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POWER PERFORMANCE AND SKELETAL MUSCLE FIBER COMPOSITION IN MAN

BY

MARY ANN MULLIGAN

B.P.E., University of Ottawa, 1976

THESIS

Submitted to the school of Graduate Studies in partial fulfillment of the requirements for the degree of Master of Science in Kinanthropology in the School of Human Kinetics, University of Ottawa, 1983.

DEDICATION

For Kevin - who said I could.

ACKNOWLEDGEMENT

Above all, I would like to thank my advisor, Dr. Michael Booth, for his kind encouragement, patience, constructive criticism and insight.

To the following people I also give my thanks: Dr. Reardon, Mrs. Carriere and Mrs. Lok for their technical assistance, Don Dickie and Bill Montlepare for their help with the statistics, Mrs. St. Michael for the typing and Doctors Reardon and Pommerville, who volunteered to perform the biopsies.

I am also grateful to my subjects who willingly submitted themselves to all the tests without complaint, on my behalf.

Finally, I'm indepted to my family and friends who gave me encouragement when it was most needed.

ABSTRACT

The purpose of this study was to determine if a relationship exists between the proportion of Type II muscle fibers and power performance in subjects not in a state of power training. Muscle biopsies were obtained from the vastus lateralis muscle of 8 young males. The muscle fibers were classified as Type I (ST) and Type II (FT) on the basis of the stain for myosin ATPase activity at alkaline pH. In addition, each subject completed an isometric strength test and the following five tests of power: (1) a standing broad jump (2) vertical jump (3) 40 m sprint (4) Margaria's stair-climbing test and (5) a vertical jump from the force platform. Maximum instantaneous power, peak force, peak velocity, relative force at peak velocity, the time to peak force and impulse were derived from the force platform analysis of the vertical jump.

The mean percent Type II distribution by area was 53%, but within the group, the values ranged from 4-77% Type II. Much individual variation was observed in both absolute and relative muscle fiber areas.

The Type II fiber distribution by area was significantly related to the standing broad jump ($r=.68$; $p<0.05$), vertical jump ($r=.61$; $p<0.05$) absolute and relative power in the Margaria test ($r=.70$; $p<0.05$ and .91; $p<0.001$ respectively)

and the absolute and relative maximum instantaneous power (r=.65 and .67 respectively; $p<0.05$), but not to the 40 m dash (r=-.47) or isometric leg strength (r=.36). Among the variables derived from the force platform analysis of the vertical jump, only peak force, relative peak force and the relative force at peak velocity were significantly correlated to the Type II distribution (r=.66; .61 and .71 respectively; $p<0.05$). Type II distribution was strongly related to body weight (r=.75; $p<0.01$) but was not related significantly to fat free mass (r=.46). Based on the results of the simple regression analysis it was not possible to predict power performance from the Type II fiber distribution and vice versa.

Mean values and ranges for absolute power in the force platform jump and Margaria's test were 3580 (2147-5712)W and 1219 (851-1451)W respectively. In relation to fat free mass (FFM), the mean values and ranges of the above variables were 49.8 (36.4-70.6) W.kg FFM^{-1} and 17 (14.2-18.3) W.kg FFM^{-1} respectively. Absolute power in the vertical jump was significantly correlated to peak force (r=.69; $p<0.05$), peak velocity (r=.61; $p<0.05$) and the impulse (.69; $p<0.05$). There was a significant correlation between absolute power as measured by the Margaria test and the force platform jump (r=.73; $p<0.05$) but the correlation between relative power as measured by these two tests was insignificant (r=.49).

The standing broad jump was moderately related to both the vertical jump (r=.63; $p<0.05$) and the 40 m sprint (r=.66; $p<0.01$). However, the correlation between the vertical jump

and the 40 m sprint was not significant (r=.53). Isometric leg strength was unrelated to any of the tests of power.

Performance in the standing broad jump was significantly related to both absolute and relative power in the Margaria test (r=.84; $p<0.01$ and .69; $p<0.05$ respectively) and the force platform jump (r=.76; $p<0.01$ and .60; $p<0.05$ respectively). Vertical jump performance was also significantly related to absolute and relative power in the Margaria test (r=.64; and .67; $p<0.05$ respectively) and the force platform jump (r=.77 and .77; $p<0.01$ respectively). Lower and nonsignificant correlations were obtained between the 40 m sprint and absolute and relative maximum instantaneous power (r=-.56 and -.45 respectively) as well as relative power in the Margaria test (r=.52). Each test of power was significantly related to body weight and/or fat free mass.

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CHAPTER ONE

THE PROBLEM

Introduction

Muscular power is a very important component of motor performance. It is fundamental to many athletic activities such as kicking, throwing, striking, sprinting and jumping.

In sprint running, a trained individual can expend power at a rate of up to four horsepower (2900 watts) (Cavagna et al., 1971b), while in a single explosive movement like the vertical jump, the power which can be expended is somewhat higher and can rise to a maximum of between five and six horsepower (3800 to 4500 watts) (Gerrish, 1934; Davies & Rennie, 1968). The power developed in exercises of this nature is indicative of the phosphagen splitting mechanism of work production alone (Margaria et al., 1966) and limited primarily by the mass of active muscles and the speed with which these muscles can contract.

Human skeletal muscle consists of two main groups of fibers which can be classified as slow twitch and fast twitch on the basis of a standard histochemical reaction for myosin ATPase at alkaline pH (Padykula & Herman, 1955; Gollnick et al., 1972). Myosin ATPase catalyzes the rate limiting reaction for the shortening process at the level of the sarcomere and its enzymatic activity therefore reflects both a muscle's intrinsic speed of

shortening and isometric twitch contraction time (Barany, 1967). In the fast twitch fibers of human muscle, the biochemical ATPase activity of myosin is two to three times greater than in the slow fibers (Essen et al., 1975; Thorstensson, 1976). Accordingly, human muscles which have the highest proportion of fast twitch fibers also demonstrate the highest speed of shortening (Thorstensson, 1976).

In lower mammalian muscle, the fast twitch fibers can also produce greater twitch and tetanic tensions per unit area than their slower counterparts (Burke & Tsairies, 1973; Barany & Close, 1971). Due to methodological difficulties, this latter difference has not yet been established for human muscle fibers although maximum isometric leg strength has been shown to correlate with the proportion of fast twitch fibers in the vastus lateralis muscle (Tesch & Karlsson, 1977; Komi et al., 1977a). Therefore, muscle quality as well as muscle quantity may be decisive to the ability to develop force.

Fast twitch fibers are not only capable of contracting with great strength or speed, but they are also endowed with the ability to effectively combine their strength and speed to produce fast contractions with appreciable tension outputs. Fast twitch hind limb muscles of lower mammals can sustain much more force at fast motion speeds than slow twitch muscles (Close, 1964; Wells, 1965) and in human knee extensor muscles, the proportion of fast twitch fibers can be related to the amount of torque and power produced at high angular velocities (Thorstensson, 1976; Coyle

et al., 1979). Furthermore, when force must be applied during very brief periods of time, the rate at which the muscle can develop force is also important. The rate of force production in isolated muscle is related to the basic fiber structure (Brody, 1976; Close, 1964). In human experiments, the measurement of the force-time curve during voluntary isometric contraction describes the time needed for the production of different force levels. The muscle fiber composition influences the form of this curve during bilateral knee extension in such a way that the lower the proportion of fast twitch fibers, the longer is the time necessary to reach any force level less than ninety percent of maximal voluntary strength (Komi & Viitasalo, 1978). This finding is particularly significant when one considers that, for example, the total time elasped for all joint movements in throwing may be fifty milliseconds or less (Sale, 1975), or that the duration of the thrust phase in the vertical jump and in sprinting is about .03 and .07 seconds respectively (Gerrish, 1934; Cavagna et al., 1971b).

Fast twitch fibers are thus well adapted physiologically for use during short term powerful phasic activity (Close, 1972) and the proportion of these fibers within a muscle or muscles could be an important determinant of power performance.

Rationale for the Study

The number and type of a muscles's fibers appears to be fixed during man's embryonic or early infantile development (Tomaneck &

Colling-Saltin, 1977) and a change in fiber type as a result of training has not yet been demonstrated in man (Thorstensson et al., 1975; Thorstensson, 1976, Gollnick et al., 1973a). Moreover, studies conducted on monozygous and dizygous twins have disclosed that the muscle fiber composition has a very strong genetic basis (Komi et al., 1971b). This being the case, it has been suggested that the muscle fiber composition observed in elite power athletes of international calibre, which ranges from 61 to 79 percent fast twitch, is not necessarily due to their training, but rather to the "natural selection" of those individuals with the best prerequisites for high strength and/or speed performance (Thorstensson et al., 1975; Costill et al., 1976; Gollnick et al., 1972). This would mean that the destiny of athletes in various events which differ in their requirements for muscular strength, speed or endurance is determined in part, by the fiber distribution they inherit. However, the extent to which superior power performance in these athletes is due to their genetic endowment or to the effects of long-term systematic training on factors other than the muscle fiber composition is still an open question. This question can be partially resolved by determining if the muscle fiber composition can have a bearing on the power performance of individuals who have not yet been exposed to extended periods of power training. A statistically significant relationship has already been shown to exist between maximal oxygen uptake and the number of slow twitch fibers in the untrained (Bergh et al., 1978), but despite the fact that alactic

power performance is an integral part of many athletic activities, the possible interdependence between the number of fast twitch muscle fibers and power performance has not yet been studied in subjects who are not in a state of power training.

Statement Of The Problem

The problem in this study is to determine if a relationship exists between the proportion of fast twitch muscle fibers and alactic power performance in subjects who are not in a state of power training.

Delimitations

(1) The study was delimited in scope to young male volunteers untrained in sprinting or jumping.

(2) The study was delimited to the measurement of leg power performance by: (a) the method of Margaria et al. (1966), (b) a force platform analysis of the standing vertical jump and (c) the subjects' best performances in a vertical jump, standing broad jump and a 40 meter dash.

(3) The analysis of the fiber composition was restricted to one muscle only, the vastus lateralis, even though the performances under study represent the activity of several muscles around three major joints.

Limitations

(1) The number of subjects in the study was limited by the availability of both subject volunteers and medical assistance for the biopsy sampling.

(2) For ethical reasons, the muscle sampling was limited to a single small biopsy from the right leg. Some sampling error is therefore intrinsic to the study (Gollnick et al., 1973; Thorstensson, 1976) despite reports (Edgerton et al., 1975; Johnson et al., 1973) that the fiber types are distributed in a mosaic pattern throughout the vastus lateralis muscle.

CHAPTER TWO

REVIEW OF LITERATURE

Mechanical Power Defined

It is the distinctive function of skeletal muscle to perform external work and towards this end they are endowed with the ability to transform chemical energy into the mechanical work of contraction. Mechanical work is the product of the force produced by a muscle and the distance through which it is exerted, while power is a measure of the rate of performing muscular work. Power is derived from the formula: force x distance/time, but may alternatively be expressed as a product of force and velocity. Muscular power is therefore the result of two factors: strength and the speed of contraction.

Actin-Myosin Interaction as the Basis of Muscular Contraction

The contraction of all skeletal muscles is brought about by the interaction of the proteins actin and myosin. During active contraction, the association of actin and myosin is accompanied by the hydrolysis of ATP to ADP and Pi. The hydrolysis of ATP releases the stored chemical energy needed to power the contractile process. A brief overview of the molecular mechanism of muscular contraction, in terms of the sliding filament hypothesis (Huxley, 1958), is presented here in order to understand how a muscle is able to develop a force and perform mechanical work by shortening against a force.

In resting muscle, ATP and Mg^{++} ions are bound to the head of the myosin molecule; no crossbridges are formed between actin and myosin and the myosin head is in the retracted position. The binding of the myosin ATP complex with actin is prevented, in the absence of Ca^{++}, by the influence of the regulatory proteins troponin and tropomyosin, which are associated with actin. When Ca^{++} ions are released by the sarcoplasmic reticulum following neural activation of the muscle fiber, they immediately bind to troponin, causing it to relinquish its inhibitory effect upon crossbridge formation. A binding site on actin is now exposed for the energized head and they combine to form a force-generating complex. Almost simultaneously, actomyosin ATPase splits the ATP associated with myosin, and the myosin head is believed to undergo an energy yielding conformational change so that the crossbridge changes its angular relationship to the axis of the heavy filament, causing the thin filament to be moved along the thick filament. This is the power stroke (Lehninger, 1975). The myosin head is now in its de-energized conformation and the bound ADP and phosphate leave their binding site on myosin. When another molecule of ATP is taken up by the myosin head, it returns to its energized conformation and in the continued presence of Ca^{++} ions, myosin re-attaches itself to another binding site further along the actin filament. In this manner, which is analogous to a man pulling in a rope hand-over-hand (Wilkie, 1976), there is a continuous relative "rowing" movement of the filaments and an asynchronous cycling of the

crossbridges which, when added together, produce a large movement of the muscle. Relaxation of the muscle is brought about by the re-accumulation of Ca^{++} from the sarcoplasm into the sarcoplasmic reticulum, at which time troponin and tropomyosin resume their inhibitory effect upon crossbridge formation.

The Mechanism of Myosin ATPase Activity

From the above discussion, it can be appreciated that the hydrolysis of the ATP associated with the myosin head is a very important step in the contraction cycle. For this reason, the ATPase activity of myosin has been the subject of intense study. One basic observation that has been made is that myosin's enzymatic kinetics cannot be described by simple Michaelis-Menton steady state kinetics. Taylor and his associates (1970a; 1970b) observed that when equimolar amounts of myosin and ATP are mixed, myosin does not simply form an enzyme substrate complex with ATP and then dissociates into the products, myosin, ADP and Pi. Instead, the following sequence of reactions occurs:

(1) ATP + M----------M.ATP
(2) M.ATP + H20---------M*.ADP.P + H
(3) M*.ADP.P----------M.ADP.P
(4) M.ADP.P----------M + ADP + P

M* - refers to the energized form of myosin.

Reactions 1 and 2 show that when myosin and ATP are mixed there is a very rapid appearance of free H^+ in the meduim. However, free ADP and P do not appear in this medium during the early burst of H^+

formation. It was concluded that they remain tightly bound to the enzyme during this period as a complex of myosin with its products ADP and P. The complex labelled M*.ADP.P is believed to be the high energy complex in which the free energy of hydrolysis of ATP is conserved in the form of the energized conformation of the myosin molecule. Reaction 3 is very slow in the absence of actin, but it is greatly accelerated when actin in added to the solution. Hence, in resting muscle, almost all of the myosin is in the stable form of M*.ADP.P. Actin is present, but in the resting state it is prevented from influencing step 3. However, with the release of Ca^{++}, actin can react with M*.ADP.P and the latter rapidly dissociates to yield free myosin, ADP and P.

Muscular contraction is thus an obvious example of an endergonic biochemical reaction; movement of the thin filaments past the thick filaments requires energy in the form of ATP (Armstrong, 1976). An adequate supply of this high energy compound is therefore essential for normal contractile function.

Immediate Sources of ATP

Cain and Davies (1962) established that the hydrolysis of ATP is the immediate source of energy for all muscular contractions. In fact, ATP is the fundamental energy-yielding compound, not only for muscular contraction but for all biochemical processes that require energy transformation in animals. In spite of ATP's great importance as a mediator of energy, it is stored in very limited quantities in the cells of the body. In human vastus

lateralis muscle at rest, the concentration of ATP was found to be only in the order of 25 mol per gram dry weight of muscle (Hultman et al., 1967). Single twitches of frog sartorious muscle result in the hydrolysis of about .3 mol of ATP per gram of muscle (Mommaerts, 1969). Assuming a similar rate of ATP breakdown in human muscle, the concentration found in the vastus lateralis muscle would be sufficient to support approximately 85 twitches only (Armstrong, 1976). Furthermore, there is also evidence to suggest that ATP is compartmentalized within the cell. Following exhaustive exercise at work loads exceeding 90 percent of an individual's maximum oxygen uptake, ATP concentration is reduced by only 40 percent, thus leaving a relatively large intact store of ATP in the muscle which does not seem to be available to the contractile apparatus (Bergstrom et al., 1967; Karlsson & Saltin, 1970). A muscle fiber must therefore possess the ability to replace ATP as it is being utilized.

The most immediate mechanism for ATP regeneration is the reaction catalyzed by the enzyme creatine phosphokinase (ATP creatine phosphotransferase. E.C.2.7.3.2.). In this reaction, the high energy phosphate of creatine phosphate is transferred to the ADP formed by ATP hydrolysis during contraction. Creatine phosphate exists in equilibrium with ATP according to the reaction series:

(1) ATP + H20----------ADP + Pi energy
(2) ADP + CP----------ATP + creatine

At the pH of the sarcoplasm, the CPK equilibrium lies far to the right so that ATP formation is favored at the expense of creatine

phosphate (Lehninger, 1975).

In human vastus lateralis muscle, the creatine phosphate concentration is about 70 umol per gram dry weight of muscle (Bergstrom et al., 1967). Following exhaustive exercise, the CP concentration unlike that of ATP, can fall to zero (Bergstrom, 1967; Karlsson & Saltin, 1970).

Some of the ADP formed following muscular contraction also undergoes conversion to AMP by the myokinase (ATP:AMP phosphotransferase, E.C.2.7.4.3.) reaction: 2ADP-------ATP + AMP. The ATP yield from this reaction may be significant during intense muscular activity when ADP accumulates. The AMP so formed also stimulates glycolysis by acting as a very potent positive modulator for phosphofructokinase (Lehninger, 1975).

The ATP and CP stores of skeletal muscle are referred to collectively as muscle phosphagen and the amount of energy which is made available from their cleavage is referred to as the alactic, anaerobic energy output (Margaria et al., 1933). ATP and CP are stored in such limited quantities that the capacity of the alactic system is severely restricted. However, the power of the alactic system, or the rate of energy transformation, is very high.

The factors which can limit the rate of energy transformation at the level of the energy rich phosphates are:

(1) the rate of the reactions which form the energy rich phosphates;

(2) the accumulation of the by-products from the metabolism of energy rich phosphates;

(3) the maximum catalytic rate of actomyosin ATPase (Davies, 1973).

The reactions catalyzed by CPK and MK which provide for the immediate resynthesis of ATP, are very rapid. In fact, the high energy phosphate group of CP is transferred so rapidly to ADP, that the ATP content of a muscle before and after a single twitch will show essentially no decrease in ATP content, or increase in ADP content, unless CPK activity is completely inhibited by a reagent (Cain & Davies, 1962). In addition, the rapid resynthesis of ATP by CPK and MK ensures that the ADP formed from the hydrolysis of ATP does not accumulate in the muscle cell. ADP is an activator of oxidative phosphorylation and an inhibitor of myosin ATPase activity (Saka et al., 1978), which can bind ATP at its active site. The accumulation of ADP could therefore slow down the ATPase reaction quite dramatically (Davies, 1973). It thus appears that the reactions catalyzed by CPK and MK normally proceed at a rate which is sufficient to match the rate at which ATP is being hydrolyzed by actomyosin ATPase and to effectively prevent the accumulation of the by-products of the ATPase reaction. The overall limiting factor for the rate at which the transformation of energy can proceed at the cellular level therefore corresponds to the maximum rate of the ATPase reaction.

Margaria and his associates (1964) found that at the onset of very strenuous exercise, which leads to exhaustion in about 30 to 40 seconds, both the oxidative reactions and lactic acid formation were delayed processes which do not contribute to the energy requirements of the exercise to any appreciable extent in the first 4 to 5 seconds of muscular work. The power developed during this time was indicative solely of the phosphagen splitting mechanism. By plotting

the intensity of the exercise as given by its energy requirements, against the time for which the exercise can be sustained without lactic acid production, Margaria et al., (1964) determined that the maximum alactic power of normal individuals running on a motor-driven treadmill at 18 km per hour and inclines varying from 10 to 25 percent, corresponded to 750 calories per kg of body weight per minute. This was roughly three times greater than the power which could be sustained by oxidative phosphorylation. The maximal functional capacity (the total energy available) of the alactic system was set at 100 calories per kg of body weight.

Oxidative Phosphorylation and Lactacid Formation

If muscular activity is to be prolonged, phosphagen must be continually resynthesized. This is accomplished by the anaerobic breakdown of glucose and/or glycogen to lactate and by the complete oxidation of carbohydrates and lipids. While both of these reactions are quantitatively more important than phosphagen with respect to their capacity, the rate at which the energy can be made available is compromised. Neither system can produce ATP at a rate sufficient to match the maximum catalytic activity of actomyosin ATPase and thus, as the duration of exercise increases, power output in man will diminish. Conversely, power output in man will increase rapidly with decreasing duration of exercise. Table 2-1 summarizes the capacity and power of the alactic, lactacid and oxidative systems for whole body movement.

Table 2-1 The Capacity and Power of the Metabolic Processes in Muscular Contraction (di Prampero, 1971).

	Power ($cal.kg^{-1}.min^{-1}$)	Capacity ($cal.kg^{-1}$)
Alactic	750	100
Lactacid	350	250
Aerobic	220	unlimited

The Force - Velocity Relationship of Muscle

The mechanical power that can be developed by a muscle depends not only on the duration for which the work must be maintained, but also upon the amount of force a muscle can sustain at any given velocity of contraction. The relationship between the force with which a muscle contracts and the speed at which it can shorten is one of two fundamental mechanical properties of muscle that have been elucidated by carefully controlling the conditions of contraction of isolated muscle. The non-linear relation between active tension production and the velocity of shortening was first studied by Fenn and Marsh (1935) and later confirmed and expanded by Hill (1938). Hill mathematically described the force velocity curve illustrated in Figure 2-1 as: $V=b(Po-P)/P+a$, where V is the speed of shortening, Po is the maximum isometric tension, P is the load and a and b are constants with the dimensions of a force and velocity respectively.

