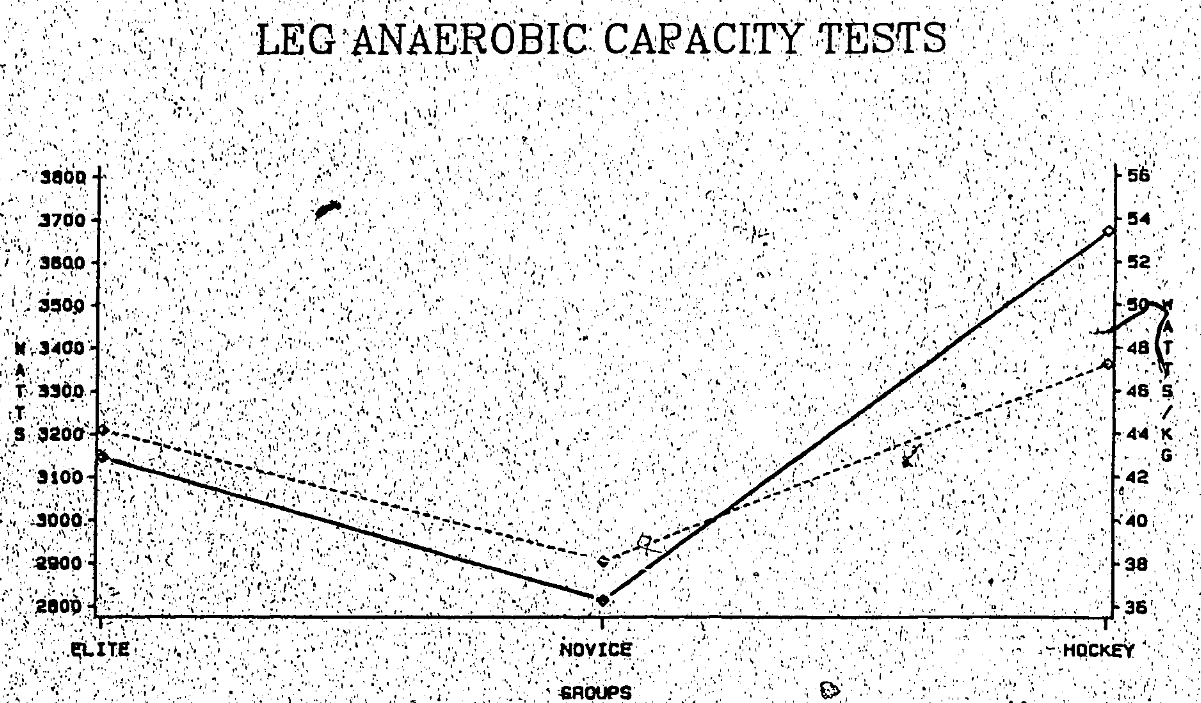

FIG. 3 LEG ANAEROBIC CAPACITY TEST RESULTS FOR STUDY GROUPS

The results of the between groups analysis of variance for each test are shown in Table V.

TABLE V

ANALYSIS OF VARIANCE-SUMMARY

TEST	MEAN SQUARE BETWEEN	MEAN SQUARE WITHIN	F RATIO	F PROB
Weight	143.15	93.61	1.53	.23
Vertical Jump	4784.87	3282.51	1.45	.25
Margaria-Kalamen	212255.90	59990.91	3.53	.04
Margaria-Kalamen·Kg^{-1}	28.61	4.80	5.95	.00
Leg Anaerobic Power	128987.03	34581.10	3.73	.03
Leg Anaerobic Power·Kg^{-1}	16.91	3.84	4.39	.02
Leg Anaerobic Capacity	2256957.18	522080.71	4.32	.02
Leg Anaerobic Capacity·Kg^{-1}	253.50	52.18	4.85	.01
Arm Pull	70084.83	4570.01	15.33	.00
Modified Arm Pull	239.48	22.71	10.54	.00
Arm Anaerobic Power	40998.59	6384.27	6.42	.00
Arm Anaerobic Power·Kg^{-1}	5.87	0.35	16.71	.00
Arm Anaerobic Capacity	699501.68	87026.96	8.03	.00
Arm Anaerobic Capacity·Kg^{-1}	93.23	4.14	22.52	.00

The results of the range test to examine for significant difference between pairs of group means is shown in Table VI.

TABLE VI

TUKEY'S RANGE TEST TO DETERMINE SIGNIFICANTLY DIFFERENT GROUP MEANS

TEST	ELITE WRESTLER(1)	NOVICE WRESTLER(2)	UNIVERSITY HOCKEY(3)
Weight	-	-	-
Vertical Jump	-	-	-
Margaria-Kalamen	-	3	2
Margaria-Kalamen·Kg^{-1}	2	1,3	2
Leg Anaerobic Power	-	3	2
Leg Anaerobic Power·Kg^{-1}	2	1,3	2
Leg Anaerobic Capacity	-	3	2
Leg Anaerobic Capacity·Kg^{-1}	-	3	2
Arm Pull	2	1,3	2
Modified Arm Pull	2	1,3	2
Arm Anaerobic Power	-	3	2
Arm Anaerobic Power·Kg^{-1}	2	1,3	2
Arm Anaerobic Capacity	3	3	1,2
Arm Anaerobic Capacity·Kg^{-1}	2	1,3	2

(1) Elite Wrestlers (2) Novice Wrestlers (3) University Hockey
Numbers indicate which pairs of groups are significantly different at the .05 level.

Figure 4 illustrates the arm pull test results for the study groups.

ARM PULL TEST

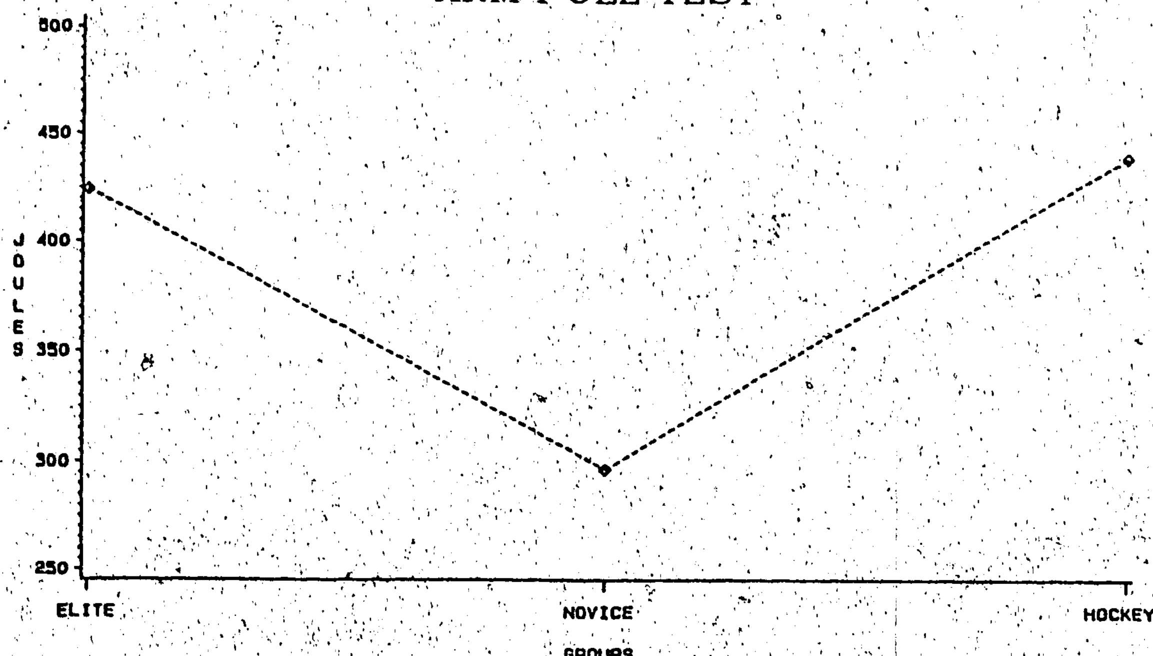

FIG. 4 ARM PULL TEST RESULTS FOR STUDY GROUPS

Figure 5 illustrates the results for the study groups from the modified arm pull test.

