A comparison of two power tests was conducted using 12 athletes (N = 7 males, N = 5 females) from the University of Wisconsin - La Crosse track and field teams. The subjects were filmed in an outdoor setting performing the Margaria stair run test and the vertical jump test. Anaerobic power output and average vertical velocity were computed for each test based upon two methods, a standard or commonly used procedure and a more complex cinematographic procedure involving center of gravity displacement techniques. Using dependent samples, paired t-tests were conducted on the various combinations to determine if a significant difference (p < .05) existed between the two methods. All differences were statistically significant except two. The two insignificant results were produced when power and velocity values were compared between the cinematographic method for the stair run and vertical jump test. This would indicate that when determining anaerobic power output based upon mechanical principles, the Margaria and vertical jump tests appeared to produce similar scientific measures. It was also found that the standard method of the vertical jump test appeared to overestimate power outputs whereas the Margaria stair run test appeared to underestimate power outputs when compared to the cinematographic methods. Although it is still uncertain which test will provide the best measure of anaerobic power, a conclusion drawn from this study was that both tests can be considered functional because of providing average values which estimate human power output.
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We recommend acceptance of this thesis in partial fulfillment of this candidate's requirements for the degree:

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CHAPTER I

INTRODUCTION

With only fractions of a second separating many winning performances, athletes are continually searching for ways to gain the competitive edge. One area thought to be an important contributor to the level of performance in many sports is that of anaerobic power, which should be of considerable value to sport specialists interested in peak performance. That may be why presently there has been more and more talk about power athletes. However, coaches, trainers, and other sport specialists have continued to misinterpret or overlook this concept of human muscle power.

Anaerobic activities consist of high intensity movements of short duration and are frequently described as explosive. Fundamentally anaerobic power is defined as, "the exertion of force through a given distance in as short a time as possible" (Beckenholdt & Mayhew, 1983; p.326). By the nature of this definition a rate becomes associated with the term power, and therefore can simply be referred to as the rate of work done by the muscles. Although this concept appears to be a theoretically valid approach, there is still some controversy surrounding the tests used to measure human power output.

Two of the more functional tests used to estimate anaerobic power are the stair climb and the vertical jump. At the present time however, there does not appear to be a universally accepted test which produces a single best measure of maximal muscle power. Since anaerobic power is
considered a key component in many athletic events, it is unfortunate that this phenomenon has not been accurately defined and tested.

**Purpose of the Study**

Anaerobic power is a complex concept comprised of physiological, mechanical, and psychomotor components. The purpose of this study was to biomechanically investigate the physical trait of anaerobic power through the use of cinematography. The Margaria stair test and the vertical jump test were used to analyze this concept and to gain some insight into the mechanical factors contributing to power output.

**Statement of the Problem**

The main problem of this study was to compare a standard method and a cinematographic method for computing power output as generated by two customary field tests used to measure anaerobic power. The standard method was based upon common procedures for determining the vertical distance used to compute power output; whereas the cinematographic method involved a center of gravity displacement procedure for determining the vertical distance used to compute power output. Also, a subproblem of the study was to examine the average vertical velocity for both the Margaria and vertical jump tests as determined by the two methods. Investigation of these problems will help determine the extent to which the stair test and vertical jump test are comparable measurements of power based upon mechanical principles.
Need for the Study

Muscular power is quite apparent and of great importance in the sporting environment. As stated by Barlow (1971) however, "because of the importance of the use of power in athletic and physical performance, tests of explosive power appear to be some of the most frequently used but also misapplied measure in physical education" (p. 234). Although anaerobic power plays an important role in many sports, a review of the literature exposed a lack of sufficient biomechanical information, leaving a gap as to how this concept of power should be interpreted and applied to an athlete's training program.

Despite the widespread concern over power production, it may be one of the most inconsistently used terms dealing with physical activity. "The label of power has been applied too loosely in the sports medicine literature, creating what now amounts to an identity problem for the term" (Sapega & Drillings, 1983; p. 7). Also, judging by the improper and inconsistent use of the term power throughout the literature, it appeared that researchers have been neglecting the true physical definition of anaerobic power. So until the confusion encompassing the term power is resolved, one will have a hard time clearly understanding and consistently applying this parameter we know as human muscle power.

The need for this study was invoked by the uncertainty surrounding the tests and measurement of anaerobic power, which is at the base of all of our existing knowledge. The validity of these tests is questionable because of the lack of objective criteria against which they were originated, and the implied over-generalization of the results (Barlow,
1971). Objectively investigating some of the kinetic and kinematic factors related to the stair climb and vertical jump tests would not only lend support to the validity of these tests used to measure anaerobic power, but also help identify whether or not these easily administered field tests are measuring power in its true mechanical form. Specifically identifying biomechanical principles related to these tests of anaerobic power might well enrich the existing body of knowledge related to power, and in turn filter its way down from a research level to a more practical level where it can improve athletic performance.

**Hypotheses**

The following null hypotheses were proposed for this study:

1. There will be no significant difference between the power output derived from the Margaria and vertical jump power tests as determined by the standard methods.

2. There will be no significant difference between the power output derived from the Margaria and vertical jump power tests as determined by the cinematographic methods.

3. There will be no significant difference between the power output derived from the Margaria test as determined by the standard and cinematographic methods.

4. There will be no significant difference between the power output derived from the vertical jump test as determined by the standard and cinematographic methods.
5. There will be no significant difference between the average vertical velocity derived from the Margaria and vertical jump tests as determined by the standard methods.

6. There will be no significant difference between the average vertical velocity derived from the Margaria and vertical jump tests as determined by the cinematographic methods.

7. There will be no significant difference between the average vertical velocity derived from the Margaria test as determined by the standard and cinematographic methods.

8. There will be no significant difference between the average vertical velocity derived from the vertical jump test as determined by the standard and cinematographic methods.

Assumptions

The following assumptions were made for this study:

1. The subjects performed naturally and to the best of their ability when executing both power tests.

2. The trials selected for biomechanical analysis were a true representation of the subject's performance capabilities.

3. The amount of learning that took place for each test was minimal and the same for all subjects.

4. The filming equipment and measurement devices were reliable and valid.
Delimitations

The following delimitations were set for this study:

1. The selection of subjects was limited to volunteers from the 1988 University of Wisconsin-LaCrosse men's and women's track and field teams.

2. The individual training methods for each subject were not controlled, but all subjects were training inseason and considered to be trained athletes.

3. The staircase used in the Margaria power test met the required standards (30-38cm for the height of two steps) set by the original research (Margaria, Aghemo & Rovelli, 1966).

Limitations

The following limitations were imposed upon this study:

1. The researcher was unable to obtain three-dimensional measurements from the film.

2. The subjects were allowed to use a natural arm swing and dip when performing the vertical jump test.

Definition of Terms

Anaerobic Power - amount of work done per unit of time (force x distance/time) or simply the rate of doing work (force x velocity; torque x angular velocity) (Laird & Rozier, 1979).
Cinematographic Method - a high speed film analysis procedure used to determine displacement of the body's center of gravity, which in turn was used as the measurement of vertical distance in the computation of power output.

Cinematography - camera techniques that are commonly used to examine the external mechanics of human motion from a quantitative standpoint (Miller & Nelson, 1973).

Center of Gravity - the central point around which the lines of gravity intersect and the mass is equally balanced, and as parts of the body move so too does the body's center of gravity (Hay, 1985).

 Explosive - describes the ability to develop fast-forceful movements, which are related to strength but at the same time involves a factor of speed (Councilman, 1976).

Kinematics - that branch of biomechanics concerned with describing the motion of bodies (Hay, 1985).

Lewis Nomogram - an indirect method of determining anaerobic power from a jump and reach score and body weight (Fox & Mathews, 1981).

Margaria Stair Test - a measure of anaerobic power determined by a subject approaching from two meters and running up a set of stairs, two at a time, at maximum speed with time being recorded between the second and sixth steps. (Margaria et al., 1966).

Standard Method - a commonly used procedure for determining power output. The standard method for the vertical jump involved use of the Lewis Nomogram, and the standard method for the stair test involved use of a fixed vertical distance between the second and sixth step.
Velocity - displacement of an object with respect to time (Laird & Rozier, 1979).

Vertical Jump Test - a measure of anaerobic power that is determined from the maximum height to which the subject can vertically jump. (Fox & Mathews, 1981).

Watt - the metric unit for power (1 W = 0.73756 foot-pounds/second) (Laird & Rozier, 1979).

Work - a force moving a resistance through a distance (Laird & Rozier, 1979).
CHAPTER II
REVIEW OF LITERATURE

Anaerobic power plays an integral part in the performance of many sporting events. However, this element has often taken a backseat to the more popular aerobic component. Although both are important factors to physical activity, Margaria et al., (1966) commented that "measurement of maximum anaerobic power has received little attention despite the fact that it is indicative of a kind of work important in many common situations" (p. 1662). The following review of literature will focus on the anaerobic component of physical activity and will be presented within a framework that examines the fundamental components needed for power production, the misuse of the concept of power, the measurement and assessment of power, the relationship of power to athletic performance, and the factors that may influence power production.

Components of Power Production

Many physical educators and coaches have been concerned with the development of muscular power and its relationship to athletic performance. Power athletes or power type activities have often been described as explosive (Lamb, 1984; Councilman, 1976). Explosive activities consist of high intensity movements of short duration and are often classified as anaerobic. Mechanically, these type of activities are often explained by looking at the force-velocity relationship in skeletal muscles. Power is calculated as a function of time because the rate of
work performed is constantly changing throughout the movement. Muscle power then becomes a product of the net muscle moment and the angular velocity at any given joint (Winter, 1979).

Since force and velocity are the two components required for muscular power, it is of value to understand this relationship when measuring anaerobic power output. Basically, very heavy work can be performed for a short amount of time, but as the total duration of the activity increases the total power output will decrease (Wilkie, 1950a; Wilkie, 1950b; Davies & Reenie, 1968). The converse of this theory also holds true. In the opinion of Wilkie (1950b), the force-velocity relationship is not only of theoretical value, but also of practical value because it determines the mechanical behavior of muscles loaded under various conditions. According to Vandewalle, Peres, and Monod (1987) a set of monarticular force-velocity tests may be more useful than the practical tests of anaerobic power because they specify possible weaknesses in different joints, which would be most helpful in planning individual training programs. Therefore, seeing how force and velocity are important mechanical characteristics of anaerobic power, this relationship can become of great significance when assessing this physical parameter.

The amount of resistance that has to be overcome to produce movement will determine the speed at which a muscle shortens, so that if a large amount of force is needed the slower the muscle will shorten and vice versa (Wilkie, 1950a; Fox & Mathews, 1981). Therefore, the greatest force or torque is obtained when the speed of movement is slowest. In regards to power, as the velocity of the movement increases
an exponential increase in muscular power will occur (Fox & Mathews, 1981). An observation made from the power-velocity curve by Fox and Mathews (1981) was that power increased more rapidly at lower speeds of movement and less rapidly at higher speeds, with a possible leveling off or decrease in power when very high velocities of movement were produced. Theoretically, the amount of force and velocity that can be developed has no limitation. However, human skeletal muscles have what is known as muscle viscosity, which becomes a limiting factor when trying to achieve muscle contractions at maximum velocity (Wilkie, 1950b). Therefore, this viscosity factor would apparently pose a limitation on human muscle power.