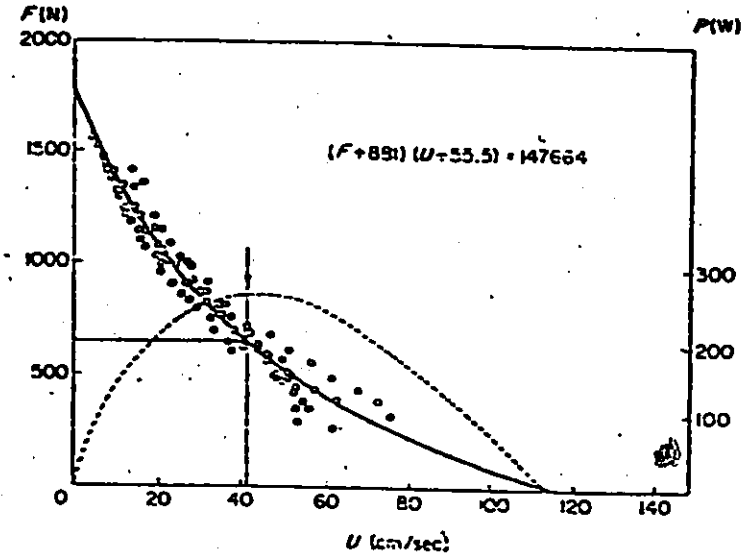


Figure 2-1 Instantaneous force-velocity relation. Maximal concentric contractions of the biceps brachii have been performed by the same subject against six different inertia obtained by loading the forearm. Shortening velocity (U) is plotted versus the exerted force (F). Equation of the hyperbola is given. The dotted line indicates the instantaneous power (P) as the product FU. The speed corresponding to the maximal power is shown by the arrow. (Pertuzon and Bouisset, 1971.)

Although the force-velocity relationship was originally established for maximally stimulated isolated animal muscle, various other studies have indicated that human muscles *in vivo* appear to exhibit virtually an identical force-velocity relationship (Wilkie, 1950; Komi, 1973; Thorstensson, 1976). A muscle's speed of shortening is thus inversely related to the load against which it shortens. A more recent investigation by Perrine and Edgerton (1978) did disclose, however, that in *in vivo* human muscle, the force-velocity curve may be bi-phasic. At high angular velocities, all subjects of their study did exhibit the same general relationship between

force and velocity and the curve was very similar to the isolated muscle hyperbola. But at low angular velocities, when the force of contraction was near maximal values, a plateauing of the curve occured. In attempting to explain this phenomenon, Perrine and Edgerton (1978) suggested that some kind of neural mechanism was operating in a fashion to restrict the muscle's maximum tension. The maximum "safe" tension level may be as little as 50 percent of its actual peak mechanical potential at zero speed.

The force-velocity curve illustrated in Figure 2-1 shows that when a muscle is unloaded, the speed of movement is greatest. This is the muscle's intrinsic speed of shortening. The intrinsic speed of shortening is a true property of the contractile material which ultimately reflects the speed of shortening at the sarcomere level (Barany, 1967). By isolating the myosin from fourteen different muscles of known maximal speed of shortening, Barany (1967) determined that the maximum speed of shortening of each muscle was proportional to the actin and Ca^{++} activated ATPase activities. Thus, the greater the intrinsic speed of shortening, the higher the ATPase activity. In another series of experiments in which the myosin was isolated from 11 different muscles with known isometric twitch contraction times, Barany (1967) further demonstrated that the ATPase activity of the myosins was inversely proportional to the isometric twitch contraction time. It was concluded that the intrinsic speed of muscle shortening is primarily a characteristic property of the ATPase activity of myosin. The work of Barany (1967) has since been confirmed by Close and Barany (1971) who

showed a direct proportionality between the intrinsic speed of sarcomere shortening and the actin-activated ATPase activity of myosin of normal and cross-innerveted mammalian muscle. The reciprocal changes in the speed of contraction of the cross-innervated rat muscles not only correlated directly with changes in the kinetic properties of myosin ATPase, but also provided strong evidence in support of the hypothesis that neural influences determine the dynamic properties of the contractile material through an effect on the ATPase site of myosin.

The force-velocity curve also shows that when a load is so large that it cannot be lifted, the force of contraction rises to a maximum under isometric conditions. Tension generation in a muscle is controlled by actomyosin formation. The actin-binding ability of myosin, unlike its ATPase activity, is quite stable and it appears that the amount of tension a muscle may develop will be reflected primarily in a difference in the actomyosin concentration, or in the number of cross-linkages formed per square centimeter of cross-section of active muscle (Barany, 1967). For each square centimeter of cross-sectional area, isolated animal muscles can produce from 1 to 2 kg of force (Lamb, 1978). According to Hettinger (1961), the muscular strength per square centimeter in human muscles is 4 kg. Others (Ikai & Fukunaga, 1968; Haxton, 1944), have reported values of between 3.9 and 6.3 $kg \cdot cm^{2}$.

The efficiency of a muscle, expressed in terms of maximizing tension output per unit of its cross-sectional area, depends upon

not only the actual volume of the contractile machinery, but also upon its volume relative to the total volume of the non-contractile components. The mechanical force developed by the myofibrils is partially absorbed by the elastic components in series and in parallel, consisting of the sarcolemma, the connective tissue surrounding the fiber bundles, the fascia and the tendons of the muscle. The relative balance between the contractile components and the non-contractile components listed above will therefore be of consequence to the amount of external force developed and also, to a much more limited extent, to the speed of contraction, since the non-contractile components may act as a "drag" on myofibril shortening (Huddart, 1975).

The interrrupted line in Figure 2-1 reveals that when a contraction is isometric, or when the speed of muscle shortening is greatest, the power output of the muscle is zero. However, between these extremes, an increase in force results in a hyperbolic decrease in velocity and the power curve shows a definite maximum. There is thus a certain combination of force and velocity at which the mechanical power output of the muscle will be optimal. In the study from which Figure 1 was reproduced (Pertuzon & Bouisset, 1971), as well as in a separate study by Wilkie (1950), it appears that for the greatest power output, load and speed should have about one third of their maximal values. In the region of this optimum, human muscles can produce from .2 to .3 hp per kg during the course of a single movement (Wilkie, 1950).

The fibers of mammalian skeletal muscles are not uniform either with respect to their speed of shortening, or, in some cases, in the amount of force which they can produce per unit of cross-sectional area (Burke & Tsairis, 1973, Wells, 1965, Close, 1964). Although the general qualitative character of the force-velocity curve remains the same for fibers with different physiological characteristics, the curves are quantitatively different. Fast-contracting muscles can, at the same relative load, shorten at a much greater rate than slow-contracting muscles (Wells, 1965; Close, 1964). Thus, even though the conditions under which a muscle must contract are far from ideal with respect to exploiting to the full the intrinsic force-velocity relationship of a muscle, at any given point on the curve the instantaneous power production of a fast muscle will be greater than that of a slow muscle. The various proportions of each type of fiber found within a mixed muscle should therefore have an important bearing upon a whole muscle's power performance.

Skeletal Muscle Fiber Types: Basis of Classification and Nomenclature

More than a century ago, Ranvier (1874 - cited in Close, 1972) observed that mammalian skeletal muscles differed in their colour, the speed with which they could contract and in the microscopic appearance of their component fibers. Subsequent studies by microscopists (Grutzner, 1884 and Knoll, 1891 - both cited in Close, 1972) showed that the smaller fibers of a muscle were more grandular and darker in appearance than were those of a larger diameter. The

small fibers were predominant in slow-contracting muscles, while the larger fibers were more predominant in the fast-contracting white muscles. Use of the terms "red" and "white" or "slow" and "fast" thus became standard terminology for differentiation.

Within the past two decades, the development of sophisticated physiological, histochemical and biochemical techniques has permitted further characterization of the fibers of mammalian muscles at the molecular and ultrastructural levels. These new techniques were once largely confined to studies on animal muscles, but since the development and widespread use of the muscle biopsy technique (Bergstrom, 1962), studies on the heterogeneity of human muscle fibers have become more numerous.

In general, two factors have been taken into consideration when a fiber classification system is proposed:

(1) speed of contraction;
(2) metabolic characteristics.

The contractile speed of muscle fibers is determined by measuring the contraction time of whole muscles, or motor units, whose fiber population is homogeneous. The contractile speed may also be designated as fast or slow on the basis of bioassays of myosin ATPase and by histochemical staining techniques directed at myofribrillar ATPase activity. The histochemical myofribrillar ATPase activity has been shown to correlate with its biochemical activity (Guth & Samaha, 1969; Barnard et al., 1971; Burke et al., 1973) and with the twitch contraction time (Barnard et al., 1971; Burke et al., 1973). The metabolic characteristics are determined by either

histochemical or biochemical techniques applied to the glycolytic and oxidative enzymes of the muscle fibers. The separate application of these two factors has led to numerous classification systems and much confusion. A long standing controversy still exists with respect to which nomenclature best describes the characteristics of skeletal muscle fiber types.

Peter and his associates (1972) designated the fibers of guinea pig and rabbit muscle as: fast twitch-high glycolytic-low oxidative (FG), fast twitch-oxidative-glycolytic (FOG) and slow twitch-high oxidative-low glycolytic (SO). This nomenclature was based upon extensive quantification of the fibers' biochemical and physiological characteristics and their histochemical profiles. For human muscle, the more neutral terms Type 1, Type IIa and Type IIb are used most often to differentiate the fibers because it remains to be proven if there is also a close correlation between the enzyme activity levels of a fiber, its contractile characteristics and the metabolism taking place in it (Essen et al., 1975; Saltin et al., 1977). The Type 1, Type IIa and Type IIb classification system was proposed by Brooke and Kaiser (1970) and is based upon the pH lability of the myofribrillar ATPase of the fibers. The fibers designated as FG and SO in animal muscle are more or less compatible with those designated as Type IIb and Type 1 in human muscle (Brooke & Kaiser, 1974). Human Type 1 fibers are slow contracting (Buchthal & Schmalbruch, 1970; Eberstein & Goodgold, 1968) and have a high oxidative and low glycolytic potential (Essen et al., 1975). Type IIb fibers are fast contracting (Buchthal &

Schmalbruch, 1970; Eberstein & Goodgold, 1968) and have a high glycolytic and low oxidative potential (Essen et al., 1975). It must be remembered however, that the terms "slow" and "fast" or "low" and"high" are only relative and cannot be used for quantitative comparisons of muscle fiber types in different species (Essen et al., 1975).

There are several important differences between the fibers designated as FOG and Type IIa in animal and human muscle respectively. Although both of these fibers differ from the FG and Type IIb fibers in their oxidative potential and ability to resist fatigue (Essen et al., 1975; Peter et al., 1972; Burke et al., 1973), FOG fibers are much more predominent in animal muscle than are the Type IIa fibers in human muscle. Also, the oxidative potential of FOG fibers is greater than that of the SO fibers in animals (Peter et al., 1972, Barnard et al., 1971; Baldwin et al., 1972), whereas the oxidative potential of Type IIa fibers rarely exceeds that of the Type I fibers in human muscle (Essen et al., 1975; Edgerton et al., 1975; Schmalbruch & Kamieniecka, 1974). Moreover, the distinction between the oxidative and glycolytic enzymatic activities of the Type IIa and Type IIb fibers is not as clear as it is in lower mammalian FOG and FG fibers and seems to reflect more of a continuum or spectrum rather than distinct separable groups (Houston, 1978; Saltin et al., 1977). For this reason, many investigators still choose to limit their classification of human muscle fibers to two rather than three groups on

the basis of the fibers' speed of contraction. The speed of contraction can be conveniently identified by the histochemical ATPase reaction at pH 9.4 (Padykula & Herman, 1955). This reaction gives a clear and constant separation of the muscle fiber types into two distinct populations labelled Type 1 (slow twitch) and Type 11 (fast twitch).

Skeletal Muscle Fiber Types: Speed of Shortening and Isometric Twitch Contraction Time.

It was concluded by Barany (1967) that the intrinsic speed of muscle shortening is primarily a characteristic property of its myosin ATPase activity. Biochemical assays carried out on animal muscle of an essentially homogeneous fiber type composition have revealed that the FG fibers contain a myosin ATPase enzyme with a catalytic rate two to three times greater than that of SO muscle fibers (Barany, 1967; Barnard et al., 1971; Barany et al., 1965; Barany & Close, 1971). The difference in the catalytic rate of myosin ATPase has a high correlation with the differences in both the intrinsic speed of shortening and the isometric twitch contraction time (Barany & Close, 1971; Barany, 1967; Barnard et al., 1971). For example, the intrinsic speed of shortening of the EDL muscle of the rat is about twice as fast as that of the soleus and the rate of ATP hydrolysis catalyzed by myosin is 2.3 times greater for the EDL muscle than for the soleus muscle (Barany & Close, 1971).

In contrast to animal muscles, in which the whole muscle or large portions of it are homogeneous with respect to fiber type, most human skeletal muscles contain a mixture of FT and ST fibers

whose relative distribution varies considerably. It is therefore technically difficult to determine the biochemical activity of myosin ATPase in human fast and slow fibers and to directly determine their speed of contraction. However, it has been possible, by the biochemical analysis of homogenates of muscles with a wide range of fiber compositions, to show a muscle fiber dependency for myosin ATPase (Taylor et al., 1974). In human vastus lateralis and gastrocnemius muscles, the ATPase activity was found to be .34 umol Pi. mg. protein^{-1}.min^{-1}, whereas in the soleus muscle the ATPase activity was .23 umol Pi. mg. protein^{-1}.min^{-1}. The average percentage of FT fibers in the muscle samples was 48 and 23 respectively. When Taylor et al. (1974) extrapolated a regression line to represent 100 percent ST and 100 percent FT, the Ca^{++}-activated ATPase values were .16 and .49 umol Pi. mg. myosin^{-1}.min.$^{-1}$ respectively, which are very similar to the data of Barany (1967) for lower mammalian muscle. Such ATPase activities would suggest contraction times of 58 msec. for the soleus and 37 msec. for the vastus lateralis. Subsequent to this study, the difficulty in measuring the APTase activity in different fiber types was overcome by a technique developed by Essen et al. (1975) in which individual fibers of a specific type could be dissected out of a mixed muscle sample and pooled in order to perform biochemical assays. Using this method, Essen et al. (1975) found that the biochemical activity of fast-twitch myosin ATPase was 2.8 times greater than its activity in slow fibers. Thorstensson (1976) reported a FT to ST activity ratio for Mg^{+}-stimulated ATPase activity in pooled fibers

from the vastus lateralis muscle of approximately 3:1. These activity ratios seem to confirm what had earlier been predicted by Taylor et al. (1974) by extrapolation.

The difficulty in measuring the isometric twitch contraction time of human muscle fibers has been partially overcome by the development of indwelling needle transducers, which, when used in conjunction with histochemical analysis, can make possible the correlation of contractile properties with histochemical characteristics (Ianuzzo, 1976). In one such study by Buchthal and Schmalbruch (1970) the twitch contraction times of small bundles of fibers were recorded in in vivo muscles of normal subjects and correlated with the mitochondrial content of the fibers of the same muscles. A profound difference in the number and distribution of mitochondria exists in the fast and slow fibers of both humans and animals and can be used as a method to differentiate these fibers at the ultrastructural level (Gauthier, 1969; Schmalbruch & Kamieniecka, 1974; Schafig et al., 1966). Buchthal and Schmalbruch (1970) found that in the muscles which had a high percent of fibers rich in mitochondria (ST), the contraction times were greater than 60 msec. Fibers which were poor in mitochondria (FT) had contraction times less than 60 msec. The correlation between the isometric twitch contraction times of the fiber bundles and their mitochondrial content was quite high. For example, in the triceps surae muscles, 90 percent of the fibers were rich in mitochondria and 90 to 95 percent of the contraction times were greater than 60 msec. In the biceps brachii muscle,

one third of the fibers were rich in mitochondria and 30 percent of their twitch contraction times were greater than 60 msec. Trained subjects exhibited the same spectrum of contraction times as the untrained in the biceps muscle. This same observation was made by Taylor et al. (1974), who interpreted this finding as indicating that there is probably no large training effect on myosin ATPase activity.

Buchthal, Dahl and Rosenflack (1973) electrically stimulated intact human muscle and found a range of contraction times of 16 to 68 msec. in the gastrocnemius and 52 to 120 msec. in the soleus. Eberstein and Goodgold (1968), who examined the mechanical properties of human skeletal muscle in vitro reported similar values but with a smaller range. The contraction times of fast and slow muscle fiber bundles were 55 to 80 msec. and 100 to 140 msec. respectively.

One additional observation which can be made with respect to the speed of shortening of slow and fast twitch muscles is that the velocity of shortening of corresponding muscles from different animal species varies considerably, with those from small animals being generally more rapid (Barany, 1967; Hill, 1950). This observation was first made by Hill (1950) who stated that the speed of sarcomere shortening of the same muscles of different species is inversely proportional to body size. Within a species, muscles that are required to move light structures such as the extraocular muscles also have higher intrinsic speeds of shortening than those required to move larger structures such as the hind limb muscles (Close, 1972).

Skeletal Muscle Fiber Types: The Isoenzymes of Skeletal Muscle Myosin ATPase

Extensive study of the myosin molecule has disclosed marked differences in the properties of the myosin from fast and slow muscles of the same species and these might account for the differences in ATPase activity. These differences may be summarized as follows (Syrovy & Gutmann, 1975):

(1) fast muscle myosin is alkaline stable, whereas the ATPase of slow muscle is alkaline labile;

(2) slow muscle myosin is more resistent to tryptic digestion, trypsin being a proteolytic enzyme which splits the myosin molecule into its LMM and HMM portions;

(3) slow muscle myosin has no 3-methylhistidine, but fast muscle myosin contains two such residues;

(4) the sulfhydryl groups of fast muscle myosin are more reactive than those of slow muscle myosin;

(5) there are different patterns of light chains in fast and slow myosin.

Of all these differences, the latter one has received the most attention. There are four light chains in the head of a myosin molecule. Two of these light chains are identical while the remaining two, which are phosphorylated on a serine side chain, differ quantitatively and qualitatively in slow and fast myosin. Removal of these latter components from myosin results in a loss of its ATPase activity, but the enzymatic activity can be partially restored upon the addition of these components back to the heavy fraction of myosin (Stracher, 1969). They are therefore thought to be involved in regulating the hydrolytic activity of myosin (Lowry & Risby, 1971; Sarkar et al., 1971;

Weeds & Pope, 1971). Although there is considerable disagreement as to the number of electrophorectically distinguishable light chain components and their molecular weights in the myosin prepared from different muscles in various species (Close, 1972), the results of many studies (Perrie & Perry, 1970; Sarkar et al., 1971; Weeds & Pope, 1971; Sreter et al., 1966; Trayer & Perry, 1966) suggest that myosin exists in at least two different molecular forms. Unlike other isoenzyme systems such as LDH, in which the isoenzyme pattern found in different types of muscle cells is due to a difference in the proportional distribution of the same two subunits, the myosin isoenzyme of fast muscle is distinguishable from that of slow muscle by a specific set of polypeptide chains (Sarkar et al., 1971). More recent work by Pette and Schnez (1977) has shown that FOG fibers are indistinguishable, with respect to their light chain pattern, from FG fibers in rabbit poas and soleus muscle. Trayer and Perry (1966) suggested that foetal myosin represents the most primitive type of skeletal muscle myosin whereas that present in fast muscle represents the highest degree of specialization, possessing a very active ATPase and hence, the capacity to hydrolyze ATP at the fast rate required by the rapid contractile response characteristic of this tissue. Myosin from slow muscle would represent an intermediate form.

Few reports have dealt with the structural differences in myosin prepared from human muscle and, as a result, the basis of

its heterogeneity with respect to its ATPase activity is poorly understood (Libera et al., 1978). In one study by Bailin (1976), it was found that the myosin from the vastus lateralis and vastus medialis muscle contained at least three different light chains which were designated as L1, L2 and L3. These light chains resembled those found in rabbit fast muscle (Pette & Schnez, 1977). Libera et al. (1978) also isolated the myosin from many different human muscles and found them all very similar with regards to their electrophoretic pattern of light chains. The myosins consisted of two major bands LC1 and LC2 and a third minor band, LC3. The light chains from muscles which were predominantly slow (soleus) and fast (rectus abdominus) were very similar: the primary variability observed among the several myosin preparations concerned the LC3 material, which in some cases was present in trace amounts and in other instances virtually absent. The only evidence for the presence of slow type light chains was found in the myosin obtained from a pathological muscle sample (nemaline myopathy). The myosins could, however, be divided into two main catogories according to the peptide composition of tryptic HMM. The peptide pattern found within the human rectus abdominus and vastus lateralis muscles closely resembled the two banded pattern of animal fast muscle HMM, while in the soleus muscle, the pattern appeared to be similar to that of tryptic HMM from rabbit soleus muscle. Libera et al. (1978) concluded that the difference in the HMM portion of the myosin molecule is the only structural feature which can distinguish the "fast" from the "slow" form of the myosin isoenzyme in human muscle.

Skeletal Muscle Fiber Types: Regulation of the Isometric Twitch Contraction Time

Regulation of the isometric twitch contraction time of skeletal muscle fibers has been ascribed to the activity of myosin-ATPase and to the rate of Ca^{++} uptake by the sarcoplasmic reticulum (Brody, 1976; Burke & Edgerton, 1975). The rate of Ca^{++} uptake is thought to play a secondary role in determining the isometric twitch contraction time since Sexton and Gerstein (1967) have shown that there is still a big difference in the twitch time of fast and slow fibers after glycerol extraction and activation with ATP.