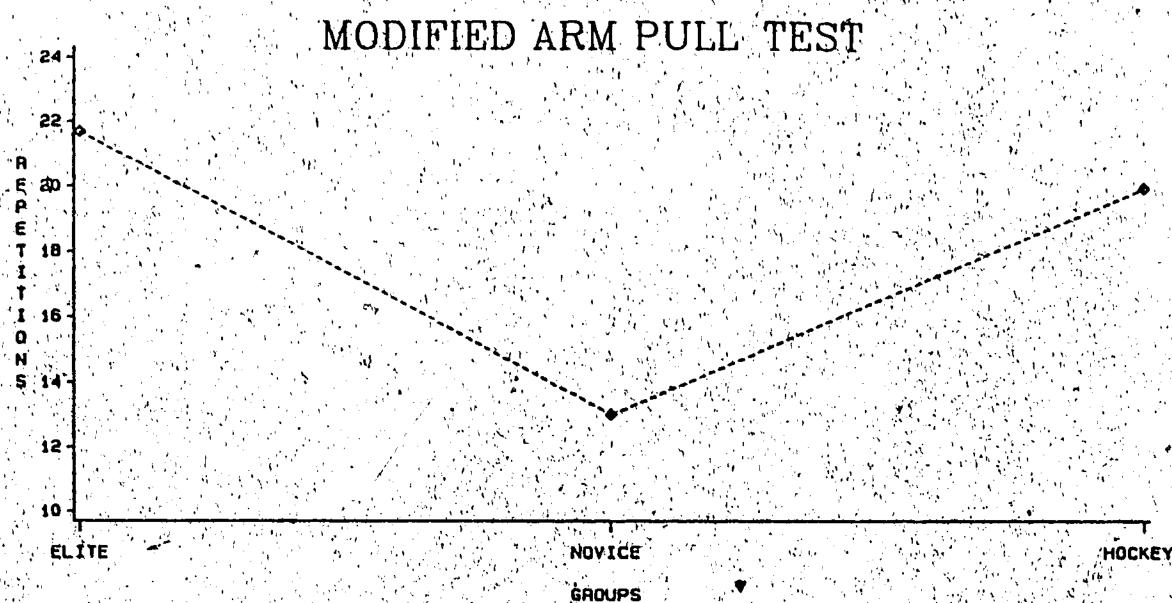

FIG. 5 MODIFIED ARM PULL TEST FOR STUDY GROUPS

The study groups results for arm anaerobic power and capacity are illustrated in Figures 6 and 7.

