5-2013

The Relationship of Strength (IPF(N), IPFkg) Compared to Running Endurance (VO2 and time to Exhaustion) in Recreationally Competitive Athletes.

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The Relationship of Strength (IPF(N), IPFkg) Compared to
Running Endurance (VO2 and time to Exhaustion) in
Recreationally Competitive Athletes.

A thesis

presented to

The Honors College and to the faculty of the Department of
Exercise and Sport Science

East Tennessee State University

In fulfillment

of the requirements for the Midway Honors Program

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by

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Janurary 2013

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Key Words: Strength, VO2, Endurance, Body Composition, and Body Mass Index

ABSTRACT

The method of training for long distance running has been to build up to the actual run distance and to keep similar volume. Although this is great for cardio it neglects the strength aspect of running. **Purpose**: The purpose of this research was to examine leg strength and compare it to running endurance (VO2) among male recreational runners, in order to determine any relationship. **Methods:** The subjects will be tested primarily on two pieces of equipment. The isometric mid-thigh clean pull apparatus which is used to measure a subject's leg strength. The VO2 max machine will be used to determine a subject's maximum oxygen consumption. BMI will be calculated to correlate it with time to exhaustion. The results of this study, when compared, will show how strength relates to endurance of runners. The subject's characteristics and subject data were expressed in averages and standard deviations. Pearson Correlations were performed comparing the strength in relation to endurance (VO2) for total test duration. The Pearson Correlations were further broken into three stages that every subject finished. Stage 2, 3, and 4 were then analyzed to find relationships among strength and endurance among those stages. Finally, standard correlations will be done on subject data averages to find the relationship to time of exhaustion. **Results:** The average age of the 12 subjects that participated was 37.17 years with a standard deviation of 7.50 years. The average BMI (kg/m^2) was 25.55 with a standard deviation of 3.13. The average time to exhaustion was 2 minutes and 03 seconds with a standard deviation of 4 minutes and 56 seconds. The strength in relation to endurance for total test duration is as followed. The strength IPF had a large positive correlation of 0.72 with max absolute VO2. The characteristic IPFkg had a large positive correlation of 0.60 with max relative VO2. The strength characteristics in relation to endurance characteristics that are broken up into the upper stages, which were completed by everyone, are as followed. In 2nd stage the subjects walked 2.5 mph with a 12% incline that lasted from the 3 to 6 minute marker. The IPF

had a large positive correlation of 0.54 with absolute VO2 in this stage. The IPFkg on the other hand had a very small negative correlation of -0.03.During stage 3 the subjects walked 3.4mph with 14% incline that lasted from 6 to 9 minute marker. The IPF had a moderate positive correlation of 0.45 in relation to absolute VO2. The strength characteristic of IPFkg had a small negative correlation of -0.19 in relation to relative VO2kg. During stage 4 the subjects reached a jog at 3.4 mph with a 16% incline that lasted from the 9 to 12 minute marker. There was a large positive correlation of 0.65 when comparing IPF to absolute VO2. A small positive correlation was found among the subjects when comparing IPFkg to relative VO2kg. Body mass index (BMI) had a perfect negative correlation of-1.00 when correlated with time to exhaustion.

Conclusion: Strength and Body Mass Index (BMI) has an effect on running endurance at walking speeds. This improvement during walking speeds is important because not every runner will be operating at maximal intensity during longer runners. The runner may actually be at a walk or slow jog which is a sub-maximal intensity, or sub-VO2.

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CHAPTER 1: INTRODUCTION

Statement of Problem

The purpose of this research was to examine leg strength and compare it to running endurance (VO2) among male recreational runners, in order to determine any relationship. To measure maximal leg strength we used the isometric mid-thigh clean pull apparatus, modified squat rack, with a force plate located directly underneath. Maximal aerobic capacity (VO2max) will be measured while running on a treadmill using a metabolic cart. We will measure the subjects' characteristics such as body weight, %percent fat free mass, and height using traditional scales and BodPod.

Hypothesis

It is hypothesized that there will be a correlation between the athlete's strength characteristics in reference to running endurance among the male recreational runners.

Introduction

When running in long races such as 5km, 10km, half marathon, and full marathons running economy is vital. Running economy is the energy cost of activating the muscles and of generating a unit of force per a given amount of contact time (Støren et al, 2011). Good running economy is the ability to effectively use energy, ATP, generated by the anaerobic and aerobic glycolic system, in submaximal velocities, from a limit supply of glucose, stored glycogen, fats, and lastly proteins. The more effective at utilizing ATP, decrease use of anaerobic glycolic system and the resultant lactic acid buildup, results in optimum performance in an endurance running event (Saunders et al, 2004). Several factors such as VO2max have been shown to affect the reliance on the anaerobic system. That is why VO2max has been shown to be a good indication of running performance (Saunders et al, 2004). Certain biomechanical aspects that is determined by genetics such as percentage of slow-twitch muscle fibers, with greater mitochondria density, in addition to VO2max has been correlated with 10km performance (Saunders et al, 2004). Interestingly enough when performing long distance races runners typically operate at a sub VO2max for races >15minutes.

Alternatively, muscle training has been shown to improve running economy without improving VO2max or body weight in certain studies (Støren et al, 2011). It is hypothesized that the improvements is due to neuromuscular improvements rather than hypertrophic responses. Theoretically, at submaximal running velocities a lesser percentage of maximal strength is required. Upon improved strength in the lower-limb which would require less activation of extensors muscles per stride, thus reducing the actual demand of number of motor units and thus improving running economy (Støren et al, 2011). It is also possible that improved rate of force production per given unit of time has resulted from strength training which may also result in improved running economy (Støren et al, 2011). A reduction in time allows for increase circulatory flow through the working muscles which would provide a greater availability of oxygen and other nutrients (Støren et al, 2011) (Østerås et al, 2002). If lower motor units combined with increased rate of force production, a longer time to exhaustion at a submaximal running velocity could be expected (Støren et al, 2011). If a possible correlation is found in slower velocities among recreational runners proper strength exercises can be implemented along with their daily endurance training in order to improve running economy. It is probable that strength characteristics may be better predictors than VO2max in submaximal running velocities.