In order to achieve approximately 25% efficiency of movement, which is considered an optimal conversion of chemical to mechanical energy, it is necessary for the force and speed of movement to be appropriately matched to one another (Wilkie, 1950a). As cited in Wilkie (1950a), this optimum movement is a result of the force being one-half and the speed being about one-fourth of their respective maximal values. According to Astrand and Rodahl (1986), a muscle contracting at a velocity of 25-30% of the maximal value combined with a force that is approximately 30% of maximum isometric strength will provide the conditions to attain the highest power values. Also, it was noted that in the muscles this conversion of chemical to mechanical energy is a one way process; but regardless of the economy, in order to produce the greatest power outputs a somewhat greater speed and somewhat lesser force should be involved (Wilkie, 1950a).

The dynamic nature of muscle contractions is what produces the
classical force-velocity curve, which creates an S-shaped relationship (Astrand & Rodahl, 1986). Examining the properties of muscular activity is necessary for understanding the source of human muscle power. Therefore when available, looking at force-velocity and power-velocity curves can serve as a valuable tool when assessing human power output.

**Misuse of the Term Power**

Power may be one of the most inconsistently used terms dealing with physical activity. According to Laird and Rozier (1979), power would fall into a category labeled as definable terms. This would allow researchers to subjectively describe power based on the needs of their study, which could possibly explain some of the discrepancy surrounding the power concept. However, to understand the literature related to anaerobic power, one should become familiar with the true scientific definition, and the terminology used to characterize it.

In general power is a term that can be used to describe muscular activity. The true physical definition of power is the amount of work done per unit of time, or the rate at which work is performed (Laird & Rozier, 1979; Stamford, 1985; Knuttgen, 1978). A true measurement of power should be expressed as Joules per second (Watts), horsepower, or foot pounds per second, which are all common units of power (Sapega & Drillings, 1983). Two synonymous interpretations of power are force times velocity and torque times angular velocity. In essence, anything that does not comply to the above guidelines is not power in its true scientific realm.

One of the common mistakes associated with power is that it is used
interchangeably with the word strength, and that coaches and athletes are unaware of the difference between the two (Stamford, 1985; Counsilman, 1976). According to Stamford (1985) power can only be increased if a shorter amount of time is taken to accomplish the same amount of work, or the same amount of time is taken to do an increased amount of work. In contrast, strength involves the amount of tension each muscle fiber can generate during a muscle contraction and the nerve's ability to recruit large numbers of muscle fibers needed to produce a maximum amount of tension (Stamford, 1985). Therefore, one can clearly see that an actual difference exists between power and strength.

When dealing with power, speed becomes an important factor. This is not to be misinterpreted as meaning that power and strength can be measured based upon speed of the movement. Tests of fast muscular force are not necessarily measurements of power nor tests of slow force measurements of strength. Sapega and Drillings (1983) stated that power can be measured regardless of the movement speed. This same principle holds true for power when looking at contractile velocities of the muscle. Output capabilities at high and low speed power can represent measurements of fast and slow contractile velocities respectively.

However,

When proper physical definitions are applied, measures of dynamic muscular performance cannot be separated into strength values and power values on the basis of movement speed or contractile velocity (Sapega & Drillings, 1983; p. 8).

Using an isokinetic device, Moffroid and Kusiak (1975) defined power in the following ways: 1) conventional power; 2) peak power;
3) average power; 4) instantaneous power and; 5) contractile power.

The authors conventionally defined power as the rate of doing work. Peak power was only suitable for isokinetic contractions and was defined as the peak torque divided by the duration of the contraction (Moffroid & Kusiak, 1975). In disagreement with this definition of peak power, Sapega and Drillings (1983) pointed out that to be a genuine measure of power one would have to include angular displacement in the computation (torque x angular displacement/time). Therefore, simply using peak torque divided by time to represent power would be incorrect, and should not be expressed in true power units.

Power measured over a specified amount of time was termed average power, and has also been used as a way of expressing muscular endurance (Moffroid & Kusiak, 1975). The fourth term used to describe power was instantaneous power and was defined as the power that could be generated from the time muscular tension begins until peak torque is reached (peak torque/time to reach peak torque). From the earlier discussion, one can see that this may represent a functional definition of performance, but once again would not be considered a true measurement of instantaneous power because it did not include angular displacement (Sapega & Drillings, 1983). Lastly, the rate at which a muscle develops tension and the ability to sustain that tension within practical ranges of limb speeds has been defined as contractile power (Moffroid & Kusiak, 1975).

From the five types of power previously mentioned, Sapega and Drillings (1983) suggested that power should be measured and qualified as either average or instantaneous. They agreed with Moffroid and Kusiak (1975) in that average power should represent the rate of doing
work over some period of time, but indicated that instantaneous power should represent the rate of doing work at some instant in time rather than over a period of time (Sapega & Drillings, 1983).

Counselman (1976) suggested that "explosive power" may provide a more meaningful term to convey the ability to produce fast-forceful movements. Although explosive power may sound like a redundant connotation, it is used quite frequently to describe this physical anaerobic trait. But according to Sapega and Drillings (1983),

There is no single correct muscular performance test for evaluating muscular power output. As long as a proper method of calculating muscular power is applicable, the actual muscular performance task can be selected in accordance with the functional and/or experimental requirements of the testing situation (p. 8). Therefore, they advised that a more functional term be adopted by researchers when describing these explosive type activities and, limit the term power to its true physical definition.

After perusing the literature one will clearly become aware of the improper use of the term power. In an attempt to add some consistency throughout the literature, Knuttgen (1978) released a statement describing guidelines for a number of terms commonly misused in the professional field. These guidelines were to be followed when submitting research articles to that particular journal. Power was one such term that drew concern, and according to Knuttgen (1978) was only to be used when indeed it was power in its true physical sense (force x distance / time) and not simply work (force x distance).
Measurement of Anaerobic Power

Anaerobic power is looked upon as the maximal rate at which energy can be produced or work can be done without a major contribution from aerobic energy sources (Lamb, 1984). Traditionally, anaerobic power activities require all-out muscular efforts lasting several seconds. Some of the methods commonly used to estimate maximal anaerobic power include the Wingate bicycling test, maximal stair climb, oxygen debt, 50 yard dash, and the vertical jump. This section will deal with two of the more functional tests used for estimating human power, the vertical jump and the Margaria stair climb.

Vertical Jump

In 1921 D.A. Sargent presented the vertical jump test which he called "the physical test of man". His test generally consisted of vertically jumping into the air as high as possible. To perform the vertical jump Sargent (1921) had each subject jump toward a box suspended above his/her head. The height of the jump was considered to be the distance between standing height and the height reached with the top of the head. The subject was instructed to swing the arms backward and bend the knees about ninety degrees while leaning slightly forward. The subject was then told to swing the arms forward and upward while trying to jump as high as possible. Then just before one reached the highest point of the jump, the subject was supposed to swing the arms back down along side the body to complete the jump. After the jump was completed, jump height and weight were used to determine power output, which was expressed in terms of an efficiency index.
Sargent (1921) considered the vertical jump a test which combined speed, strength, energy, and dexterity, which in his opinion was a fair physical test of man. However, in 1924 L.W. Sargent viewed this vertical jump test as a dimension of work instead of a dimension of power. Also, the formulas used to determine the mechanical concept of power were found to be invalid when measuring athletic or physical ability (McCloy, 1932b). Primarily, McCloy (1932b) acknowledged the Sargent jump test as an ability to develop power relative to individual body weight. The strength needed to perform the jump was found to be considerably less than the potential force of the legs as determined by a dynamometer, so the viscosity of the muscles appeared to be the limiting factor (McCloy, 1932b). Therefore, projecting the body upward to a maximum height involved the combination of force and the highest possible contractile velocity of the muscles (McCloy, 1932b; Van Dalen, 1940). In other words, the test is not based primarily on strength but on how fast the muscles in one's body can work.

Further study revealed that the relationship between the Sargent jump and body build, relative leg length, height, and weight were not significant (Sargent, 1924). Sargent (1924) also found that the amount of squat or dip which preceded the jump had no bearing on the height jumped. However, the arm swing was viewed as an important factor for successfully executing the jump. Therefore, the coordination or skill factor necessary to complete the jump appeared as a possible limitation of the Sargent Jump test (McCloy, 1932b). To clarify the types of jumps being used for this test, Van Dalen (1940) analyzed seven variations of the Sargent Jump. From the results it was concluded that the Sargent jump
was a valuable test for predicting power ability only if the test was standardized, practiced, and administered correctly (Van Dalen, 1940).

A modification of the Sargent Jump that can also be employed is the jump and reach test using the Lewis Nomogram chart. This variation involves measuring the difference between the subject's standing reach and the height to which he/she can maximally jump and reach with the fingertips. Height of the jump and body weight are then used to find the corresponding power output on the Lewis Nomogram (Fox & Mathews, 1981). Although time is not measured directly using this method, power output is still reported in one of its true physical units. This type of test can be easily administered and interpreted and has therefore, become a commonly used method among physical educators and coaches. However, according to Vandewalle et al., (1987), the validity of Lewis's Nomogram was questionable because the formula from which it was derived reported power as an equivalent of potential energy change divided by the duration of the ascending flight, instead of the duration of the thrust. Therefore, Lewis's formula did not take into consideration the work performed from the crouch position to the takeoff position.

Gray, Start and Glencross (1962a) pointed out that assessing power in terms of inches jumped and body weight does not comply with the requirements of power in its true physical sense, but that the vertical jump may be the best indication of general muscular power. Gray and his associates (1962a) also suggested that the vertical jump was not a pure test of leg power because movements such as swinging the arms and extending the trunk may contribute to the height jumped. Therefore, they would argue that arm swing should not be used to obtain a
measurement of leg power. Based on that premise, Gray et al., (1962a)
developed a study that eliminated extraneous body movements while
performing the vertical jump and used the center of gravity as the
measurement point. They termed this modification of the Sargent jump
the vertical power jump.

Using the center of gravity technique was based on the following
theoretical assumptions: 1) the center of gravity remains in the same
position relative to the fingertips; 2) movement of the center of
gravity is primarily caused by the vertical thrust and is very minimal
in the anterior, posterior, and lateral directions and; 3) the leg
thrust accelerates the body in a uniform manner (Gray et al., 1962a).
By assuming that the acceleration of the center of gravity was constant,
this method would also calculate the duration of the thrust and account
for the work performed before takeoff. To measure power as it was
scientifically defined, a formula based on the mathematical logic of the
force of gravity, the weight of the person, and the displacement of the
center of gravity was validated and used by Gray et al., (1962a) to
obtain power output in horsepower. In conclusion, Gray et al., (1962a)
established that the vertical power jump had a high test-retest
reliability ($r = .985$) and seemed a valid test of genuine leg power based
on the coefficient of objectivity ($r = .981$).