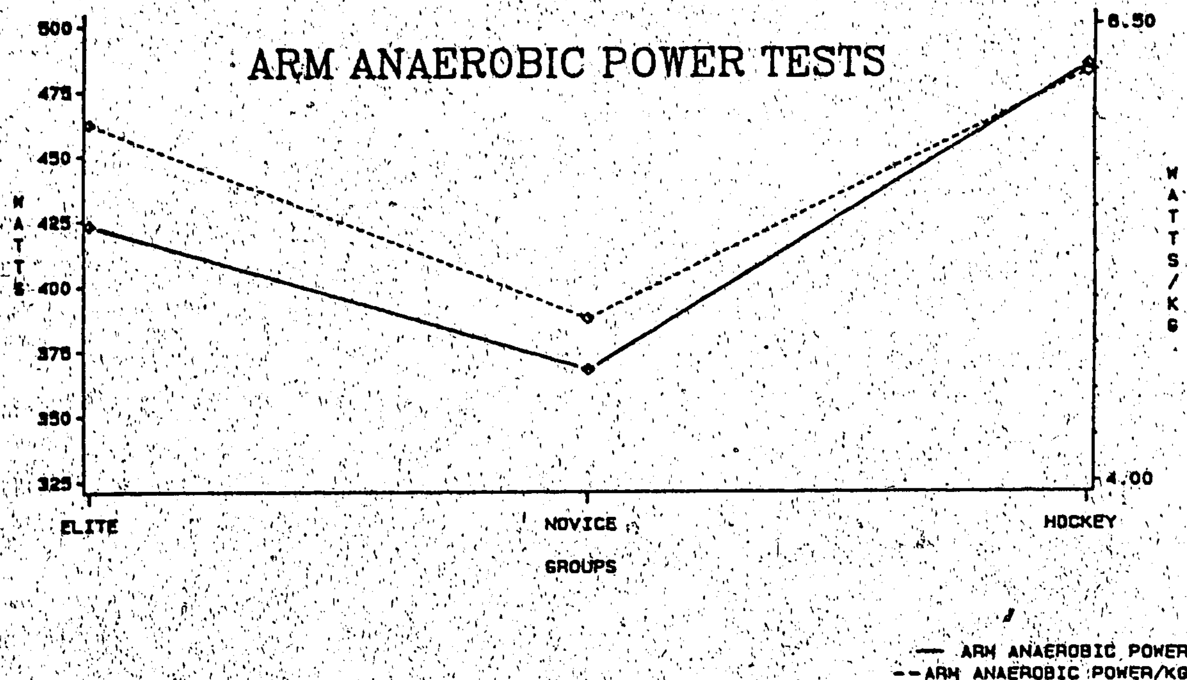

FIG. 6 ARM ANAEROBIC POWER TEST RESULTS FOR STUDY GROUPS

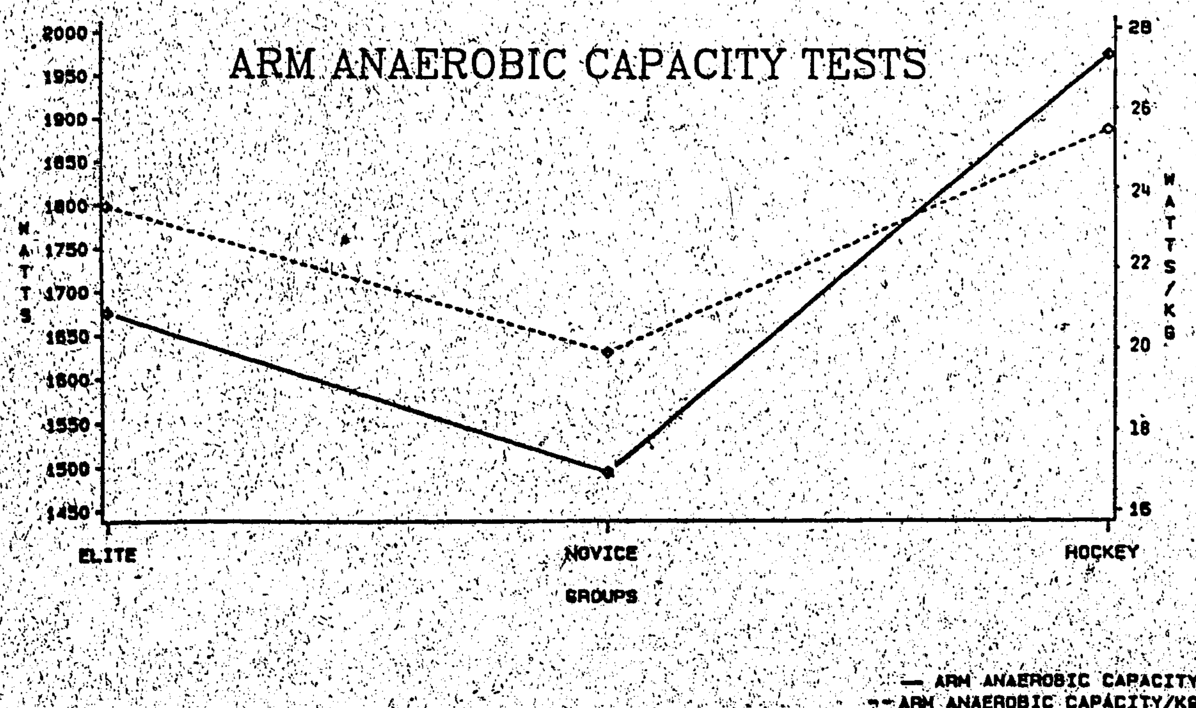

FIG. 7 ARM ANAEROBIC CAPACITY TEST RESULTS FOR STUDY GROUPS

The analysis of variance shown in Table V indicates significant differences (.05 level) between the study groups for all tests except for body weight and vertical jump. The results of Tukey's Range Test shown in Table VI indicates which pairs of study group means are significantly different. While there was no statistically significant difference between group means for body weight it should be noted that the difference between the university hockey players and the elite wrestlers was 6.72 kilograms and this may influence test results in this study. In Figure 1 the novice wrestlers (1383.51 watts) are significantly different from the university hockey players (1649.73 watts) for the Margaria-Kalamen Test. This indicates the possibility that the lower body emphasis in hockey will result in higher Margaria-Kalamen Test scores. However, when the same test (Figure 1) is examined per unit body weight the elite wrestlers also differ significantly from the novice wrestlers. This may be attributed to the type of training programs followed by the elite wrestlers or by their attempts to maintain low percentages of body fat.

The results of the leg anaerobic power test (Figure 2) indicate the university hockey players are significantly different from the novice wrestlers. When the results of this test are examined per unit body weight the elite wrestlers and the university hockey players differ significantly from the novice wrestlers.

The leg anaerobic capacity and capacity per unit body weight results (Figure 3) show significant differences between the university hockey players and the novice wrestlers. This difference may be a result of the longer durations of anaerobic activity in hockey (Green 1976). The typical duration of maximal activity in wrestling is less than five seconds, whereas, in hockey the duration of activity may approach thirty seconds, but maximal activity is usually of five to ten seconds duration.

The arm pull test (Figure 4) and modified arm pull test (Figure 5) results shown are significantly different for the study groups. For both tests the elite wrestlers and university hockey players differ significantly from the novice wrestlers. This suggests that the arm pull tests may not be more appropriate for testing athletes in activities where upper body musculature plays a major role in the performance of the activity. The results of this study indicate that these tests did not discriminate between the elite wrestlers and the university hockey players.

The results of the arm anaerobic power (Figure 6) and arm anaerobic capacity (Figure 7) tests shown are significantly different for the study groups. In both tests the university hockey players differ significantly from the elite and novice wrestlers. This difference is desirable for the hockey players since they will be competing against opponents of varying body weight and absolute expression of arm anaerobic power and capacity would be the most beneficial to performance. However, when the same tests are examined per unit body weight the elite wrestlers and the university hockey players differ significantly from the novice wrestlers, but not from each other. These results are similar to the findings of the arm pull tests. These results further support the suggestion that the upper body tests selected for this study may not be more appropriate for those activities where upper body musculature plays a major role in the performance of the activity, since the elite wrestlers and university hockey players do not differ significantly.