The aim of this study is to determine relationships between strength characteristics and VO2max in sub maximal running velocities, jogging or a slow gait. Twelve healthy male runners that regularly engage in recreational running between the ages of 18-44 will engage in the study. Every subject will undergo questionnaires to verify that they do not have any medical conditions to hinder them from participating. Subjects will then undergo a series of measurements that will help us determine the relationship between strength and endurance. We will measure maximal leg strength, time to exhaustion, and VO2max (maximal aerobic capacity) for comparison.

Pertinent Vocabulary and Definitions

1. IPFkg- This is isometric peak force that has been scaled to the mass in kg per 1 kg (Østerås et al, 2002).
2. Isometric Mid-Thigh Pull (IMTP): A test of overall maximum body strength, the athlete is positioned on top of a force plate in a partial squat position with their back perpendicular to the ground and hands fixed to a stationary bar. The athlete is instructed to pull as hard and as fast as possible while remaining in the isometric (unchanged muscle length) position (Østerås et al, 2002).
3. Isometric Peak Force (IPF)in (N) -stands for isometric peak force and is the maximum amount of force that you exerted during the isometric mid-thigh pull test. IPF is strongly related to sport performance in events that are dependent on strength and explosive strength (sprinting, running, shot put, etc…) (Østerås et al, 2002).
4. Neural adaption: A broad description involving a number of factors, such as selective activation of motor units, synchronization, selective activation of muscles, ballistic contractions, increased rate coding (frequency), increased reflex potential, increased

recruitment of motor units and increased co-contractions of antagonists (Østerås et al, 2002).

5. Rate of Force Development (RFD): A measure of explosive strength, which is related to acceleration. RFD is the ratio of force development to time, measured in Newton's per second (N/s) (Østerås et al, 2002).
6. Series Elastic Elements (SEE): The structures within the tendon complex of the connective tissue of the skeletal system (Østerås et al, 2002).
7. Strength- The ability of the neuromuscular system to produce force against an external resistance (Østerås et al, 2002).
8. Stretch-Shortening Cycle (SSC): The increase in force production due to a rapid pre-stretching (eccentric action) of a muscle immediately prior to a concentric action of the same muscle (Østerås et al, 2002).
9. VO_2max (ml/kg/min)- The maximum amount of oxygen that the body can use during exercise. A high VO_2max is strongly related to endurance performance (Østerås et al, 2002).

Chapter 2 Review of Literature

Physiology and Mechanics for Generation of Force

Nervous system

In order to relate variables such as strength, rate of force development, and VO2 max to running, it is essential to first analyze the anatomical and physiological aspects of running. When starting with muscle movement it is important to start with the nervous system. The nervous system can be broken down into two categories, which are the central nervous system and the peripheral nervous system (Widmaier et al, 2008)..

Then central nervous system consists of the brain and spinal cord. The peripheral nervous system can be broken down into two more categories, which are the afferent division and the efferent division. The afferent division is the sensory neurons that send information to the brain. The efferent division is the neurons that go from the brain to various muscles. The efferent division can further be broken down into the somatic and autonomic motor divisions. Skeletal muscle control while running involves the somatic motor division which results in movement. The autonomic motor division deals more with control of the cardiac and smooth muscles (Widmaier et al, 2008).

While the autonomic motor division is vital to running and everyday life, the primary focus will be the somatic motor division. Desired movement from the brain is transmitted to the muscle along the spinal cord via neuron axons to a motor neuron via synaptic clef to a desired muscle via the somatic motor neurons. Skeletal movement only involves the contraction of muscles; muscle relaxation involves inhibition of the motor neurons in the spinal cord. The muscle is then elongated by another muscle contracting (Widmaier et al, 2008).

Skeletal Muscle

A skeletal muscle is referred to as a striated muscle, which is named due to its alternating light and dark bands perpendicular to the long axis while viewed under the microscope. The muscle is refers to a number of muscle fibers bound together by connective tissue. Skeletal muscles are usually attached to bones by bundles of collagen fibers known as tendons. The muscle fiber can further be broken down into individual units linked together to form a fiber known as a sarcomere (Widmaier et al, 2008).

Sarcomere and Contraction of the Sarcomere

A sarcomere is composed of thick and thin filaments. The thick filaments are composed almost entirely of the protein myosin. The thin filaments are about half the diameter of the thick filaments and are composed of the protein actin. The thin filaments have troponin and tropomyosin that cover the actin protein in order to regulate contraction of the sarcomere. The thick filaments are located in the middle of the sarcomere arranged parallel to form a dark band known as the A band. Each sarcomere contains two sets of thin filaments, one at each end. One end of the thin filament is anchored to a network of interconnecting proteins known as the Z line. The other end of the thin filament overlaps the thick filament myosin. The light band is between the Z line and the thick filament (A band) is referred to as the I band, which is in the middle of the Zlines. In addition to the filaments, an elastic protein titin extend from the Z line to the M line, the middle of the A band. Titin is linked to the M-line and the thick filaments in order to align the thick filament in the middle of each sarcomere (Widmaier et al, 2008).

Each thick filament is surrounded by a hexagonal array of six thin filaments, and each thin filament is surrounded by a triangular arrangement of three thick filaments. The space between overlapping thick and thin filaments is bridged by portions of the myosin molecule known as cross-bridges. During muscle contraction calcium is released from the sarcoplasmic reticulum and binds to troponin in order to relax tropomyosin and reveal the actin binding site underneath so the cross bridges can bind. Binding occurs in the presences of sufficient ATP. As contraction is continued the I band gets shorter as the myosin pulls the actin with its cross-bridges into the thick filament A band (Widmaier et al, 2008).

Muscle Contraction Overview

In order for the muscle contraction to start it has to be initiated by an action potential of a neuron. The action potential is the signal from the bran that is transmitted by the motor neuron to the muscle. Before getting to the action potential the neuron has to have a gradient that creates a difference in charge across the membrane. The Na/K (Sodium/ Potassium) pump helps with this by using ATP to pump three Na out and two K into the axon. A difference is further intensified by a leaky K channel that lets some K out of the axon. This creates a resting potential of -070mV along the axon (Widmaier et al, 2008).

When a neuron has received enough excitatory stimulants, which depolarize the neuron, it reaches the threshold where it is an all or none response. The neuron quickly depolarizes by first opening the Na channel in a region of the axon allowing Na to overcome the gradient by diffusing inside the axon. After the Na starts to pour in, the K channel opens allowing K to diffuse ,along its gradient, out of the axon, which hyperbolizing the cell membrane. The Na/ K gradient is restored back to its previous state, after the action potential, by the Na/K pump that uses ATP to create the gradient (Widmaier et al, 2008).