After this in depth analysis of the vertical power jump, Gray,
Start and Glencross (1962b) went on to determine the usefulness of their
technique. To accomplish this purpose, the researchers eliminated use of
the center of gravity procedure and simply used body weight and height
jumped to calculate power output. The jump and reach, standing broad
jump, and squat jump were the other tests used to determine if an absolute measure of leg power, which did not account for time, would predict power scores on the more precise vertical power jump method. It was concluded that the modified simple version of the vertical power jump was acceptable as a substitute for the in-depth mathematical method (Gray et al., 1962b). It also appeared that the simple jump and reach version was superior to the other jump tests used as a measure of leg power.

The more recent experiments that utilized a force platform however, provided results that disagree with the assumption that acceleration is constant throughout the vertical jump (Offenbacher, 1971; Davies & Reenie, 1968; Davies & Young, 1984). These findings would certainly question the validity of previous results, such as the study done by Gray and his associates. However, based upon the high correlation found between the jump height and peak power output as calculated from a force platform, it would appear that considering jump height would be a simple way to determine power output (Davies & Young, 1984). Use of force platforms also made available instantaneous values of force, velocity, and acceleration, therefore making the calculation of peak/instantaneous and average power output from a jump rather easy.

When looking at jumping as a measurement of power, Adamson and Whitney (1971) described jumping as an impulsive (force x time) muscular activity. Total impulse can be expressed as the sum of an infinite number of small impulses and can be viewed as being mathematically equal to the area under the force-time curve (Hay, 1985; Miller & Nelson, 1973). Adamson and Whitney (1971) stated that the
success of the subsequent jump was directly related to the size of the impulse. Therefore, the shape of the impulse curve was the best indication of the muscular activity used to generate the jump. It was concluded that power in its strict mechanical sense was an unjustified concept when dealing with impulsive actions such as jumping (Adamson & Whitney, 1971). Perhaps this would be true if sophisticated devices such as the force platform did not exist.

In other words, Adamson and Whitney (1971) were criticizing the use of instantaneous power when dealing with jumping activities. However, Bosco, Luhtanen and Komi (1983) pointed out that the development of instantaneous power does not necessarily parallel the development of average power. Keeping this in mind, Bosco et al., (1983) developed a simplified mechanical power jumping test, which recorded work-power output performed during a 60 second continuous jumping task. The test was supposed to evaluate the average power output of the leg extensor muscles during a natural motion. Based on the results, the test appeared suitable for evaluating leg power while performing an explosive type exercise involving both stretching and shortening of the extensor muscles (Bosco et al., 1983).

In an attempt to mechanically validate six different tests recognized as measures of leg power, Considine (1971) utilized a force platform. In his study a test similar to the original Sargent jump, but with restricted arm movement, was used as the criterion measure for leg power. The tests used in this analysis were the vertical jump and reach, standing broad jump, chalk board jump, 5 yard sprint, 10 yard sprint, and a running 5 yard sprint. Basically, Considine (1971)
concluded that use of these tests as valid measures of leg power did not appear to be justified. More specifically, the vertical jump and reach test had the greatest relationship to the criterion measure, but once again was viewed as an invalid assessment of true leg power.

Only a few studies were found that assessed vertical jumping performance in relation to objective mechanical measures other than those involving a force platform. Martin and Stull (1969) examined forty-eight knee angle, foot spacing combinations and revealed that they independently influenced performance in the vertical jump. It was concluded that the preliminary stance that resulted in the greatest inches jumped consisted of a combination of the knees being bent at approximately a 115 degree angle with the feet spread 5-10 inches laterally and slightly greater than 5 inches anteriorly-posteriorly (Martin & Stull, 1969). In an original research investigation, Robertson and Flemming (1987) determined the vertical jump was a result of the hip, knee, and ankle muscles contributing 40.0 %, 24.2 %, and 35.8 % respectively. It was also discovered that the leg extension musculature used to create the external work needed for jumping was produced by all three muscle moments acting simultaneously.

To mechanically assess power Barlow (1971) used high speed cinematography and analyzed the jump and reach test and the modified vertical power jump. The film analysis involved vertical displacement of the center of gravity, time of displacement, and total body weight. It was found that the relationship between the administrative score and actual power developed in the respective tests were negligible ($r = .14$). Therefore, the subject who attained the highest administrative score did
not necessarily generate the most power. On that premise it was concluded that the measure obtained by the typical physical jump and reach test was not indicative of human power (Barlow, 1971). Total vertical displacement (lowest to peak position) of the body's center of gravity was also found to be a non-significant factor in power output for both the jump and reach test ($r = .04$) and the modified vertical jump test ($r = -.08$). Total body weight was viewed as the most influential factor effecting the mechanical measure of power in both variations of the vertical jump used in Barlow's study.

**Margaria Stair Test**

Margaria et al., (1966) devised another test for measuring anaerobic power, and felt that their new stair climb test could measure leg power more precisely than the Sargent Jump. Basically, their new test consisted of running up a staircase, two steps at a time, as fast as humanly possibly. A reason this test could be considered more accurate was because it directly measured time and included this factor into the power output calculation. Margaria et al., (1966) proposed that performing the stair climb test did not require a particular skill and was primarily a measure of leg and lower trunk power.

Subjects performing the stair climb began with a two meter approach and were instructed to run up the stairs, two steps at a time. Each step was 17.5 cm, so that each jump of two steps covered a distance of 35 cm. The vertical component of running up the stairs at maximum speed was measured using a photoelectric clock, which recorded scores to the nearest one hundredth of a second. For timing purposes, an even number of jumps were used so that the subject would be in the same position, or
landing on the same foot, for every other jump. The time used to
determine power was the amount of time recorded to traverse four steps
(70 cm height).

Margaria and his associates (1966) used a two meter acceleration
phase so that the subject could reach maximum forward velocity sooner.
This would also assure that power was being measured when the subject
reached a constant level of speed. To determine the effect that step
height would have on power, the exercise was tested on step heights
ranging from 17 to 41 cm. Margaria et al., (1966) concluded that for
people of normal body build, an optimal step height (2 steps combined)
was approximately 35 cm. If the stairs were any higher than optimal,
muscle contraction was too long and too great a force was needed to
climb the staircase. If a lower than optimal step height was used,
maximal power output was not reached by the subject because too great a
frequency was needed to obtain maximal forward velocity. Through this
experimentation, it was found that a step height of 30 to 38 cm produced
reliable values within margins of 5% (Margaria et al., 1966).

In 1968 Kalamen modified the step test proposed by Margaria. The
major changes that grew out of Kalamen's investigation included the
following: 1) using a six meter approach; 2) running up the staircase
three steps at a time and; 3) recording time as how long it took to
traverse six steps, step 3 to step 9 (Kalamen, 1968). Power was
computed as the product of the subject's body weight and vertical
distance between first and last step divided by time \( P = W \times D / t \).

**Evaluation of Anaerobic Power Tests**

Many standard methods as well as modified methods exist for the
purpose of measuring human muscle power. After looking at the vertical jump and stair climb methods, it appeared that different results could be obtained from tests supposedly measuring the same parameter. It was thought that several of the obvious differences were worth mentioning, since any one area might be the important factor toward justifying that these two tests actually measure the same thing.

In the vertical jump, all of the work needed to project the body to a maximum height must be accomplished in the amount of time the feet are in contact with the floor. The body will not leave the ground if this work is done too slowly, but when done fast enough the momentum of the body will continue and cause the individual to jump off the ground. Once the subject leaves the ground, he/she becomes a free falling body and can no longer use the legs to thrust and propel the body upward against the force of gravity (Sargent, 1924). Therefore, all of the force needed to vertically jump and reach a maximum height must be produced between the crouch and the extended positions (Sargent, 1924).

On the other hand, the stair climb allows the subject to make contact with the ground several times while performing a maximum muscular effort. This results in power being determined from several muscular contractions opposed to the single muscular effort of the vertical jump (Kalaman, 1968). Kalaman (1968) pointed out another difference as being the number of points making contact with the ground. In both tests a force great enough to lift the weight of the body upward must be produced. However, the difference lies in the way in which human muscle power is initiated. In the vertical jump, the subject must contract the muscles of both legs at the same time in order to thrust
the body upward; in the stair run, the subject must contract one leg at a time in order to climb the stairs.

As stated in Kalamen's 1968 investigation of anaerobic power,

The Sargent Jump test, used so often in physical fitness tests as a legpower measure, does not measure the same thing as stair running tests which can be computed into power directly from the data obtained in the test (p.44).

However, when partialling out the effect of body weight, Kalamen (1968) found the correlation between power tests to be significant, and reasoned that body weight should be considered in the tests attempting to measure individual power efforts. According to Olsen (1987) the vertical jump and the Margaria stair climb tests are both multijoint exercises which measure similar power production elements. A positive correlation \( r = .827 \) was found between the two tests. Also, it appeared from the literature that power outputs obtained from various other methods agree fairly well and share some common elements (Kyle & Caiozzo, 1986; Alyalon, Inbar & Bar-Or, 1974; Vandewalle et al., 1987)

**Relationship of Power to Athletic Performance**

McCloy (1932a) used the term athletic ability as reference to the ability to skillfully utilize force in relation to one's body size at high speeds. In a sense, this description of athletic ability was limited to the mechanical use of strength and velocity, and was therefore expressed as athletic power (McCloy, 1932a). Power events in athletics were those considered as involving the element of velocity and measured in terms of time, distance or height (McCloy, 1932a; McCloy, 1942).

Since McCloy (1932a) viewed the measurement of power useful in connection
with track and field events, he went through a comprehensive analysis to identify and verify a relationship between power and performance in the sport of track and field. Out of McCloy's extensive research, as well as other studies, grew the relationship between the Sargent Jump and power athletics. More specifically, it was concluded that a high correlation existed between the Sargent jump and track and field events, and when combined with measures of age, size, and strength it could be considered a useful predictor of track and field ability (McCloy, 1942).

Over the past 50 years the Sargent jump has been used for purposes such as classifying students, predicting athletic ability, measuring physical fitness, and validating new fitness tests (McCloy, 1932b; Carpenter, 1938; Van Dalen, 1940; DiGiovanna, 1943; Burley & Anderson, 1955). In a study that investigated strength, power and femininity of college women, Carpenter (1938) concluded that power was by far the most important factor influencing athletic performance. DiGiovanna (1943) investigated body build, muscle strength and explosive power in relation to the following college athletics: 1) baseball; 2) basketball; 3) football; 4) gymnastics; 5) tennis and; 6) track and field. It was concluded that these three factors were associated with athletic success, but with no pattern to a specific sport. In agreement with this finding, Burley and Anderson (1955) found that athletes were significantly better than non-athletes when looking at vertical jump scores. This would imply that a good performance on the vertical jump test would be indicative of athletic success. The same study also revealed that power was more closely related to baseball, basketball, track, and swimming opposed to boxing, tennis, wrestling, and football
(Burley & Anderson, 1955). All of these studies used the vertical jump to measure power which would imply that this test could be used as an indication of who was going to succeed in athletics.

In an attempt to determine the effects of systematic weight training on power as it relates to sprinting, jumping, and throwing events, Chui (1950) found that weight training seemed to have a positive effect on athletic power. It appeared that systematic weight training could increase strength, which could provide the extra strength needed to overcome the viscosity of the muscle, and hence add to the speed of contraction allowing for greater power outputs (Chui, 1950; Capen, 1950).