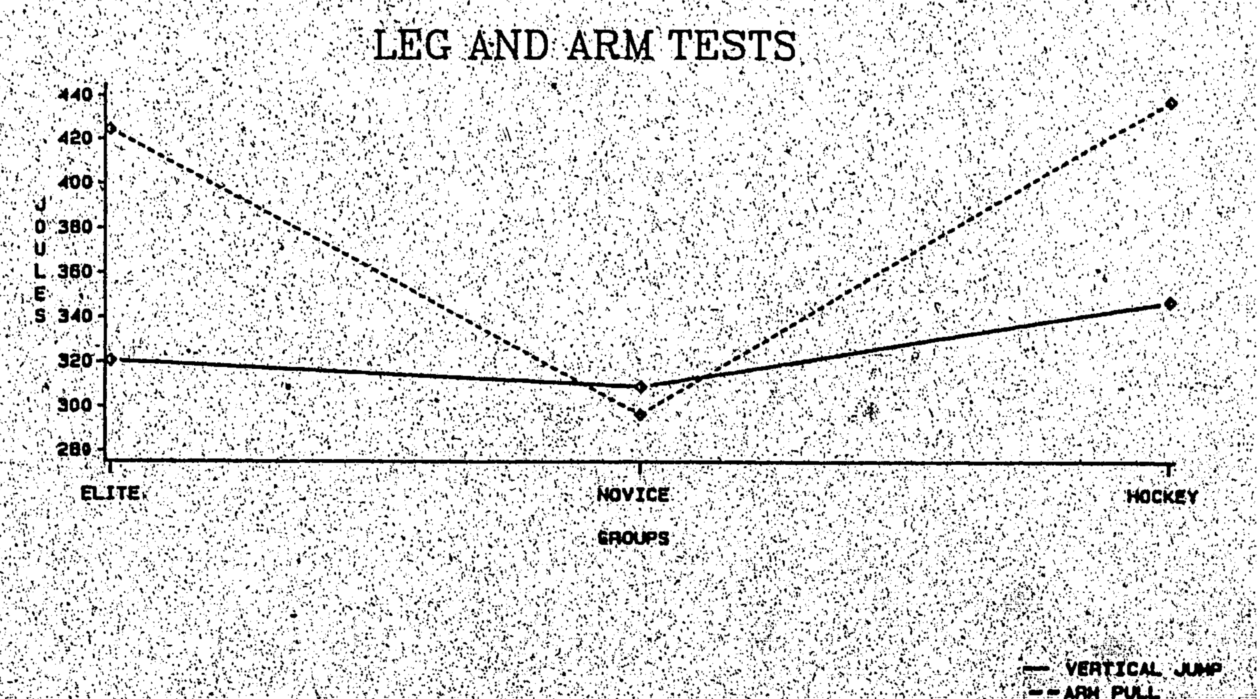

FIG. 8 VERTICAL JUMP AND ARM PULL TEST RESULTS FOR STUDY GROUPS

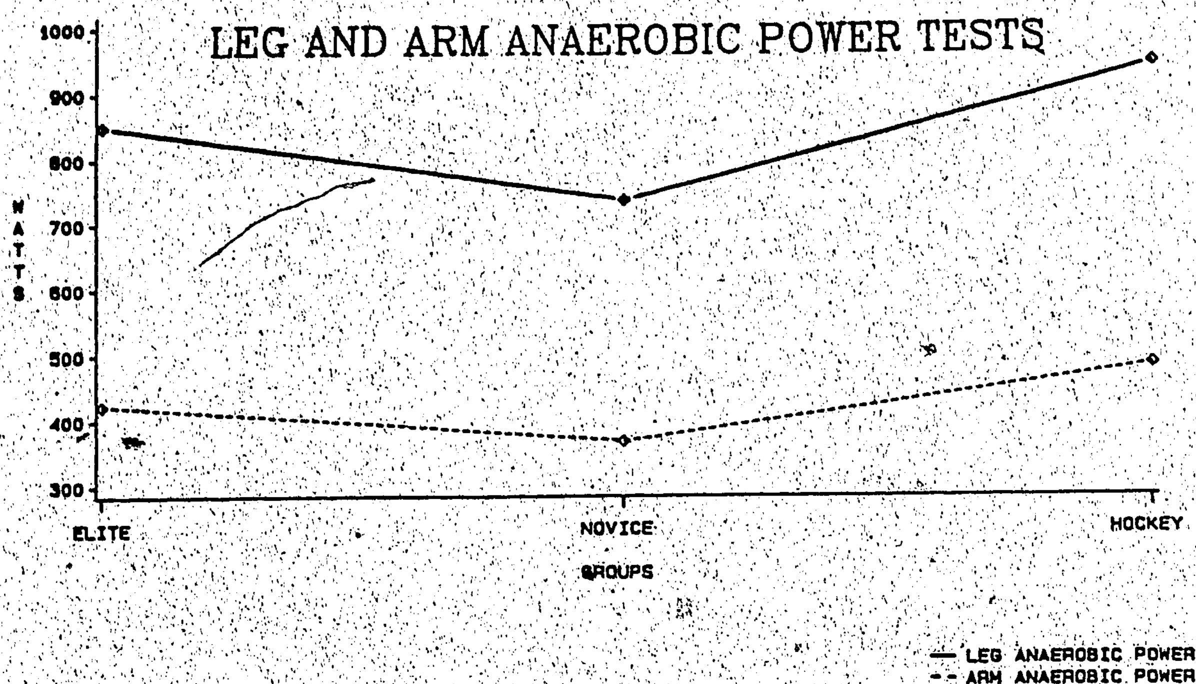

FIG. 9 LEG AND ARM ERGOMETER
ANAEROBIC POWER TESTS
FOR STUDY GROUPS

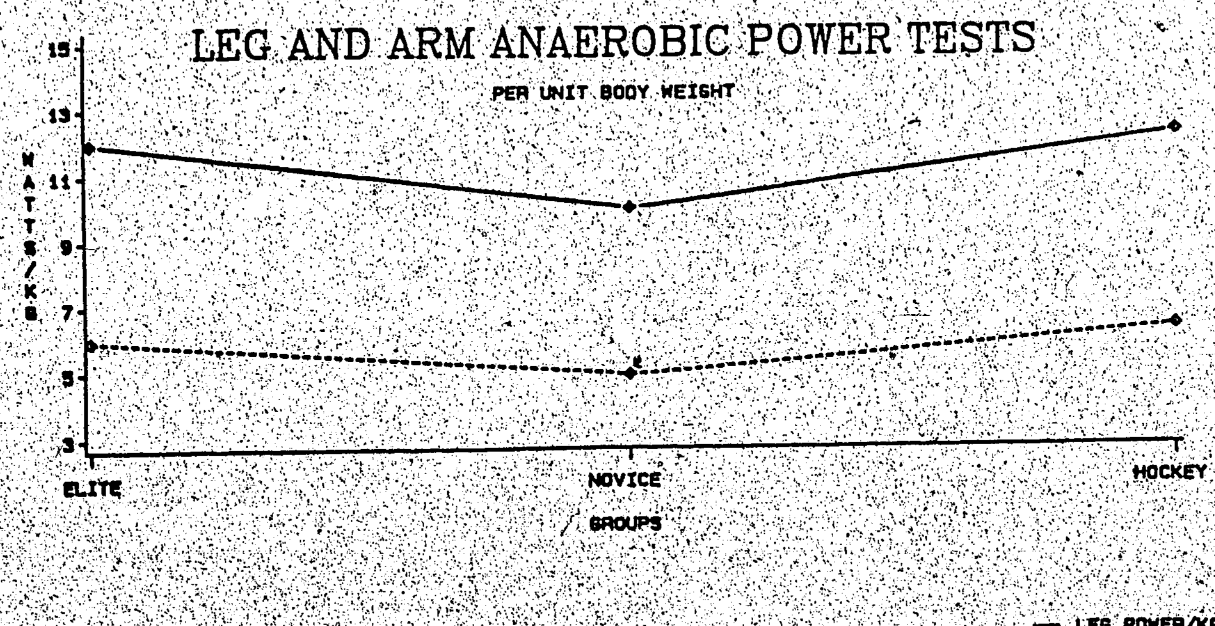

FIG. 10 LEG AND ARM ERGOMETER
ANAEROBIC POWER TESTS PER UNIT BODY WEIGHT
FOR STUDY GROUPS

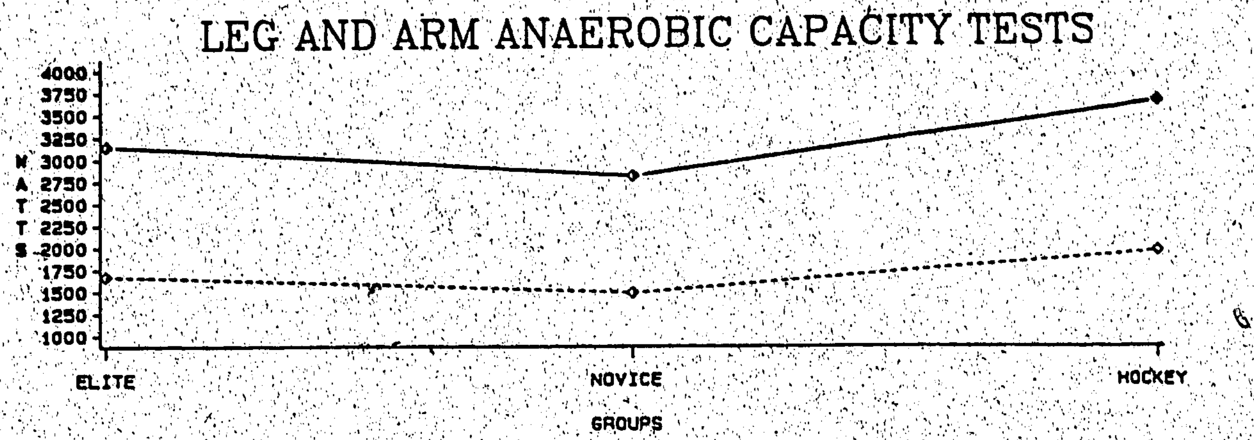

FIG. 11 LEG AND ARM ANAEROBIC CAPACITY TEST RESULTS FOR STUDY GROUPS

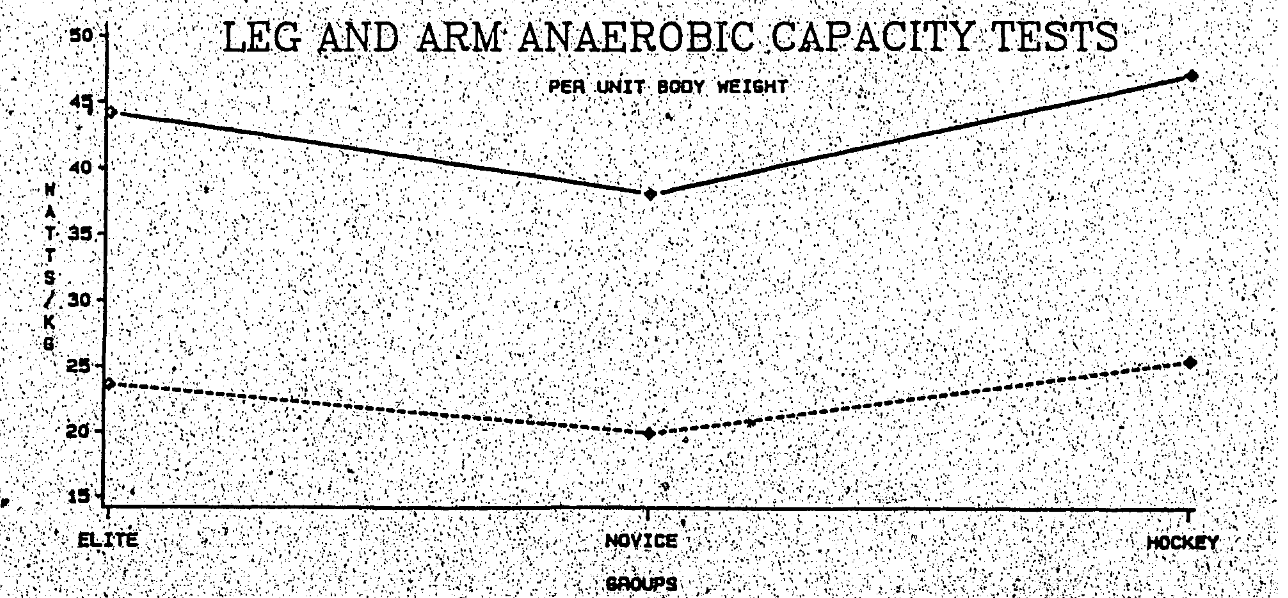

FIG. 12 LEG AND ARM ANAEROBIC CAPACITY TEST RESULTS PER UNIT BODY WEIGHT FOR STUDY GROUPS

The results of the vertical jump and the arm pull test (Figure 8), leg and arm anaerobic power tests (Figure 9), leg and arm anaerobic power tests per unit body weight (Figure 10), leg and arm anaerobic capacity tests (Figure 11), and leg and arm anaerobic capacity tests per unit body weight (Figure 12) as illustrated show a similar pattern in all tests. The elite wrestlers and/or hockey players scored significantly higher than the novice wrestlers in each of the tests being compared. This again indicates that the tests utilized in this study are not necessarily more appropriate to assess anaerobic power and capacity in athletes participating in an activity where upper body musculature plays a major role in performance. This ranking of the three groups is reflective of the intensity of the training programs in which each of the groups is participating. These results may also indicate that because of the nature of the training program followed by the university hockey player group a training effect occurred similar to the elite wrestlers in arm anaerobic power and capacity.

Elite Wrestlers Group

The correlation matrix between the study variables for the elite wrestlers group are shown in Tables VII and VIII.

TABLE VII

CORRELATION MATRIX FOR ELITE WRESTLERS FOR STUDY TESTS

TEST	1	2	3	4	5	6	7	8	9
1 Vertical Jump	-								
2 Margaria-Kalamen	.40	-							
3 Leg Ana Power	.43	.45	-						
4 Leg Ana Capacity	.50	.53	.96*	-					
5 Arm Pull	.02	.71*	.62**	.65**	-				
6 Modified Arm Pull	.23	.15	.21	.19	.07	-			
7 Arm Ana Power	.34	.88*	.64**	.69*	.73*	.29	-		
8 Arm Ana Capacity	.44	.84*	.61**	.71*	.67*	.19	.95*	-	
9 Performance Rating	.05	.15	.54	.54	.31	.59**	.00	.15	-

* Significant at .01 level

** Significant at .05 level

TABLE VIII

CORRELATION MATRIX FOR ELITE WRESTLERS

FOR STUDY TESTS PER UNIT BODY WEIGHT

TEST	1	2	3	4	5	6	7	8
1 Margaria-Kalamen·Kg^{-1}	-							
2 Leg Ana Power·Kg^{-1}	.17	-						
3 Leg Ana Capacity·Kg^{-1}	.02	.95*	-					
4 Arm Pull	.40	.42	.49	-				
5 Modified Arm Pull	.13	.47	.45	.06	-			
6 Arm Ana Power·Kg^{-1}	.50	.19	.24	.69*	.19	-		
7 Arm Ana Capacity·Kg^{-1}	.38	.12	.31	.54*	.00	.73*	-	
8 Performance Rating	.28	.69*	.71*	.31	.59**	.03	.29	-

*Significant at .01 level
**Significant at .05 level

The correlations shown in Table VII indicate several significant relationships (r=.59-.96) for the absolute test results. The 0.05 level of significance was selected for evaluating the correlations because of the sample size (n=12) of the elite wrestlers group. The Margaria-Kalamen Test results are related to the arm pull (r=.71), arm anaerobic power (r=.88), and arm anaerobic capacity (r=.84). Leg anaerobic power and leg anaerobic capacity are highly (r=.96) correlated. Leg anaerobic capacity is related to arm