In fast twitch human and animal fibers, the sarcoplasmic reticulum is more extensive and more highly organized than in the slow twitch fibers (Shafiq et al., 1966; Murata & Ogata, 1969; Gauthier & Padykula, 1966). The number of triadic junctions per area of longitutional sections of fast muscle fibers is also greater than in the slow twitch fibers (Shafiq et al., 1966; Gauthier, 1969; Schmalbruch & Kamieniecka, 1974). Together, the more extensive development of the sarcoplasmic reticulum and the higher amount of triadic junctions would give Ca^{++} a shorter diffusion distance and thereby initiate the cross-bridge coupling process at a faster rate in these fibers (Bolstad & Ersland, 1978).

Fast twitch fibers have also been shown to differ from slow fibers in the rate at which their fragmented sarcoplasmic reticulum can accumulate Ca^{++}. In the studies by Fiehn and Peter

(1971) and Briggs et al. (1977), which compared the yield and biochemical characteristics of the fragmented sarcoplasmic reticulum from the fast and slow muscles of animals, it was found that the rate of accumulation was significantly greater in the fast fibers. This also appears to be the case in human muscles (Samaha & Gergeley, 1965), although the difference in the two types of fibers is not as pronounced as it is in animal muscles. A greater rate of accumulation of Ca^{++} in the fast fibers coupled with a greater amount of sarcoplasmic reticulum would favour an early and rapid relaxation of the myofibrils and consequently, a shorter isometric twitch contraction time and a more rapid rise in twitch tension (Brody, 1976).

In the rat, it can be shown that two muscles with a similar myosin ATPase activity can have different twitch contraction times by virtue of a difference in the ability of their sarcotublules to accumulate Ca^{++} (Brody, 1976). Following the electrical stimulation of a fast muscle at a frequency characteristic of that of a slow motorneuron, it has also been observed that the time to peak of an isometric twitch contraction can increase long before any changes in the myosin ATPase activity or in the pattern of the myosin light chains takes place (Pette et al., 1976). The increase in the time to peak tension in this experiment could be explained by a slower reaccumulation of Ca^{++} by the stimulated fibers. This type of evidence suggests that the rate of Ca^{++} uptake by the sarcoplasmic reticulum of different fiber types does not necessarily play a secondary role in determining the isometric

twitch contraction time, but rather, that it is probably equally as important as the myosin ATPase activity in this respect.

When radioactive Ca^{++} is injected into rat muscle, its distribution between the organelles differs with respect to the type of muscle (Patriarca & Carafoli, 1969). The Ca^{++} pool associated with the sarcoplasmic reticulum is higher in fast muscle, whereas the amount of mitochondrial Ca^{++} is higher, and the sarcoplasmic Ca^{++} almost negligible, in slow muscle. Thus, in slow muscle, the mitochondria function as the Ca^{++} segregating organelles by supplementing the activity of the sarcoplasmic reticulum, while in the fast muscles, the sarcoplasmic reticulum alone seems able to fulfill this role.

Skeletal Muscle Fiber Types: Contractile Force

In some lower mammalian species, motor units composed of fast-contracting fibers not only have a higher intrinsic speed of shortening, but they can also produce greater twitch and tetanic tensions than the slow motor units (Burke & Tsairis, 1973; Barany & Close, 1971). The amount of tension that a motor unit can produce is dependant upon the fiber area, the innervation ratio and the specific tension output of the muscle fibers (Burke & Tsairis, 1973). Burke and Tsairis (1973) found that fast contracting motor units in cat gastrocnemious muscle could produce from 30-120 grams of tetanic tension, while their slower counterparts could only produce from 1.6 - 12.6 grams of tetanic tension. The slow motor units contained on the average, about as many fibers as the fast contracting units, so that their small tension outputs were probably

due to the small area of the individual fibers and their relatively small specific tension outputs. The specific tension output per unit area of the fast motor units was 1.5-2.5 $kg \cdot cm^{-1}$, while the specific tension output of the slow motor units was only .6 $kg \cdot cm^{-1}$. Barany and Close (1971) also found that fast contracting motor units of the rat could produce 3 $kg \cdot cm^{-1}$ of tension per unit area whereas the slow motor units produced only 2.09 $kg \cdot cm^{-1}$ of tension. They pointed out that this difference is not necessarily due to a difference in the number of filament cross bridges per half sarcomere because the myosin yield and content per gram of muscle was approximately the same in the fast and slow muscles. The differences in specific tension output might then have reflected a difference in the intrinsic strength of the contractile materials of the fast and slow fibers (Sexton & Gerstein, 1967), or might have been due to some extrinsic factors influencing activation (Close, 1972).

Twitch tensions of motor units have also been recorded in human muscles (Sirca & McComas, 1971; Milner-Brown et al., 1973; Desmedt, 1977). In the study of Sirca and McComas (1971), the recorded twitch tensions of single motor units in the extensor hallucis brevis muscle varied considerably and ranged from 2 - 14 grams. The twitch tensions produced by the first dorsal interosseous muscle of the hand have also been shown to vary widely from .1 - 10 grams (Milner-Brown et al., 1973). Thus, human motor units appear to exhibit a wide range of tensions as has been reported by Burke and Tsairis (1973) for lower mammalian muscle.

However, unlike the motor units in animal muscle where those generating the largest tensions were also those with the fast contraction times, no correlation between twitch time and tension was found by Sirca and McComas or Milner-Brown et al. The first indication that such a correlation may exist can be found in a more recent study by Desmedt (1977). In the first interosseous muscle, he found that the fibers which displayed an average time to peak tension of 65 msec. reached a peak tension of only .3 grams, while those with average twitch times of 39 msec. achieved peak tensions of 1.5 grams. This would suggest that not only muscle quantity but also the quality of muscle might be important to the ability to develop strength.

The relationship between the muscle fiber composition and isometric leg strength has also been studied though the results are somewhat controversial and not yet conclusive. Tesch and Karlsson (1978) reported a linear positive correlation between maximal isometric leg strength and the relative distribution of fast twitch fibers in the vastus lateralis. Both relative and absolute isometric leg strength was also shown by Komi et al. (1977a), Komi and Karlsson (1978) and Mero et al. (1981) to correlate with FT fiber number. However, this has not always been shown to be the case, as Thorstensson (1976), Clarkson et al. (1980; 1982), Gregor et al. (1979) and Edstrom and Ekblom (1972) failed to observe any relationship between the relative maximum isometric leg strength and fiber type. Nevertheless, as Thorstensson suggested, even if there is no difference

in the strength of the two fiber types, both the intrinsic speed of shortening and the higher rate of rise in tension in the FT fibers should enable a muscle with a high proportion of these fibers to sustain more force at fast motion speeds.

Skeletal Muscle Fiber Types: Force-Velocity and Force-Time Curves

The difference in the shape of the force-velocity and force-time curves of fast and slow twitch muscles gives some insight into the functional significance of the differences in the intrinsic properties of the contractile material of these muscles (Close, 1972).

Both Wells (1965) and Close (1964) have studied the force-velocity relations of fast and slow muscles of the rat. The force-velocity curves obtained by Close and Wells are illustrated in Figures 2-2 and 2-3 respectively.

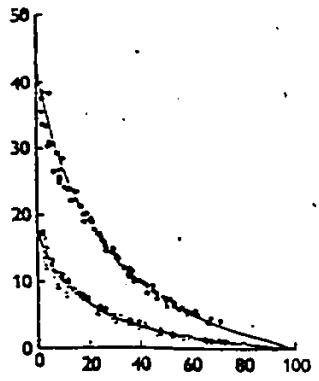


Figure 2-2 The relation between the load and speed of shortening during after-loaded isotonic contractions of EDL (o) and SOL (o) muscles from 100 day old rats. The ordinate is the velocity of shortening per 1000 sarcomeres and the abscissa is the load expressed as the percentage of the load equivalent to the maximum isometric tetanic tension (Close, 1964).

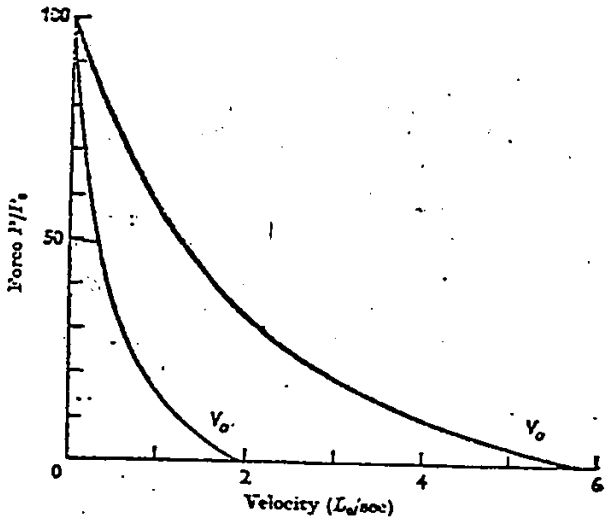


Figure 2-3 Relation between force and shortening velocity derived from anterior tibial (heavy curve) and soleus muscles in rats. The force on the ordinate is expressed as a fraction of maximal force. The velocity on the abscissa is maximal shortening velocity in lengths per second. (Wells, 1965).

Both graphs show that the general qualitative character of the curves are similar in the two types of muscle. However, at any given speed of shortening less than Vo (the maximum intrinsic speed of shortening) a fast muscle can produce more force relative to the maximal isometric tension than a slow muscle. Similarly, at any relative load less than Po (maximal isometric tension) fast fibers can shorten with a greater velocity. This situation arises primarily because of the difference in the ATPase activity of the myosin in fast and slow fibers (Close, 1964). The variation of the force at different velocities of shortening is a result of variations in the number of cross bridges that are attached and

generating tension at any one time. This variation in the number of cross bridges that are attached at any given velocity is in turn, governed by the rate of turnover for the cross bridges of a particular muscle (Huxley, 1972). This being the case, then the number of tension-generating cross bridges would always be such as to match the load, and the velocity of shortening would then arrive at a value which, in the steady state, would maintain that number constant. The velocity at which the correct number of cross bridges could be maintained would depend upon the rate of cross bridge turnover, which is determined by the myosin ATPase activity. Because fast muscle has a higher ATPase activity, the average rate of cross bridge turnover will be greater than a slow muscle's while maintaining the same load. Accordingly, the velocity of shortening and the amount of ATP used per second is high, so the power of the whole muscle is high. In a slow-contracting muscle, every cross bridge may turnover several times, but the slower average rate of turnover of the cross bridges reduces the power output of the whole muscle.

The force-velocity relationship of human knee extensor muscles has been studied by Thorstensson (1976) using an isokinetic dynamometer, which permits the force output of different muscles during maximal contractions to be recorded at different muscle shortening velocities. Figures 2-4 and 2-5 from Thorstensson's study show that:

(1) at high shortening velocities a difference due to muscle fiber composition does exist;

(2) there is a difference in the peak torque output during dynamic contractions depending upon muscle fiber composition;

(3) when peak torque at the highest angular velocity (180 degrees per second) is expressed in relation to the Po of each subject (Fig.2-5), a significant correlation is obtained between this value and the proportion of FT fibers. The sprinters and jumpers who had the highest percent of FT fibers by area, also had the highest peak torque values at an angular velocity of 180 degrees per second.

Thorstensson's results have since been supported by the work of Gregor et al. (1979) and Coyle et al. (1979), who studied torque-velocity relationships and muscle fiber composition in elite female athletes and untrained males. Together, their findings illustrate that there is a relationship between muscular performance with respect to maximal contraction speed and the ability to produce force at high angular velocities and the distribution of FT muscle fibers.

The form of the force-time curve in human muscle is also influenced by the relative proportion and absolute area of FT fibers (Komi & Viitasalo, 1978). A recording of the force-time characteristics of muscular contraction expresses the rate at which tension is developed. Komi and Viitasalo (1978) investigated how the form of the force-time curve was influenced by the skeletal muscle fiber composition and found that the time of tension development in bilateral knee extension at force levels less than 90 percent of maximum strength, was positively related to the number of ST fibers. That is, as the percent of ST fibers increased, the time taken to reach any force level also increased. When the contraction is isokinetic, there is also a significant relationship (r=.68) between the percent

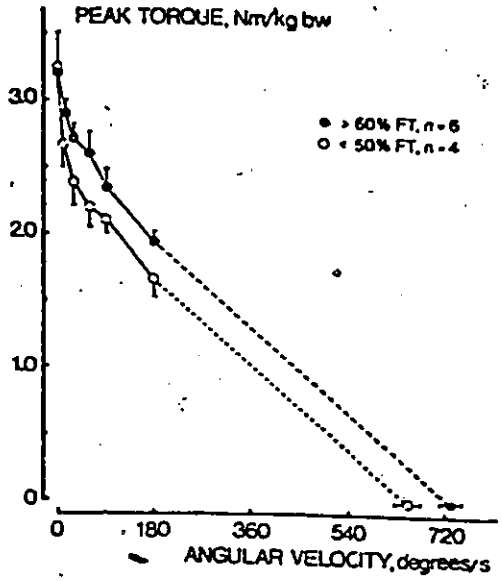


Figure 2-4 Peak torque values, expressed as Nm per kg of body-weight vs. angular velocity in degrees per s for two groups of subjects differing in fibre composition. The torque-velocity curves were extrapolated to the approximated values for maximal velocity of knee-extension. Values are means + or - SE.

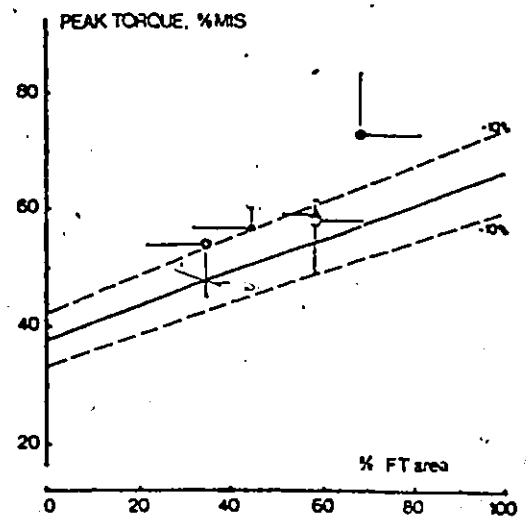


Figure 2-5 Peak torque, expressed as a percent of maximal isometric strength vs. the relative area of fast twitch fibres. The regression line ($y=0.29x-38$, $r=0.46$, $p<0.05$) was drawn from individual values for 25 habitually active men (range 39-80% FT area) and extrapolated to the extreme points. Also included are mean values (+ or - SE) for elite athletes in orienteering (●, n=7) competition walking (★, n=7), downhill skiing (▲, n=6), sprinting and jumping (●, n=9), and an age-matched group of sedentary men (○, n=10).

of FT fibers and the time required to accelerate to a constant velocity. This is consistent with animal experiments which show that both the rise time of isometric twitch contractions and the 1/2 relaxation times are faster in FT fibers and correlate with the ability of the sarcoplasmic reticulum to release and take up Ca^{++} (Brody, 1976).

The mechanical properties of lower mammalian and human FT fibers indicate their probable function, in so far as these fibers would appear to be designed for use during short-term powerful phasic activity (Close, 1972). Measurements of the efficiency with which fast and slow muscles can perform isotonic work and maintain isometric tension, as well as motor unit recruitment studies, tend to confirm this statement.

Awan and Goldspink (1970) reported that the fast biceps brachii muscle of the guinea pig is more efficent in performing isotonic work than the slow soleus muscle. The results of this experiment showed that although the biceps muscle uses more CP upon stimulation than does the soleus, it performs much more work. The efficiency, when expressed as work done per umole of ATP, was found to be more than twice as high in the case of the fast muscle. Awan and Goldspink suggested that the longer cross bridge engagement time of the soleus, which causes it to shorten more slowly, also makes the muscle less efficient for performing work because the cross bridges that are pulling are working against those that are holding.

In another study by Goldspink et al. (1970) the utilization of ATP by the biceps brachii, diaphragm and EDL muscles of the

guinea pig in developing and maintaining isometric tension was studied. The amount of tension developed and maintained per micromole of ATP for each of these muscles was as follows: 30.8×10^3, 36.6×10^3 and 191×10^3 $g.sec^{-1} .g^{-1}$. The efficiency of the muscles was inversely proportional to the rate of contraction, suggesting that the efficiency in maintaining tension is governed by the rate at which the cross bridges make and break. Goldspink et al. (1970) concluded that the evolution of contraction of different muscles appears to have been concomitant with the evolution of their function. The function of slow twitch muscles like the soleus is to maintain the position of the limbs and the skeleton. Therefore, this muscle is required to maintain an isometric tension for long periods of time and in order to do so it must function economically; hence, the long cross bridge engagement time. Fast muscles, on the other hand, are required to do isotonic work and it appears that in order to do this economically, they must have a fast ATPase activity and a short cross bridge engagement time so that the cross bridges are not continually working against themselves whilst the muscle is shortening.

Data comparable to that of Goldspink et al. (1970) is not yet available for human muscle, although the energy turnover in contracting muscle has been studied by measuring the rate of temperature rise during isometric contractions of the biceps and soleus muscles (Bolstad & Ersland, 1978). In this study, a linear relationship between the rate of temperature rise and force intensity was demonstrated in the biceps and soleus muscles.

Furthermore, the rate of heat production at maximal voluntary strength showed a positive correlation to the percentage of FT fibers in these muscles (r=.90). The rate of heat production at maximal voluntary strength averaged 1.46 $cal.min^{-1}.g^{-1}$ in the biceps and .5 $cal.min^{-1}.g^{-1}$ in the soleus. The area occupied by the FT fibers in the biopsies taken from these muscles were 62 and 8 percent respectively. Linear extrapolation indicated that a muscle composed exclusively of FT fibers would have a maximal energy turnover six times that of a muscle composed only of ST fibers. This is comparable to the difference in the energy turnover reported by Goldspink et al. (1970) for the fast and slow animal muscles that they studied.

The histochemical glycogen depletion pattern of skeletal muscle fiber types during exercise has been used extensively as a means by which to assess the dynamic usage of motor units in human muscle. Glycogen depletion studies have shown that when an individual performs work at an intensity below his or her maximal oxygen uptake, there is a greater recruitment of ST fibers (Gollnick et al., 1973b; 1974b; Costill et al., 1975). However, when the workload exceeds an individual's maximal oxygen uptake, there is a primary reliance upon the FT fibers (Gollnick et al., 1973c; 1974b). The reliance upon FT fibers when there is a demand for forceful and/or rapid contractions is in keeping with their mechanical properties and their greater relative efficiency for performing work.

The Distribution of Skeletal Muscle Fiber Types in Untrained Men and Athletes: Significance to Athletic Performance.

Table 2-2, which was compiled from various reports in the literature, clearly demonstrates the considerable variation in the fiber composition which exists in the same muscles of different untrained individuals.

Table 2-2 The Distrubution of Fiber Types in Various Muscles of Untrained Men

Muscle	No. of subjects	$\bar{X}$%ST	Range	Sources
Biceps	14	48.9	27-61	Edstrom, 1968 Edstrom & Nystrom,1969
Deltoid	66	42	14-98	Gollnick et al.,1972
Gastroc.	61	37	27-82	Costill et al.,1973 Edstrom & Nystrom,1969 Edgerton et al.,1975 Gollnick et al.,1974
Soleus	45	68.3	58-100	Edgerton et al.,1975 Edstrom & Nystrom,1969 Gollnick et al.,1974
Vastus Lateralis	164	57.8	13-96	Gollnick et al.,1972;1974 Edstrom & Nystrom, 1969 Edstrom & Ekblom,1972 Edgerton et al.,1975 Prince et al.,1976 Thorstensson,1976 Larsson, 1978

Although there is a wide range of fiber compositions in the same muscles of different individuals, some similarities seem to exist. Muscles like the vastus lateralis, gastrocnemius, biceps and the deltoid appear to average approximetly 50% ST and 50% FT. The soleus on the other hand, generally has a greater percentage of ST fibers. The triceps muscle, although not shown here, has

been said to posses about 10 to 30% more FT fibers than any other arm muscle (Johnson et al., 1973; Buchthal & Schmalbruch, 1970).

The variability in the proportion of fiber types present in most human muscle is further compounded by the effects of fiber size, since in the majority of muscles from most untrained individuals, the FT fibers have a greater cross-sectional area than the ST fibers (Edström & Nystrom, 1969; Gollnick et al., 1972; Edstrom & Ekblom, 1972; Prince et al., 1976; Thorstensson, 1976; Larsson, 1978). This fact may in part, explain why Desmedt (1977) found that FT muscle fibers can produce greater twitch tensions than the ST fibers.

The "twin study" concept has been applied to human skeletal muscle by Komi et al. (1977b) in order to assess the significance of the genetic component in determining the interindividual variation observed in the skeletal muscle fiber composition. This study, conducted on monozygous (MZ) and dizygous (DZ) twins, disclosed that in contrast to the DZ twins, the MZ twins of both sexes had identical muscle fiber compositions. The heritability estimate for this parameter was 99.5 and 92.8 % for males and females respectively.

Additional twin studies (Klissouras, 1971; Komi et al., 1976) have been designed to estimate the heritability of maximal aerobic, anaerobic and alactic power. Klissouras's study (1971) revealed that the variability in aerobic and anaerobic power is genetically determined by 93.4 and 81.4% respectively. The

maximal blood lactate was used as an index of the maximal anaerobic capacity and an asymptote of oxygen consumption following a series of runs of progressively increasing intensity on a treadmill was used as the primary criterion of maximal oxygen uptake. Komi et al. (1976) reported that maximal alactic power, as measured by the method of Margaria et al. (1966), is also nearly identical in MZ twins. The heritability index for the male twins was 97.8%. Based on these observations, it could be concluded that there is a predominent genetic influence on the skeletal muscle fiber composition and on an individual's capacity to perform exercise. Thus, there might also be an interdependence between the skeletal muscle fiber composition and an individual's performance capacity. Descriptive data has shown a relationship between the type of sport activity at which an individual is successful and his/her muscle fiber composition. This is evident in Table 2-3, which shows that endurance athletes have a predominance of ST fibers, while sprinters have a predominance of FT fibers.