Relating selected power tests to the 50 yard dash, Kalamen (1968) contrasted the earlier findings when he established that a non-significant relationship existed between performance on the Sargent jump and the all-out sprint. However, it was shown that scores from the Margaria power test (two-meter, two-step method) and the Kalamen power test (six-meter, three step method) correlated with performance in the 50 yard dash (Kalamen, 1968). It was concluded by Kalamen (1968) that both methods could be used to predict potential for athletic success, but that Margaria's two-meter, two-step test was less accurate.

In an investigation where the primary purpose was establishing and isolating events that could be used as predictive measures for muscle velocity and athletic power, Hutto (1938) used a group of high school boys and analyzed eighteen different tests and measures. Utilizing a factor analysis method, six common elements were identified as underlying physical accomplishment. The six major factors included the
following: 1) strength; 2) weight; 3) muscle velocity; 4) structure such as leg length; 5) arm strength and; 6) artifact of a factor too small to identify (Hutto, 1938). Based on the results, specific regression equations were developed which were viewed as being a fairly easy and accurate method to predict muscle velocity and athletic power.

**Factors Influencing Power Production**

Over the years, power has been a controversial issue in human performance and can be a difficult concept to comprehend. Searching the literature made evident the many components that could influence performance on a power test. In this section the effort was made to review factors such as leg strength, leg speed, and body composition as they relate to human power production.

Originally when investigating the stair climb, Margaria et al., (1966) pointed out that step height can affect power output. Caiozzo and Kyle (1980) further suggested that stride frequency, leg length, stair angle, or loading might affect one's ability to produce power. The primary concern for Caiozzo and Kyle's study was to examine external loading as it relates to power production while performing Margaria's stair climb. The subject performed the test under the following five experimental conditions: 1) body weight or no external loading; 2) body weight plus 10.1 kg; 3) body weight plus 19.2 kg; 4) body weight plus 24.2 kg and; 5) body weight plus 29.2 kg (Caiozzo & Kyle, 1980). These conditions represented increases in weight of 0, 14, 27, 33, and 44 % respectively.

Caiozzo and Kyle (1980) reported a mean power output of 15.9 W/kg
without external loading. This value was representative of the anaerobic power output set by Margaria et al., (1966), which was 14.7 to 15.7 W/kg. External power outputs significantly increased under the loaded conditions. On the average, the 29.2 kg situation represented a 16% increase in power production (Caiozzo & Kyle, 1980).

It was unclear as to why the external loads resulted in increased power outputs. One possibility discussed by Caiozzo and Kyle (1980) was that climbing the stars with extra weight optimized the running speed-load interaction. Added weight producing an increased ground reaction force might well have been another reason for the increased power output. It was also thought that the additional weight could have effected stride length. Therefore, making the stride more conducive to running up the steps.

The standard staircase can confine stride length and place some limitations on obtaining true measurements. It was thought that this built-in limitation probably prevented the subjects from reaching their maximal capacity while performing the stair task (Caiozzo & Kyle, 1980). To eliminate the mechanical constraint of stairstreads, Kyle and Caiozzo (1985) compared running up a staircase to running up a ramp. To test the subjects an incline of 30 degrees or 58% gradient was used for both the staircase and ramp conditions. The five external loading conditions used in their previous experiment were also used in this study. However, a sixth loading condition of 34.2 kg was used in the latter study when the subjects ran up the ramp.

According to Kyle and Caiozzo (1985), significant differences in power outputs were found between the ramp and the stairs in each of the
experimental conditions. The ramp produced the highest mean power output at a load of 19.2 kg, which after this point power values began to progressively decrease. The ramp revealed a 9% increase in power output from the unloaded condition to the loaded condition of 19.2 kg. In contrasting these values to the stairs, the highest average power output occurred at the 29.2 kg load, which represented a 13.9% increase in power from the unloaded condition. Also when comparing the ramp to the stairs, a 23.5% increase in power output was reported between the unloaded condition on the stairs to the 29.2 kg load on the ramp.

Subjects appeared to run up the ramp more easily and faster than the stairs when carrying the extra weight against gravity. Through this experiment it became evident that the ramp could produce power values that reach maximum capacity and begin to level off; whereas in climbing the staircase, power values at maximum load still seemed to be increasing (Kyle & Caiozzo, 1985). In the latter study the ramp materialized as being better than the stairs, possibly because it allowed subjects to individualize stride length and stride frequency. However, it is still debatable as to which mode, a properly designed staircase or a properly designed ramp, could produce the greater power outputs.

When studying the effects of external loading on power output during vertical jumping, Davies and Young (1984) reported results that were opposite to those found during stair climbing. It was shown that adding weight to the subjects produced a linear decrease in power output, which was due to a decrease in the take-off velocity when jumping (Davies & Young, 1984). The discrepancy between the studies can
probably be linked to several mechanical factors. One such factor that was given some consideration was that of kinetic energy.

According to Margaria et al., (1966), when an all-out effort is expended running up gradients beyond 30%, the only factor contributing to external work is body lift. Other factors such as speed changes and impact of the body on the ground become negligible (Margaria et al., 1966). Therefore the 58% incline used by Caiozzo and Kyle would allow the kinetic energy of the body to be continuously lifted throughout the test, and the majority of energy produced can be used for external work (Davies & Young, 1984). Whereas the vertical jump involves an abrupt change in kinetic energy, thereby consuming rather than converting energy into external work (Davies & Young, 1984). In regards to the efficient recovery of kinetic energy, Kyle and Caiozzo (1985) considered stair climbing intermediate between cycling and the vertical jump.

In other words when performing the vertical jump, all of the energy produced is wasted upon impact. External loading may require the subject to produce more energy to initially lift the body off the ground, therefore decreasing rather than increasing the individual's ability to produce external power (Davies & Young, 1984). However, it has been pointed out that within the limits of each exercise, optimal loading conditions are necessary to determine maximal power outputs (Kyle & Caiozzo, 1985). Davies and Young (1984) summed up this matter by stating, "Clearly the effects of human loading experiments on mechanical power output must be treated with caution. The results do not have universal application" (p. 354).

Only adding to the problems involved with external loading is the
consideration of how individual body composition could influence power output. Several researchers have examined the concept of body composition and what effect it can have on anaerobic power. When comparing lean, obese, and average male subjects, Kitagawa, Suzuki and Miyashita (1980) reported that the obese group had the lowest vertical velocity but the highest power output per kg of lean body mass. On the average, the obese individual produced 14% more power than the lean individual when lifting only body weight. Kitagawa et al., (1980) also analyzed the effects of external loading on the lean subjects. They found that when adding extra weight to give the effect of obesity, the lean group performed almost equal to that of the obese group (Kitagawa et al., 1980).

In the experiment by Kitagawa et al. (1980) the added weight produced lower velocities and higher power outputs. Although no details of velocity were given in the loading experiments by Kyle and Caiozzo, according to Davies and Young (1984) the increase in power found in their experiments was solely due to an increase in the amount of applied force. Therefore it appears that the role of excess fat or added weight in power measurements is that of serving as an inert mass (Kitagawa et al., 1980). In conclusion it would seem that obesity represents a form of external loading, which serves as an advantage when performing the stair climb (Kitagawa et al., 1980; Caiozzo & Kyle, 1980; Kyle & Caiozzo, 1985). However, the obese individual would be at an apparent disadvantage when performing the vertical jump (Davies & Young, 1984).

While it appeared that the more ponderous individual had an advantage when performing the stair climb, Mayhew, Schwegler and Piper
(1986) speculated that this was a superficial correlation caused by the use of body weight in the computation of power. This point was brought forward when the researchers used the Margaria-Kalamen test with a six meter approach to question the relationship of acceleration momentum to anaerobic power. Overall, it was observed that the greater the acceleration, the greater the vertical velocity (Mayhew et al., 1986).

The magnitude was low when correlating the two velocities to absolute power. Acceleration accounted for 9% and vertical velocity accounted for 17% of the total variance. When removing the influence of body weight, the results showed a negative relationship between power output and percent fat (Mayhew et al., 1986). This effect also increased the relationship between absolute power and acceleration and vertical velocity, so that now over 45% and 92% of the variance could be explained by these two respective variables. Mayhew and his associates (1986) also reported that for male subjects the deviations in absolute power scores could be attributed to variations of 63.6% in body weight, 36.4% in stair climb time, and about 0.1% in acceleration velocity. For the female subjects the variation was accounted for by 55.5%, 39.4%, and 5.1% respectively.

Considering the influence body weight seems to have on power, the relationship between anaerobic power and acceleration momentum was also analyzed in relative terms. According to Mayhew et al., (1986) the males and females who had faster acceleration times also had greater relative power outputs. Correlating relative power to absolute power produced a low relationship, which might indicate that factors other than body weight can have a major influence on power production.
However, once again the correlation increased when the body weight factor was held constant. In conclusion, these results suggested that perhaps the Margaria-Kalamen power test is reflecting body composition to a greater extent than was ever imagined (Mayhew et al., 1986).

Another important factor that has drawn considerable attention from several researchers is that of strength and its relationship to power. Out of a series of tests administered to determine explosive leg power, Costill, Miller, Meyers, Kehoe and Hoffman (1968) found the squat weight lift to be the only test significantly related to anaerobic power. Taking a closer look at this relationship disclosed a correlation between body weight and the squat lift. Considering body weight is a direct measurement used in the calculation of power output, it was implied that this factor rather than dynamic leg strength may have accounted for the relationship found between anaerobic power and the squat lift (Costill et al., 1968).

After investigating four different training programs designed to strengthen the leg and thigh muscles, McClements (1966) concluded that all programs were equally effective in increasing power production in the vertical jump. However, the more important issue may be the conclusion, "although strength (agonistic and antagonistic) is related to power, gains in strength are not related to gains in power" (McClements, 1966; p. 78). Also looking at this relationship. Berger and Henderson (1966) established that both static and dynamic leg strength are related to leg power as measured by the vertical power jump. Also of prevalence in this study was the finding that static leg strength and dynamic leg strength are not significantly different from
each other, and that neither one is more related to leg power (Berger & Henderson, 1966). Considine and Sullivan (1977) provided little support to these other findings, and concluded that isometric leg strength had a low correlation to leg power. This would suggest that strength may be only one component contributing to this complex concept of human power.

German (1984) added support to the idea that power is comprised of many facets. He indicated that absolute dynamic strength was a good indicator of absolute power and leg speed was a good indicator of relative leg power. However, a combination of both leg speed and leg strength was favorable over any one factor when determining absolute and relative leg power (German, 1984). After investigating 19 various measurements taken from the lower limb, analysis revealed that power was linked to speed opposed to strength (Start, Gray, Glencross & Walsh, 1966). The measure of leg speed is yet another variable that seems to be related to power.

To look at this relationship between leg speed and anaerobic power, Gray, Start and Walsh (1962) used the bicycle ergometer to measure leg speed and the vertical power jump to measure leg power. A positive correlation was found between leg speed and leg power. Although this relationship was significant, it was very low and only accounted for approximately 25% of the common variance. The evidence presented in this section should make it clear that anaerobic power is a complex concept with many influencing factors, and that many unanswered questions still remain in this area.
Summary

Throughout this chapter one can get a feel of the historical perspective related to anaerobic power. However, it appeared that at the present time the concept of power is still being misinterpreted. A review of the literature revealed the inconsistent use of the term power, as was shown by the many definitions being applied to this physical trait.