anaerobic power (r=.69) and arm anaerobic capacity (r=.71). Arm pull is related to arm anaerobic power (r=.73) and capacity (r=.67). Arm anaerobic power and arm anaerobic capacity are highly correlated (r=.95). The only test result related to performance rating was the modified arm pull test (r=.59). These results indicate there are significant relationships between tests involving upper body and lower body musculature. This suggests tests involving upper body musculature for the measurement of anaerobic power and capacity may not be more appropriate for those activities where the upper torso plays a major role in the performance of the activity.

The correlations shown in Table VIII for the study relative test results indicate several significant relationships (r=.54-.95). Leg anaerobic power and leg anaerobic capacity per unit body weight are highly corelated (r=.95). Arm pull and arm anaerobic power (r=.69) and capacity (r=.54) are related. Arm anaerobic power and capacity are related (r=.73). Performance rating is related to leg anaerobic power (r=.69), leg anaerobic capacity (r=.71), and modified arm pull (r=.59). These correlations suggest no significant relationships between the upper body tests and lower body tests for the elite wrestlers group when expressing the results per unit body weight. These results suggest there may be tests that are more appropriate for those activities where the upper body musculature plays a dominant role. However, the wrestlers will be competing against opponents of similar weight and this may negate the suggestion that there are more appropriate tests since these relationships are based on test results expressed relative to body weight. The most significant relationships with performance ratings were with lower body tests. This indicates for this group lower body musculature played a significant role in successful performance.

In this elite wrestler group the arm pull test relates to arm anaerobic power (r=.73) and capacity (r=.67), and arm anaerobic power (r=.69) and capacity (r=.54) per unit body weight. The modified arm pull test related to performance rating (r=.59). This indicates some support for considering these absolute tests as appropriate measures of anaerobic power and capacity for wrestlers.

The correlations between arm anaerobic power and capacity (r=.95), and arm anaerobic power and capacity per unit body weight (r=.73) suggest a significant relationship between anaerobic power and capacity in elite wrestlers. These correlations further support the use of the arm pull test as a measure of anaerobic power and capacity for this group. This relationship may be the result of the nature of the training programs employed by elite wrestlers, that is, arm activity of high intensity for periods longer than thirty seconds. It should be noted for this group similar correlations for the legs were r=.96 and r=.95 respectively. The significance of these relationships for the arm tests and the leg tests suggests the nature of energy delivery necessary for success at this level of competition and is probably reflective of the training process. This training process involves high intensity training for both arms and legs.

Total Study Group

The correlation matrix between the study tests when the three study groups are combined into a composite group are shown in Tables IX and X.