The action potential is propagated along the axon by the change in membrane potential that depolarize the region adjacent to it. The action potential cannot go in the reverse direction in which it just came from because there is a refractory period where it cannot be depolarize again. To add to the speed of propagation the axons are wrapped in myelin that creates nodes of Ranvier. The channels can only open at the nodes of Ranvier which causes the action potential to trigger adjacent nodes of Ranvier instead of every adjacent area, in a process called salutatory conduction (Latin, saltare, to leap) (Widmaier et al, 2008).

Once the action potential has reached the axon terminal a change in the membrane causes Ca+ to enter the terminal end, which causes ACH, neurotransmitter, in synaptic vesicles to be released. The first motor neuron called the presynaptic neuron excites the post synaptic neuron to its threshold via the neurotransmitter that binds to the dendrite receptors of the postsynaptic neuron in the gap that is referred to as the synapse. The postsynaptic neuron repeats the same process as the presynaptic neuron except its Ach neurotransmitter binds to receptors on the motor end plate of the muscle in a space called the neuromuscular junction (Widmaier et al, 2008).

An action potential is generated in the muscle similar to the action potential in a neuron. The action potential travels down T-tubules that go into a muscle and connects to sarcoplasmic reticulum of sarcomeres. The action potential causes Ca+ to be released which binds to Troponin and causes a change in Tropomyosin which reveals Cross-bridges binding site. If sufficient ATP is available to bind to the cross-bridges the sarcomere shortens via movement of the thin filaments past the stationary thick filaments. The attachment of the ATP causes forwarding and binding of the cross-bridge. The hydrolyzed causes the movement of the cross bridge that pulls thin filament past the thick filament. The attachment of another ATP causes the release of the cross bridge from the thin filament and the readjustment so it can bind to another binding site if made available by Ca+ binding. An ATP Ca+ pump is constantly pumping Ca+ back into the sarcoplasmic reticulum, even when the action potential is causing release of the Ca+. The pump only overcomes the release when the action potential has ended which causes cessation of the release of Ca+. This overall process causes a shortening of the sarcomere which in turns shortens the muscle (Widmaier et al, 2008).

<u>Major Voluntary Muscles Involved in Running</u>

Since muscles are constantly changing their role, it is simpler just to list major voluntary muscles involved in walking, jogging and running as outlined by Winter in 1991 which is used in studies when analyzing the human gait. The 32 muscles are as followed starting with the lower torso: tibialis anterior, flexor digitorum brevis, gastrocnemius lateralis, gastrocenemius medialis, rectus femoris, sartorius, biceps femoris (long head), semitendinosus, adductor longus, tensor fascia latae, gluteus maximus, and gluteus medius (Cappellini et al, 2010).

The torso muscles involved are as followed: external oblique, internal oblique, latissimus dorsi, iliopsoas, rectus abdominis, superior portion, and erector spinae recorded at T1, T9, and L2 (Cappellini et al, 2010).

The muscles dealing with the shoulder, arms, and neck are as followed: biceps brachii, triceps brachii, deltoideus anterior and posterior portions, trapezius inferior and superior portions, sternocleido mastoideus, and splenius (Cappellini et al, 2010).

Mechanics of Skeletal System

The skeletal system is composed of bones held together by ligaments and crossing muscles that form joints. Bones perform many functions, including support, attachment sites for muscles and tendons, and levers. With regards to leverage, the skeletal system provides levers and axes of rotation, while the muscular system contracts in order to create movements. Levers magnify the force, speed or both of movement and consist of a rigid rod that is rotated about a fixed point called the fulcrum. The skeletal lever system is primarily the longer bones of the body and the joints serve as the fulcrum (Hamill et al, 2009).

There are three types of levers, and they are the first class lever, the second class lever, and finally the third class lever. The first class lever contains an axis (fulcrum) that lies between the effort and the resistance. The second class lever is where the resistance lies between the axis and effort. The third class lever is where effort lies between axis and resistance. The axis lies perpendicular to the plane of movement of the lever. The effort is the point at which the contracting muscles are attached. The resistance is the point at which the external object is applied. Force is amplified by the effort arm which is the length of the axis to the site of muscle attachment, the effort. The muscle force is the product of the force acting perpendicular to a lever and its perpendicular distance moment arm from the axis of rotation. The third class lever is the most common in the human body. One main disadvantage of the third class leaver is that mechanical advantage is low due to the short effort arm. On the other hand the advantage of a third class lever is it has greater speed and range of motion. Generally with levers one is sacrificed for the other (Adrian et al, 1989 80-117).

Physiology and Mechanics for Endurance

<u>VO2 max</u>

Oxygen consumption increases with exercise intensity. When oxygen consumption does not increase with intensity and the oxygen consumption plateaus or increases only slightly with additional increases in exercise intensity it represents the maximal oxygen consumption. This is also referred to as maximal oxygen uptake, maximal aerobic power, aerobic capacity, or, simply VO2max. VO2 is a good representation of aerobic energy production, kreb cycle. The higher the VO2 max the higher intensity a person can sustain for a given amount of time. VO2max depends on the functional capacity and integration of systems required for oxygen supply, transport, delivery, and use. The oxygen transport system consists of the pulmonary ventilation, hemoglobin concentration, blood volume and cardiac output, peripheral blood flow, and aerobic metabolism (McArdle et al, 2007 170-173).

There are two types of muscles fibers that exist in humans, fast-twitch (FT) or type II and the slow-twitch (ST) or type I which determines aerobic capacity by mitochondria density. Oxygen is the final electron receptor at the end of the electron transport chain. As long as there is oxygen available for the electron receptor, substrate will be used for ATP. Substrates such as fat, carbohydrates, and/or protein provide energy for the muscles to operate (Nelson et al, 2008). When energy demand exceeds oxygen availability, the plateau occurs. The plateau can also be caused by the lack of ATP in which the mitochondria cannot keep up with the need.