Also, it was shown that muscular power is considered an important component contributing to athletic performance. Therefore, it becomes critical that this physical trait is accurately measured in order to provide reliable information to coaches and other specialists. The vertical jump and the stair run are viewed as two of the more functional tests used to estimate power, however various other methods are also being employed to measure human power output. Although it seemed that these different power testing procedures obtained similar results, it is still questionable as to which method would produce maximal power outputs and assess power in a true mechanical sense.

As was pointed out, power is a complex entity comprised of many influencing variables. Many researchers have devoted time to investigating such factors, but it is still apparent that the results are nondefinitive and further research is needed in the area of human muscle power. Hopefully, looking at anaerobic power from a mechanical viewpoint will help resolve some of the presently unanswered questions, and lead to a clearer understanding of this complicated physical parameter.
CHAPTER III
METHODS

The intent of this project was to go beyond actual eye observation and utilize high speed cinematography to investigate two frequently used tests for determining human power output. This investigation was used to gain an understanding of the mechanical concept of power. The main problem of the study was to determine the extent to which a standard method of measuring power output compared to a more complex cinematographic method of measuring power. A comparison between the two methods will help determine what effect the application of mechanical principles had on the power generated in both the Margaria and vertical jump tests. Details of subject selection, preliminary investigation, testing procedures, cinematographic procedures, kinematic analysis, and statistical analysis will be included within this chapter.

Subject Selection

Track athletes were chosen as participants in this study due to the relationship found between anaerobic power and performance in track and Field events (Digiavanna, 1943; Burley & Anderson, 1955; McCloy, 1942). Those athletes training for jumping and sprinting events were of primary interest to the study. The sample for this study consisted of a total of twelve volunteer athletes, both male (n = 7) and female (n = 5), from the 1988 track and field teams at the University of Wisconsin - La Crosse.
Prior to being tested, all subjects were explained the nature of the experiment and asked to sign an informed consent form. (see Appendix A). The subjects performed both tests in shorts, shirt, and running shoes, and the performance was not hindered by any extra devices or equipment. Prior to the first filming session, each subject was weighed on a medical scale and this value was recorded in pounds.

**Preliminary Investigation**

Prior to testing a pilot study was conducted in the Mitchell Hall fieldhouse to obtain the proper arrangement for filming purposes. After viewing the pilot study film, it was concluded that the stairs constructed for use in the Margaria test were hindering the natural performance of the subjects. The vertical jump test posed no such problems in an indoor setting. However, to keep conditions consistent, a decision was made to film outdoors which allowed for performance in a more natural setting for both tests.

**Testing Procedures**

The testing procedures included in this section will describe the protocols used for the vertical jump and Margaria stair tests. Along with these procedures, the standard and cinematographic methods used to determine power output and vertical velocity will also be presented.

**Vertical Jump**

The vertical jump test was administered using a Vertec vertical jump measuring and training device. The standing reach of the subject was determined using the method described by Considine and Sullivan.
(1973). This was accomplished by having the subject stand beneath the colored Vertec measurement vanes and stretch to reach as high as possible with his/her preferred hand. During this preliminary measurement the subject's feet remained flat on the ground and the non-preferred hand remained at the side of the body. This measurement was taken directly from the Vertec device and was recorded as the standing reach of the subject.

For the preparatory phase of the jump, the subjects were told to stand with their feet approximately shoulder width apart and both feet stationary. This two foot take off prevented the subjects from gaining momentum by stepping into the jump. To perform the jump the subjects were instructed to flex their knees and jump as high as possible, reaching for the colored measurement vanes with their preferred hand. The size of the preparatory crouch and the use of the non-preferred arm were not restricted, thereby, permitting each subject to perform as naturally as possible.

Once the jump was completed, the height was recorded and the Vertec device was prepared for the next trial. Each subject performed a total of six trials. The first three trails were considered warm-up or practice and the last three trails were the actual test with scores being recorded. The highest jump of the last three trials was the value used to determine power output, and was also the trail selected for film analysis. Of the twelve subjects only nine performed the vertical jump test (n = 6 males; n = 3 females).
Standard method. The vertical distance jumped was determined by taking the difference between the maximum jump height and the standing reach height. This value, which was recorded in inches, along with the weight of the subject were marked on the Lewis Nomogram (See Appendix B) (Fox & Mathews, 1981). A ruler was placed on the Lewis Nomogram to connect these two values with a straight line. The estimate of power output was found by reading the value where the straight line intersected the middle graph on the Lewis Nomogram, and was read in ft-lbs/sec. The final value for power output was converted to the metric units of Watts (1 Watt = .73756 ft-lbs/sec). The Lewis Nomogram procedure was considered as the standard method for determining power output from the vertical jump. The average vertical velocity was computed by taking the vertical distance jumped, as computed above, and dividing by the time as derived from film analysis \((v = d/t)\).

\[
\begin{align*}
    v &= \text{average vertical velocity (ft/sec)} \\
    d &= \text{vertical displacement of jump (ft)} \\
    t &= \text{amount of time from takeoff to peak position of jump (sec)}.
\end{align*}
\]

Cinematographic method. The cinematographic method of determining power was based on time and distance measurements derived directly from the film analysis. The displacement of the center of gravity was determined from position one, or the low point of the crouch, to position two, or the peak point in the jump. This displacement value was considered as the vertical distance jumped, and was used along with body weight and time to calculate the amount of power generated in the vertical jump. The formula \((P = W \times D / t)\) was used to calculate
power output values in foot-pounds per second which were then converted to watts of power (Fox & Mathews, 1981).

\[ P = \text{anaerobic power (ft-lbs/sec)} \]
\[ W = \text{weight of the subject (lbs)} \]
\[ D = \text{displacement of the total body center of gravity from position one to position two (ft)} \]
\[ t = \text{amount of time taken from position one to position two (sec)} \]

The average vertical velocity was computed by taking the vertical distance jumped, as determined from the center of gravity displacement, and dividing by the time taken to complete the jump.

**Margaria Stair Test**

In 1966 Margaria and his colleagues used a two step height of approximately 35 cm, but concluded that a step height from 30-38 cm would furnish values that were within \(\pm 5\%\) of the results. Margaria et al., (1966) also noted that the external work for running up an incline of approximately 30 \% was produced primarily by body lift. Therefore, providing that the effort was maximal while running up a given incline of steps exceeding this value, the vertical component became the important contributing factor to mechanical work and power. This would render that all other factors, such as speed changes at each step and impact of the body on the ground during the last phase of the step, became negligible.

For the purpose of this study the Margaria power test was conducted on the stadium stairs primarily because they met the standard requirements set forth by the original researchers. The height measured for two of the stadium steps was equal to 14.5 inches or 36.83 cm. Also, the stairs had an incline of 27.8 degrees or 52.7 \% grade, which clearly indicated that power could easily be determined based upon
vertical displacement. Secondly, the stadium stairs solved the problem of finding a standard staircase with the necessary space needed for filming procedures. Using the stadium stairs allowed for ease of collecting data in a natural setting which would produce a quality film for analysis. Lastly, it was also thought that the stadium stairs served a practical purpose, since it is an easily accessible place for almost all coaches and could possibly serve as a common site for testing athletes.

The stair climb power test was executed according to the methods described by Margaria et al., (1966). Starting with a two meter approach, each subject was instructed to run up the stairs two at a time at maximum speed. The time taken to perform the test was determined by switchplates placed on the second and sixth step. This permitted the subject to step on the plates using the same foot, allowing the measurement of one full step cycle. Time was measured directly from a Dekan timer accurate to the nearest .01 second.

A signal light mechanism was wired to the Dekan timer to allow the investigator to accurately identify when the switchplates were being activated. The light was turned on when the subject stepped on the first switchplate to activate the timer; and turned off when the subject stopped the clock by stepping on the second switchplate. The light device was placed facing the camera and housed in a black box, which negated any reflections from the sunlight and made for ease of viewing the light on film.

Each subject performed a total of six trials; the first three trials were considered practice and the last three were considered test
trials. Of the three test trials, the one with the fastest time was used for film analysis and power computations. The time recorded on the Dekan timer was used solely as a screening mechanism to determine which trial was the fastest, therefore determining the trial to be used for film analysis. Time was determined from the film to the nearest .001 second and used in all calculations of power output generated from the Margaria stair test.

**Standard method.** Power was determined from the formula in Fox and Mathews (1981) where \( P = \frac{W \times D}{t} \):

- \( P \) = anaerobic power (ft-lbs/sec)
- \( W \) = weight of the subject (lbs)
- \( D \) = vertical distance between the second and sixth steps (ft)
- \( t \) = amount of time taken from foot contact on the second step to foot contact on the sixth step (sec).

Since power was computed in ft-lbs/sec it was converted to Watts of power by dividing by .73756 ft-lbs/sec \((P/.73756)\). This was considered the standard method for determining power which used a fixed vertical distance. In the case of this study the vertical distance between the second and sixth stair step was equal to 2.417 feet. Determining the average vertical velocity for this standard method involved using the fixed vertical distance measurement of 2.417 feet and dividing by the time taken to complete the stair climb \((v = \frac{d}{t})\).

**Cinematographic method.** The cinematographic method for computing power generated in the Margaria power test used the same formula as previously stated \((P = \frac{W \times D}{t})\), with the exception that vertical distance was based upon the individual displacement of the body's center of gravity. The displacement of the center of gravity was determined by taking the difference between position one (when the subject made
initial contact with the second step) and position two (when the subject made contact with the sixth step). This value was substituted into the previous formula \(D = \text{displacement of the total body center of gravity from position one to position two}\), with all other variables remaining the same. The power values from this method were also obtained in measures of foot-pounds per second and converted to Watts of power. The average vertical velocity for the cinematographic method was computed by taking the vertical distance measurement based on the center of gravity displacement, and dividing by time taken to complete the test.

**Cinematographic Procedures**

The filming of this project took place at two outside locations on the University of Wisconsin - La Crosse campus. The study consisted of two separate filming sessions, the vertical jump, and the Margaria stair test. The Margaria power test was filmed during the first session and took place on the cement stairs in the bleacher area of Memorial Stadium (See Figure 1). The following day the vertical jump test was filmed on the sidewalk outside the West end of Mitchell Hall (See Figure 2).

A motor driven Cine 8 super 8 motion picture camera capable of a maximum transport speed of 250 frames per second was used to film this study. The camera operates with a speed stability of \(\pm 2\%\) or one frame, whichever is the greater. Both testing conditions were filmed at the selected speed of 150 frames per second. To hold the film stationary during exposure time, the camera functioned with an intermittent pin registered film transport mechanism, which had a registration accuracy
(6th STEP) SWITCHPLATE

(2nd STEP) IDENTIFICATION MARKERS

SWITCHPLATE

IDENTIFICATION MARKERS

7 3

SIGNAL LIGHT MECHANISM

DEKAN TIMER

2 METER APPROACH

DISTANCE FROM CAMERA TO SUBJECT = 45 FT.

LENS HEIGHT = 4 FT.