TABLE IX

CORRELATION MATRIX FOR COMBINED GROUP FOR STUDY TESTS

TEST	1	2	3	4	5	6	7	8
1 Vertical Jump	-							
2 Margaria-Kalamen	.63*	-						
3 Leg Ana Power	.39*	.55*	-					
4 Leg Ana Capacity	.49*	.58*	.93*	-				
5 Arm Pull	.22	.52*	.62*	.59*	-			
6 Modified Arm Pull	.20	.13	.24	.23	.43*	-		
7 Arm Ana Power	.61*	.78*	.64*	.72*	.55*	.15	-	
8 Arm Ana Capacity	.59*	.74*	.66*	.77*	.53*	.14	.94*	-

*Significant at .01 level
**Significant at .05 level

TABLE X

CORRELATION MATRIX FOR COMBINED GROUP PER UNIT BODY WEIGHT FOR STUDY TESTS

TEST	1	2	3	4	5	6	7	8
1 Vertical Jump	-							
2 Margaia-Kalamen·Kg^{-1}	.24	-						
3 Leg Ana Power·Kg^{-1}	.10	.22	-					
4 Leg Ana Capacity·Kg^{-1}	.23	.18	.90*	-				
5 Arm Pull	.22	.45*	.54*	.54*	-			
6 Modified Arm Pull	.20	.43*	.48*	.49*	.42*	-		
7 Arm Ana Power·Kg^{-1}	.35**	.52*	.34**	.43*	.56*	.45*	-	
8 Arm Ana Capacity·Kg^{-1}	.29	.42*	.36**	.54*	.52*	.45*	.85*	-

*Significant at .01 level
**Significant at .05 level

results for the combined group. Vertical jump, Margaria-Kalamen test, leg anaerobic power, and leg anaerobic capacity results are significantly correlated. Leg anaerobic power and capacity are highly correlated (r=.93). This suggests these four tests are appropriate for measuring lower body anaerobic power and capacity. Arm pull is significantly related to the Margaria-Kalamen test, leg anaerobic power and capacity and the modified arm pull test. These results reveal a relationship between arm and leg anaerobic power and capacity as indicated by the r=.64 correlation between leg and arm anaerobic power and the r=.77 correlation between leg and arm anaerobic capacity as measured on the bicycle ergometer. The modified arm pull test correlated with only the arm pull test (r=.43). This indicates the modified arm pull test is not a good measure of absolute anaerobic power and capacity. The arm anaerobic power and capacity results correlated significantly with all the other absolute test results except for the modified arm pull test. The correlations between these two arm tests was higher than the correlation between similar leg tests with the vertical jump and Margaria-Kalamen test. This again suggests a relationship between arm and leg anaerobic capacity.

The failure of the arm pull test and the modified arm pull test to correlate significantly with the test results indicates these two tests may not be appropriate measures of upper body anaerobic power or capacity. This high correlation between arm anaerobic power and capacity (r=.94) and a similar high correlation between leg anaerobic power and capacity suggests improvements in the anaerobic power energy delivery system may result in improvements in the delivery of energy for anaerobic capacity.

The correlations shown in Table IX in general indicate the tests utilized in this study may not be more appropiate for those activities where upper body musculature plays a major role in performance as the upper and lower body test results are significantly related; or the training programs followed by the subjects had similar influences on arm and leg anaerobic power and capacity.

The correlations shown in Table X indicate significant relationships (r=.34-.90) between relative test results for the combined group. The Margaria-Kalamen test, leg anaerobic power, and leg anaerobic capacity correlated significantly with upper body test results. This suggests the relationship between arm and leg anaerobic power and capacity exists when test results per unit body weight are considered. Arm pull test and modified arm pull test results correlate significantly with all of the relative test results. This suggests that these two tests may be and capacity per unit body weight. This supports the results of the elite wrestlers group where arm pull correlated with arm anaerobic power (r=.69) and arm anaerobic capacity (r=.54) per unit body weight. Relative arm anaerobic power and capacity correlated with the Margaria-Kalamen test, leg anaerobic capacity, arm pull, modified arm pull and performance rating. This further reinforces the relationship between arm and leg anaerobic power and capacity. The high correlation that exists between relative leg anaerobic power and capacity (r=.90) and between relative arm power and capacity (r=.85) supports the suggestion made when discussing absolute values for these tests that improvements in the energy system supporting anaerobic power appears to result in improvements in the energy system supporting anaerobic capacity.

The correlations shown in Table X in general indicate: the tests utilized in this study are not more appropriate for those activities where upper body musculature plays a major role in performance as they do not discriminate between upper and lower body anaerobic power and capacity; or the test results are confounded by the training programs followed by the subjects in this study.

The primary purpose of this study was to determine appropriate measures of anaerobic power and capacity for those activities where upper body musculature plays a major role in the performance of the activity. The subjects for the study included: elite wrestlers (n=12); novice wrestlers (n=11); and university hockey players (n=13). The three groups were of similar age and weight (Table I). The design of the study provided for the administration of eight tests: Vertical Jump, Arm Pull, Modified Arm Pull; Leg Bicycle Ergometer Anaerobic Power and Capacity; Arm Bicycle Ergometer Anaerobic Power and Capacity; and the Margaria-Kalamen Test. Results relative to body weight were determined for five of the tests: Leg Bicycle Ergometer Power and Capacity; Arm Bicycle Ergometer Power and Capacity; and the Margaria-Kalamen. Each of the groups completed the testing over a two week period. Members of all groups were training and competing in regularly scheduled activities prior to the testing. All subjects completed a standardized warmup prior to each testing session. All subjects completed the tests in the same order (Table II) at approximately the same time of day.

Based on the results of this study the following initial conclusions can be made:

on the vertical jump test. This indicates in this study the vertical jump test results were not influenced by the type or level of activity in which the subject was participating;

2. The novice wrestlers differed significantly from the university hockey players for the Margaria-Kalamen test. This indicates for this study the results in the Margaria-Kalamen test are influenced by participation in hockey;
3. The elite wrestlers and university hockey players differed significantly from the novice wrestlers for the relative Margaria-Kalamen test results. This indicates in this study both wrestling and hockey influence leg power output relative to body weight;
4. The novice wrestlers differed significantly from the university hockey players for the leg anaerobic power test. This indicates for this study the results in the leg anaerobic power test are influenced by participation in hockey;
5. The elite wrestlers and university hockey players differed significantly from the novice wrestlers for the relative leg anaerobic power test. This indicates for this study both wrestling and hockey influence leg power output relative to body weight;
6. The novice wrestlers differed significantly from the

university hockey players for the leg anaerobic capacity test. This indicates for this study the results in the leg anaerobic capacity test are influenced by participation in hockey;

7. The novice wrestlers differed significantly from the university hockey players for the relative leg anaerobic capacity test. This indicates for this study the results in the relative leg anaerobic capacity test are influenced by participation in hockey;
8. The elite wrestlers and university hockey players differed significantly from the novice wrestlers for the arm pull test. This indicates for this study both wrestling and hockey influence arm pull test results;
9. The elite wrestlers and university hockey players differed significantly from the novice wrestlers for the modified arm pull test. This indicates for this study both wrestling and hockey influence modified arm pull test results;
10. The novice wrestlers differed significantly from the university hockey players for the arm anaerobic power test. This indicates for this study the results in the arm anaerobic power test are influenced by participation in hockey;
11. The elite wrestlers and university hockey players

differed significantly from the novice wrestlers for the relative arm anaerobic power test. This indicates for this study both wrestling and hockey influence arm power output relative to body weight;

12. The university hockey players differ significantly from both the wrestling groups for the arm anaerobic capacity test. This indicates for this study the results in the arm anaerobic capacity test are influenced by participation in hockey;

13. The elite wrestlers and the university hockey players differed significantly from the novice wrestlers for the relative arm anaerobic capacity test. This indicates for this study both wrestling and hockey influence relative arm anaerobic capacity.