Type II has rapid contraction speeds and high capacity for anaerobic ATP production in glycolysis. Type II becomes activated in fast movements such as changing pace and stop-and-go activities. Type I muscle generates energy primarily through aerobic pathways. The fiber possesses a relatively slow contraction speed compared with type II muscles. A muscles capacity to generate ATP aerobically, intimately relates to numerous large mitochondria and high levels of enzymes that are required for aerobic metabolism. Slow-twitch muscle fibers has greater mitochondria and enzymes, which can continuous supply a steady rate of aerobic energy transfer for endurance running (McArdle et al, 2007 170-173). Hunter et al in 2005 found further evidence that support McArdle. A positive correlation between VO2 walking at 3 mph and type IIa muscle fiber percentage in gastrocnemius muscle of sedentary woman and both of these variables were positively correlated with VO2max. According to Hunter et al in 2005 individuals with high proportions of energetically inefficient type IIa muscle fibers will tend to be less economical and have a greater oxidative capacity, with the greater capacity being a consequence of higher O2 demand of the inefficient type IIa fibers(Sawyer et al, 2010), (Millet et al, 2002).

<u>Absolute and Relative VO2</u>

There are two types of VO2 that we will be dealing with in this study and they are absolute and relative VO2. Absolute VO2 is measured in liters per minute (L/min) or milliliters per minute (ml/min). This type of VO2 provides a measure of energy cost for non-weight-bearing activities. This type of VO2 is directly related to body size and body weight, thus men typically have a larger absolute VO2max than women.

Relative VO2 is typically expressed relative to body weight, that is, in (ml/kg . min). This type of VO2 is good to compare fitness levels of individuals differing in body size. This type of VO2 is good to estimate energy cost of weight-bearing activities such as walking, running, and stair-climbing (Heyward, 2006, p56).

<u>Anatomical analysis of running</u>

<u>Walking Gait</u>

The two phases of walking are the stance (support) phase and the swing phase. The stance phase composed of heel strike, foot flat, heel off, flexion at the knee, and toe off which is 60% of the walking cycle. The swing phase composed of toe clearance and leg swing, which is 40% of the walking cycle. The stance phase encompasses the heel strike, midstance, and pushes off. The swing phase includes the beginning of the acceleration of the leg as the foot is lifted from the ground and the body's center of mass is over the other foot. The leg in the swing phase starts to decelerate in preparation for the heel strike (Adrian et al, 1989, 280-281). In following one leg through the whole cycle starting with heel strike, going to midsupport, toe-off, forward swing, foot descent, and back to heel strike (Hamill et al, 2009 82).

The determinants of walking are as followed: the pelvic rotates 8 degrees forward with the leg that is also swinging forward which reduces the drop of the center of gravity. The pelvis tilts downward during the stance phase of one leg to shorten the distance of the hip to group, and to keep the center of gravity from rising too much. The knee is in full extension during heel strike. When the foot is in flat flexion, the knee is (5 to 15 degrees); there is extension at the knee and flexion again at push off. The flexion and extension of the knee prevents the center of gravity from rising. The foot and ankle helps take up shock and smooth out the path of the center of gravity during heel strike. The foot is in dorsiflexion at heel strike and as the heel off and toe off phases, occur the leg begins to flex. The foot, ankle, and knee work together as a damper at heel strike. The knee has two separate actions during walking. As the ankles rises during the heel off and toe off phase, the knee flexes during each phase. This serves as a shock absorber and reduces the degree to which the center of gravity rises. Lateral movement of the pelvis is 4.45 cm at each step. The femurs are adducted and the tibias are in slight valgus. Walking starts with ankle flexion. When the center of gravity is in front of the ankle joint the ankle extensor, of the rear foot, permit the center of gravity to move forward. As the forward moving foot is placed on the ground the momentum of the body and the push from the rear foot carry the center of gravity over the new support. As walking continue the momentum is conserved and variation occur in timing, range, and speed of joint actions during increase walking stride (Adrian et al, 1989, 285-286).

Running Gait

Defining step and stride may vary among scholars so the one given by Marlene Adrian and John Cooper will be used. A "step" is part of the running action which commences at the moment when both foot terminates contact with the ground and it continues until the other foot contacts the surface. A "stride" consists of two steps during which there is a period of support and a period of flight. As the leg strikes the ground, kinetic and gravitational potential energy is temporarily stored as elastic strain energy in muscles, tendons, and ligaments and then all the energy is almost recovered during the propulsive second half of the stance phase (Cappellini et al, 2010). The arms are used as a counterbalance to the swinging leg which is a180 degrees out of phase with the swinging arm. The arms are flexed to partially extended position while moving forward and backward in toward the midline of the body. The nonsupport time increase and the support time decreases while running. The times are closer to 50 percent for distance running. Some different in phases is also noticeable when comparing running to walking. During one phase neither foot is in contact with the ground; second at no point is both feet are in contact with the ground. All of the dimensions are similar to walking, but in a greater degree such as greater pelvic rotation, pelvic tilt, lateral motion of the pelvis, flexion at the knee, foot and ankle motion, and knee motion. There is greater extension and flexion of the legs and arms resulting in a wider range of motion. Posture is upright, which is similar to walking, but now there is vigorous arm movement back and forth to balance the torso (Adrian et al, 1989 439-446).

Affect of an Incline on Gait

When walking on an incline of 3 ^{o}, 6 ^{o}, 9 ^{o}, or 12 ^{o} there are changes to trunk orientation and the lower limb trajectory. During toe-off, test subjects adopted a posture that increases slightly, the amount of forward pith of the trunk from 87.9 ^{o} observed during level ground to 85.5 ^{o} at the highest ramp inclination. The swing limb motion demonstrated an increased elevation of the toe trajectory that was observed with increased ramp inline. The increases in the height of the toe began directly following toe-off and continued until heel contact on the ramp. Increase in hip, knee, and ankle angle was observed beginning at toe-off and continuing until foot contact. The hip, knee, and ankle angels increased from 17.7^{o}, 34.7 ^{o}, and -1.5 ^{o} during 0 ^{o} incline to 28.0 ^{o}, 46.8 ^{o}, and 4.2 ^{o}, respectively for the 12 ^{o} degree incline (Prentice et al, 2004). During an increase inclination of 5 and 10%, there is a decrease in pelvic lateral drop toward the swinging limb and a gradual increase in stride length as the uphill slope became steeper (Leroux, 2002). A study of a 15% and 39% increase in grade showed increased activation of gastrocnemius medialis, biceps femoris, semimembranosus. vastus medicalis , and rectus femoris for the hip and knee joints. Knee and ankle joints showed an increased in medial gastrocnemius, and, soleus activity, and an increase tibialis anterior to increase plantar flexor moment (Lay et al, 2007).