CINE 8 CAMERA

TLG

LED

STADIUM BLEACHERS

Figure 1. Filming Set-up for the Margaria Stair Test
Figure 2. Filming Set-up for the Vertical Jump Test
of ±.0002 inch from frame to frame. To operate the camera an A.C./D.C. power converter was necessary to change the A.C. source to a 28 Volt D.C. current.

The variable setting (10 to 160 degrees) double blade shutter was adjusted to an opening of 120 degrees for both filming sessions. The camera, equipped with an Angenieux 12-120 mm zoom lens, was attached to a Quick-Set Husky tripod, leveled and positioned perpendicular to the plane of action. To minimize perspective error the camera was located a distance of 45 feet from the subject for both filming sessions. The tripod was adjusted so that the height to the center of the lens was 5 feet for filming of the vertical jump test and 4 feet for filming of the Margaria stair test.

The shutter opening and the frame rate determined the exposure time of 0.0022 second (1/450). The appropriate lens aperture (f-stop) was found based upon the exposure time, film ASA, and the amount of available light. A Sekonic light meter was used to measure the available light and obtain the correct f-stop setting. Natural sunlight provided adequate lighting to film at high speeds, and an f-stop setting of 8 was needed for both the Margairra and vertical jump conditions. The project was filmed with a total of seven Kodak Ektachrome Type G color film cartridges each with 50 feet of available footage and an ASA of 160.

The camera was also equipped with an internal light emitting diode (LED) which was connected to a timing light generator (TLG). The TLG/LED driver was set at 10 Hertz and served the purpose of inputting a
signal which pulsed the camera's internal LED to mark the edge of the film 10 times per second. After the film was developed, these timing marks were used to compute the actual speed at which the camera was operating.

A set of identification markers were included within the photographic field of view, with the first marker indicating the subject number and the second marker indicating the trial number. At the beginning of each film cartridge, a three foot reference measure was filmed in both a horizontal and vertical direction in a plane parallel to the plane of the film. This reference measure of known length was used during kinematic analysis to scale film images into life size dimensions. All three test trials of the Margaria and vertical jump tests were filmed from a lateral perspective. The camera was shut off after each trial and then turned on one second before the next trial to allow the camera to achieve the selected speed.

**Kinematic Analysis**

For each subject, the test trials with the greatest distance jumped and the fastest stair run time were selected for analysis. All films were carefully reviewed to select the individual frames for analysis in each trial. The films were projected onto an Editor-Viewer console using a Lafayette Model 927 Super 8 Motion Analyzer. This is a precision built movie projector equipped with a mechanical counter and designed for viewing of high speed films. The procedures and equipment required to collect the kinematic data will be explained within this section.
A total of 15 frames per trial were digitized for the vertical jump test. The frames for each subject were selected as follows:

frames 1-3 downward movement in the preparatory phase of jump
frame 4 low point of preparatory phase
frame 5 beginning of upward movement from the crouch position
frame 6 slightly before takeoff; hands positioned above shoulders
frame 7 takeoff; feet leave the ground
frame 8 midpoint of ascending flight of jump
frame 9 peak point of jump
frame 10 beginning of descending flight of jump
frame 11 midpoint of descending flight of jump
frame 12 contact with the ground
frames 13-15 follow through of jump

Three frames were of primary concern for the vertical jump. The frames of interest were those when the subject reached the low point of the preparatory phase, takeoff, and peak point of the jump. The remaining frames were selected subjectively to furnish the necessary data points needed to obtain various data curves.

A total of 15 frames per trial were also digitized for the Margaria stair run test. The frames for analysis were selected on the basis of the following foot positions on each step: 1) foot contact; 2) heel rise and; 3) toe off. These positions were selected for contact with the second, fourth, and sixth steps and accounted for nine frames. Three frames were chosen on the approach step and three frames on the follow through of the test, which provided the remaining frames needed for data smoothing. The two frames of primary concern in the Margaria test were the frame in which the subject made contact with the second step to start the timer, and the frame in which the subject made contact with the sixth step to stop the timer.

The Numonics Model 1224 Electronic Digitizer was used to digitize each frame. In the digitizing mode, the position of the cursor detected
points in a single plane surface in relation to a Cartesian Coordinate System. The graphic data were converted into a series of horizontal (X) and vertical (Y) coordinates and displayed on the Numonics console. The information displayed on the console was directly transferred to an IBM personal computer by depressing a footswitch connected to the digitizer. The IBM personal computer was interfaced with an Epson MX 100-III printer.

Using the traverse arm with attached cursor, the digitizing consisted of locating 19 segmental endpoints and one reference point, for a total of 20 endpoints per frame (See Appendix C). This procedure for locating X and Y coordinate values was followed for all frames being analyzed. All of the digitizing was done by the principal investigator to insure consistency in locating the segmental endpoints. After all segmental endpoints were digitized per trial, the data file was considered complete. However, to execute the computer analysis program a time file also had to be completed.

Temporal data was attained by taking the time per frame, which was computed based upon the timing marks located on the film. The timing mark method was used to calibrate the actual frame rate of the camera. The frame rate was computed by locating two frames with a similar relationship between the location of the timing marks and the sprocket holes of the film. The number of frames and timing marks were counted between these two similar frames. Determining the frames per second required dividing the number of frames by the number of timing marks, and then multiplying by the timing pulse rate (10 Hertz). This procedure was executed on all seven film cartridges, and it was found
that the camera was consistently running at a speed of 148.18 frames per second. The time interval between two consecutive frames was computed to be 0.0067 second (1/148.18) and served as the multiplier for time between any number of selected frames.

After completion of the data and time files, the JFILM computer program was executed. The JFILM program was designed in 1979 by James Richards of Indiana University for use in two-dimensional film analysis. In 1983 Daniel Abts of the University of Wisconsin - La Crosse converted the program to BASIC for use by an IBM personal computer. The computer program converted digitized film data to produce both linear and angular kinematic output for each entered endpoint.

Statistical Treatment of Data

The third edition of the Statistics Package for the Social Sciences (SPSSx) was utilized on the VAX computer operating system manufactured by Digital Equipment Corporation. The SPSSx is a general statistics program designed to analyze batch oriented data. Paired t-tests were executed to determine if a significant difference existed in any of the stated hypotheses. The .05 level of significance was used for acceptance or rejection of the null hypotheses.
CHAPTER IV
RESULTS AND DISCUSSION

The purpose of this study was to determine if two functional tests of anaerobic power are measuring this human trait in its true scientific form. The results for this study were obtained from a comparison between a standard and cinematographic method for measuring anaerobic power. The comparison was based on the variables of power output and vertical velocity as derived from the stair climb and vertical jump tests. Using dependent samples, paired t-tests were conducted on the various combinations to ascertain if any significant differences existed between the two methods. This chapter will present a summary of the data as well as an interpretation of the results.

Summary of Results

The data summary will be organized as follows: 1) subject characteristics; 2) vertical jump test; 3) Margaria stair test; 4) statistical analysis.

Subject Characteristics

The sample of individuals who performed in this study consisted of both male \( n = 7 \) and female \( n = 5 \) track athletes. The twelve subjects ranged in age from 18-21 years and had a mean weight of 153.3 pounds. The characteristics for each subject can be found in Table 1. The subject order from Table 1 was held constant throughout this chapter to allow for ease of comparison. The first nine subjects performed both the Margaria and vertical jump tests, whereas the last three subjects...
participated in only the Margaria test.

### TABLE 1. SUBJECT CHARACTERISTICS

<table>
<thead>
<tr>
<th>SUBJECT</th>
<th>SEX</th>
<th>AGE(yrs)</th>
<th>WEIGHT(lbs)</th>
<th>TRACK &amp; FIELD EVENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>M</td>
<td>21</td>
<td>192.00</td>
<td>high jump &amp; sprints</td>
</tr>
<tr>
<td>02</td>
<td>M</td>
<td>18</td>
<td>178.00</td>
<td>sprints &amp; hurdles</td>
</tr>
<tr>
<td>03</td>
<td>M</td>
<td>21</td>
<td>167.25</td>
<td>sprints</td>
</tr>
<tr>
<td>04</td>
<td>M</td>
<td>18</td>
<td>181.00</td>
<td>long jump</td>
</tr>
<tr>
<td>05</td>
<td>M</td>
<td>19</td>
<td>159.00</td>
<td>triple jump</td>
</tr>
<tr>
<td>06</td>
<td>M</td>
<td>20</td>
<td>149.00</td>
<td>long jump</td>
</tr>
<tr>
<td>07</td>
<td>F</td>
<td>18</td>
<td>133.00</td>
<td>long jump</td>
</tr>
<tr>
<td>08</td>
<td>F</td>
<td>21</td>
<td>126.00</td>
<td>triple jump &amp; sprints</td>
</tr>
<tr>
<td>09</td>
<td>F</td>
<td>19</td>
<td>136.00</td>
<td>triple jump</td>
</tr>
<tr>
<td>10</td>
<td>F</td>
<td>19</td>
<td>143.00</td>
<td>triple jump &amp; high jump</td>
</tr>
<tr>
<td>11</td>
<td>F</td>
<td>18</td>
<td>120.00</td>
<td>high jump &amp; sprints</td>
</tr>
<tr>
<td>12</td>
<td>M</td>
<td>19</td>
<td>155.50</td>
<td>long jump &amp; sprints</td>
</tr>
</tbody>
</table>

**MEAN** 19.25 153.31
**SD** 1.22 22.96

### Vertical Jump Test

The values for power output and vertical velocity were compared between the standard and cinematographic methods. A summary of the vertical jump test results are presented in Table 2. The standard method yielded higher values for average vertical velocity than the cinematographic method. Since the resistive force or body weight remained the same for both methods, the greater velocities found in the standard method also resulted in greater power outputs for this method. In all cases, except subject 8, power output from the standard or Lewis Nomogram method was considerably higher than the power output from the cinematographic method. Considering the cinematographic procedure as a true scientific measurement of power, the standard method exposed an approximate 7.7% overestimation of anaerobic power.
### TABLE 2. VERTICAL JUMP TEST RESULTS

<table>
<thead>
<tr>
<th></th>
<th>STANDARD METHOD</th>
<th>CINEMATOGRAPHIC METHOD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>POWER (Watts*)</td>
<td>VERT VEL (FT/SEC)</td>
</tr>
<tr>
<td>SUB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>01</td>
<td>1717.487</td>
<td>9.057</td>
</tr>
<tr>
<td>02</td>
<td>1588.440</td>
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<tr>
<td>03</td>
<td>1320.381</td>
<td>7.041</td>
</tr>
<tr>
<td>04</td>
<td>1687.714</td>
<td>7.249</td>
</tr>
<tr>
<td>05</td>
<td>1429.579</td>
<td>8.209</td>
</tr>
<tr>
<td>06</td>
<td>1310.456</td>
<td>9.168</td>
</tr>
<tr>
<td>07</td>
<td>943.123</td>
<td>6.397</td>
</tr>
<tr>
<td>08</td>
<td>962.973</td>
<td>8.507</td>
</tr>
<tr>
<td>09</td>
<td>972.897</td>
<td>6.567</td>
</tr>
<tr>
<td>MEAN</td>
<td>1325.894</td>
<td>7.802</td>
</tr>
<tr>
<td>SD</td>
<td>309.645</td>
<td>1.033</td>
</tr>
</tbody>
</table>