Based on these conclusions for this study the following summary can be made:

1. The university hockey players differed significantly from the novice wrestlers for all tests except the vertical jump test. This indicates there are significant differences in the other anaerobic power and capacity test results utilized in this study following participation in hockey;

2. The university hockey players and elite wrestlers differed significantly from the novice wrestlers for each of the relative tests utilized. This indicates

for this study there are significant differences in relative anaerobic power and capacity test results following participation at the elite level in wrestling and in hockey;

3. The university hockey players and elite wrestlers differed significantly from the novice wrestlers for the arm pull test and the modified arm pull test. This indicates for this study there are significant differences in arm pull and modified arm pull following participation at the elite level in wrestling and in hockey.

Based on this summary the following general conclusions can be made:

1. Arm and leg anaerobic power and capacity are both developed by and play a significant role in the performance of wrestling and hockey. This is supported by the relationship between the elite wrestler group results and the university hockey group results for the tests utilized in this study;
2. The university hockey players scored higher than the novice wrestlers in the tests of anaerobic power and capacity utilized in this study. This may be attributed to several factors: the nature of the practice sessions being utilized by the hockey team; the regular weight training program being followed by

the hockey team; or the tests utilized in this study are not more appropriate for determining anaerobic power and capacity for those activities where upper body musculature plays a major role in the performance of the activity;

3. The university hockey players and the elite wrestlers scored higher than the novice wrestlers in the relative measures of anaerobic power and capacity utilized in this study. This difference may be as a result of: the previously mentioned factors for the university hockey players; the nature of the practice sessions utilized by the wrestling team; the regular weight training program followed by the wrestling team; or the failure of the tests utilized in this study to discriminate between subjects who participate in activities where either upper or lower body musculature dominates performance of the activity;

4. The university hockey players and elite wrestlers had similar results on the arm pull power and modified arm pull power tests. This suggests that these two tests are not more appropriate as a method to determine anaerobic power and capacity for those activities where upper body musculature plays a major role in the performance of the activity since they did not discriminate between these two study groups.

The test results achieved by the elite wrestlers and the university hockey players validate the tests utilized in this study since it could be expected that these two groups should perform better than the novice wrestlers.

Based on the results of the examination of the elite wrestlers group in this study the following conclusions can be made:

1. There are significant relationships between tests to measure upper body anaerobic power and capacity and tests to measure lower body anaerobic power and capacity. This indicates the upper body test results are not specifically influenced by participation in wrestling;
2. There are no significant relationships between tests to measure relative upper body anaerobic power and capacity and tests to measure relative lower body anaerobic power and capacity. This indicates the relative upper body test results may be influenced by participation in wrestling and these tests would be appropriate to measure sport specific anaerobic power and capacity;
3. Anaerobic power and capacity absolute test results are not related to performance rating. This indicates for this group higher anaerobic power and capacity did not necessarily enhance competitive

success;

4. Lower body anaerobic power and capacity relative test results are related to performance rating. This indicates the contribution of the lower body to competitive success for this group, and the benefit of examining relative values when comparing test results for activities in which the body weight must be supported.

A secondary purpose of this study was to examine the test results when the total study group was combined into a composite group and to comment on the appropriateness and applicability, of the tests, to a variety of sport testing situations. Based on the analysis of the results of the composite group the following conclusions can be made:

1. The lower body tests of anaerobic power and capacity utilized in this study are significantly related;
2. The upper body tests of anaerobic power and capacity, with the exception of modified arm pull, utilized in this study are significantly related;
3. The upper and lower body tests of anaerobic power and capacity utilized in this study are significantly related;
4. The lower body tests of relative anaerobic power and capacity are not significantly related, with the

exception of leg anaerobic power and capacity;

5. The upper body tests of relative anaerobic power and capacity are significantly related;
6. The upper and lower body tests of relative anaerobic power and capacity utilized in this study are related, but for the most not to the same level as for the absolute test results.

These conclusions suggest the following general conclusions regarding the appropriateness and applicability of the tests utilized in this study:

1. The tests utilized in this study are valid measures of upper and lower body anaerobic power and capacity;
2. The upper body tests included are not necessarily more appropriate for use in activities where upper body musculature plays a major role in the performance of the activity since the upper and lower body test results are significantly related for most tests.

Upon reviewing conclusions from the three study groups, the elite wrestlers group, and the total study group it appears in this study that:

1. In each of the three different subject groupings the upper body tests utilized in this study are not more appropriate measures of anaerobic power and capacity, than the lower body tests, in those activities where

upper body musculature plays a major role in the performance of the activity;

2. There is a generality of expression of anaerobic power and capacity by either the upper or lower body musculature by the subjects participating in this study. This concept has been expressed in previous studies (Ayalon et al 1974, Lamb 1984);
3. If this generality of expression of anaerobic power and capacity exists it may be appropriate to utilize the lower body tests because of ease of test administration. However, to examine individual differences and to determine appropriate training programs it will be necessary to complete both arm and leg tests.

Recommendations

The following recommendations are based on the results and conclusions of this study:

1. That further research be pursued to develop sport related laboratory and field tests of upper body anaerobic power and capacity, utilizing for comparative purposes athletes who participate in activities where there is very limited involvement of the upper body (cycling, speedskating);
2. That the appropriate duration of tests for anaerobic power and capacity and the methods of application of

resistance during testing be further investigated;

3. That additional research be undertaken to examine the relationships between the arm pull test, modifications of the arm pull test, and other field tests of anaerobic power and capacity for trained and untrained subjects, and for subjects who participate in sports other than those utilized in this study.

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APPENDIX 1

ANAEROBIC POWER STUDY

INFORMED CONSENT

ANAEROBIC POWER STUDY

Informed Consent

In this study you will perform a series of tests to measure maximum power output. The tests you will perform include:

1. Vertical Jump Test
2. Stair Climb Test
3. Leg Bicycle Ergometer Test
4. Arm Bicycle Ergometer Test
5. Arm Pull Test

During an orientation session you will be allowed a practise experience for each test.

Since these tests require maximum effort on your behalf you may experience some discomfort during and following the testing session. This discomfort should be no greater than you would experience in a maximum performance of your activity.

If you have any questions regarding the procedures in each test, please ask for further explanation.

It is understood that you may withdraw from participation in the study at anytime.

I have read this form and following the orientation session consent to participate in this study.

DATE: ______________ **Participant** ________________________

Witness ________________________

APPENDIX 2

ELITE WRESTLERS

SUBJECTIVE PERFORMANCE RATING

ELITE WRESTLERS

Subjective Performance Rating

Wrestler	Rating Coach 1	Rating Coach 2	Rating Coach 3	Performance Rating
LK	5	6	6	6
RL	3	3	3	3
GB	6	6	6	6
WM	6	7	7	7
TM	7	8	8	8
RM	8	9	8	8
SB	10	10	10	10
AG	3	3	4	3
KJ	4	4	5	4
AL	4	5	6	5
WB	4	5	6	5
MB	7	7	8	7

APPENDIX 3

RECORDING FORM

ANAEROBIC POWER STUDY

ANAEROBIC POWER STUDY

GROUP ____________________

NAME ____________________ AGE ______ WEIGHT ________

PERFORMANCE RATING __________

VERTICAL JUMP POWER TEST

TRIAL	1	2	3
DISTANCE (CMS)			

MARGARIA-KALAMEN POWER TEST

TRIAL	1	2	3	4	5	6	7	8	9	10
TIME										

LEG BICYCLE ERGOMETER POWER TEST

Load (.066 kp/kg) ________________kp.

TIME	6	12	18	24	30	TOTAL
REVS						
REVS/MIN.						
P.O. (Watts)						
P.O./Kg						

ARM PULL POWER TEST AND MODIFIED ARM PULL POWER TEST

TRIAL	1	2	3
DISTANCE (cms)			

Pull (cms) ____________ 50% Pull (cm) ______

Trials to Reach 50% Pull ________

ARM BICYCLE ERGOMETER POWER TEST

Load (.033 kp/kg ________________kp.