Because the distribution of FT and ST fibers is largely governed by genetic factors, many investigators have concluded that the predominance of one fiber type in a given category of athletes is a consequence of "natural selection" (Gollnick et al., 1972; Thorstensson et al., 1977; Costill et al., 1976). An athlete's success in strength, speed or endurance events thus results, in part, from his or her genetic endowment. If such is the case, then one would expect that among the elite athletes in power events like sprinting, jumping or throwing, "natural selection"

Table 2-3 Fiber Distributions and Sizes in Athletes and Untrained Men

Subjects	Muscle	$\bar{X}$%ST	FT/ST area ratios	Source
untrained: n=2		51.8	.95	
sprinters: n=4		25.7	1.03	Costill et al.,
distance runners: n=5	Gastroc.	69.4	1.15	1976
long-high jumper: n=5		47.7	1.31	
shot-put & discus throwers: n=6		44.4	1.18	
untrained: n=3	Vastus	32.6	1.27	Gollnick et al.,
sprinter: n=1	Lateralis	26	1.25	1972
distance runners: n=2		72.5	1.21	
weight lifters: n=2		24.6	1.26	
untrained: n=8	Vastus	48	1.1	Edstrom &
endurance runners: n=6	Lateralis	52	1.1	Ekblom, 1972
weight lifters: n=8		44	1.7	
untrained: n=4	Vastus	73.5	1.13	Prince et al.,
power lifters: n=3	Lateralis	55.5	1.56	1976
endurance runners: n=3		83.9	.88	
untrained: n=10	Vastus	44	1.2	Thorstensson
sprinters/jumpers: n=9	Lateralis	39	1.5	et al., 1977
race walkers: n=7		59	1.25	
orienteers: n=7		67	1.1	
untrained: n=23		46	-	
power events: n=6	Vastus	37	-	Komi et al.,
X-country skiing: n=17	Lateralis	63	-	1977a
distance runners: n=8		88	-	
sprinters: n=3		39+	-	
pentathletes: n=6	Vastus	54+	-	
middle distance runners: n=9	Lateralis	63+	-	Gregor et al.,
distance runners: n=4		73+	-	1979

+ denotes that the ST fiber population represents a combination of both fiber size and number

would have left only those with a high proportion of FT fibers, since these fibers are capable of producing substantial amounts of force at fast motion speeds (Thorstensson, et al., 1977). Although the track and field sprinters do have the lowest percent of ST fibers in all cases in Table 2-3, the jumpers, throwers and lifters do not appear to have the same predominance of FT fibers. However, it is interesting to note that the FT/ST fiber area ratios of these athletes are greater than those of the endurance athletes, and thus, a higher proportion of FT fiber, in relation to the total muscle volume, could be achieved despite a low relative number of FT fibers (Thorstensson et al., 1977). One long jumper in the study of Thorstensson et al. (1977), who had only 45 % FT fibers, had a FT/ST area ratio of 2.0. Similarly, two of the long jumpers studied by Costill et al. (1976) also had a comparatively low percent of FT fibers (51 & 57 %) whereas the FT/ST area ratios were 1.41 and 1.35 respectively.

Komi et al. (1977a) elaborated on the subject of relating the muscle fiber composition to athletic performance capacity by studying 87 athletes of international calibre representing sports events which differed in their requirements for muscle force, speed and endurance. The muscle fiber distribution expressed as the percent of FT fibers, showed the highest mean value of 63±19 % in the power athletes. The long distance runners had on the average, only 12±6 % FT fibers in their vastus lateralis muscle. The power athletes also achieved the highest power scores and vertical velocities as measured by the method of Margaria et al. (1966). Whether this is the result of training and/or the genetic endowment

of these athletes is difficult to determine. The fact that the muscle fiber composition of the power athletes did not differ significantly from that of the controls (54±10 %) suggests that training, rather than the muscle fiber composition, is the principle factor accounting for the superior performance of the power athletes.

Komi et al.. (1977a) also found that the vertical velocity and relative isometric leg strength were correlated with FT fiber number in all male athletes regardless of their event specialization. Similar results were reported by Mero et al. (1981) in a more recent study on the relationships between the muscle fiber composition, maximal running speed and a number of other variables. The subjects of this study were 25 male sprinters who were divided, for comparison, into three groups on the basis of their precent FT fibers in the vastus lateralis muscle. The FT fiber distribution correlated with maximal running velocity ($r=.58$; $p<0.01$), stride rate ($r=.67$; $p<0.001$), vertical jump height ($r=.47$; $p<0.05$), and maximal absolute isometric force ($r=.47$; $p<0.05$). These results together with those of Komi et al. (1977a) imply that while training may determine an athlete's ultimate capacity for performance, success in events which require high muscle power may also, in part, be predetermined by the muscle fiber composition. Studies on individuals who have not been exposed to extended periods of training are needed to determine just how significant the genetic component is in determining power performance. Only two such studies, with conflicting results, have been reported (Komi and Bosco,1978;

Campbell et al. 1979). Komi and Bosco reported that untrained individuals with more than 60 percent of FT fibers in their vastus lateralis can jump higher than those with less than 50 percent FT fibers. A correlation coefficient of .48 was obtained between the height of the vertical jump and the percent of FT fibers. The mechanical parameters (average force, net impulse and mechanical power) which were calculated from force platform analysis of the vertical jump, also correlated significantly with FT fiber number. Campbell et al. (1979) found no relationship between the percent FT fiber content of the vastus lateralis and jumping performance in a group of untrained women.

The importance of the hereditary factor with respect to the muscle fiber composition is emphasized when one considers that the number and type of fibers in a muscle becomes fixed during embryonic and early infantile development (Tomaneck & Colling-Saltin, 1977) and cannot be modified by either strenth or endurance training (Gollnick et al., 1973a; Thorstensson, 1976; Thorstensson et al., 1975).

Although training does not appear to cause a change in the muscle fiber distribution when fibers are classified into two main groups according to contractile speed, an increase in the percentage of high oxidative at the expense of low oxidative fast fibers has been reported to occur in man and animals following endurance training (Anderson & Henricksson, 1977; Janson & Kaijser, 1976; Edgerton et al., 1972; Nygaard Jensen, 1976; Barnard et al., 1970). Similarly, following strength and high intensity training, an increase in the Type IIb fibers may occur at the expense of the

Type IIa fibers (Prince et al., 1976). This process is commonly referred to, or has been interpreted as, a training-induced conversion of Type IIa to Type IIb fibers or vice versa. Prolonged endurance training also seems to be able to modify the subtle differences in the pH sensitivity of the ATPase reaction within the subgroups of the fast fibers, although it has not yet been established if these subtle differences are quantitative and/or qualitative in nature and whether they are of any functional significance (Janson & Kaijser, 1976).

The proportion of ST and FT muscle fibers can definitely be altered in animal muscle following the operative cross-union of motor nerves (Buller et al., 1960a; 1960b; Barany & Close, 1971), chronic electrical stimulation (Salmons & Vrbova, 1969), surgical excision of synergists and denervation (Gutmann et al., 1971). However, these procedures involve considerable interference with the physiological situation of the test muscle (Burke & Edgerton, 1975). Only one study, that by Syrovy et al. (1972), has found that a normal physiological type of overload (swimming) can alter both the ATPase activity and the proportion of fibers within the exercised muscle. These changes took place in the muscles of 14 day old rats and not in the muscles of 105 day old rats, suggesting that the muscle fiber composition can be altered with training only when differentiation and ATPase synthesis during development are not yet complete. Others (Baldwin et al., 1975; Staudte et al., 1973) have found that the ATPase activity and twitch contraction time in the hindlimb muscles of animals can be changed following training without any evidence of a shift

in the muscle fiber composition. Two possible mechanisms which have been suggested to explain these changes are changes associated with the Ca^{++} transport system (Staudte et al., 1973) and conformational changes in the myosin molecule occurring at or near its active sites, such that availability of its regulatory sulfhydryl groups may modify its ATPase activity (Malhotra et al., 1976).

The Tests and Measurement of Muscular Power

The vertical jump is one of the oldest performance tests in physical education (Smith, 1961). Originally designed by D.A. Sargent in 1921, the "Physical Test of Man" was considered to be a test of neuromuscular efficiency involving strength, speed, coordination and driving power (Henry, 1942). McCloy (1932) stated that the Sargent jump and the standing broad jump were the best available tests for predicting power relative to the body weight and size of an individual, by virtue of their significant relationship to success in selected track and field events. Jumping ability was thought to best reflect the way in which force could combine with the highest possible contraction velocity of the muscles to project the body upward or outward to achieve maximum height or distance. McCloy also stated that the sprinting, throwing and jumping events of track and field were "power events" because they all require a maximum, or a series of maximum, contractions over a minimum period of time. McCloy's statements concerning the elements and events of power have since been the premise upon which most attempts to measure power have been based. Power is still measured by an individual's performance in jumping,

sprinting or throwing, even though the results of these tests are at best, only simple expressions of work performed, distances covered or time elasped (Barlow, 1970).

One of the earliest and most comprehensive attempts to measure the power developed during a standing vertical jump in its true mechanical sense, as the rate of doing work, was made by Gerrish (1934). Gerrish designed his own force meter, which transmitted the force of a jump from a platform to a pressure gauge. By timing the rate of change in the center of gravity of the subjects during a vertical jump using motion photography, he was able to determine the velocity of the center of gravity. A power curve could then be constructed by multiplying the force and the velocity. In Gerrish's analysis of 270 jumps of 45 college men, he found that the jumpers demonstrated a mean peak instantaneous power score of 5.4 hp (4027 watts).

The accuracy of Gerrish's measurements has since been confirmed by Davies and Rennie (1968) and Cavagna et al. (1971a) using a force platform. A force platform is an apparatus which, in its simplest form, consists of a baseboard fitted with stain gauges to detect mechanical forces applied to the platform in multidimensional planes. The peak instantaneous power outputs recorded by Davies and Rennie (1968) for men (n=7) and women (n=8) were 5.22±1.19 and 3.15±.48 hp (3893±887 watts and 2349±348 watts) respectively. These results were comparable to those of Cavagna et al. (1971a), whose subjects (5 males and 2 females) obtained a mean peak instantaneous power score of 4.66 hp (3475 watts).

Gray, Start and Glencross (1962a) devised a test to measure average leg power without the use of a force platform. This test entailed calculating the rate of change of the position of the center of gravity of an individual while executing a modified Sargent jump. The modification of the original Sargent jump involved eliminating the upward thrust of the arms and extension of the trunk during the jump by having the subject hold one arm behind the back while the preferred hand is held firmly against the side of the head. The jumper also assumes a full squat before jumping. The total work done in elevating the body was defined as a function of the body weight of the individual times the sum of the distances through which the center of gravity was moved, from the full squat position to the point of take-off (h1) and from take-off to the peak of the jump (h2). By using the third and first laws of motion, Gray et al. were able to calculate the velocity with which the subjects left the ground, the acceleration provided by the legs, and the time during which the feet were in contact with the ground ($t=h1\sqrt{\frac{2}{gh2}}$). In this time, an amount of work equal to the body weight times the sum of h1 and h2 had been done. The average power could then be calculated as the total work divided by the time taken to do the work. The mean score achieved by 80 male students was 1.65 hp. (1230 watts).

The assumptions and mathematical logic upon which the validity of Gray et al.'s (1962a) "vertical power jump" rests have been tested by others (Barlow, 1970; Aegerter, 1973; Cavagna et al., 1971a). With the use of high speed cinematography

and precision motion analysis these authors have reported average power scores in the same order of magnitude as those recorded by Gray et al. (1962a).

The average power which can be developed during the vertical jump is somewhat higher than Gray et al's (1962a) figure when the upward thrust of the arms, the extension of the trunk and the preliminary countermovement of the legs are not eliminated.

Komi and Luhtanen (1978) have analyzed the performance of the vertical jump with respect to the contribution of the different body segments to the forces acting on the whole body center of gravity. Relative contribution to the take-off velocity was found to be as follows: knee extension 56%, plantar flexion 22%, trunk extension 10%, armswing 10% and head swing 2%. The upward thrust of the arms and extension of the trunk therefore contribute to the displacement of the body upwards and if these actions are eliminated, power as defined by Gray et al. (1962a) will be reduced.

In most movements, the muscles are stretched before shortening; a positive work phase is preceeded by a negative work phase. Cavagna et al. (1971a) have assessed the effect of this prestretching on the amount of positive work performed, the maximal vertical speed attained and the power output during the vertical jump. They found that when the vertical jump is started from a static flexed position, the vertical velocity begins to increase slowly, whereas when the upward movement is preceeded by stretching (downward movement) it increases at a much greater rate. The counter movement also results in a significant increase in the

velocity of take-off of 6.4%, which corresponded to an increase in the positive work or height of 10 %. The time of positive work was about 55 % greater if no previous stretching took place. Accordingly, the average power output was only 1.64 hp (1223 watts) when the vertical jump was started in the flexed position as compared to 2.73 hp (2036 watts) when the jump was performed immediately after stretching the contracted muscles. Asmussen and Bonde-Peterson (1974) also compared the heights of a vertical jump performed with and without a countermovement and found the height to be higher in the former case. Both Cavagna et al. (1971a) and Asmussen and Bonde-Peterson (1974) contend that the increase in power and jumping performance with the use of a countermovement is due to the elastic rebound of the muscles.

When a muscle or muscles are active during stretching in order to decelerate a limb or body, the contractile components strongly resist lengthening and the structures transmitting the muscle force are set under tension. These structures, called the series elastic components are represented anatomically by the tendons and the contractile component itself. When the series elastic components are stretched, elastic energy is stored and this energy can be utilized during a movement in the opposite direction with two possible effects:

(1) to spare some chemical energy otherwise necessary to perform the mechanical work done during the following shortening phase;

(2) to allow performances which would be impossible, were the transformation of chemical energy into mechanical work by the contractile machinery the only source of power during positive work (Cavagna et al., 1974).

An example of this is given in sprint running. An analysis of the mechanics of sprint running (Cavagna et al., 1971b) has shown that the power developed during the forward push of each step increases to reach a maximum of 2.5 hp (1864 watts) at about 18 $km \cdot hr^{-1}$. The power then tends to decrease when the speed is increased to 25 $km \cdot hr^{-1}$, which is what one might expect on the basis of the force-velocity relationship of the contractile component. However, at speeds greater than 25 $km \cdot hr^{-1}$ trained individuals can increase their power output to reach a maximum of 4 hp (2983 watts). The onset of this increase in power was found to coincide with the onset of a phase in the run in which the contracted muscles were forcibly stretched before shortening. Thus, the high power developed by some sprinters at the highest speeds is made possible by the contribution of the elastic energy stored in the contracted muscles.

On the basis of their observation that both the oxidative reactions and the formation of lactic acid from glycogen are delayed processes that do not contribute to the energy production during the first four to five seconds of exercise, and that during this time the maximum power output can be sustained at the expense of the phosphagen splitting mechanism alone, Margaria and his coworkers (1966) described a method for measuring maximal alactic power. Their test consisted of having a person run up an ordinary staircase two steps at a time at maximal speed. It was found that the speed of progression increased from the start to reach a maximum constant value in 1.5 seconds; the speed was then maintained constant for at least 4 to 5 seconds. Maximal speed of climbing

could be reached sooner by allowing a short two meter sprint on the flat so that the subjects initiated the climbing at approximately the maximal forward velocity. The speed of climbing could then be measured after only .5-1 second, or from the fourth to the twelfth step. Since velocity is constant and no acceleration is taking place after the fourth step, the total work done can be identified with the vertical component, or that involved in lifting the body weight through the height of 8 steps. The time taken to complete the test was measured with an electronic timing device between the fourth and twelfth steps. Thus, both the relative and absolute power output can be calculated directly and expressed as $kgm.kg^{-1}.sec^{-1}$ and $kgm.sec^{-1}$ respectively. Margaria et al. (1966) tested 131 subjects of both sexes and found that the results obtained were very reproducible, with repeated tests giving values whose variability was less than two percent. The alactic power increased with age to reach a maximum of 1.5 to 1.6 $kgm.kg^{-1}.sec$ at 20 - 30 years of age, thereafter decreasing to a value of less than half at about 70 years of age. The mean score of 1.5 $kgm.kg^{-1}.sec^{-1}$ is equivalent to .01 hp or 14.7 watts and represents an energy expenditure of about 50 $kcal.kg^{-1}.hr^{-1}$ assuming 25 percent efficiency in performing the work. This is in agreement with the figure which Margaria et al. (1964) originally obtained with treadmill running. The highest score recorded was 2.8 $kgm.kg^{-1}.sec^{-1}$, which was obtained by an olympic sprinter.

Kalamen (1968) raised the question as to whether or not maximum power could be obtained using Margaria et al.'s (1966)

2 step, 2 meter protocol. He felt that by varying the approach distance and the number of steps to climb in a single stride, a greater power function could be generated. Towards this end, Margaria's test and four variations of it were studied in order to make comparisons on the maximum power output an individual could achieve by running up an ordinary staircase in the following ways:

(1) 2 steps with a 6 meter start;

(2) 3 steps with a 10 meter start;

(3) 3 steps with a 6 meter start;

(4) 4 steps with a 10 meter start.

With the exception of the 4 step, 6 meter start test, which proved impractical since most subjects had difficulty performing it, Kalamen's results indicated that the Margaria test and the remaining three variations of it were all representative of an individual's power output and that any of the four tests could be used as reliable measures. However, the variation which led to the achievement of maximum power was the 3 step, 6 meter start test, during which the body efficiency approached 30 percent. The efficiency coefficient of Margaria's test was .25. The mean power score achieved by the subjects using the 3 step, 6 meter start test was 2.27 $kgm \cdot kg^{-1} \cdot sec^{-1}$ or 22.3 watts, in contrast to a mean of 1.8 $kgm \cdot kg^{-1} \cdot sec^{-1}$ or 17.6 watts using the Margaria test. The superiority of the Margaria-Kalamen test of power must however, be accepted with some reservation since Kalamen did not determine whether the forward velocity from the third to the ninth step was constant.

Glencross (1966a) designed a more versatile instrument to measure the horsepower developed in a variety of single explosive movements of the body. Glencross's "power lever" consisted of a lever arm to which a subject's arm or leg was attached via a type of bicycle pedal capable of moving in both directions through 180 degrees. The lever arm was connected to a pulley from which weights were suspended to provide a resistance against an applied force. Two chronoscopes controlled by adjustable microswitches were used to measure the time of the applied force. Using this power lever, Glencross measured the power developed in 29 movements including preferred and non-preferred leg extension. Leg extension was a composite movement of hip and knee extension and ankle plantar flexion. The average power developed in both of these movements by 85 college men was .45 hp (336 watts).

The Validity of Jumping and Sprinting Performances as Tests of Power

It can be recalled that most motor and physical fitness tests measure power by an individual's performance in jumping and/or running tests, even though a score in inches or time does not conform with the mechanical definition of power as the rate of doing work. A number of investigations have thus been conducted in order to ascertain and analyze the empirical validity of these performance tests by using statistical tests of correlation to study the relationship between power and measures of vertical displacement and/or speed.

Gray, Start and Glencross (1962b) related their vertical power jump to four other types of jumps:

(1) a common vertical jump;

(2) a modified vertical power jump;

(3) a standing broad jump;

(4) a squat jump.

The four tests were scored both as the distance jumped and the work performed. Work performed was determined by mutiplying the body weight by the height or distance jumped. The correlations between the four jumping tests, scored as the work done and the distance jumped, and the criterion test of power were: .989 and .818 for the modified vertical power jump, .84 and .708 for the squat jump, .78 and .685 for the jump and reach and .682 and .607 for the standing broad jump.

Glencross (1966b) reported similar correlations of .71 and .716 between non-preferred leg power and the distances jumped in the vertical and standing broad jumps respectively.

In direct contrast to the results of Gray et al. (1962b) and Glencross (1966b), Considine (1970) found a very limited relationship between his criterion measure of power, which was a vertical jump performed from a force platform, and the vertical jump and reach test, the standing broad jump, a five and ten yard sprint and a five yard sprint with a running start. The correlations were: .508, .355, -.34 and -.299 respectively. Similarly, negligible relationships were recorded by Barlow (1970) and Aergerter (1973) between vertical jump performance and power.

Kalamen (1968) studied the relationship between power obtained by the Margaria test and the height of the vertical jump. The correlations between the Margaria test and any of Kalamen's variations were very low and nonsignificant. However, when each of the subject's body weights were taken into consideration, that is, when the relative power output was correlated to the performance in the vertical jump, the correlations increased beyond significance. In attempting to determine whether the Margaria test, the 3 step, 6 meter start test or the vertical jump might also be used as predictive indices for potential success in sprinting, Kalamen correlated the scores of these tests obtained by a university track team to their performance times in a fifty yard dash with a 15 yard flying start. The high correlation between the 3 step, 6 meter start test and the sprinters' times ($r=.97$) indicated that this test could be used as a predictive index. Margaria's test was also significantly correlated ($r=.84$) though not as highly. The vertical jump was found to be of little value as a predictive index for sprinting ability, producing a correlation which was not significant ($r=.59$).

Costill et al. (1968) also compared the power production of the legs measured by the method of Margaria (1966) to the performance in the vertical jump, standing broad jump and a 40 yard dash. Like Kalamen (1968), they did not find a significant relationship between absolute power and the vertical jump. This was also the case for the standing broad jump. Relative leg power was however significantly related to the speed in the 40 yard dash. The

speed of the 40 yard dash was also related to the vertical and standing broad jumps.