*1 Watt = 0.73756 FT-LBS/SEC

**Margaria Stair Test**

Results of the Margaria stair test are summarized in Table 3. For all twelve subjects, the cinematographic method furnished greater power output and average vertical velocity values. Measuring vertical distance based upon the individual's center of gravity displacement resulted in greater values than the fixed vertical distance used in the standard procedure (See Appendix D). As a consequence of time and force being constant, the cinematographic method produced greater average vertical velocities which resulted in greater power outputs. Observing the power scores to be considerably less in the standard method, an underestimation of anaerobic power of approximately 12.5% was evident when compared to the cinematographic method.
### TABLE 3. MARGARIA STAIR TEST RESULTS

<table>
<thead>
<tr>
<th>SUB</th>
<th>STANDARD METHOD</th>
<th>CINEMATOGRAPHIC METHOD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>POWER (Watts*)</td>
<td>VERT VEL (FT/SEC)</td>
</tr>
<tr>
<td>01</td>
<td>1490.614</td>
<td>5.726</td>
</tr>
<tr>
<td>02</td>
<td>1381.923</td>
<td>5.726</td>
</tr>
<tr>
<td>03</td>
<td>1298.465</td>
<td>5.726</td>
</tr>
<tr>
<td>04</td>
<td>1427.879</td>
<td>5.819</td>
</tr>
<tr>
<td>05</td>
<td>1215.127</td>
<td>5.637</td>
</tr>
<tr>
<td>06</td>
<td>1138.704</td>
<td>5.637</td>
</tr>
<tr>
<td>07</td>
<td>879.072</td>
<td>4.875</td>
</tr>
<tr>
<td>08</td>
<td>893.153</td>
<td>5.228</td>
</tr>
<tr>
<td>09</td>
<td>733.473</td>
<td>4.195</td>
</tr>
<tr>
<td>10</td>
<td>885.347</td>
<td>4.566</td>
</tr>
<tr>
<td>11</td>
<td>733.662</td>
<td>4.509</td>
</tr>
<tr>
<td>12</td>
<td>1246.824</td>
<td>5.914</td>
</tr>
<tr>
<td>MEAN</td>
<td>1110.353</td>
<td>5.296</td>
</tr>
<tr>
<td>SD</td>
<td>273.062</td>
<td>0.602</td>
</tr>
</tbody>
</table>

*1 WATT = 0.73756 FT-LBS/SEC

**Statistical Analysis**

Since the same subject performed both tests of anaerobic power, a paired difference t-test was used so that a comparison of the effects from the two methods of measurement could be made on the same subject and test. Using dependent samples reduced the variability of difference between the paired observations and provided results that were due to the effect of the two methods. To obtain a significance at the .05 level, a critical t-value of ±2.306 was needed for 8 degrees of freedom and ±2.201 for 11 degrees of freedom for the respective vertical jump and the Margaria test. The statistical analyses of the various combinations are summarized in Table 4.
Table 4. Results of Paired T-Test Statistical Analysis

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>NUMBER OF CASES</th>
<th>MEAN DIFFERENCE</th>
<th>T-VALUE</th>
<th>TWO-TAIL PROBABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>POWSRS WITH POWSRF</td>
<td>12</td>
<td>-158.501</td>
<td>-6.29</td>
<td>0.000*</td>
</tr>
<tr>
<td>POWVJS WITH POWVJF</td>
<td>9</td>
<td>94.609</td>
<td>3.90</td>
<td>0.005*</td>
</tr>
<tr>
<td>POWSRS WITH POWVJS</td>
<td>9</td>
<td>-163.849</td>
<td>-5.57</td>
<td>0.001*</td>
</tr>
<tr>
<td>POWSRF WITH POWVJF</td>
<td>9</td>
<td>106.196</td>
<td>2.02</td>
<td>0.078</td>
</tr>
<tr>
<td>VELSRS WITH VELSRF</td>
<td>12</td>
<td>-0.750</td>
<td>-6.72</td>
<td>0.000*</td>
</tr>
<tr>
<td>VELVJS WITH VELVJF</td>
<td>9</td>
<td>2.132</td>
<td>7.91</td>
<td>0.000*</td>
</tr>
<tr>
<td>VELSRS WITH VELVJS</td>
<td>9</td>
<td>-2.406</td>
<td>-8.44</td>
<td>0.000*</td>
</tr>
<tr>
<td>VELSRF WITH VELVJF</td>
<td>9</td>
<td>0.530</td>
<td>2.19</td>
<td>0.060</td>
</tr>
</tbody>
</table>

* Significant at the .05 level

POWSRS = Power Stair Run Standard Method
POWSRF = Power Stair Run Film Method
POWVJS = Power Vertical Jump Standard Method
POWVJF = Power Vertical Jump Film Method
VELSRS = Vertical Velocity Stair Run Standard Method
VELSRF = Vertical Velocity Stair Run Film Method
VELVJS = Vertical Velocity Vertical Jump Standard Method
VELVJF = Vertical Velocity Vertical Jump Film Method

As shown in Table 4, all pairs were significant at the .05 level except two. The two insignificant differences were found between the pairs of POWSRF with POWVJF and VELSRF with VELVJF. This would indicate that the Margaria and vertical jump test produced similar results when based upon the cinematographic method of measurement involving mechanical principles.

Discussion of Results

Anaerobic power is a very complex human movement parameter. Mechanically, power combines force, displacement, and time or all three of the fundamental measures of motion. Therefore, the concept of power
becomes extremely important to the analysis and description of almost all human movement. This may also explain why the ability to develop power becomes such a critical factor contributing to athletic success. Thus, the need to kinematically and kinetically investigate the physical trait of human power becomes quite relevant to the exercise sciences. The discussion that follows will examine the results of this qualitative study on anaerobic power along with an interpretation of the factors which may have been of influence.

Maximal power output is related to both force and velocity of the muscular effort (Winter, 1979; Vandewalle et al., 1987). Muscular power can be viewed as the ability of the muscles to contract forcefully with speed or simply as the rate of work done by the muscles. Regardless, power must be integrated over a period of time since the rate of work done by the muscles is rarely constant (Winter, 1979). According to Sapega and Drillings (1983) that time is either at some instant or over some period, and to qualify as a true scientific measurement, power must be expressed as either instantaneous or average values and reported in either units of Joules per second (Watts), foot-pounds per second or horsepower.

Although time is not directly measured in the standard method of the vertical jump, it has been accepted that the derived formula of the Lewis Nomogram indirectly incorporates a time component (Fox & Mathews, 1981). Gray et al., (1962a) investigated a jump and reach procedure based on scientific principles and decided that what he termed the vertical power jump was a valid measure of true power. It has also been found that a simple jump and reach technique is an acceptable substitute
for the in-depth scientific method (Gray et al., 1962b). Reporting results from the standard method of the vertical jump in Watts should therefore be considered a true measure of anaerobic power. However, others have objectively studied the vertical jump and concluded that this commonly administered test was unjustified as a measure of human power (Barlow, 1971; Considine, 1971). The standard method of the Margaria stair test directly measures time and the validity of this anaerobic power test has not been questioned like that of the vertical jump. Also, the cinematographic methods for the two functional tests incorporate all three quantities of motion required for power output, thereby making it correct to be reported as such a measure.

Instantaneous values are difficult to obtain unless one has force plates or other sophisticated and expensive measuring devices. It should be noted that the power values reported in this study were in no way instantaneous, and therefore should be considered as average measurements of power. The primary reason why the methods for the Margaria and vertical jump tests used in this study render only average measures is related to the force component of anaerobic power.

Based on Newton's Third Law of Motion, we know that for every action there is an equal and opposite reaction (Hay, 1985). This action-reaction principle would indicate that in order for the body to move against gravity it would have to exert a muscular force against the ground that was greater than body weight. Therefore, simply using body weight as the force component for computing power would not result in optimal power outputs. Biomechanical studies have found that the forces involved with jumping are actually two to three times greater than one's
own body weight (Davies & Reenie, 1968; Brancazio, 1984; Offenbacher, 1970; Miller & Nelson, 1973). Also, using just body weight as the resistive force does not account for the acceleration of the body mass, which provides an important contribution to force production. This could possibly lead to some of the discrepancies associated with the effect of body weight on power production.

Barlow (1971) found that power as it was scientifically measured from the vertical jump had a high positive correlation with body weight, which was also the case in the stair test. Mayhew et al., (1986) noted that for males performing the Margaria-Kalamen stair test, a difference of 63.7% in power was accounted for by variances in body weight and 36.4% by variations in stair run times, and for female subjects these percentages were 55.5% and 39.4% respectively. When investigating the effects of external loading or added body weight on power output from the vertical jump (Davies & Young, 1984) and the Margaria test (Caiozzo & Kyle, 1980; Kyle & Caiozzo, 1985), the results reported were not in agreement. Mayhew and his associates (1986) also found that removing the effects of body weight significantly improved the correlation between power, acceleration, and vertical velocity as determined from the Margaria-Kalamen anaerobic power test. These several studies might well be an indication that the Margaria and vertical jump tests express body composition to a greater degree than was expected, and that the effects of body weight on power output should be carefully examined when interpreting results from these two tests.

The path that the center of mass takes during any activity is an important concern when dealing with human motion. Any object,
including the human body, has a specific point or center of gravity around which the mass of that object is balanced. Therefore, the human body moves as if all its mass was centered around the point through which the force of gravity acts (Brancazio, 1984; Miller & Nelson, 1973).

In tests such as the Margaria stair and the vertical jump, it is assumed that the vertical displacement of the center of gravity is equal to the measured vertical distance. However, as shown from this study, a significant difference was found between the standard and cinematographic methods of measuring power. Every subject who performed the Margaria test showed an increase in vertical displacement over the fixed vertical displacement measured in the standard method (See Appendix D). Since time and body weight remained the same in the standard and cinematographic method of the Margaria test, the factor contributing to the significant difference would appear to be vertical displacement of the body’s center of gravity. The increase in vertical displacement would also indicate that an increased amount of work was performed in the same amount of time, which would provide the increase shown in power output from the cinematographic method. Additionally, the cinematographic method seemed to bring about individual differences attributed to body positions at the beginning and end of the test. This implied that using a fixed vertical distance could be a possible limitation of power production from the Margaria stair test, therefore explaining the underestimation of anaerobic power shown in the standard method.

A significant difference was also discovered between the standard
and cinematographic methods of the vertical jump. This test condition posed a different situation in that the standard method overestimated power outputs when compared to the cinematographic method. However, the significance found between the two methods of the vertical jump can likewise be attributed to vertical displacement of the body’s center of gravity.

The standard method of the vertical jump using the Lewis Nomogram does not take into consideration the muscular effort needed to lift the body from the crouch position to takeoff. However, this is the portion of the jump that determines what happens once the jumper leaves the ground. It is this period, while the jumper is in contact with the ground, that he/she must generate enough force to project the body upward. Therefore, it would make sense to include this portion of the jump when computing power outputs.