Economy of Movement (Strength)

Walking

According to several studies there are several anthropometric variables that have been hypothesized to contribute to economy during walking and/or running, including leg length, stride characteristics, body mass, and weight distribution between the trunk and the limbs (Sawyer et al, 2010). Preferred walking speeds that is self selected is usually between 1.2 to 1.4 m/s. Biomechanical factors such as leg length and step frequency plays a role in selection of desired waking speeds. Energy expenditure is optimal in this range and a decrease or increase in speed causes an increase in energy expenditure (Reisman et al, July/August 2009).

It was found that obese children had similar economy of movement until they started walking at higher speeds (100m.min -1). This is related not to the adiposity but to the total mass of the individual. Although the adiposity did not affect economy of movement it did affect aerobic fitness. The obese children operated at a considerably higher percentage of their VO2peak and had a higher sub maximal heart rate at all velocities (Ayub and Bar-or, 2003). This raises the question if body mass has an effect on fatigue or time to exhaustion.

Eston et al. study showed increased vertical displacement during walking as measured by triaxial accelerometry is likely associated with decreased walking efficiency in children due to increased energy expenditure that does not drive the body forward. Furthermore Martin et al in 1992 concluded that vertical displacement of energy expenditure was reported improved by preventing decline or improving thigh-muscle strength and was verified by Iwashita et al (Iwashita et al, 2003).

Iwashita found walking velocity and isometric extension torque was strongly correlated. Gleim et al suggested this was due to decrease flexibility of trunk rotation and lower limb turnover that decreased with increased leg muscle strength, which increased the efficiency of walking and jogging over the range of 0.3-12km/h. They suggest this was due to a more rigid musculoskeletal system that is more resistant to the rotator forces imparted by increased speed of movement, suggestion decreased movement in the vertical direction whereas increased motion in anterior/mediolateral directions (Iwashita et al, 2003).

It was suggested that knee extensor strength during both concentric and eccentric muscle actions is very important for energy efficient ambulation, and becomes more important as velocity increases (Kramer et al, 1994). When transitioning from walking to running there is greater knee flexion due to the knee acting like a spring as opposed to acting like a flexible strut that is mostly extended. The greater flexion is accompanied by an increase in activation of force which is determined by an increase in muscle recruitment volume. There is also an increase in frequency due to stride frequency increase. These variable increases the overall expenditure of energy when increasing speeds to a run (Biewener et al, July 2004).

Running

Running economy is characterized by the distance covered and the energy expended. With the increase distance with lower energy expended being favored. The lower the energy the lower the oxygen consumed (Nummela et al, 2007). Factors such as less vertical oscillation, longer strides, less change in velocity during the ground contact, and lower first peak in the vertical component of the ground reaction force, associated with a tendency to have smaller anterior posterior peak forces. It is interesting to note that if a runner is economical at a given speed that they will economical at a higher speed (KYRÖLÄINEN, 2001).

According to Morgan DW and Daniel DW in 1994 there is an inverse relationship between running economy and VO2max among competitive endurance athletes. If an athlete has a lower running economy then they compensate with a higher movement economy to achieve the same performance (Sawyer et al, 2010).

A study found that plyometric training improved running economy without improving lactate threshold or VO2max. The improvement of running economy was contributed to increased tendon stiffness that improved reactive power during foot contact which decreased energy cost of running (Spurrs et al, 2003), (KYRÖLÄINEN, 2001). During preactivity and braking phase of running the plantarflexors and knee extensors generate actively high tension, which can be released passively during running. This release in force will cause a decrease in the change of contact force velocity with a decrease need for chemical energy to make up the given change. The elasticity can contribute to the muscles' structure (extracellular matrix and muscle fibers), along with titin. The protein titin aids in force transmission from the myosin filaments to the z-disk but also in sparing chemical energy expenditure due to its elastic structure (KYRÖLÄINEN, 2001).

Similar results were suggested to contribute to the improvement in RE in a study that assessed maximal strength training with running economy. Maximal strength training is defined as strength training using high loads, few repetitions, and emphasis on neural adaptations. Along with improved RE there was an improved time to exhaustion and 1RM. There wasn't an increase in body weight which could be contributed to hypertrophy and there wasn't an increase in VO2max. Thus the improvement was contributed to RE which was speculated to tendon stiffness, neural adaptations, and changes in recruitment patterns as the main training response from the training intervention. As a result of increased 1RM increase tendon stiffness may have occurred, which would lead to decrease number of motor unit recruited and thus would lead to a longer time to exhaustion at a given velocity (Støren et al, 2008).

Increase tendon stiffness has also been associated with plyometric training (Spurrs et al, 2003). The increase in running economy with no changes in VO2 is indicated by an increase in velocity, which is explained by the aforementioned adaptations. The increase may be better enhanced by explosive-strength training instead of just heavy weight training. A decrease Golgi tendon inhibition that increases force output can be associated with strength training (Millet et al, 2002). Another explanation could be that strength training increases rate of force production and thus increases running economy and time to exhaustion, which was found to be significant correlated, as was the case in study by Støren in 2008(Støren et al, 2008).

In another study, short contact times, fast force production, exhibited statistically significant correlations with both running economy and maximal running speed. The results suggest that the short braking phase and use of elastic energy are important factors both in economical and high speed running in a group of young well-trained endurance athletes (Nummela et al, 2007). A study data supports that neural control and the ability of the neuromuscular system to produce power above VO2max affects running economy. Thus rapid force production is not only beneficial for sprinters but for distance runners (Nummela et al, 2006). Sprinting has been shown to help in synchronization of motor units in cyclists which results in force potentiation, which improves efficiency and coordination. An increase in synchronization due to neural alterations can increase running economy (Nummela et al, 2006). An increase in the rate of force development may also be due to the motor units developing a lower recruitment threshold and an increase firing frequency. Such as the case with heavy weight training that works the fastest motor units because they are the ones that develop the most force. Since the fast motor units are worked, increased rate of force development develops. Increased time to exhaustions has been correlated with rate of force development (Østerås et al, 2002).