There would appear to be, at best, only a moderate correlation between a score in inches and/or time based on the performance of running and jumping tests and power measured as the time rate of doing work. Despite the versatility and apparent applicability of these tests, their use as valid measures of power does not seem strictly justified. However, this conclusion is often reached (Barlow, 1970; Considine, 1970, Kalamen, 1968) by comparing criterion scores of absolute power to tests of relative power. For example, a person weighing 70 kg and jumping 25 cm vertically into the air exhibits more actual or absolute power than a 60 kg person jumping the same height. Yet in terms of actual performance, they have similar power relative to the body weight, since both jumped the same distance (Berger & Huffman, 1972). Thus, the only way that a score in inches or time can be used to compare individuals on the basis of absolute power is when the body weights are identical. Otherwise, these scores indicate power relative to the body weight or relative power. The results of Grey et al. (1962b) and Kalamen (1968) illustrate this point well. In the latter study, vertical jump performance was significantly related only to relative muscular power and not absolute power. Grey et al. (1962b) showed that the correlations between all four experimental tests and their vertical power jump were higher when the results of the tests were scored as the work

performed. By doing so, absolute rather than relative power was compared to the absolute criterion measure of power.

Theoretically, the absolute power of a muscle should be limited by its mass and its proportion of FT fibers, since the proportion of these fibers has a direct bearing on the force and speed of contraction. However, when the absolute power of a muscle or muscles is used to project the body weight through a given distance in the shortest possible time period, or to a certain height, it need not be reflected in the criterion of inches jumped and/or speed. In relative tests of power, performance will also be affected or limited by excess weight, skeletal proportions and the proportion of lean body mass to fat. A high body weight is not always a burden to power performance though. In fact, the body weight of Olympic sprinters exceeds the average weight of marathon runners by 12.5 kg (Khosla, 1978). But, much of this excess weight in trained sprinters is composed of muscle mass. Since muscular strength increases more or less proportionally with mass, then the absolute power of these individuals which is to be applied to move their body weight will be greater. However, in the untrained individual, changes in weight can arise primarily from changes in body tissues other than muscle. In this case, excessive weight can be a burden to power performance by hindering the projection of the body. Thus, even though the muscles of two individuals have the same intrinsic capacity for the production of power, but the lean body mass to body fat ratio for one individual is lower than the other, then this individual will be at

a disadvantage in performing the traditional tests of power. The absolute power capacity of a muscle in terms of its mass and percent composition of FT fibers may therefore not always correlate with the relative power performance.

Summary

The mean peak instantaneous mechanical leg power production for the adult male is between 4 and 5 horsepower (3700 and 4500 watts). The energy which is necessary for this amount of power is derived solely from the hydrolysis of intramuscular stores of phosphagen. The capacity of the alactic system is very limited by the small size of the phosphagen stores and therefore the period of time for which the maximum power output can be sustained at the expense of muscle phosphagen is less than 10 seconds. However, the rate of these hydrolytic reactions is much greater than the rate of phosphagen resynthesis from either lactic acid formation or oxidative phosphorylation, both of which are a much more complex and time consuming series of reaction. Therefore, maximum muscular power is first limited by the duration of the exercise. When an individual engages in an exercise whose duration does not exceed the capacity of the alactic system, then the only limit to the amount of power the muscles can produce is the speed and strength with which they can contract. The skeletal muscle fiber composition influences the strength and speed of contraction and therefore may be an important determinant of athletic power performance.

Fast twitch muscle fibers have a faster intrinsic speed of shortening and isometric twitch contraction time than slow twitch

muscle fibers. The biochemical and morphological correlates of these dynamic properties are the myosin ATPase activity, the amount of sarcoplasmic reticulum and the rate of release and uptake of Ca^{++} from this reticulum. The functional significance of these properties is that human muscles with a high proportion of fast fibers can produce more force and power at fast velocities of contraction than muscles with a low proportion of these fibers. Thus, a high percentage of FT fibers would seem favorable in power activities which require maximal force production at high contraction velocities.

In comparison to sedentary and endurance trained persons, power athletes as a group tend to have a predominance of FT fibers in their trained muscles. This circumstance suggests that heredity with respect to the muscle fiber composition is a predisposing element to successful power performance, since the muscle fiber composition is genetically determined and not influenced by training. However, athletes are exposed to extended periods of training and can, even with a weak genetic potential with respect to their muscle fiber composition, compete quite successfully at the national or international level, indicating that there must also be many important training adaptations which can affect performance and overcome the limitations imposed by genotype. Therefore, the extent to which the superior power performance of athletes is due to heredity or training is still an open question. The supposition that there is an interdependence between power performance and the muscle fiber composition can therefore be strengthened if this relationship is tested on the untrained.

The measurement of human power output is quite complex and most explosive movements of the body do not easily lend themselves to accurate measurement. There are many discrepancies in the research in this area which can be ascribed primarily to the lack of standardization of performance tests, to the manner in which power is measured and the failure in many cases to consider the differences between absolute and relative power performance. At the present time, however, although jumping tests and short sprints appear to measure a combination of strength and limb speed, they appear to have only a limited application as valid measures of power.

CHAPTER THREE

METHODOLOGY

Experimental Procedure

The subjects of this study were eight young healthy male volunteers. The volunteers were informed about the nature and purpose of the experiment and about the risks involved in all aspects of the experiment before agreeing to participate. Consent was obtained in writing (Appendix I) and the subjects were then further informed that they were free to leave the study at any time thereafter.

On the first test day of their experiment, the subjects reported to the laboratory as a group to complete an isometric leg strength test and five tests of power. Each of the tests was preceded by a demonstration and a supervised practice when necessary. Three trials were administered in the following order: standing broad jump, vertical jump and reach, Margaria test of power, 40 meter sprint, vertical jump from a force platform and maximal isometric leg strength. In order to minimize the possible fatigue effects of consecutive efforts, the trials of each test (except isometric leg strength) were interspersed; that is, each member of the group had one trial before any subject could have a second trial. A consecutive trial method with a rest between each trial was used for the measurement of isometric leg strength, since the

apparatus had to be adjusted for each individual subject. The best performance in each test of strength and power was recorded for statistical treatment.

After all the performance tests had been completed, anthropometric measurements were taken and underwater weight was determined for densitometric analysis of body composition.

On the second test day one week later, all the tests were repeated following the same protocol to obtain a second set of scores for use in test-retest reliability calculations.

Once all the testing had been completed, muscle biopsies were taken at a time that was mutually convenient for the subjects and the physician.

Anthropometric Measurements and Densitometric Analysis of Body Composition

Age in years, height to the nearest centimeter and weight to an accuracy of .2 lbs were recorded with the subject clad only in a light swimsuit. Vital capacity was then measured with a Collins Siprometer, with the subject in a sitting position in air. Three trials were required with each measurement being recorded to the nearest 100 ml at A.T.P.S. Body fat was then determined by the underwater weighing technique.

The underwater weighing apparatus consisted of a large waterfilled tank containing a weighing cage. The cage was suspended from a pre-calibrated load cell which transmitted the weight of the immersed subject in water to a reading scale in millivolts.

To determine the underwater weight, the subject was instructed to climb into the tank and thoroughly "scrub" himself to dislodge any gas bubbles which may have adhered to the skin, hair or bathing suit. The subject then stepped into the cage and assumed a crouch position with the shoulders submerged. When ready for assesment, the subject placed noseclips on his nose and quickly lowered his head under the water. While submerged, the subject made a maximal expiration and then held his breath for about 15 seconds while the reading was being recorded. This test was repeated five times. The highest and lowest underwater weights were eliminated and the final underwater weight was recorded as the average of the remaining three trials.

Body density was obtained by dividing the total body weight in air (BWa) by the body volume (Vb). Using the principle of Archimedes, the volume of the body is determined by its displacement of water. The difference between the body weight in air and the body weight completely immersed in water represents the weight of the displaced volume of water. This difference, divided by the density of the water corrected for temperature, yields the volume of water displaced and hence the body volume: $Vb = \frac{BWa - BWw}{\text{water density}}$. This body volume was then reduced by a constant value of 100 ml for the volume of gas in the gastrointestinal tract and by 27 percent of the vital capacity (converted to B.T.P.S.) for the residual volume of gas in the lungs.

Total body fat, expressed as a fraction of body weight was then calculated from the Keys and Brozek equation (1953):

Total Body Fat (Fb)= $\frac{4.5770}{\text{Body Density}}$ (Db)-4.142. This formula is the most applicable for the estimate of the fat content of young males in whom the body weight has been free from large recent fluctuations (Brozek et al., 1963).

The fat free body mass (FFM) was calculated by subtracting the product of the subject's weight and percent body fat from the subject's weight: FFM=body weight-(body weight x percent body fat).

Isometric Leg Strength Measurement

Maximum isometric strength of the right knee extensor muscles was determined at a knee angle of 90 degrees with the subject in a sitting position. The force was measured with a pre-calibrated load cell and the output recorded with a low-voltage potentiometer. The load cell was attached via a chain and belt to the subjects' ankles.

Tests of Muscular Power

(a) The Standing Broad Jump

The standing broad jump was performed on a gymnasium mat marked off into one cm intervals. The subject assumed a starting position, at the take-off line, in which the hips and knees were flexed, with the arms elevated behind the body. When balanced in this position, the subject was instructed to swing the arms forward and jump as far as possible onto the landing mat. The distance jumped was the perpendicular measurement to the nearest cm from the rearmost point of contact of the heels on the mat to the take-off line.

(b) The Vertical Jump and Reach Test

The scoring apparatus for this test consisted of a cardboard jump board secured to a wall and marked off into one cm intervals. The subject first stood sideways against the wall with the preferred arm extended above his head onto the jump board. With both feet together at the center of a restraining circle, on his tip-toes and with the other arm behind his back, the standing reach was recorded. Without changing the position of the arms, the subject was instructed to flex his knees and without pausing, jump upwards. The maximum height of the jump was recorded by having the subject make a mark with a piece of chalk held in the fingertips of the reaching hand. The height of the jump was calculated to the nearest cm as the distance between the standing reach and the maximum height reached in the jump. The jump was started and finished within a restraining circle 50 cm in diameter in order to limit any anterior-posterior as well as lateral projection. If the subject landed on or outside the restraining circle, the jump was repeated.

(c) The Margaria Test of Power

According to the method of Margaria et al. (1966), each subject was asked to run up an ordinary staircase, 2 steps at a time, at top speed with an approach of 2 meters on the flat. The time required to cover an even number of steps was measured by placing electronic pressure pads sensitive to .01 seconds on the fourth and eighth step. The Deacon electronic timer was started with the contact of the foot on the first mat and stopped with contact of the foot on the second mat.

Margaria et al. (1966) have shown that, in this exercise, the running speed rises to a maximum after only .5 to 1 second, or after the first two to three steps, and thereafter remains constant. Thus, for a given incline of the steps, the total mechanical work done can be determined from the body lift alone, or that work done in lifting the body weight through the height of four steps. Both the absolute and relative power can then be easily calculated and expressed as watts $.sec^{-1}$ and watts $.kg^{-1}$ $.sec^{-1}$ respectively.

(d) 40 Meter Sprint

Each subject was asked to perform a 40 meter sprint indoors. A standing start was used in order to minimize the effect of technique associated with the crouch start. Electronic photo-sensitive devices were placed at the start and the 40 meter mark to record the subject's performance time.

(e) Force Platform Analysis of the Vertical Jump

Although both a standing broad jump and a vertical jump have traditionally been used as tests of power, neither test is a valid measure of power in its true mechanical sense, that is, as the time rate of doing work. Therefore, a force platform analysis of the vertical jump was undertaken to determine the maximum instantaneous power that the subjects were capable of producing.

The ground reaction force was measured by a Kistler (model #9261A) force platform. The signal from the force platform was conditioned and amplified by a Type 5001 charge amplifier and simultaneously recorded by a Honeywell Visicorder (model #1508B) in order to obtain a permanent record. The subjects assumed a

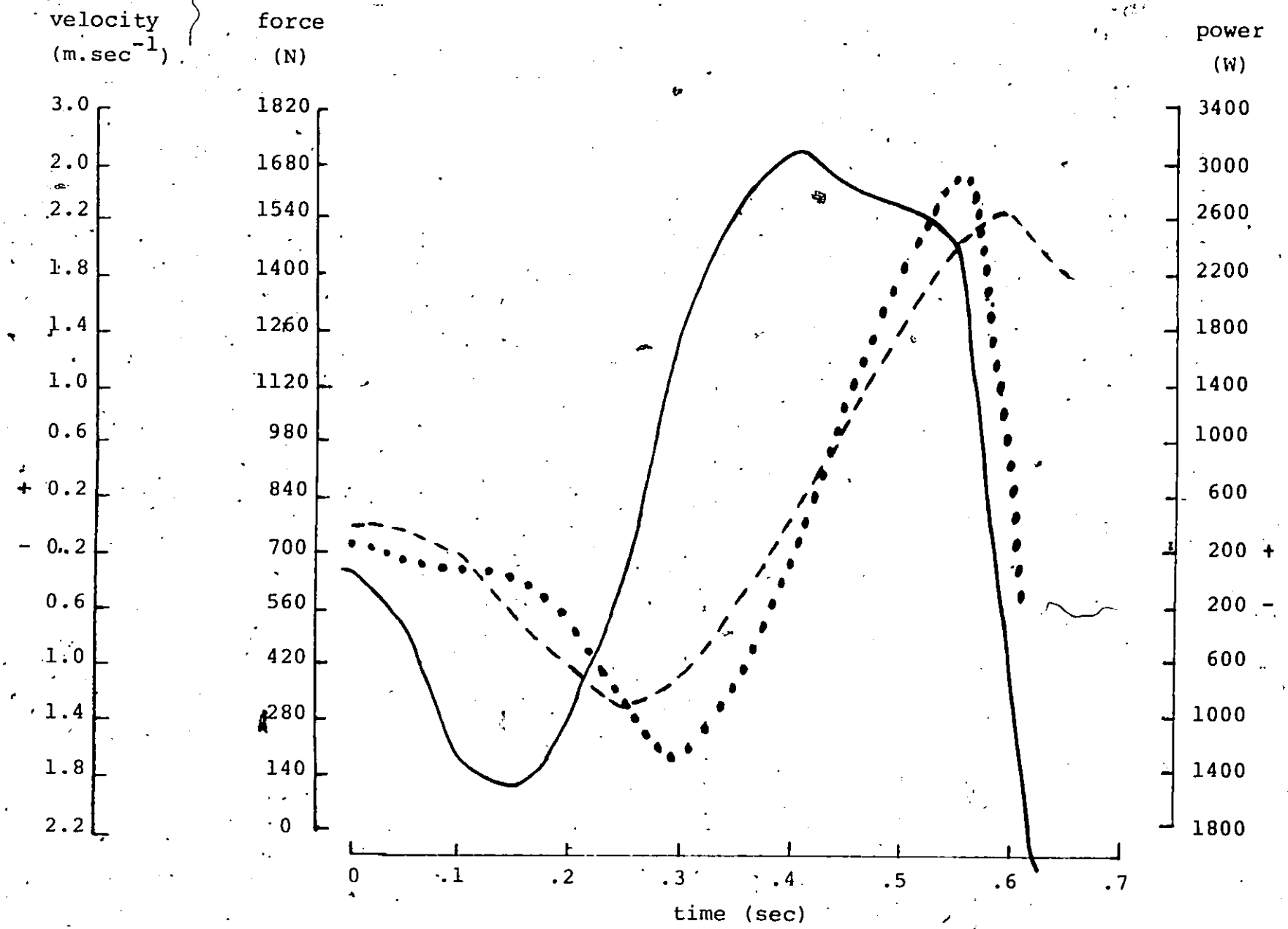
starting position on the force platform with legs extended, feet together and hands held on the hips. From this position, they were instructed to flex their knees and without pausing, jump upwards.

A typical record of the vertical ground reaction forces acting on the platform throughout the performance of a vertical jump is illustrated in Figure 3-1.

Using this record, the vertical ground reaction force curve can be compared with the measurements of zero and the known body weight to obtain a measure of force. Acceleration (A) of the center of gravity is calculated as $A=9.81 \times \frac{(F-W)}{W}$ $N.sec^{-1}$, where F is the force and W is the body weight. The vertical velocity can then be obtained by integration of the area under the acceleration curve. Values for instantaneous power are determined as the product of velocity and the appropriate ordinate of the force curve. Figure 3-1 illustrates the velocity and power changes that take place during the performance of a vertical jump.

By comparing the relative magnitudes of the body weight and the vertical component of the ground reaction force, the force curve can be divided into three distinct phases (Miller & East, 1975). These phases are called: the preliminary unweighting, weighting and final unweighting phases. The preliminary unweighting represents a major portion of the curve near the beginning of the jump during which the reaction force is less than the body weight, resulting in a negative acceleration of the body. The weighting phase begins when the acceleration is zero and the force applied by the limbs is equal to the body weight. Maximum downward velocity

Figure 3-1 A graphical analysis of the force (——), velocity (---) and power (...) changes during the performance of a vertical jump.



is reached at this point. Throughout the weighting phase, the jumper accelerates positively during which time the reaction force rises to reach a maximum, occuring when the body is at or near its lowest position. The point of maximum upward velocity is reached during this phase just before take-off. The final unweighting occupies a very brief interval of time immediately before the jumper leaves the ground, during which time the velocity is decreasing and the acceleration is negative. Maximum instantaneous power is reached as the vertical force falls and the upward velocity is almost at its peak.

The impulse applied to the body during the vertical jump was calculated by integration of the area under the force-time curve.

The time from the start of the jump to the point of maximum force (time to peak force) and the relative force (force per kg of body weight) at peak velocity were also calculated directly from the force-time curve.

Muscle Sampling

Skeletal muscle biopsy samples were taken from the resting vastus lateralis muscle of the right leg using the needle biopsy technique described by Bergstrom (1962). The vastus lateralis muscle is a major contributor to the forces generated during knee extension and it is also located at a site which is convenient for biopsy sampling (Thorstensson, 1976). The sampling site was about one third the distance from the patalla to the illiac crest, three centimeters from the midline of the thigh and at a depth of approximately three centimeters below the skin surface.

After shaving and disinfecting the skin, the skin, subcutaneous tissue and underlying fascia were infiltrated with xylocaine. A small incision was made in the skin and subcutaneous tissue with a Swan-Morton scalpel blade, through which the biopsy needle was inserted. Once the biopsy sample was secured within the barrel of the needle, the needle was rapidly withdrawn from the muscle and the incision closed with adhesive tape.

Once obtained, the biopsy samples were orientated and mounted on a labelled piece of bottlecork in tracacanth gum and frozen in isopentane cooled with liquid nitrogen. After freezing, the cork and attached specimen were stored in a freezer at -40 degrees celsius until required for sectioning.

Histochemical Techniques and Morphometric Procedures

The biopsy samples for histochemistry were placed in a (Damon) cryostat and warmed to -20^{C} degrees. Two serial sections 10 u thick were cut in the cryostat and mounted on coverslips. The sections were stained for myofribrillar ATPase activity and reduced nicotinamide adenine dinucleotide-diaphorase (NADH-D) according to the methods of Padykula and Herman (1955) as modified by Guth and Samaha (1969), Brooke and Kaiser (1970) and Novikoff et al. (1961) respectively.

In the reaction for myofribillar ATPase, as described by Guth and Samaha (1969) both the preincubation and the incubation of the tissue sections are carried out at pH 9.4. Those fibers which react strongly are then classified as Type II (FT) and those that react weakly as Type I (ST).

Following the staining, each serial section was photographed using a Lietz research miscroscope with the corresponding 4 x 5 photographic attachment by a photographic technician from the Department of Biology. The muscle fibers were then typed as either Type I or Type II and counted.

The cross-sectional areas of the Type I and Type II muscle fibers were measured, with a graph/pen sonic digitizer (GP-series 6) at the University of Montreal, from the photomicrographs of the myosin ATPase stained sections. Fiber areas were calculated only from those portions of the photomicrographs where the cross-section appeared perpendicular to the fiber orientation. The graph/pen sonic digitizer consists of three basic components:

(1) a graph/pen stylus which creates sonic impulses at rates and modes set by the operator and which is used by the operator to trace around the circumference of each muscle fiber;

(2) sensors, which detect the arrival of each sonic impulse at the X and Y axes of the active field of the graph/pen and convert the impulse to electrical signals which are transmitted to the control unit;

(3) a control unit, which initiates the energy pulses which are converted into sonic waves by the pen stylus, measures the times required for the sonic energy to reach the X and Y sensors and converts these times into distance measurements in digital form.

The measurements of the muscle fiber areas was used to determine the Type II/Type I fiber area ratios and to calculate the relative area that the Type II fibers contributed to the total muscle. Relative area was calculated by multiplying the Type II fiber number by its mean area in each biopsy sample and expressing it relative to the total area.

Statistical Analysis

The reliability of the isometric strength measurements and the five tests of power were determined using the test-retest method, by correlating the best of three performances on the first test day with the best of three performances on the second test day. The test-retest reliability of the underwater weighing technique was established by correlating the percent body fat calculated from the final underwater weights on the first and second test days.

The mean percent body fat and the best of all six performances in the strength and power tests were used in all further statistical procedures. Means, ranges and standard deviations were calculated from individual values for all variables. Pearson product-moment coefficients of correlation were calculated in order to ascertain the interrelationships among the subjects' physical characteristics, leg strength, power and Type II fiber distribution. The variables derived from the force platform analysis of the vertical jump (peak force, velocity, instantaneous power, impulse, time to peak force and the relative force at peak velocity) were also intercorrelated and correlated to the Type II fiber distribution. All correlations were tested for significant difference from zero at the 0.001, 0.01 and 0.05 level of probability.

A student's t-test was used to test the difference between the mean Type II and Type I fiber sizes.

Simple regression analysis was used to determine if power performance scores could be predicted from the muscle fiber

composition and vice-versa. An F-test was used to test the significance of the regression equations.