TIME	6	12	18	24	30	TOTAL
REVS						
REVS/MIN.						
P.O. (Watts)						
P.O. (kg)						

APPENDIX 4

STUDY DATA

STUDY DATA

ELITE WRESTLERS

Subject	Weight	Test 1	Test 2	Test 3	Test 4	Test 5
1	73	343.63	1303.87	17.86	838.50	11.48
2	70	260.86	1490.73	21.29	882.64	12.60
3	63	383.06	1395.32	22.14	823.79	13.07
4	61	227.32	1228.20	20.13	627.65	10.28
5	83	415.13	1914.87	23.07	1294.54	15.59
6	68	333.43	1568.81	23.07	1059.16	15.57
7	62	304.01	1144.31	18.45	941.48	15.18
8	68	373.45	1448.13	21.29	661.98	9.73
9	77	392.67	1740.20	22.60	686.49	8.91
10	67	282.53	1545.74	23.07	529.58	7.90
11	68	206.73	1568.81	23.07	617.84	9.08
12	87	324.21	1784.14	20.50	1240.60	14.25

Subject	Test 6	Test 7	Test 8	Test 9	Test 10
1	3354.03	45.94	300.68	21	397.11
2	3133.37	44.76	459.94	12	419.25
3	2706.76	42.96	339.81	31	353.05
4	2157.56	35.36	400.81	16	333.44
5	5232.10	63.03	561.64	22	566.36
6	3839.49	56.46	453.47	36	397.18
7	3452.10	55.67	419.54	30	353.05
8	2294.86	33.74	313.43	15	419.25
9	2844.06	36.93	437.98	21	441.32
10	2206.60	32.93	420.52	17	397.18
11	2250.73	33.09	446.80	24	441.32
12	4285.71	49.26	537.52	15	559.00

Subject	Test 11	Test 12	Test 13	Test 14
1	5.44	1677.01	22.97	6
2	5.98	1434.29	20.48	3
3	5.60	1392.61	22.10	6
4	5.46	1372.99	22.50	7
5	6.82	2373.32	28.59	8
6	5.84	1566.08	23.03	8
7	5.69	1412.22	22.77	10
8	6.16	1588.75	23.36	3
9	5.73	1789.80	23.24	4
10	5.92	1677.01	25.03	5
11	6.49	1677.01	24.66	5
12	6.42	2147.76	24.68	7

STUDY DATA

NOVICE WRESTLERS

Subject	Weight	Test 1	Test 2	Test 3	Test 4	Test 5
1	65	293.22	1199.68	18.45	708.56	10.90
2	60	258.90	1054.66	17.57	627.65	10.46
3	79	294.40	1305.74	16.52	823.79	10.42
4	96	433.07	1586.72	16.52	701.20	7.30
5	95	400.61	1783.10	18.76	735.53	7.74
6	60	229.48	1054.66	17.57	549.19	9.15
7	73	250.56	1206.57	16.52	745.34	10.21
8	76	335.39	1618.50	21.29	833.60	10.96
9	65	312.35	1599.57	24.60	666.88	10.25
10	68	280.08	1195.28	17.57	794.37	11.68
11	86	312.06	1614.17	18.76	902.25	10.49

Subject	Test 6	Test 7	Test 8	Test 9	Test 10
1	2709.21	41.68	299.60	12	264.79
2	2510.62	41.84	282.44	16	333.44
3	2934.78	37.14	240.17	9	392.28
4	2996.07	31.20	338.92	14	541.84
5	3126.02	32.90	223.59	11	446.22
6	2392.93	39.88	258.90	15	254.98
7	2422.36	33.18	357.95	12	318.73
8	2598.88	34.19	387.57	12	343.25
9	2667.53	41.03	248.60	16	419.25
10	3045.11	44.78	313.43	14	286.85
11	3552.63	41.30	312.05	12	441.32

Subject	Test 11	Test 12	Test 13
1	4.07	1147.43	17.65
2	5.55	1314.15	21.90
3	4.96	1716.24	21.72
4	5.64	2167.37	22.57
5	4.69	1880.51	19.7[illegible]
6	4.24	1216.08	20.2[illegible]
7	4.36	1250.40	17.12
8	4.51	1225.89	16.13
9	6.45	1522.55	23.42
10	4.21	1279.83	18.82
11	5.13	1706.44	19.84

STUDY DATA

UNIVERSITY HOCKEY

Subject	Weight	Test 1	Test 2	Test 3	Test 4	Test 5
1	87	443.66	2049.86	23.56	1015.03	11.66
2	75	301.56	1695.00	22.60	980.71	13.07
3	86	387.96	1867.38	21.71	916.96	10.66
4	77	309.60	1671.95	21.71	1029.74	13.37
5	71	313.33	1456.02	20.50	838.50	11.80
6	74	333.83	1321.73	17.86	882.64	11.92
7	72	324.80	1449.68	20.13	706.11	9.80
8	67	387.67	1426.84	21.29	750.24	11.19
9	76	372.66	1957.26	25.75	882.64	11.61
10	89	366.58	2011.40	22.60	1353.38	15.20
11	72	324.80	1533.32	21.29	838.50	11.64
12	88	353.83	1522.67	17.30	1184.21	13.45
13	71	299.40	1483.49	20.89	885.09	12.46

Subject	Test 6	Test 7	Test 8	Test 9	Test 10
1	3778.19	43.42	503.39	22	566.36
2	3187.31	42.49	367.76	17	441.32
3	3937.56	45.78	413.26	19	566.36
4	3726.70	48.39	468.18	21	441.32
5	3398.16	47.85	369.03	17	397.18
6	3726.70	50.36	341.08	20	514.87
7	2912.71	40.45	501.33	25	441.32
8	3089.24	46.10	453.37	20	419.25
9	3481.52	45.80	372.66	22	514.87
10	5526.31	62.09	576.06	21	588.42
11	3177.50	44.13	437.78	17	353.05
12	4567.66	51.90	474.65	15	588.42
13	3214.28	45.27	417.77	23	465.83

Subject	Test 11	Test 12	Test 13
1	6.50	1968.78	22.62
2	5.88	1765.28	23.53
3	6.58	2103.62	24.46
4	5.73	1936.90	25.15
5	5.59	1787.34	25.17
6	6.95	2010.46	27.16
7	6.12	1765.28	24.51
8	6.25	1654.95	24.70
9	6.77	2108.53	27.74
10	6.61	2500.81	28.09
11	4.90	1721.15	23.90
12	6.68	2324.28	26.41
13	6.56	1961.42	27.62

STUDY DATA

Key for Test Numbers

Test 1	Vertical Jump (Joules)
Test 2	Margaria-Kalamen (Watts)
Test 3	Margaria-Kalamen Per Kilogram (Watts)
Test 4	Leg Anaerobic Power (Watts)
Test 5	Leg Anaerobic Power Per Kilogram (Watts)
Test 6	Leg Anaerobic Capacity (Watts)
Test 7	Leg Anaerobic Capacity Per Kilogram (Watts)
Test 8	Arm Pull Test (Joules)
Test 9	Modified Arm Pull Test (Repetitions)
Test 10	Arm Anaerobic Power (Watts)
Test 11	Arm Anaerobic Power Per Kilogram (Watts)
Test 12	Arm Anaerobic Capacity (Watts)
Test 13	Arm Anaerobic Capacity Per Kilogram (Watts)
Test 14	Performance Rating (1-10)

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