It has been suggested that VO2max is not the solely determinant parameter and that other variables would also contribute to race walking, such as blood lactate variables which has shown to have a stronger correlations with performance (Yoshida et al, 2012). When sub maximal VO2 in long-term constant-rate exercise energy demand is above the lactate threshold and above the aerobic capacity a reduce work efficiency occurs. It has been suggested that increased strength training has reduced the rise in energy demand above lactate threshold and aerobic capacity which leads to improved work efficiency, (running economy). This may be due to the suggested component being 85% at the muscular level (Millet et al, 2002). Previous studies have supported this theory by showing that during fatigued conditions an increased H^+ concentration occurs above lactate threshold. This is related to the increased blood lactate concentration during a 5 K running, which impairs the contractile properties of the muscles. It has been suggest that explosive heavy weight training improves the neuromuscular characteristics to allow the muscles to still contract under such conditions. The improvement is not contributed to hypertrophy because the contraction time is short for this type of training. The hypothesis was confirmed through calf measurements that did not change before and after training (Paavolainen et al, 1999).

<u>Strength Characteristics>VO2 (fatigue)</u>

VO2 characteristics have been shown to cause fatigue in individuals, but strength characteristics can lead to early fatigue even if oxygen and substrate are readily available.

Muscular fatigue is observed biomechanically as a reduced level capacity of the muscle to maintain a specified force output (Komi and Teshch 1979; Viitasalo and Komi, 1977). Reduced motor function is a possible outcome when neuromuscular fatigue is present in individuals who perform dynamic movement over sustained period of time (Granata and Gottipati, 2008).

Walking

One of the predominate muscles that can fatigue during walking is the tibialis anterior. Premature fatigue of this muscle can cause an early transition from walking to running. A study found that induced fatigue of the tibialis anterior results in a quicker transition to running in which the tibialis anterior is activated less due to the change in angle of the ankle. The fatigue may also induce instability in the ankle which may contribute to an earlier transition to running where it is more stable due to less activation of the tibialis anterior (Segers et al, 2006). Another way to gain stability in the ankle to avoid injury when fatigue sets in is to slow gait. A Group of individuals walking until onset fatigue first demonstrate fatigue at tibialis anterior, followed by instability of gait rhythm and then they slow their gait rhythm to enhance local dynamic stability (Yoshino et al, 2004). When instability starts to occur, other muscles may compensate until they also become fatigued. When selective fatiguing of the posterior tibialis occurred it showed to cause rear foot eversion following fatigue. Greater eversion has been reported following fatigue of all invertor muscles. The difference may be that other muscles were compensating for the fatigue of posterior tibialis (Pohl et al, 2010).

Looking at larger muscles further up the leg, the body has other ways of compensating for fatigue. At faster walking speeds the force developed by the knee extensor muscles increases and greater proportion of fast-twitch fibers was thus recruited. The down side to switching to fast-twitch fibers is that they have been shown to be less economical and thus contribute to greater energy expenditure, which leads to faster fatigue (Malatesta et al, July 2003).

Factors such as being obese can cause an onset of early muscle fatigue. When an individual is obese it has been hypothesized that the onset of quadriceps fatigue is sooner than normal followed by a more distinct flat-footed heel strike, which is common with fatigue (Syed et al, 2000).

Moving further up the body, changes in gait have been found to occur due to induced back muscle fatigue. The back muscles are important to maintain spine alignment during heel strike (Olson, 2010). The changes of gait affect the economy of movement and fatigue of other muscles due to increase energy expenditure from preferred walking speeds.

The importance of strength in relation to endurance can be pointed out better with older individuals that suffer from decrease muscle strength. A study that reduced muscle strength in older individuals is related to mobility related fatigue which is associated with a decrease in walking speed and thus efficiency. The study also points out the essential of knee extension strength has been shown to be associated with better walking ability (Mänty et al, 2011).

<u>Running</u>

When an individual is running, VO2 max is more of a key role than it is during walking. It has been suggested that hypoxia developed in the active muscles during exercise causes fatigue and thereby limits maximal exercise performance. This is why VO2max and the utilization of sub VO2max level are good indicators of endurance performance. VO2max represent the safe upper limit for aerobic energy delivery. Even though they are good indicators it does not explain the difference with top athletes with similar VO2 max which can be better explained by the energy cost of the performance or also known as running economy (Nummela et al, 2006).

When fatigue starts to occur while running, numerous changes occur that affect running economy. A study observed while running a 5km time trial which showed running velocity and EMG activity of lower extremities decreased during the time trial. This was speculated to do with overestimation of their running abilities, which led to muscle fatigue. In addition, the degree to which athlete level of muscle recruitment was maintained at high level at the critical phase of the time trial determines performance during the 5km. A decrease in such represents the fatigue on an individual (Nummela et al, 2006), (Nummela et al, 2006). Along with decrease EMG activity a decrease in stride length, but not stride frequency occurs. Stride frequency has been shown to be positively correlated with velocity. An increase in contact time and a decrease in flight time have been shown to result of muscle fatigue (Nummela et al, 2006).

In order for a runner to continue it is not only vital for the muscle, but the central neural system ability to drive the motor neurons. A decrease in the neuromuscular characteristics can be measured by a decrease in rate of force production and maximal strength which may also represent an increase in the number of motor unit firing, which would ultimately result in a decrease time to fatigue at a given velocity (Støren et al, 2008). Neural fatigue can cause a decrease in synchronization which may cause a decrease in time to fatigue (Nummela et al, 2006). In the instance of combing explosive strength training and endurance training a reduction in power and running economy has been observed due to neural fatigue (Mikkola et al, 2007).

Summary

Walking or running is a rigors activity that involves muscle activation via neuron that contracts muscles. These muscles are attached to the skeletal system that acts as levers to create movement which can be repetitive for a given duration of time. VO2 has been shown to be a good indicator of such endurance. Several studies have shown that running economy also has an effect on performance. Strength characteristics are one factor that has been shown by several studies to have an effect on running economy. This is shown by not only the improvement of economy with strength characteristics, but also the decrease in running economy due to muscle fatigue. This brings the question forward about the direct relationship between strength and VO2 for not only running, but also walking and jogging.

CHAPTER 3: Methods

Subjects

The study is first approved by East Tennessee State University IRB review board. Subjects were then gathered and invited to a meeting where they were told about the risks and benefits of the study. Each subject was required to sign health and informed consent forms. The criteria to be able to participate in this study are that they must be a healthy male recreational runner between the ages of 20 and 44 years of age. Also the males must not have any underlining medical conditions that would inhibit them from participating in a research study, which is recognized through a detailed health questionnaire.

