A Study of Factors Influencing Performance on the Wingate Test In Females

by

K.A. Brian Paquin

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INTRODUCTION

Recent studies have attempted to correlate performance on supramaximal tests with muscle fibre morphological profile (Bar-Or et al., 1980; Jacobs & Tesch, 1981). The premise for these studies is based on the observation that fast twitch (FT) muscle fibres are more suited to anaerobic work and therefore their percent distribution should be correlated with performance on an anaerobic test (Essen et al., 1975; Thorstensson et al., 1977a).

Bar-Or et al. (1980) and Kaczkowski et al. (1982), in studies that used male physical education students as subjects, attempted to correlate the Wingate Test (WT), a 30 second all-out sprint on a cycle-ergometre with a resistance relative to body weight, with muscle fibre morphological profile. Both investigations reported a significant correlation between maximal anaerobic power and capacity, and both the percent FT fibres and the area of the muscle occupied by FT fibres. Conversely, in a study that used females as subjects, no significant correlation was found between the percent area occupied by FT muscle fibres and performance on the WT (Jacobs & Tesch, 1981). In a similar investigation using female subjects Campbell et al. (1979) failed to find a significant correlation between performance on two

supra-maximal cycle-ergometre tests and either the percentage of FT fibres or the area occupied by FT fibres.

This investigation used female intercollegiate athletes and physical education students in an attempt to correlate performance on the WT with muscle fibre morphological profile and body composition.

Statement of the Problem

The purpose of this study was two-fold:

1. To determine the relationship between the percentage of FT muscle fibres or the percent area occupied by FT fibres and peak power, average power and power decrease as computed on the Wingate Test.
2. To determine the relationship between body weight or lean body mass and peak power, average power and power decrease as computed on the Wingate test.

Delimitations

1. Only eight athletes and 10 physical education students were used as subjects due to:
   a) the availability of suitable subjects
   b) the complexity of histochemical procedures used in the study
2. Subjects were volunteers and therefore may not be a truly representative sample.

Definitions

Peak Power (PP): As used in this study, is the highest mechanical power output produced during the WT.

Average Power (AP): As used in this study, is the average power output for the 30 seconds of the WT.

Power Decrease (PD): As used in this study, is the difference between the peak power and the lowest power output recorded on the WT.

Anaerobic power: As used in this study, is the highest mechanical power output produced during the WT.

Anaerobic Capacity: As used in this study, is the total power output for the WT.

REVIEW OF LITERATURE

Sources of Anaerobic Energy for Muscle Contraction

Many reactions within the body produce energy, but the majority of these are cyclical reactions, in which there is no net gain in energy (Marechal, 1981). The only significant energy producing reaction utilizes the hydrolysis of the adenosine triphosphate (ATP) molecule (Cain & Davis, 1962).

Anaerobically, the crucial reaction for the production of ATP is the Lohman reaction:

$$CP + ADP \xrightarrow[\text{creatine kinase}]{} \text{creatine} + ATP$$

Although ATP can also be produced by the following reaction:

$$2\ ADP \xrightarrow[\text{myokinase}]{} ATP + AMP$$

its significance for energy production in man has not been established (Gollnick & Hermansen, 1973).

ATP-PC System

The average concentrations of CP and ATP are 16 mmole/kg wet muscle and 4 mmole/ kg wet muscle, respectively. During intense anaerobic exercise, CP stores are virtually exhausted, whereas the ATP levels do not fall below 40% of the resting value (Karlsson & Saltin, 1970).

The ATP-PC system produces useful energy very quickly due to the rapid turnover of the Lohman reaction (Marechal, 1981). Mathews and Fox (1976) estimate that, for a 70 kg man, the maximal power of the system is 3.6 moles ATP/minute (151 kj/min) and the maximal capacity is 0.7 moles of ATP (29 kj). For an athlete of the same weight, power and capacity can be 750 kj/min and 55 kj respectively.

Capacity of the ATP-PC System in Males and Females. No significant differences have been reported between males and females in either ATP or CP concentrations. Females, however, have been reported to have significantly more CP in ST fibres than in FT fibres (Harkonen et al., 1982).