CHAPTER FOUR

RESULTS

Tables 4-1, 4-2, 4-4 and 4-7 contain the raw data for physical characteristics, muscle fiber analysis, tests of strength and power and force platform analysis. Table 4-8 is a summary table of the means, standard deviations and ranges of all of the above variables. The correlations between (a) the subjects' physical characteristics, (b) the subjects' physical characteristics and the tests of strength and power (c) the tests of strength and power, (d) the subjects' physical characteristics and the variables derived from the force platform analysis of the vertical jump and (e) the force platform variables are presented in Tables 4-3, 4-5, 4-6, 4-9 and 4-10 respectively. The results of the simple regression analysis are found in Table 4-11. Multiple regression analysis was not done because of multicollinearity. Multicollinearity refers to the situation in which some or all of the independant variables are very highly correlated, because of which, regression coefficients may not be determined.

Subject Physical Characteristics

The subjects of the study (Table 4-1) were a group of eight young male volunteers between the ages of 23 and 35 years. They were all physically active, with the exception of subject number

seven, who was found to have a high percentage of body fat (27.2%) relative to the rest of the group (mean 10.6%), as determined by densitometry (reliability .97). Subjects three and eight were highly trained marathon runners, but none of the subjects were trained in sprint or power activities. A considerable range was evident in body weight (59 to 81 kg) and in fat free mass (FFM) (52 to 71 kg).

Fiber Type Composition of the Muscle

The results of the muscle fiber analysis are found in Table 4-2. The number of fibers that could be counted per subject depended upon the size of the biopsy specimen, the size of the fibers and the quality of the section. In most cases the count was considered satisfactory (171 to 584 fibers) but in subject number three, only 80 fibers were suitable for both sizing and counting. The average Type II fiber distribution in the vastus lateralis sample was 53%, but within the group of eight subjects, the values ranged from 7% to 75%. The extreme case was subject number eight, whose biopsy showed only 44 Type II fibers within a field of 584 (i.e. 7% Type II). The other marathon runner (subject three) showed the next lowest percentage of Type II fibers (41%). When the effect of fiber size was taken into account also, to yield a value for the percentage of total muscle area occupied by Type II fibers, the values in the two marathon runners were reduced even further (to 4% and 35% respectively), whilst the group mean did not change.

The mean Type I and Type II fiber areas were 5180 um^2 and 5382 um^2 respectively and these were not significantly different

Table 4-1 Subjects' Physical Characteristics

Subject number	Age (yrs)	Height (cm)	Body Weight (kg)	Body fat* (%)	Fat free mass (kg)	Comments
1	35	186	80.9	12.0	71.1	physically active
2	25	182	76.7	11.5	67.8	physically active
3	27	182	69.2	6.8	64.5	marathon runner
4	23	171	70.4	12.3	61.7	physically active
5	27	178	76.3	12.4	66.8	physically active
6	32	174	65.7	8.8	59.9	physically active
7	27	173	71.3	27.2	51.9	not active
8	26	168	58.9	10.2	53.0	marathon runner
Mean	27.75	176.88	71.21	12.65	62.02	
Standard deviation	3.88	6.13	6.91	6.21	7.08	

*test - retest reliability of % body fat was .97; $p<0.001$

Table 4-2 Muscle Fiber Analysis

Subject number	Number of fibers counted	%Type II* by number	%Type II* by area	Mean Type II area (um^2)	Mean Type I area (um^2)	Type II/Type I area ratio
1	439	75	73	6334	6839	.92
2	80	55	56	6439	6178	1.04
3	402	41	35	3699	4805	.76
4	312	72	77	6849	5355	1.27
5	199	64	64	4907	4910	.99
6	171	51	56	6571	5397	1.21
7	428	59	62	3780	3355	1.12
8	584	7	4	2866	6274	.45
Mean	326.8	53.2	53.4	5180+	5383+	.97
Standard deviation	130.1	21.5	23.9	1568	1078	.24

* the correlation between percentage of Type II fibers by area and by number was .99; $p<0.001$

+ there was no significant difference between the Mean Type II and Type I fiber areas

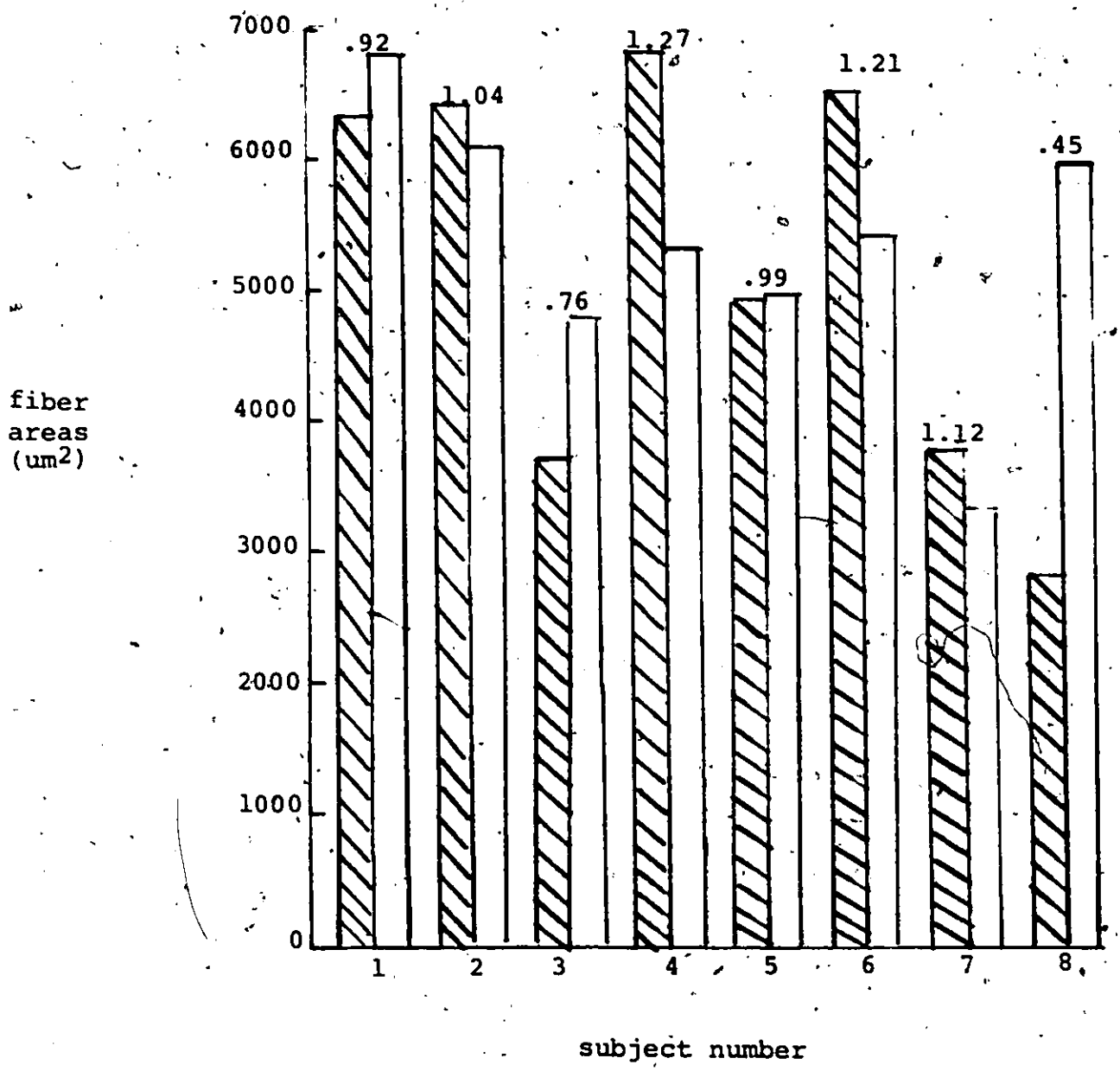
from each other. Much individual variation was observed, however, in both absolute and relative cross-sectional areas (Figure 4-1). The subject differences in absolute mean fiber size covered almost a two-fold range, from 6587 um^2 in subject number one to 3568 um^2 in subject number seven (the most inactive subject). The tendency was for subjects with large fast fibers to also have large slow fibers, but this was not the case for the marathon runners (subjects three and eight) who revealed Type II/Type I fiber area ratios which were unusually low (.76 and .45 respectively). The largest ratio observed was 1.27 for subject four.

Correlations Between Subject Characteristics

Not surprisingly, Table 4-3 indicates that height was correlated with body weight ($r=.79$; $p<0.01$) and with the fat free mass ($r=.83$; $p<0.01$) and that weight and fat free mass were also correlated with each other ($r=.76$; $p<0.01$). Also, as expected, percent body fat was independant of height, weight and fat free mass.

An unexpected result of this study was the high and statistically significant correlation between the percentage of Type II fibers and body weight ($r=.82$ and .75 respectively, by number and by area; $p<0.01$). Fat free mass, on the other hand was not significantly related to the percentage of Type II fibers. The coefficient of correlation for the latter relationship was however, still in the vicinity of .5 whereas it would be expected to approximate zero. The spurious relationship between these variables in this study should be kept in mind as it could

Figure 4-1 Mean Fiber Areas and Fiber Area Ratios. The shaded and unshaded bars represent Type II and Type I fiber areas respectively. The numbers above the bars are the Type II/Type I fiber area ratios.



tend to confound the correlations obtained for both the percentage of fiber type and fat free mass.

The correlation between percent Type II fibers by area and by number was .99 ($p<0.001$). This near perfect relationship reveals itself in the almost identical correlations of percent Type II fibers by area and by number with the various strength, power and force platform tests. Consequently, a decision was made to retain only the correlations with percent Type II by area for subsequent use in the study.

Performance Test Data

The wide range in the results of the performance tests of strength and power (Table 4-4) indicates high individual performance variability. This wide range of performances probably reflects the tendency in this study for subjects with a high body weight or fat free mass also to have a high percentage of Type II fibers, thus enhancing both their absolute and relative power capability. Subjects with a low percentage of Type II fibers would likewise be doubly handicapped.

The test-retest reliabilities of the standing broad jump ($r=.94$; $p<0.001$), vertical jump ($r=.97$; $p<0.001$), Margaria test of power ($r=.99$; $p<0.001$) and maximum instantaneous power ($r=.95$; $p<0.001$) appear acceptable. However, the reliabilities of the 40 meter sprint ($r=.88$; $p<0.01$) and isometric leg strength ($r=.90$; $p<0.001$) were somewhat lower.

Table 4-3 Correlations among the Subjects' Physical Characteristics

	height	weight	% body fat	fat free mass	% Type II by number
weight	.79++				
% body fat	-.22	.17			
fat free mass	.83++	.76++	-.50		
% Type II (by number)	.46	.82++	.27	.54	
% Type II (by area)	.36	.75++	.31	.46	.99+

++ significant at the 0.01 level of probability

+++ significant at the 0.001 level of probability

Table 4-4 Performance Tests of Strength and Power

Subject number	Leg strenth (N)	*SBJ (cm)	*VJ (cm)	40 m sprint (sec)	Margaria absolute (W)	Margaria relative ($W. kg\ FFM^{-1}$)	*MIP absolute (W)	MIP* relative ($W. kg\ FFM^{-1}$)
1	828.6	254	43	5.52	1451	20.38	5712	80.25
2	704.0	263	36	5.92	1351	19.91	3781	55.73
3	378.8	220	42	5.47	1250	19.38	3452	53.51
4	672.9	235	33	5.33	1275	20.65	3564	57.72
5	570.5	227	31	5.88	1407	21.03	3162	47.27
6	450.0	240	35	5.33	1151	19.20	3691	61.60
7	530.4	200	37	6.48	1016	19.57	3132	60.34
8	615.0	180	19	6.45	851	16.04	2147	40.46
Mean	593.8	227.37	34.65	5.80	1219.29	19.52	3580.24	57.11
Standard deviation	144.1	27.37	7.52	.46	204.24	1.53	1002.99	11.68
Test-retest reliability	.90 ($p<0.001$)	.94 ($p<0.001$)	.97 ($p<0.001$)	.88 ($p<0.01$)	.99 ($p<0.001$)	- -	.95 ($p<0.001$)	- -

*VJ: vertical jump
*SBJ: standing broad jump
*MIP: maximum instantaneous power

Correlations Between the Subjects' Physical Characteristics and the Tests of Strength and Power

The correlations between the subjects' physical characteristics and the tests of strength and power are presented in Table 4-5. Body weight was highly related to absolute and relative power as measured by Margaria's test and absolute and relative maximum instantaneous power (MIP) on the force platform ($r=.87$; $p<0.01$, $.83$; $p<0.01$, $.75$; $p<0.05$ and $.62$; $p<0.05$ respectively). Body weight was also correlated to the standing broad jump (SBJ) ($r=.72$; $p<0.05$) and vertical jump (VJ) ($r=.68$; $p<0.05$), but not the 40 meter sprint ($r=-.26$). Height, because of its correlation to weight, was related to about the same degree, except that it was not significantly related to either measure of relative power (Margaria test or the force platform).

Fat free mass was correlated to the standing broad jump ($r=.82$; $p<0.01$), 40 meter sprint ($r=-.62$; $p<0.05$), Margaria's test of absolute power ($r=.62$; $p<0.05$) and absolute maximum instantaneous power ($r=.71$; $p<0.05$), but was not related to relative maximum instantaneous power ($r=.43$) or the vertical jump ($r=.54$).

A significant relationship was expected between fat free mass and isometric leg strength but this was not the case ($r=.40$), possibly as a result of the poor test-retest reliability of isometric leg strength ($r=.90$). Leg strength and the proportion of body fat were unrelated to any of the test variables.

The percentage of Type II fibers by area was significantly related to absolute and relative power as measured by Margaria's test ($r=.70$; $p<0.05$ and $.91$; $p<0.01$ respectively) and absolute

Table 4-5 Correlations between the Subjects' Physical Characteristics and the Tests of Strength and Power

	height	weight	fat free mass	% body fat	% Type II fibers
leg strength	.25	.52	.40	.08	.36
*SBJ	.69^{+}	.72^{+}	.82^{++}	-.28	.68^{+}
*VJ	.79^{++}	.68^{+}	.54	.07	.61^{+}
40 m sprint	.38	-.26	-.62^{+}	.59	-.47
Margaria absolute	.78^{++}	.87^{++}	.94^{+++}	-.25	.70^{+}
Margaria relative	.52	.83^{++}	.62^{+}	.15	.91^{+++}
*MIP absolute	.76^{++}	.75^{++}	.71^{+}	.08	.65^{+}
MIP relative	.58	.62^{+}	.43	.16	.67^{+}

$^{+}$ Significant at the 0.05 level of probability

$^{++}$ Significant at the 0.01 level of probability

$^{+++}$ Significant at the 0.001 level of probability

*SBJ: standing broad jump
*VJ: vertical jump
*MIP: maximum instantaneous power

and relative maximum instantaneous power ($r=.65$; $p<0.05$ and .67; $p<0.05$ respectively), as well as to performance in the vertical jump ($r=.61$; $p<0.05$) and standing broad jump ($r=.68$; $p<0.05$). There was no significant correlation however, with the 40 meter dash ($r=-.47$) or isometric leg strength ($r=.36$).

Correlations Among the Tests of Strength and Power

As Table 4-6 indicates, there was a significant correlation between absolute power as measured by the Margaria test and the force platform jump ($r=.73$; $p<0.05$), but the correlation between relative power as measured by these two tests was insignificant ($r=.49$). The within-test correlations of absolute and relative power were significant in both cases ($r=.85$; $p<0.01$ and $r=.93$; $p<0.001$ for the Margaria and MIP tests respectively), but the between-test correlations were not ($r=.50$ and .57).

Absolute power as measured by the Margaria test was significantly related to the standing broad jump ($r=.84$; $p<0.01$), the vertical jump ($r=.64$; $p<0.05$) and the 40 meter sprint ($r=.62$; $p<0.05$). Maximum instantaneous power was significantly related to the standing broad jump ($r=.76$; $p<0.01$) and the vertical jump ($r=.77$; $p<0.01$), but not to the 40 meter sprint ($r=-.56$). When the results of the Margaria test and maximum instantaneous power were expressed in relative units, similar relationships were found, except that the correlation between the Margaria test and the 40 meter sprint lost significance ($r=.52$).

The standing broad jump was moderately related to both the vertical jump ($r=.63$; $p<0.05$) and the 40 meter sprint ($r=-.66$; $p<0.05$), but the correlation between the vertical jump and the

Table 4-6 Correlations Among the Tests of Strength and Power

	leg strength	*SBJ	*VJ	40 m sprint	Margaria absolute	Margaria relative	*MIP absolute
SBJ	.40						
VJ	.01	.63^{+}					
40 m sprint	.03	-.66^{+}	-.53				
Margaria absolute	.37	.84^{++}	.64^{+}	.62^{+}			
Margaria relative	.19	.69^{+}	.67^{+}	-.52	.85^{++}		
MIP absolute	.53	.76^{++}	.77^{++}	-.56	.73^{++}	.57	
MIP relative	.43	.60^{+}	.77^{++}	-.45	.50	.49	.93^{+++}

$^{+}$ Significant at the 0.05 level of probability

$^{++}$ Significant at the 0.01 level of probability

$^{+++}$ Significant at the 0.001 level of probability

*SBJ: standing broad jump
*VJ: vertical jump
*MIP: maximum instantaneous power

40 meter sprint was not significant (r=-.53). Isometric leg strength was not related to any of the tests of power.

Force Platform Analysis of the Vertical Jump

Descriptive data on the positive vertical impulse, peak velocity (PV), peak force (PF), peak relative force (PRF), absolute and relative maximum instantaneous power, relative force at peak velocity (RFPV) and the time to peak force (TPF) achieved by each subject is presented in Table 4-7.

There was a very wide range in the subjects' maximum instantaneous power scores (5712-2147 W) but when this variable was expressed relative to the fat free mass ($W \cdot kg\ FFM^{-1}$) the range was reduced somewhat (80.25-40.46 W). Other variables, such as the impulse, peak force and time to peak force also showed considerable variation.

Table 4-8 presents a summary of the means and dispersion characteristics of all the variables in this study.

Fat free mass and body weight were both significantly related to peak absolute force (r=.67; $p<0.05$ and .68; $p<0.05$ respectively) but not to peak relative force (Table 4-9). Body weight was also correlated to the relative force at peak velocity (r=.66; $p<0.05$), apparently as a reflection of the peculiar relation of this latter variable to percent body fat (r=.76; $p<0.01$). Percent body fat was unrelated to other force platform variables.

For reasons that appear obscure, impulse (r=.75; $p<0.01$) and peak velocity (r=.65; $p<0.05$) were significantly related to

height, but not to body weight and FFM. Time to peak force was not related to any of the subject characteristics.

The Type II fiber distribution was shown previously (Table 4-5) to be related to the absolute and relative maximum instantaneous power ($r=.65$; $p<0.05$ and .67; $p<0.05$ respectively). It now appears to also be related to peak force ($r=.66$; $p<0.05$), relative peak force ($r=.61$; $p<0.05$) and the relative force at peak velocity ($r=.71$; $p<0.05$).

Figures 4-2 and 4-3 illustrate how the force-time curves differed between "fast" and "slow" subjects. Subjects who had more than 60 percent Type II fibers tended to produce greater relative force, showed faster rates of development of the force and had shorter contact times than those with less than 40% of Type II fibers.

Table 4-10 contains the intercorrelations for the force platform variables. Absolute and relative maximum instantaneous power correlated significantly with peak velocity ($r=.61$ and .71 respectively; $p<0.05$), peak force ($r=.69$; $p<0.05$ and .74; $p<0.01$, respectively) and impulse ($r=.69$; $p<0.05$ and .76; $p<0.01$ respectively). Peak velocity in turn, was strongly related to impulse ($r=.84$; $p<0.01$), but neither peak velocity ($r=-.02$) nor impulse ($r=.05$) bore any relation to peak force. Peak force was, however, closely inter-related with relative peak-force and time to peak force ($r=.91$; $p<0.001$ and $r=-.71$; $p<0.05$). The time to peak force was also related to relative peak force ($r=.80$; $p<0.01$).

Simple Regression Analysis

The results of the simple regression analysis are contained in Table 4-11. The regression coefficients were not statistically significant at the 0.05 level of probability, with the small number of subjects in this study. It was therefore not possible to predict either the muscle fiber composition from power performance or power performance from the muscle fiber composition.

Table 4-7 Force Platform Variables

Subject number	Positive vertical impulses (N sec)	*PV ($m.sec^{-1}$)	*PF (N)	*RPF ($N.kg\ FFM^{-1}$)	*RFPV ($N.kg\ FFM^{-1}$)	*TPF (sec)	*MIP absolute (W)	*MIP relative ($W.kg\ FFM^{-1}$)
1	855.79	3.06	2475.56	34.78	13.23	.45	5712	80.25
2	658.69	2.72	1669.69	24.61	11.07	.62	3781	55.73
3	672.95	3.03	1662.38	25.77	10.50	.69	3452	53.51
4	379.04	2.35	2371.93	38.41	11.67	.38	3564	57.72
5	587.37	2.57	1887.03	28.21	13.42	.55	3162	47.27
6	689.22	3.14	1307.54	21.82	10.78	1.03	3691	61.60
7	691.05	2.69	1410.72	27.18	14.72	.59	3132	60.34
8	467.56	2.34	1280.66	24.13	9.19	.59	2147	40.46
Mean	625.20	2.73	1758.18	28.11	11.82	.61	3580.24	57.11
Standard deviation	147.30	.31	459.31	5.66	1.82	.19	1002.99	11.68

*PV: peak velocity
*PF: peak force
*RPF: relative peak force
*RFPV: relative force at peak velocity
*TPF: time to peak force
*MIP: maximum instantaneous power

Table 4-8 Means, standard deviations and ranges of the subjects' physical characteristics, the tests of strength and power, the force platform variables and the muscle fiber analysis.