Experimental Design

The subjects returned to be tested primarily on two pieces of equipment. The isometric mid-thigh clean pull apparatus is similar to a squat rack which is found in a weight room. It has been modified to where the bar does not move and there is a force plate located directly underneath the modified squat rack. This device is used to measure a subject’s leg isometric peak force, instantaneous forces, and rate of force development. The VO2 max machine will be used to determine a subject’s maximum oxygen consumption. While performing the VO2 max test a subjects will be timed and their intensity will be changed so the subject will meet their max performance. This type of procedure is used to measure endurance of a subject. VO2 max is measured because it is a good indicator of endurance. The higher the VO2 max of a subject the higher the endurance of an individual. The endurance of the runner will be measured on a standard treadmill while performing a VO2 max test. The subject's time and intensity level will be recorded along with VO2 max and heart rate. Body mass was determined using an electronic scale. Body composition was determined using BodPod air displacement plethsmography instrumentation. The subjects' height was measured with a standard scale. The results of this study, when compared, will show how strength relates to endurance of runners.

DURATION

Testing will take place 3 or 4 times for approximately 45 minutes per session during August 2010 at ETSU mini-dome room 113E.

PROCEDURES

1. The bar height will be measured and adjusted so when the subject is attached to the bar via hands and squat belt, they will have a knee angle of 125 to 135 degrees.

2. Demonstrations of the proper technique when performing the isometric mid-thigh clean pull and VO2 max will be shown to the subjects prior to practice and testing.

3. The subjects will be asked to perform the mid-thigh clean pull four or five times in order to familiarize themselves with the machines.

4. The subjects will come back another day in order to perform the actual tests.

5. On test day the subjects will perform two pulls that are less than or equal to 75% and than two pulls that are at 100% effort. If the last two pulls are different by more than 250 Newton's then the subject will be asked to perform an additional pull.

6. The subject than will perform a VO2 max test in order to assess their endurance. The subjects will continue to run until VO2 max has been reached unless a problem occurs. The subjects will be asked to rate their perception of comfort through a rate of perceived exertion scale in order to monitor their comfort and exertion.

7. In addition to the tests mention above, the subjects will have their lean body mass accessed via body pod. The subjects are familiarized with the apparatus prior to testing in order to remove any anxiety. At any time the subject can signal and a quick release can be pulled to open the door.

Statistical Analysis

The subject's characteristics and subject data was expressed in averages and standard deviation. The data aforementioned was age (years), height (cm), body mass (kg), VO2 max (ml/kg.min), %body fat, %fat free mass, IPF (N), and IPFa (N/kg$^{0.67}$). Pearson Correlations were done comparing the strength and relation to endurance (VO2) for total test duration. The Pearson Correlations were further broken into three stages that every subject finished. Stage 2, 3, and 4 were then analyzed to find relationships among strength and endurance. The characteristics of strength and endurance were IPF and max absolute VO2, and IPFkg and max relative VO2. Standard correlations was done on subject data averages to find the relationship of mass(kg), IPF, and IPF(kg) to time of exhaustion. Standard correlations were done on IPF, Stage 2, Stage 3, and Stage 4 VO2 (L/min) to Mass. The correlation 0.0-0.1 was considered very small, 0.1-0.3 was considered small, 0.3-0.5 was considered moderate, 0.5-0.7 was considered large, 0.7-0.9 was considered very large, and 0.9-1 was considered nearly perfect.

CHAPTER 4: Results

The mean with standard deviation of the subject characteristics and subject data can be found in table 1 and 2. The correlation of strength and its relationship to absolute VO2max (ml/kg/min), relative VO2 (kg), and relative VO2 (Allo) is found in table 4. The same relationship is broke down per stage 2, 3, and 4 in table 3. Table 5 and 6 is used to further explain table 3, 4, and 7. Finally, table 7 shows the correlations of %fat free mass, mass (kg), height, IPF, IPFkg, and BMI to time of exhaustion.

<u>The Averages of Subject Characteristics and Subject Data Averages</u>

The average age of the 12 subjects whom participated was 37.17 years with a standard deviation of 7.50 years. The average height was measured at 172.99 cm with a standard deviation of 6.21cm. The data that was used to compare the relationship between strength and endurance was also averaged and the standard deviation documented. The average VO2 max (ml/kg/min) taken by the VO2 machine while running on the treadmill at different stages was 54.8 (ml/kg/min) with a standard deviation of 7.9 (ml/kg/min). The body mass was 78.8 kg with a standard deviation of 14.5 kg. The percent body fat measured with the BodPod was 16.26% with a standard deviation of 7.31%. The percent of fat free mass measured per BodPod was 83.76% with a standard deviation of 7.31%. The isometric mid-thigh clean pull apparatus measured the subjects strength characteristic IPF at 3719.1 N with a standard deviation of 605.2 N. The apparatus also measured the strength characteristic IPFkg at 379.11 with a standard deviation of 61.70. The average BMI (kg/m^2) was 25.55 with a standard deviation of 3.13. The average time to exhaustion was 2 minutes and .03 seconds with a standard deviation of 4 minutes and 56 seconds.

<u>The Correlations of the Strength in Relation to Endurance (VO2) for Total Test Duration and Broke down in Stages</u>

The strength characteristics in relation to endurance characteristic for total test duration are as followed. The strength characteristic IPF had a large positive correlation of 0.72 with max absolute VO2.

The strength characteristics in relation to endurance characteristics are broken up into the upper stages, which were completed by everyone, are as followed. In stage 2 walking (2.5 mph, 12% incline, minute 3 to minute 6); IPF had a large positive correlation of 0.54 with absolute VO2, while IPFkg had a very small negative correlation of -0.03.

Stage 3 (walking 3.4mph, 14% incline, minute 6 to minute 9), IPF had a moderate positive correlation of 0.45 in relation to absolute VO2 and IPFkg had a small negative correlation of -0.19 in relation to relative VO2kg.

Stage 4 (jogging, 3.4 mph, 16% incline, minute 9 to minute 12), there was a large positive correlation of 0.65 when comparing IPF to absolute VO2 and small positive correlation was found among the subjects when comparing IPFkg to relative VO2kg.