Sawka et al. (1980) found that whereas the alactic capacity was 429 joules/ kg for males, it was only 317 joules/ kg for females. The authors indicated that the discrepency between men and women would have been less if lean body weight had been used instead of gross body weight.

Anaerobic Glycolysis

ATP is also produced via anaerobic glycolysis which is a series of reactions whose end product is lactic acid (Stryer, 1981). The anaerobic breakdown of one mole of free glucose or one mole of glucose from glycogen stores yields two or three moles of ATP, respectively. The availability of glucose is dependent upon plasma glucose concentration as well as upon hormonal factors (Kipnis et al., 1959). The total

volume of blood glucose has been reported to be 4.3 g (Keul et al., 1972). Glycogen content varies among muscles, for example Hultman (1967) reported a concentration of 1.0 to 2.0 g/ 100 g wet muscle in the quadriceps femoris and approximately 1.0 g/100 g wet muscle in the deltoid muscle. Concentrations depend upon nutritional status, training status and hormonal factors (Keul et al., 1972). The rate and magnitude of glycogen and glucose degradation to lactate depends upon the intensity and the duration of the exercise. Although the amount of energy production from glycolysis is substantial during short term work, glycogen reserves are not a limiting factor (Gollnick & Hermansen, 1973).

The rate of glycogen breakdown to lactate is under enzymatic control. Phosphorylase and phosphofructokinase (PFK) have been identified as the two key enzynmes in this process (Newsholme, 1980). The former controls the breakdown of glycogen to glucose, while the latter is the principal control point for glucose metabolism. PFK is very sensitive to ADP levels with high levels leading to increased PFK activity (Stryer, 1980). Phosphorylase exists in either the inactive b form or the active a form. Within the muscle cell, the b form can be activated into the a form either by the adrenergic system or by electrical stimulation. Adrenergic stimulation involves the adenyl-cyclase system, whereas increased electrical stimulation involves an increased sensitivity to calcium ion concentration (Stull & Mayer, 1971).

Mathews and Fox (1976) indicate that 1.6 moles/minute (67.2 kj/min), and 1.2 moles (50.4 kj) reflect the power and the capacity, respectively, of the glycolytic system for a 70 kg. man. For the equivalent sized athlete, the power and the capacity would be 500 kj/min and 130-205 kj, respectively. Peak blood and muscle lactic acid (LA) values are considerably higher in males than in females (Mathews & Fox, 1976; Komi & Karlsson, 1978). Karlsson (1971) reported peak blood LA concentrations of over 20 mmoles/litre in males. In untrained females, Komi & Karlsson (1978) reported a value of 6.4 mmoles/litre, whereas Komi et al. (1977) found a blood LA concentration of 11.0 mmoles/litre in a trained female cross-country skier.

Limiting Factors to Anaerobic Work

The exact mechanisms by which anaerobic work is limited are not known, but two mechanisms postulated by Hermansen (1981) are of interest. The first theory is based on the observation that during intense, short term work the lactic acid concentration and, concomitantly, the hydrogen ion concentration, increase in the blood. Although a large percentage of these hydrogen ions are buffered, the net effect is a lowering of blood pH. The intramuscular pH is also lowered as well as the activity of PFK and phosphorylase, which in turn leads to a lower rate of ATP production and consequently to a reduction in force development by the muscle.

A second mechanism has to do with the contractile process within the muscle. At present it is thought that actin and myosin would bind to each other if it were not for the fact that troponin covers the binding sites (Stryer, 1981). When the levels of Ca^{++} are sufficiently great, troponin no longer covers the binding sites and the actin and myosin filaments can bind to each other, thus allowing the muscle to contract. This process is affected by the pH within the muscle (Wenger & Reed, 1976).