Variable	Mean	Standard deviation	Range
age (yrs)	27.7	3.88	23-35
height (cm)	176.9	6.13	168-186
weight (kg)	71.2	6.91	58.9-80.9
body fat (%)	12.7	6.21	6.8-27.2
fat free mass (kg)	62.0	7.08	51.1-71.1
leg strength (N)	593.8	144.1	379-829
SBJ (cm)	227.4	27.4	180-263
VJ (cm)	34.6	7.52	19-43
40 m sprint (sec)	5.80	0.47	5.33-6.48
Margaria absolute (W)	1219	204	851-1451
Margaria relative ($W.kg\ bw^{-1}$)	17.0	1.68	14.2-18.3
Margaria relative ($W.kg\ FFM^{-1}$)	19.5	1.53	19.2-21.0
MIP absolute (W)	3580	1003	2147-5712
MIP relative ($W.kg\ bw^{-1}$)	49.8	10.4	36.4-70.6
MIP relative ($W.kg\ FFM^{-1}$)	57.1	11.7	40.5-80.3
positive vertical impulse (N sec)	625.2	147.3	379-856
PV ($m.sec^{-1}$)	2.73	.31	2.34-3.14
PF (N)	1758	459	1281-2476
RPF ($N.kg\ FFM^{-1}$)	28.1	5.66	21.8-36.4
RFPV ($N.kg\ FFM^{-1}$)	11.8	1.82	9.19-14.72
TPF (sec)	0.61	0.19	0.38-1.03
% Type II (number)	53.2	21.5	7-75
% Type II (area)	53.4	23.9	4-77
Type II area (um^2)	5180	1568	2866-6846
Type I area (um^2)	5383	1078	3355-6839

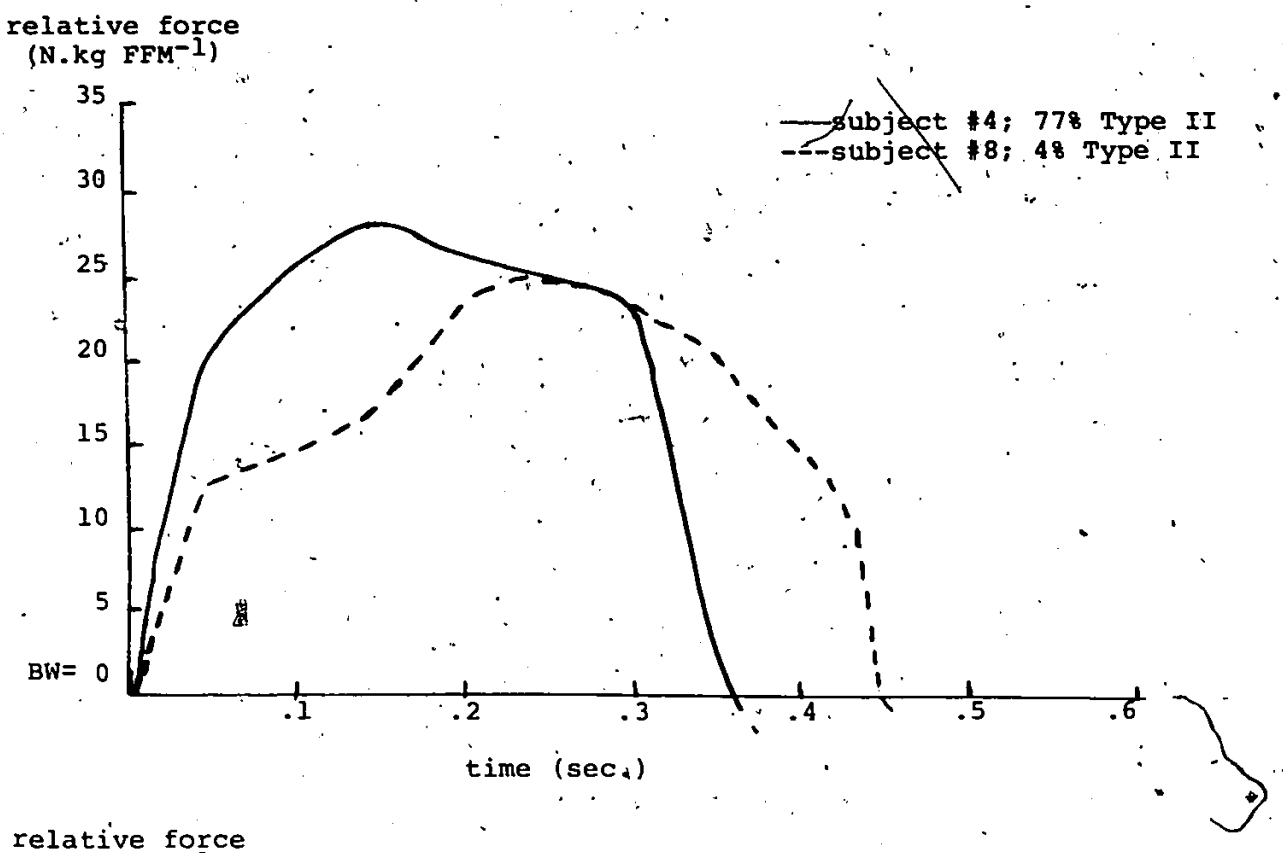
Table 4-9 Correlations Between the Subjects' Physical Characteristics and the Force Platform Variables

	height	weight	fat free mass	% body fat	% Type II
impulse	.75++	.54	.39	.11	.25
peak velocity	.65+	.29	.39	-.21	.20
peak force	.45	.68+	.67+	-.10	.66+
peak relative force	.12	.45	.32	.12	.61+
relative force at peak velocity	.25	.66+	.07	.76++	.71++
time to peak force	-.09	-.40	-.19	-.25	-.26

+ Significant at the 0.05 level of probability

++ Significant at the 0.01 level of probability

Figures 4-2 and 4-3 Comparison of the force-time curves of "fast" (>60% Type II) and "slow" (<40% Type II) subjects.



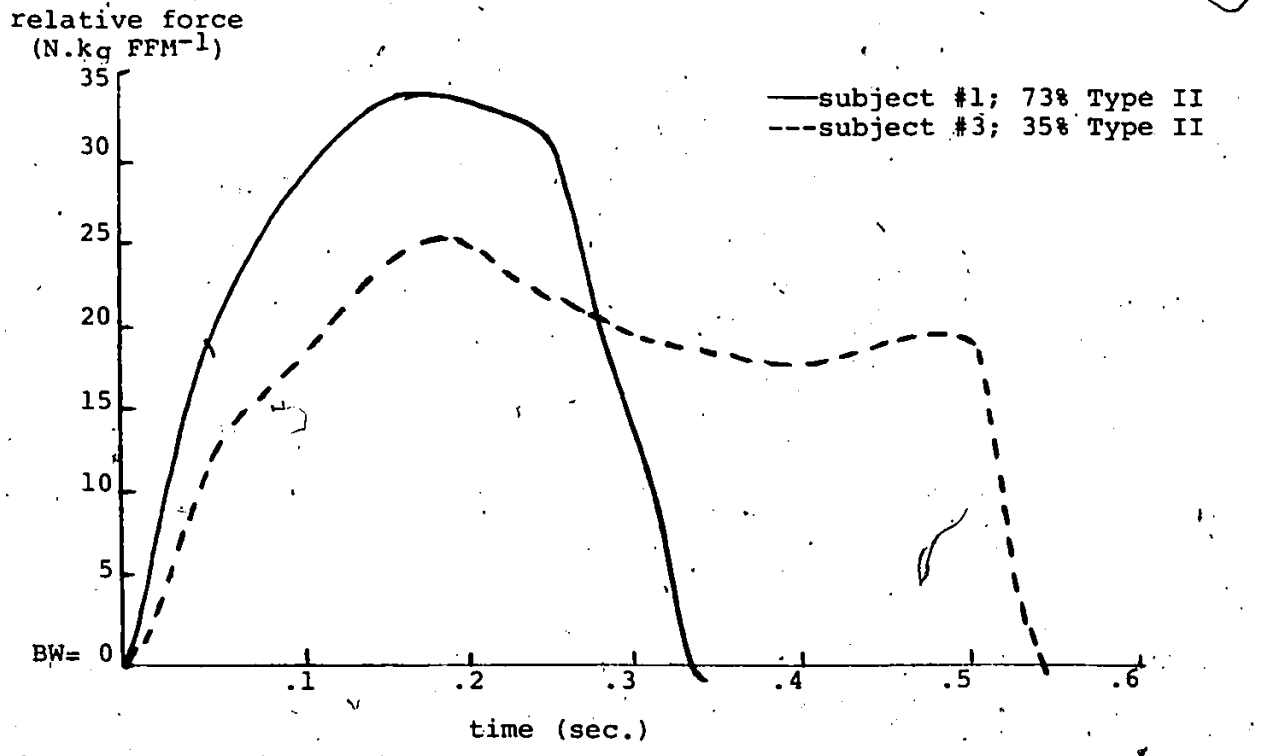


Table 4-10 Correlations Among the Force Platform Variables

	*MIP absolute	*MIP relative	*PV	*PF	*RPF	*RFPV	*TPF
MIP (relative)	.93^{+++}						
PV	.61^{+}	.71^{+}					
PF	.69^{+}	.74^{++}	-.02				
RPF	.47	.58	-.27	.91^{+++}			
RFPV	.36	.59	.09	.34	.38		
TPF	-.17	.33	.58	-.71^{+}	-.80^{++}	-.33	
impulse	.69^{+}	.76^{++}	.84^{++}	.05	-.18	.40	-.41

\+ Significant at the 0.05 level of probability

\++ Significant at the 0.01 level of probability

\+++ Significant at the 0.001 level of probability

*MIP: maximum instantaneous power
*PV: peak velocity
*PF: peak force
*RPF: relative peak force
*RFPV: relative force at peak velocity
*TPF: time to peak force

Table 4-11 Results of the Simple Regression Analysis With Type II Fiber Distribution as Both the Independant and Dependant Variable.

Dependant Variable	Independant Variable	Regression Equation
Type II distribution	vertical jump	x=1.93y-13.94
	standing broad jump	x=.548y-71.46
	Margaria-absolute	x=.081y-46.03
	Margaria-relative	x=13.85y-216.95
	MIP-absolute	x=.015y-.922
	MIP-relative	x=1.33y-14.91
vertical jump	Type II distribution	y=.237x-22.01
standing broad jump		y=.887x-180.1
Margaria-absolute		y=7.30x-824.86
Margaria-relative		y=.059x-16.36
MIP absolute		y=.32.89x-1828.8
MIP relative		y=.320x-40.02

CHAPTER FIVE

Discussion

Force Platform Test of Power

Human power output, in exercises of a very short duration, has been the subject of study for more than half a century. Though the measurement of human power output can be quite complex and difficult to quantify in most explosive movements of the body involving large muscle groups, an accurate mechanical assessment of power can be made in single movements having a duration of one second or less.

In this study, the subjects achieved a mean peak power output on the platform jump of 3580 W. Mean peak velocity and force were 2.73 $m.sec^{-1}$ and 1758 W respectively. These results are comparable to those of several others, whose values are listed in Table 5-1, though it must be taken into consideration that the different researchers did not use a standardized technigue for the performance of the vertical jump.

Table 5-1 A Comparison of the Findings of Others Regarding Force, Velocity and Power During the Vertical Jump.

Researcher	Velocity ($m.sec^{-1}$)	Force (N)	Power (W)
Desiprés (1975)	2.90	1244	-
Davies (1971)	3.40	1647	3900
Cavagna et al. (1971)	2.67	-	3475
Gerrish (1934)	3.2	1468	4026
Adamson & Whitney (1971)	2.2	1147	-

The mean peak force of this study is rather high when compared with the results of others. However, the range of the subjects' maximum forces was from 191 to 312 percent of their static weight. Gerrish's (1934) subjects demonstrated a similar range of maximum forces from 210 to 375 percent of their static weight. Others (Murray et al., 1967; Payne et al., 1968) have reported maximal vertical thrusts of up to five times a subject's body weight in jumping and running events performed by skilled adults.

The absolute and relative maximum instantaneous power produced during the vertical jump was related not only to force and velocity, but also to the positive vertical impulse. It can be noted from Figure 3-1 that the peak force precedes peak velocity and that the instantaneous velocity of the body is not due to the current force, but to the preceding force-time integral. This integral is the impulse generated by the jumping action.

Newton's second law describes the relationships between applied force, mass and acceleration as F=ma. As a is the rate at which a change in velocity occurs, this may be substituted for a in the above equation and F then becomes the time rate of change in momentum: $F=\frac{mv-mvo}{t}$, where v is the final velocity, vo the initial velocity and t the time during which the force was applied. The impulse (Ft) is then equal to mv-mvo. In a vertical jump, the upward motion starts from zero velocity, therefore the second term in the foregoing equation can be ignored and it becomes apparent that for a performer of mass m, the velocity

achieved by the body during a vertical jump can be related to the size of the impulse. In order to maximize the vertical jump height and power (Fv), the positive vertical impulse can be increased by increasing the peak force and/or the duration of the positive force phase.

Sargent (1921 - cited in Barlow, 1971) had originally stated that vertical jump height is independent of both body height and weight and that these two variables therefore had little effect upon the development of "power". Many of the earlier vertical jump studies have since accepted this assumption that jump height is indicative of power, regardless of weight and stature. However, in this study, absolute maximum instantaneous power was found to have a strong positive relationship to body weight ($r=.75$; $p<0.01$), height ($r=.76$; $p<0.01$) and the fat free mass ($r=.71$; $p<0.05$). Davies (1971) and Barlow (1971) have also reported significant correlations between these latter three variables and both the maximum instantaneous and average power developed during a vertical jump. Since muscle strength is dependent upon the cross-sectional area of muscle, strength and power should increase in proportion to muscle mass. Assuming, in turn, that fat free mass and to a more limited extent, body weight, provide a rough estimate of muscle mass, then both weight and fat free mass should correlate with force and absolute power.

Body weight and height were related ($r=.79$; $p<0.01$) and therefore it was not unexpected to find a similar relationship between absolute power and height ($r=.76$; $p<0.01$).

Margaria Test of Power

The average alactic anaerobic power of the subjects obtained by the stair-running method of Margaria et al. (1966) was 17 W.kg bw^{-1}. This figure is consistent with normative values previously reported for adult men by Margaria et al. (1966) (14.7 W.kg bw^{-1}) and Kalamen (1968) (17.6 W.kg bw^{-1}) and is about three times higher than the maximum rate of energy production likely to be supplied by oxidation (Margaria et al., 1966).

The alactic power outputs (1219 W) were roughly one third the value achieved for maximum instantaneous power output (3580 W) during the vertical jump. This is because Margaria's test is not a measure of instantaneous power, but of average power calculated by dividing the mechanical work by the time of work. When the average absolute power developed during a vertical jump is calculated, it has been reported at between 1204 and 1218 W (Grey et al., 1961, Cavagna et al., 1971). This is very similar to the average absolute power as calculated by the method of Margaria et al. (1966), even though stair-climbing is, mechanically, a much more complex alactic activity.

Absolute alactic power, like the maximum instantaneous power, was strongly dependent upon body weight ($r=.87; p<0.01$) and fat free mass ($r=.94; p<0.001$), but to a greater degree. Much the same results were documented by Davies (1971), in young males (n=47), when weight and fat free mass were correlated to power performance in both the vertical jump and Margaria's test. Table 5-2 provides a summary of the results of this study compared to those of Davies (1971).

Table 5-2 The Relationship Between Absolute Power, Weight, and Fat Free Mass

	Absolute Power		
	force platform	stair-climbing	
weight	.58^{+}	.79^{+}	Davies,
FFM	.68^{+}	.86^{+}	1971
weight	.75^{++}	.87^{++}	This
FFM	.71^{+}	.94^{+++}	study

$^{+}p<0.05$; $^{++}p<0.01$; $^{+++}p<0.001$

The correlation of only .73 ($p<0.05$) between the absolute alactic power and maximum instantaneous power suggest that they may not strictly be used as comparable test forms. The common variance (r^2) accounts for only 53 percent of the total. In the case of relative power capacity ($r=.47$) the variance common to the two tests is even less. In each case one component of the specific variance might be the skill factor, since jumping and stair-climbing are two distinct gross-motor activities.

In this study, absolute power has been divided by the fat free mass, to obtain an index of relative power capacity (i.e. power exertable per kg of muscle mass) which is independent of both body size and composition. There was a high degree of relationship between absolute and relative power ($r=.85$; $p<0.01$ and .93; $p<0.001$ for the Margaria test and the force platform jump respectively) though this would not be expected.

Performance Tests of Power

Two features common to the vertical jump, standing broad jump and 40 m sprint, are that each tests an individual's ability

to develop "power" in relation to the body weight that must be moved and that each requires a combination of muscular strength and speed. As such, some degree of relationship should be evident amongst them. The results of this study indicate that the standing broad jump was moderately related to the vertical jump ($r=.63$; $p<0.05$) and the 40 m sprint ($r=-.66$; $p<0.05$). These correlations are similar to those obtained by Costill et al. (1968), Considine (1970) and Glencross (1966). Vertical jump height and the 40 m sprint were not significantly related ($r=-.53$), though the coefficient is rather similar in magnitude to those above. The variance predictable from any one test to the other is low ($r^2=28\%$ to 40%), which again attests to the degree of specificity inherent in each motor performance or test.

Another common feature shared by the two jump tests is their relationship to body weight and fat free mass. The standing broad jump was significantly correlated to weight ($r=.72$; $p<0.05$) and the fat free mass ($r=.82$, $p<0.01$), while the vertical jump was similarly related to weight ($r=.68$; $p<0.05$) but not to the fat free mass ($r=.54$). The latter correlation was probably affected by subject seven's high percent body fat (27.2%) and the difference in his performances in the standing broad jump and vertical jump relative to the group means.

The 40 m dash, in addition to being significantly related to fat free mass ($r=-.62$; $p<0.05$) was the only performance test that was close to reaching significance in its relationship ($r=.59$) to the percentage of body fat. Costill et al. (1968) have also reported that 40 yard running speed, as well as the distances jumped in a vertical jump and standing broad jump can

be affected by the percentage of body fat (r=.64, -.63 and -.61 respectively). These correlations are indicative of the detrimental effect that a low lean body mass/fat mass ratio has on performance test which require an individual to move his weight through a height or distance.

Correlations between different performance tests are always subject to error. However, the test-retest reliability coefficients obtained in this study for the Margaria test (.99), maximum instantaneous power (.95), standing broad jump (.94) and vertical jump (.97), as well as for percent body fat (.97) suggest that error due to technical inconsistency was relatively small. The reliability of the 40 m sprint was only slightly lower (.90), but this difference may have been sufficient to account for some of the inconsistencies between the performance test intercorrelations.

While the distances jumped in a standing broad jump or vertical jump and the time elapsed during a short sprint are only simple expressions or approximations of power, a force platform analysis of a vertical jump and the Margaria test, provide means by which power in its true mechanical sense can be measured. However, the correlations obtained between the Margaria test and maximum instantaneous power on the one hand and the standing broad jump, vertical jump and 40 m sprint on the other, attest to the degree of validity of these latter three tests as indices of leg power.

In this study, there were moderate to strong relationships between jumping performance and absolute power. Running speed

was also significantly related to absolute power developed during the vertical jump from the force platform. However, these correlations are due, in part, to the strong relationships which were evident between body weight and fat free mass and the various tests of power. The influence of body size and composition can be minimized by comparing the results of the jumping and running tests to the relative power outputs. When compared to the relative power in the Margaria test, the correlation of the standing broad jump decreased substantially but remained significant, while the correlation to the vertical jump remained about the same. A similar trend was noted in the relationships between the relative maximum instantaneous power, standing broad jump and vertical jump. The correlation between the 40 m sprint and relative power, as measured by Margaria's test, decreased to the point of becoming non-significant. This might not be expected since power, in the Margaria test when expressed in relative terms, is a function of the vertical running velocity, a major component of which would be the speed of leg movement. The speed of leg movement would contribute significantly to performance in the 40 m dash and thus, a high degree of relationship between the relative power and running speed should be evident. This has, in fact, been shown to be the case by Costill et al. (1968) and Kalamen (1968), whose relative measures were calculated by dividing absolute power by total body weight rather than the fat free mass.

The validity coefficients obtained for each of the performance tests indicate that they have only a limited application as valid

measures of power and are therefore only suitable for use in testing programs other than those in which the most rigorous measures of power are required. A similar conclusion was reached by Gray et al. (1962b) and by Glencross (1966b) but not by others (Barlow, 1970; Considine, 1970; Kalamen, 1968). However, the results of these studies are difficult to compare since the techniques for the jumping tests, the length of the sprints and the caliber of the subjects were not standardized. Furthermore, each study used a different criterion measure of power against which jumping and running performance were validated.

Muscle Fiber Distribution

Biopsy and autopsy studies have shown that, like most human skeletal muscles, the vastus lateralis is composed of a mixture of fibers, histochemically classifiable as Type I or Type II, which are distributed in a mosaic pattern throughout its depth (Gollnick et al., 1972; 1974; Edgerton et al., 1975; Johnson et al., 1973). Fiber distribution data from the studies of Gollnick et al. (1972; 1974), Edgerton et al. (1975), Larsson (1978) and Edstrom and Ekblom (1972) indicate that the vastus lateralis is composed, on the average, of 50 percent Type I and 50 percent Type II fibers, although considerable variation exists between individuals. Comparable results were obtained in this study, in which the mean Type II fiber population of the vastus lateralis was 53 percent. The range in the Type II fiber number was very wide (7-75), but similar to a range extending

from 4-87 percent Type.II fibers observed in the vastus lateralis muscle of athletes and non-atheletes in the study by Gollnick et al. (1972).