Although the jumper was in flight the same amount of time for both methods, the addition of the crouch phase increased the vertical displacements as well as the amount of time taken to complete the jump. The increases seen in the cinematographic method resulted in the subjects having slower average vertical velocities, which in turn produced less power because force remained constant. Barlow (1971) found that vertical displacement of the total body center of gravity was not a significant factor in the development of power produced in the vertical jump. However, this study would indicate that the vertical displacement of the body’s center of gravity does contribute to the significance between two methods of measurement, and that the method of measurement can make a difference in the power outputs obtained from the
vertical jump. It appears that the preparatory phase is critical to the production of power and not accounting for it could produce inadequate estimates, which could possibly explain the overestimation of power output derived from the standard method of the vertical jump.

Comparing the standard method of the Margaria and vertical jump tests revealed a significance at the .001 level. As discussed, the standard methods of these two tests inaccurately measure vertical displacement when compared to the more scientific means of measurement. So it should come as no surprise to find that comparison between the standard methods provided significantly different power outputs. The significance could, however, also be related to other differences that can be detected when observing how each test is performed. This could be supported by the moderate correlations found between the Margaria and vertical jump tests which would imply that they are not perfectly related tests (Olsen, 1987; Kalamen, 1968). Although measuring these other differences was beyond the scope of this research project, they could be very important when evaluating anaerobic power from a mechanical viewpoint.

A primary difference between the two tests is the process by which the muscular power is initiated. In the vertical jump both legs are contracting simultaneously to thrust the body upward. However, in the Margaria test only one leg at a time contracts in order to climb the stairs. This can also be related to how the body utilizes the kinetic energy that is produced during the muscular efforts. (Davies & Young, 1984; Kyle & Caiozzo, 1985; Vandewalle et al., 1987).

Another difference between the two tests is the number of times the
subject makes contact with the ground. The vertical jump requires that all the force needed to vertically jump to a maximum height be produced while the feet are in contact with the ground; whereas the stair climb allows force to be produced each time contact is made with a step. Therefore, this difference results in power being determined from several muscular contractions opposed to a single muscular effort from the vertical jump. This also affects how the subject can be analyzed based on mechanical principles. In the vertical jump once the subject breaks contact with the ground he/she can be treated as a free falling body. However, in the Margaria test the subject has contact with the ground several times and those same free falling biomechanical principles cannot be as easily applied to this condition. This may pose some problem when trying to compare takeoff velocities between the two tests. However, a way to reinforce this difference may be to investigate what is referred to as impulse.

This impulse, or force that acts over an interval of time, causes a change in the motion known as momentum (Miller & Nelson, 1973). The amount of time the subject is in contact with the ground is one area that can be easily measured from biomechanical studies, and as found in this study that time was different between the two tests (See Appendix D). To achieve a successful performance in both the Margaria and the vertical jump however, the subject must generate a substantial impulse from the ground reaction force. Adamson and Whitney (1971) criticized the connection of power to impulsive actions such as jumping, but perhaps this would be a way to analyze power between the Margaria and vertical jump tests. However, impulsive actions are better suited to be
reported as instantaneous values and researching this concept with force plates would be much more valuable than the average values obtained in this study.

In the case of this study, the nonsignificant result found when comparing the cinematographic methods of the two tests was a good indication. This meant that when evaluating power using the same mechanical principles the individual was producing somewhat equal estimates of power output. Using total body center of gravity as the vertical displacement measurement appeared not to impose any limitations on the tests, which permitted the subjects to perform each test relative to their mechanical capabilities.

The similarities between the two tests may be related to factors such as those mentioned by Sargent in his 1924 investigation of the vertical jump. The common features shared by the Margaria and vertical jump test include the following: 1) both are functional field tests of anaerobic power; 2) both require several muscle groups to produce a force greater than body weight; 3) both are multijoint impulsive actions and; 4) both involve neuromuscular efficiency or an agility and coordination factor.

The results reported for vertical velocity followed the same pattern as the variable of power output. A significant difference was found between the cinematographic and standard methods for both the Margaria and vertical jump, as well as significance between standard methods. This should be expected since velocity is derived from distance divided by time. The variance found between vertical displacement of the two methods would account for the difference in vertical velocities, which
also would explain the varying power values already discussed. The nonsignificance revealed between the vertical velocities produced by the cinematographic method would simply reinforce the idea that the two tests are providing similar measurements of anaerobic power. Finding that the Margaria and vertical jump tests can produce similar measures of power perhaps may warrant that the matter be further investigated, so that a regression equation could be developed to predict scores on the complex cinematographic methods based upon the simple standard methods.

Despite all the significant differences found when comparing the two methods of measurement, the nonsignificant results provided some evidence that the Margaria and vertical jump tests could be considered as similar average values of human power output when measured from a strictly mechanical procedure. Also, basing the investigation on true scientific measures appeared to bring out the individual differences between the subjects. The results of this study would imply that different tests of anaerobic power can provide comparable measures of human power output when this scientific concept is accurately and consistently defined.
Summary

Anaerobic power is a very complex physical trait and is quite often a misinterpreted concept. The study was undertaken in an attempt to discover if two functional tests of anaerobic power were measuring the same trait based upon the true physical definition of the term power. A biomechanical analysis was employed to objectively investigate the Margaria and vertical jump power tests. High speed filming procedures were utilized so that a comparison could be made between common field procedures used in testing anaerobic power. Therefore, this study was designed to determine if significant differences existed between the more complex cinematographic methods and the frequently used standard methods of measuring anaerobic power output. Twelve track athletes trained for jumping and sprinting events were tested and filmed while performing the Margaria and vertical jump tests. For each subject, the trial with the fastest Margaria stair time and the highest vertical jump were analyzed. Paired t-tests were computed to statistically determine if a significant difference existed between any of the methods.
Findings

Based on the hypotheses tested the following statistical results were obtained:

1. There was a significant difference when comparing the power outputs derived from the standard methods of the Margaria and vertical jump tests.

2. There was no significant difference when comparing the power outputs derived from the cinematographic methods of the Margaria and vertical jump tests.

3. There was a significant difference when comparing the power outputs derived from the standard and cinematographic methods of the Margaria test.

4. There was a significant difference when comparing the power outputs derived from the standard and cinematographic methods of the vertical jump test.

5. There was a significant difference when comparing the average vertical velocity derived from the standard methods of the Margaria and vertical jump power tests.

6. There was no significant difference when comparing the average vertical velocity derived from the cinematographic methods of the Margaria and vertical jump tests.

7. There was a significant difference when comparing the average vertical velocity derived from the standard and cinematographic method of the Margaria test.
8. There was a significant difference when comparing the average vertical velocity derived from the standard and cinematographic method of the vertical jump test.

Conclusions

This research project investigating anaerobic power provided the following conclusions:

1. The Margaria and vertical jump tests can be considered functional for they do provide an average value that is an estimation of anaerobic power output.

2. The standard method of the vertical jump test appears to overestimate power output whereas the standard method of the Margaria stair test appears to underestimate power output when compared to the cinematographic methods.

3. The Margaria and vertical jump tests appear to produce similar scientific measures of anaerobic power when based upon cinematographic methods involving displacement of the body's center of gravity.

Recommendations

The following recommendations were made as a result of this study:

1. A similar study could be done that uses a larger sample size of either male or female subjects.

2. A similar study could be done that investigates power outputs from subjects in a specific track event or perhaps in one of the other power sports.
3. A similar research project could be done to develop a regression equation that could predict power output from the cinematographic methods based upon the measurements reported from the standard methods.

4. A similar study could be done using external loading to investigate the mechanical components of power.

5. A similar study could be done involving a pre/post season investigation to see if the significant differences found would hold true over a length of time.
REFERENCES CITED


APPENDIX A

INFORMED CONSENT FORM
INFORMED CONSENT FORM
University of Wisconsin-La Crosse
La Crosse, WI 54601

Project Title: A Biomechanical Comparison of the Vertical Jump and Margaria Power Tests

Principal Investigator: Mary L. Wolk

I am agreeing to participate in a biomechanical analysis of two anaerobic power tests. In this study I will perform the vertical jump test (jumping and reaching as high as possible) and the Margaria stair test (running up steps, two at a time, as fast as possible) while being filmed by high speed cinematographic techniques. The testing will involve two filming sessions, each approximately 15 minutes.

As with any exercise or testing situation, there is a certain degree of risk involved. Through the explanation of proper techniques, every attempt will be made to reduce any of the potential discomforts and risks (muscle strains, muscle soreness, tripping on the steps). I hereby am fully aware of and understand the nature of the testing situation. The principal investigator will answer any and all inquiries concerning procedures, risks or benefits.

I __________________________, being of sound mind and ___ years of age, do hereby consent to, authorize and request the person named above, Mary L. Wolk (and her assistants) to undertake and perform on me the proposed procedure, treatment, research or investigation (herein called "procedure").

I have read the above document, and have been fully advised of the nature of the procedure and the possible risks and complications involved in it, all of which risks and complications I hereby assume voluntarily.

I hereby acknowledge that no representation, warranties, guarantees or assurances of any kind pertaining to the procedure have been made to me by the University of Wisconsin-La Crosse, the officers, administration, employees or by anyone acting on behalf of any of them.

I understand that I may withdraw from the project at any time.

Signed at __________ this ____ day of ________, 19___, in the presence of the witnesses whose signatures appear below opposite my signature.

__________________________________  ____________________________________
(SUBJECT)                                              (WITNESSED BY)
APPENDIX B

LEWIS NOMOGRAM
The Lewis Nomogram for Determining Anaerobic Power from Jump Reach Score and Body Weight

The Lewis Nomogram. A person's power output can be determined by knowing the score on the jump reach and the body weight.
APPENDIX C

KINEMATIC DATA INPUT PROCEDURE
When digitizing segmental endpoints for a total body analysis, the coordinate data points from each selected frame of film should be input in the following order.

<table>
<thead>
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<th>Order</th>
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<th>Data Point</th>
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</tr>
<tr>
<td>2</td>
<td>03-04</td>
<td>Right ulnar styloid process</td>
</tr>
<tr>
<td>3</td>
<td>05-06</td>
<td>Right center of elbow</td>
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<tr>
<td>4</td>
<td>07-08</td>
<td>Right coracoid process</td>
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<tr>
<td>5</td>
<td>09-10</td>
<td>Left coracoid process</td>
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<td>6</td>
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<td>Left center of elbow</td>
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<td>17-18</td>
<td>Right foot extremity</td>
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<td>19-20</td>
<td>Right medial malleolus</td>
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<td>11</td>
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<td>Right center of knee</td>
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<td>31-32</td>
<td>Left foot extremity</td>
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<tr>
<td>19</td>
<td>37-38</td>
<td>Crotch or midpoint of trochanters</td>
</tr>
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<td>20</td>
<td>39-40</td>
<td>Center of gravity of object (if present)</td>
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<td>21</td>
<td>41-42</td>
<td>Reference point</td>
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APPENDIX D

DISPLACEMENT AND TIME DATA
## VERTICAL JUMP TEST

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<th>SUBJECT</th>
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*CONTACT = AMOUNT OF TIME FROM LOW POINT OF CROUCH TO TAKEOFF

## MARGARIA STAIR TEST

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*CONTACT = AMOUNT OF TIME ON SECOND STEP + AMOUNT OF TIME ON FOURTH STEP