<u>The Correlations of Measured Variables in Relation to Time of Exhaustion.</u>

The total mass in kg had a large negative correlation of -0.64 when compared to time of exhaustion. The strength characteristic IPF had a large negative correlation of -0.60 when compared to time of exhaustion. The characteristic IPFkg had similar large negative correlation of -0.60 when compared to time of exhaustion. Body mass index (BMI) had a perfect negative correlationof-1.00.

<u>The Correlations of IPF, Stage 2, Stage 3, and Stage 4 VO2 (L/min) to Mass.</u>

IPF had a very large positive correlation of 0.78 when compared to mass. Stage 2 VO2 (L/min) had a very large positive correlation of 0.93 when compared to mass. Stage 3 VO2

(L/min) had a very large correlations of 0.86 when compared to mass. Stage 4 VO2 (L/min) had a very large correlation of 0.91 when compared to mass.

Chapter 5 Discussion

The results of this study revealed moderate to strong relationships between strength, body size, and endurance measures. An important factor to consider in the interpretation of the results of this study is the body mass of these individuals was 25.55 with a standard deviation of 3.13. This is significant because they are actually overweight since it falls between the 25-29.99 ranges (Romero-Corral et al, 2008). The runners measured had an endomorph body type. This is contrary to the typical ectomorph body type typically found in endurance runners (Bolonchuk et al, 2000). This has an effect on the test results because the data gathered may not apply to the highly competitive endurance runner. Another variable that had an effect on the results is the small sample size of 12 volunteers. If a larger sample size was obtained it is hypothesized that there would be less standard deviation among strength and VO2.

During the walking stages, stages 2 and 3, there were moderate to large correlations between strength (IPF) and absolute VO_2. However once the treadmill speed increased beyond a walking pace then this relationship became even stronger (Malatesta et al, July 2003). This is most likely due to the strong relationship between higher strength as well as higher VO_2 and greater body mass (Pavlou et al, 1985). Since running is a high-impact activity the heavier runners are typically less efficient in regards to energy usage when compared to lighter runners (Sawer et al, 2010), (Reisman et al, July 2009), (Ayub and Bar-or, 2003). This would be a detriment to competition as running economy is one of the most important factors in race performance (along with VO_2max and the body's ability to buffer acid associated with high intensity aerobic exercise) (Sawyer et al, 2010), (Yoshida et al, 2012), (Paavolainen et al, 1999), (Syed et al, 2000).

The strongest correlation found when correlating to time to exhaustion was BMI. This was a perfect correlation of -1.00. This tells us that as the individual BMI goes up the time to exhaustion decrease (Syed et al, 2000), (Malatesta et al, July 2003). We can draw the conclusion that the endomorph body types which was typical of the subjects in this study was related to a shorter time to exhaustion most likely due to increased energy requirements needed to move a larger mass(Syed et al, 2000).

Summary and Conclusion

This study shows that strength may have an effect on running economy during walking speeds. This was most likely due to the higher body weights of the participants in the study. Strength was related to body mass and body mass was negatively related to running economy as evident by higher absolute VO2 values at same speed and grade. Body Mass Index (BMI) may have an effect on time to exhaustion. In conclusion this study suggests that recreational endurance runners with an average BMI of 25.5 should focus on strength and possibly lowering their BMI in order to improve their performance. This improvement during walking speeds is important because not every runner will be operating at maximal intensity during longer runners. The run may actually be a walk or slow jog which is a sub-maximal intensity, or sub-VO2.

Practical Application

The increase strength shown in our study has a positive relationship with VO2 during the walking speeds. This shows the importance of including strength training along with the reduction of usual endurance training in order to improve running economy. The decrease in endurance training also reduces the chance of injury that has been notice with large volumes of endurance training (Spurrs et al, 2003). It is worth mentioning that a large volume of endurance training can lead to a decrease of the neuromuscular characteristics, which reduces running economy (Millet et al, 2002). In order for a runner to continue to run it is not only vital for the muscle, but the central neural system ability to drive the motor neurons. In order to reduce neural fatigue when combing training; a reduction of 20% endurance training has been effective (Mikkola et al, 2007). In conjunction with aforementioned recommendations it may be useful to reduce BMI below 25, which may improve runners' endurance as shown by the strong correlation to time to exhaustion.

Data Tables

Table 1: Subject Characteristics	
Age (years):	37.17 ± 7.50
Height (cm):	172.99 ± 6.21
Body Mass (kg):	78.8 ± 14.5

Table 2: All Subject Data Averages	
VO_2max (ml/kg/min):	54.8 ± 7.9
Body Mass (kg):	78.8± 14.5
%Body Fat:	16.24±7.31
% Fat Free Mass:	83.76 ± 7.31
IPF (N):	3719.1 ± 605.2
IPFkg:	379.11 ± 61.70
BMI:	25.55±3.13
Time to Exhaustion:	2.03±4.56

Data is expressed as means ± standard deviations.

Table 3: Correlations: Strength to VO2 Characteristics Per Stage		
Stage 2 (Walk 2.5 mph, 12% incline)	**Stage 3 (Walk 3.4 mph, 14% incline)**	**Stage 4 (Jog 4.2 mph 16% incline)**
IPF and Stage 2 absolute VO2: 0.54	**IPF and Stage 3** absolute VO2: 0.45	**IPF and Stage 4** absolute VO2: 0.65
IPFkg and Stage 2 relative VO2(kg): -0.03	**IPFkg and Stage 3** relative VO2(kg): -0.19	**IPFkg and Stage 4** relative VO2(kg): 0.29

Table 4: Correlations: Strength to VO2 Characteristics
IPF and Max absolute VO2: 0.72

Table 6: Description Table
The IPF in red is the correlation between strength and VO2 at each stage.
The IPFkg in green is the correlation between strength scaled to body mass and VO2 in each stage.

Table 7 Correlation:	
Variables	Time to Exhaustion
mass (kg)	-0.64
IPF	-0.60
IPF (kg)	-0.60
BMI	-1.00

Table 8 Correlations:	
Variables	Mass
VO_2 (L/min) Stage 2	0.93
VO_2 (L/min) Stage 3	0.86
VO_2 (L/min) Stage 4	0.91
IPF	0.78

Table 5: Correlation Coefficient	Descriptor
0.0-0.1	trivial, very small, insubstantial, tiny, practically zero
0.1-0.3	small, low, minor
0.3-0.5	moderate, medium
0.5-0.7	large, high, major
0.7-0.9	very large, very high, huge
0.9-1	nearly, practically, or almost: perfect, distinct, infinite

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