It is possible in this study, that part of the variation in percent of fiber composition among the different specimens may be due to sampling error. Previous research has shown that the distribution of fiber types in the vastus lateralis can be affected by variations in the biopsy site (Gollnick et al.,1972) as well as by the number of samples taken from a single site (Thorstensson, 1976; Clarkson et al., 1980; Clarkson et al., 1982). A sample size of at least 200 fibers is considered sufficient in order to determine fiber type percentages (Prince et al., 1976; Thorstensson, 1976). The specimens obtained in this study met or exceeded this requirement in all cases except for subjects six and two. The muscle fiber composition of subject two was based on a very small sample size (n=80) and it may therefore not be a true representation of the fiber content of this subject's vastus lateralis muscle.

The two marathon runners included in the study (subjects three and eight) had the lowest percent Type II fiber composition. This follows a pattern similar to that previously reported for endurance athletes when they are compared to other athlete populations and untrained control groups (Gollnick et al., 1972; Prince et al., 1976; Costill et al., 1976).

The cross-sectional areas of the Type I and Type II muscle fibers varied markedly across the group of subjects.

The great variation in absolute muscle fiber area which was observed in this and other studies (Edstrom and Ekblom, 1972; Costill et al., 1976; Thorstensson, 1976; Gollnick et al., 1972; Gregor et al., 1981; Prince et al., 1976) is thought to be partially due to a difference in the degree of muscle fiber contraction caused by the biopsy procedure (Thorstensson, 1976; Costill et al., 1976) and therefore some caution must be used when comparing fiber areas between subjects. A muscle fiber area ratio is considered to be a much more constant and reliable measure of muscle fiber area relationships (Thorstensson, 1976; Edstrom and Ekblom, 1972). In most of the subjects, the Type II/Type I fiber area ratios were within the normal range for untrained but physically active young males (Costill et al., 1976; Gollnick et al., 1972; Edstrom and Ekblom, 1972; Prince et al., 1976; Thorstensson et al., 1977). In comparison, the Type II/Type I area ratios of the two marathon runners (subjects three and eight) were low, though others have also observed that the areas of Type I fibers are larger than the areas of Type II fibers in distance and middle-distance runners (Costill et al., 1976; Gollnick et al., 1972; Gregor et al., 1981). It would appear that endurance training results in the preferential enlargement of the Type I fiber. Gollnick et al. (1973) found that following five months of endurance training, Type I fiber size in the vastus lateralis increased by 23 percent, while the Type II fiber size decreased by about 7 percent. When a muscle is composed almost exclusively of one fiber type, as was the case for subject number 8, this training effect would appear to be magnified. From Table 4-2 it

can be seen that subject eight's Type I fibers are among the largest of the group, while his Type II fibers are unusually small, resulting in a low Type II/Type I fiber area ratio.

There was a near perfect linear relationship in this study between the Type II fiber distribution by number and by area. A similar result was reported by Gollnick et al. (1972) and Edstrom and Nystrom (1969) even though samples containing vastly different fiber populations and size relationships were included. However, when a preferential enlargement or atrophy of either type of fiber occurs with training, the percent distribution of the two fiber types in a muscle may not be indicative of the relative area they occupy. Whilst the group means in this study did not change when the Type II distribution was expressed by number or by relative area, the variance was enhanced. The Type II distribution was reduced even further in the marathon runners when expressed by relative area.

Isometric Strength

Isometric leg strength was unrelated to power in this study. Such a relationship was not unexpected since it has been found that the isometric strength of a limb does not always correlate with the strength exerted during fast, forceful efforts (Smith, 1961; Clarke and Henry, 1961; Clarke, 1961; Henry, 1960). Isometric strength involves only muscular force, while explosive strength exerted during fast, forceful movements incorporates the elements of both speed and power (Atha, 1981). It has been theorized (Henry and Smith, 1961; Henry and Whitby, 1960) that the exertion of force is controlled by a

neuromotor pattern which is very specific to the limb involved in an action, the direction in which the limb is moved, whether the action is dynamic or static in nature and the angle of the involved joints. Isometric and isokinetic knee extension strength measures have been found to be highly intercorrelated by Larsson (1978) (r=.86-.95, n=89) and Clarkson et al. (1982) (r=.94-.98, n=9), when isometric strength was measured at selected knee angles which encompassed the entire range of motion over which the dynamic strengths were recorded. In this study, isometric strength was measured at a single knee angle of 90 degrees from full knee extention, while in the vertical jump, force is exerted through knee angles ranging from between approximately 85 degrees at the lowest crouched position to 102 degrees just before take-off (Offenbacher, 1970). In the standing broad jump, the knee angle just before take-off is approximately 60 degrees (Offenbacher, 1970). Therefore, the low correlations obtained between isometric strength and performance in the power tests of this study may be the result of this discrepancy and further study of the relationship between the two would be warranted.

Muscular strength is proportional to the active cross-sectional area of the muscle, which can be expressed as the total number of muscle fibers, X the average fiber area X the percent activated fibers (Larsson, 1981). However, since it has been found in animal muscles that the specific tension (tension per unit cross-sectional area) of Type II motor units is greater than that of Type I units (Barany and Close, 1971;

Burke and Tsaires, 1973), the question has been raised as to whether the muscle fiber composition in mixed human muscle can have a bearing on isometric force production. The results of the studies which have investigated the relationship between the relative muscle fiber distribution and isometric strength are conflicting. Tesch and Karlsson (1978), Komi et al. (1977a), Komi and Karlsson (1978) Mero et al. (1981), and Larsson (1981) have all found a significant correlation between isometric extensor strength of the quadriceps muscle and Type II fiber number and/or area in athletes and untrained subjects. Yet an equal number of investigators have failed to find that such a relationship exists. (Clarkson et al., 1980; 1982; Thorstensson, 1976; Gregor et al., 1979; Edstrom and Ekblom, 1972). In this study, Type II fiber distribution was not significantly related to the isometric strength of the subjects. In view of these conflicting results, it can be concluded that the importance of fiber composition to muscle strength is not yet clearly understood. Even if it is assumed that Type II fibers have a greater force capacity than Type I fibers, variations in tension production among muscle units within a type or between muscles with a similar muscle fiber composition are possible and can be accounted for by variations in the total unit area (Burke and Edgerton, 1975) and neuromuscular recruitment patterns (Milner-Brown, Stein and Lee, 1975). Variations in the total unit area are due to differences in innervation ratios or mean fiber areas or both. Little is known about innervation ratios in human muscle. However, it is known that a selective

hypertrophy of Type II muscle fiber areas can be induced with strength training (Thorstensson et al., 1977; Prince et al., 1976; Costill et al., 1976; Edstrom and Ekblom, 1972) and therefore an increase in total unit area can be achieved and these units should be capable of producing greater force. A close inspection of the data of Edstrom and Ekblom (1972), Thorstensson et al. (1977) and Gregor et al. (1981) reveals that power type athletes (power lifters, jumpers and pent-athletes) are capable of producing significantly greater isometric forces than endurance athletes and untrained controls. This is the case even though their Type II fiber composition is not significantly different from the rest of the subject population. Milner-Brown, Stein and Lee (1975) have also demonstrated that in addition to hypertrophy, maximum isometric strength can be affected by the degree of motor unit synchronization. They noted that the degree of motor unit synchronization shown by trained weight lifters were significantly greater than that of control subjects. In order to determine whether this phenomenon was the result of training or a form of natural selection, four subjects followed a training program in which maximal contractions of the thumb and first finger were performed daily for a period of six weeks. At the end of the training, these subjects demonstrated increased maximum isometric strength and this was accompanied by significant increases in the degree of motor unit synchronization.

The Relationship Between Muscle Fiber Distribution and Power Performance

The absolute power of a muscle should be dependant upon the cross-sectional area of its contractile components as well as the distribution of Type II fibers. It has been well documented that there is a positive relationship between the Type II muscle fiber composition and the ability to produce force and power at high contraction velocities (Thorstensson et al., 1977; Thorstensson, 1976; Coyle et al., 1979; Gregor et al., 1979; Thihanyi et al., 1982). This particular mechanical characteristic of the Type II fiber is attributed to its high intrinsic speed of shortening and to the rapid rate at which it develops tension (Close, 1972; Barany, 1967; Viitasalo and Komi, 1978). The biochemical properties associated with these contractile dynamics are the fibers' myosin ATPase activity and the rate of calcium release and uptake from the sarcoplasmic reticulum. Both of these capacities are high within the Type II muscle fibers (Burke and Edgerton, 1975; Brody, 1976; Feihn and Peter, 1971; Samaha and Gergeley, 1965; Barany, 1967; Close, 1972; Barany and Close, 1971; Barnard et al., 1971). Further, motor unit recruitment studies have demonstrated that there is a primary reliance upon the Type II fibers when there is a demand for high tension and/or velocity and that the usual motor unit recruitment pattern may be reversed so that the Type II fibers fire first during brief explosive movements (Gollnick et al., 1973; Gollnick, Piehl and Saltin, 1974; Edgerton and Burke, 1975; Grimby and Hannerez, 1968; Warmolts and Engel,

1973). Therefore, theoretically, performance in exercises which require considerable speed and/or tension production may rely upon the availability of the Type II fibers.

In this study, the Type II fiber distribution was significantly related to the standing broad jump ($r=.68$; $p<0.05$) vertical jump ($r=.61$; $p<0.05$) and absolute and relative power in both the Margaria test ($r=.70$; $p<0.05$ and $.91$; $p<0.001$) and force platform jump ($r=.65$; $p<0.05$ and $.67$; $p<0.05$). Komi and Bosco (1978); Komi et al. (1977a) and Mero et al. (1981) have also found that the skeletal muscle fiber composition can be related to vertical jump performance and relative power in the Margaria test. They have interpreted their correlations as being indicative of a cause and effect relationship. That is, the influence of the muscle fiber distribution on power performance can be attributed to the basic differences in the mechanical characteristics of slow and fast muscle fibers and their respective motor units. Such a cause and effect relationship between Type II distribution and power performance cannot be assumed in this study because the Type II fiber distribution was also very highly related to body weight ($r=.75$; $p<0.01$) and to a lesser degree, to the fat free mass ($r=.46$). Such relationships were not expected and have not been supported by the literature. These correlations are therefore probably due to sampling error, but since they do exist, it is difficult to determine whether the subjects with more Type II fibers displayed more power because of their fiber composition or simply because they were larger and had a high lean body mass.

However, the relative maximum instantaneous power was significantly related to the Type II distribution ($r=.67$; $p<0.05$). This variable was the least affected by the FFM ($r=.43$) and therefore the correlation between Type II distribution and the relative maximum instantaneous power might represent the extent to which power capacity co-varies with the Type II distribution.

Whereas the absolute maximum instantaneous power and absolute power in the Margaria test should depend upon both muscle mass and the Type II fiber distribution, absolute power expressed in relative terms ($W.kg\ FFM^{-1}$) would represent the intrinsic capacity or the rate capacity for the derivation of energy (per unit weight of muscle) from the intracellular stores of phosphagen. Performance in the vertical jump, standing broad jump and 40 m sprint would be indices of the absolute power-to-weight ratio, for what these latter tests actually measure is either the height or distance through which the subject can move his body weight or the time it takes him to do so. Therefore, the absolute power of a muscle or muscles need not necessarily be reflected in terms of inches jumped or speed. However, in this study because of the close interrelationships between weight, fat free mass and the Type II distribution, those subjects who displayed high absloute power also displayed high relative power. Thus, the correlations between absolute and relative power as well as the correlations between the performance tests and the Type II distribution were higher than might be expected.

The Type II distribution was also significantly related to the relative peak force ($r=.61$; $p<0.05$) and the relative force at peak velocity ($r=.71$; $p<0.05$). The latter two variables were not significantly related to the fat free mass ($r=.32$ and $.07$ respectively) and thus, the advantage of having a high proportion of Type II fibers would appear to lie in their capability for high relative force production at fast contraction speeds.

Bosco and Komi (1979) have also reported significant correlations between Type II fiber number and vertical jump height ($r=.48$; $p<0.01$), average force ($r=.52$; $p<0.01$), net impulse ($r=.45$; $p<0.01$) and the average mechanical power ($r=.52$; $p<0.01$). The subjects of their study were 24 untrained males with a Type II fiber composition ranging from 19 to 76 percent (mean 50.7 ± 15.1). The net positive impulse in this study could not be related to Type II fiber number. It can be recalled that an increase in the impulse of the reaction force can be accomplished by increasing the magnitude of the force or the time over which it acts.

Figure 4-2 and 4-3 illustrate that the relatively "slow" subjects, who had 51 percent or less Type II fibers, were able to compensate for their apparent reduced force potential by prolonging the time during which their feet were in contact with the ground, thereby achieving the same mean net impulse (609 N sec) as the "fast" subjects (607 N sec). The latter group however, were more efficient jumpers inasmuch as they

were able to achieve comparable net impulses and greater power scores with relatively short contact times on the ground.

A significant correlation between muscle fiber type and power performance in the untrained has not been found consistently (Campbell et al., 1979; Komi and Karlsson, 1978). In the study by Campbell et al. (1979) the performances of subjects with a low percent Type II fibers (35.8%) and those with a high percent Type II fibers (63.6%), on a bicycle ergometer power test and a Sargent jump, were very similar and not significantly related to the muscle fiber composition. Campbell et al. suggested that the absolute number of Type II fibers may not be the sole criteria for performance capacity. Since the synchronization of motor units containing one type of fiber is not fixed, the efficiency of recruitment of the available fibers for a given task may ultimately govern performance.

Sprinting is essentially a power performance which is dependant upon one's ability to project the body forcefully and rapidly from alternate feet. Chronological plots of world records in track and field provide evidence of irregular but consistent improvements in the performance capacity of men and women. During the last five decades, man has run the mile 16.5 seconds faster, jumped over 9 inches higher, and thrown the shot and discus 12 and 60 feet further respectively (Singh et al., 1978). However, sprinting performance has not experienced the same degree of improvement. The best results that man has been able to achieve in the 100 meter race has not

improved by more than .3 seconds following a 10.2 second record set in 1921. Thus, it has been suggested that sprinting ability among the world's best is an innate quality which is "internally" governed by high stride rate (Mero et al., 1981). Stride rate is proportional to the speed of contraction of the mover muscles (Jensen and Schuly, 1977). The speed of muscular contraction is, in turn, primarily dependent upon the proportion of Type I and Type II muscle fibers. Since the proportion of muscle fiber types is genetically fixed and not susceptible to change, it could be assumed that this is one aspect of an individual's genotype which could ultimately limit running speed. The available data on the distribution of muscle fiber types in elite athletes has shown that, in contrast to athletes in field events whose distribution of Type I and Type II fibers is not particularly skewed, sprinters usually have a high proportion of Type II fibers. This suggests that this characteristic may be a particularly important prerequisite for success in sprinting. Mero et al. (1981) studied a group of twenty five male sprinters and found that the subjects' best performances in a 100 m dash and a maximal running velocity over 30 meters were significantly related to the Type II muscle fiber composition in the vastus lateralis muscle ($r=.69$; $p<0.001$ and $r=.58$; $p<0.01$ respectively). Type II fiber distribution was also strongly correlated with stride rate ($r=.67$; p 0.01) and stride length ($r=.46$; $p<0.05$). The sprinters were all similar

in age, mass, height, limb length and in their Type II/Type I muscle fiber area ratios.

In this study, Type II fiber number was not significantly related to running speed in the 40 m dash. Although the speed of muscle contraction would appear to be an innate quality, running speed can also be affected by neuromotor coordination, sprinting technique, body size, strength and mechanical and structural features such as the length of the limbs and flexibility of joints (Jensen and Schultz, 1977). In the untrained then, factors such as neuromotor coordination and technique may be more important determinants of limb speed than the Type II fiber composition. An individual may not be able to reach his full genetic potential until errors in sprint mechanics are corrected and neuromotor coordination enhanced through training.

The results of the studies of Mero et al. (1981) and Bosco and Komi (1979) make it possible to verify that the muscle fiber composition cannot only have a bearing of the force-velocity and force-time curves in a single joint movement, but also on the running speed and the performance and mechanical parameters of a more complicated movement invloving several joints in dynamic motion (Bosco and Komi, 1979). These results for a multijoint movement could in turn, likely be extended to various sports activities. The significant correlations obtained in this study between the Type II fiber distribution and the variables derived from the force platform are similar to those of Bosco and Komi (1979). However, the inferences which

can be drawn from the results of this study are seriously limited by the confounding effect of the unexpected relationships between body weight, the fat free mass and Type II distribution, as well as by the small number of subjects.

The fact that it is possible to predict gross motor performance involving complex movement from a small muscle biopsy is in itself surprising, especially since the biopsy is taken from one of only many different active muscles. If the correlations obtained in this study were to represent the true extent of the effect of Type II fiber distribution on power performance, they might justify an attempt to preselect individuals on the basis of fiber type requirements for different sports activities. Training could also be expected to have an important effect upon factors which are important to power performance.

CHAPTER SIX

Conclusions and Recommendations

Conclusions

The major findings of this study and the conclusions that can be drawn from them, may be summarized as follows:

(1) Body weight, fat free mass, Type II fiber distribution and absolute power measured by Margaria's stair-climbing test and the force platform jump were interrelated. Thus, absolute power capacity was limited by the combined effect of muscle mass and the Type II distribution and those individuals who had both a high lean body mass and a high percent of Type II fibers were the most favourably predisposed toward high absolute power capacity. Relative power in the above two tests should be dependant upon the Type II distribution, regardless of body size and composition. In this study, the largest subjects also possessed the greatest number of Type II fibers and thus, there was a high correlation between absolute and relative power. The smaller subjects with the relatively low Type II distributions were, therefore, doubly handicapped.

(2) A high percentage of Type II fibers is beneficial in power type activities, such as jumping, where success depends upon maximizing force production at fast contraction speeds. The variance (r^2) in power performance accounted for by Type II

fiber composition ranged from 49% to 82% for absolute and relative power in the Margaria test and force platform jump and from 22% to 46% in the three performance tests. This amount of predictability is especially significant when one considers that performance in each of these five tests is also affected by anthropometric, neuro-motor and various bio-mechanical factors.

(3) The correlation obtained between absolute alactic power and maximum instantaneous power indicated that they may not strictly be used as comparable tests forms. Each of the performance tests of power also possessed a considerable amount of specific variance. In addition, these tests were found to be moderately related to power as measured by the Margaria test and force platform jump. Therefore, they have only a limited application as valid measures of power. Of the three, the 40 m sprint was the least valid and reliable.

Recommendations

The extent of the relationship obtained in this study between Type II distribution and power performance would justify further study in this area with a larger sample size. The muscle biopsy procedure is invasive and not without risk and therefore, it would be desirable to be able to predict muscle fiber composition from one or more simple laboratory tests. Unfortunately, the results of the simple regression analysis in this study were not significant, primarily because of the small subject number. Since performance capabilities are always affected by a combination of factors, a multiple

regression approach with a large number of subjects would probably be a promising area for future research. Margaria's test would be a useful test to include in any investigation of this type because it is versatile, easy to administer, provides an accurate mechanical assessment of average power and incorporates an activity (stair-climbing) with which everyone is familiar. Though less versatile for the purpose of quantifying power production, the force platform would also be a valuable tool for use in future research. The force platform provides a means through which those variables which contribute to the performance of a power-type activity can be isolated and subsequently, to determine how these variables are affected by the Type II distribution.

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APPENDIX A

CONSENT FORM

DEPARTMENT OF KINANTHROPOLOGY

CONSENT FOR PERCUTANEOUS MUSCLE BIOPSY SAMPLING

I, _____, hereby volunteer for percutaneous muscle sampling by biopsy needle as part of a research project to investigate the degree of relationship between fiber composition of skeletal muscle and maximal power performance.

I understand that two small pieces of muscle tissue (usually less than 50 mg) will be removed by a medical doctor, from the vastus lateralis muscle of one leg using a percutaneous biopsy needle. After disinfection of the skin and injection of local anaesthetic, a small incision (about 4 mm in length) will be made in the skin and subcutaneous tissue with a scalpel. The biopsy needle will then be advanced through the incision into the muscle to obtain the sample. A second sample will be obtained in the same way through the same entry point, and then the skin incision will be closed with a sterile adhesive strip.

Although the biopsy technique has been described as "relatively atraumatic", I understand that certain risks do accompany the procedures. The more significant risks would be damage to nerves resulting in paralysis, damage to large vessels producing hemorrhage and haematoma, systemic infection, and fat necrosis. Relatively minor complications could include milder hemorrhage, wound infection, reaction to local anaesthetic or cleansing solution, wound breakdown, poor wound healing, sensory impairment, weakness, stiffness and soreness. Some pain and discomfort often accompanies the procedures, while mild stiffness, soreness and slight scarring are the usual after-effects.

I realize that I can not expect to derive any direct benefit from this participation and that I am free to withdraw consent at any time. In volunteering to participate, I waive any legal recourse against the researchers, the medical physician, the Department of Kinanthropology and the University of Ottawa from any and all claims resulting from personal injuries sustained or death resulting from these tests. This waiver shall be binding upon my hiers, my executors, my administrators and my personal representatives.

DATE: _____

Subject Signature: _____

Witness Signature: _____

Muscle and Metabolic Research Lab
Department of Kinanthropology
University of Ottawa

Date: Name:

Address: Occupation:

Age:

Check the correct alternative:

Have you had before or have you now to your knowledge:

	YES	NO
1. High or low blood pressure.		
2. Predisposition to hemorrhage.		
3. Sensitivity or allergic reactions to drugs.		
4. Predisposition to muscle spasms.		
5. Diabetes.		
6. Identified heart disease such as coronary thrombosis, chest pain.		
7. Are you now suffering from any infection (fever, cough, cold etc.)?		
8. Are you using regularly any drug?		

If you answered any of the above questions in the affirmative, explain briefly the history of the illness, symptoms and therapy.

_____

_____

9. Have you previously been given local anesthesia, for instance by a dentist? If your answer is 'yes' and if it had any side-effect (for instance nausea), explain.

_____

_____

Signature _____

Witness _____