Donaldson and Hermansen (1978) found that a drop of 0.5 pH units had little effect on ST fibres, whereas, the same drop in pH resulted in tension reduction of 50% in FT muscle fibres. Some possible mechanisms to account for this phenomenon have been reported in the literature. Samaha et al. (1970) demonstrated that fast muscle myosin is less active at low pH. Brooke and Kaiser (1970 b) indicate that there are three myosin ATPase systems and that their activity is pH related. Nakamura and Schwartz (1972) found that the affinity of the sarcoplasmic reticulum (SR) for calcium depended specifically on pH. The lower the pH, the tighter the binding of the Ca^{++}. Fuchs et al. (1970) showed that with a decreasing pH, the affinity of troponin for binding Ca^{++} decreased as well. Both mechanisms would lead to a reduction of tension within the muscle.

Muscle Characteristics and Performance

Muscle Fibre Classification

The earliest classification of skeletal muscle was made by Ranvier (1873) who reported that skeletal muscle was either red or white. This fundamental division of skeletal muscle into two distinct groups has been confirmed by studies that have looked at muscle on the basis of its histochemical, ultrastructural, biochemical and physiological properties. Several nomenclature systems are based on the above properties.

Speed of contraction is a physiological response and it has been shown that red muscle fibres are slow contracting while the white fibres are fast contracting (Edgerton et al., 1975). Therefore the red and white fibres were named slow twitch (ST) and fast twitch (FT) respectively.

The most widely used method of classification is based on the use of histochemical staining procedures for myosin adenosine triphosphatase (ATPase) at pH 9.4 (Engel, 1962). Fibres with low ATPase activity are designated Type I, while those with a high ATPase activity are called Type II. Barany (1967) showed that speed of contraction is related to ATPase activity. ST fibres demonstrated low ATPase activity while FT fibres had a high ATPase activity. Thus the terms ST and Type I, and FT and Type II can be used interchangeably.

Further histochemical and biochemical evidence demonstrates that the FT group is not homgeneous in its makeup. Brooke and Kaiser (1970a) found that, after preincubation at pH 4.6, Type II fibres could be subdivided into groups which they termed IIa and IIb. In a study of rabbits and guinea pigs, Peter et al. (1972) reported that a close relationship existed between contractile characteristics and the biochemical properties of the muscle fibres. Fibres were designated slow oxidative (SO), fast oxidative glcolytic and (FOG), fast glycolytic (FG), respectively. The FOG and FG fibres are similar to the fibres termed IIa and IIb by Brooke and Kaiser (1970a), while the SO fibre is generally considered to be similar to the ST or type I fibre.

Differences Between FT and ST Muscle Fibres. Besides the aforementioned differences in histochemical staining, FT and ST fibres also differ physiologically, ultrastructurally and biochemically. Physiologically, the contractile properties of FT fibres are significantly greater than those of the ST fibres, as evidenced by their shorter time to peak tension and higher twitch tension. Ultrastructurally, FT fibres are larger and are innervated by large myelinated nerves with a high conduction velocity (Burke & Edgerton, 1975). Biochemically, FT fibres possess higher levels of ATPase, creatine phosphokinase (CPK), myokinase (MK) and phosphofructokinase (PFK).

Fibre Type Distribution in Males and Females

There is considerable variation in fibre type distribution within both sexes but the variation seems to be widest among males (Edstrom & Nystrom, 1969). Gollnick et al. (1973b) reported a mean value of 32% ST fibres in males, whereas Clarkson et al. (1982) found the percentage to be 55.6% in her subjects. The majority of studies have found that among males, the ST fibre population ranges from 45-50% (Costill et al., 1979; Thorstensson et al., 1977a). In non-athletic populations of women, the range of reported values is from 45-52% (Jacobs et al., 1983; Jacobs & Tesch, 1981; Komi & Karlsson, 1978). The average, in both sexes, appears to be about 50% ST and 50% FT.

The distribution of fibre types in athletes varies widely, with only endurance athletes and sprinters demonstrating a consistent pattern. Endurance athletes, both male and female, have significantly more than 50% ST fibres, whereas sprinters (male and female) have significantly more than 50% FT fibres (Costill et al., 1976b; Gollnick et al., 1972). Athletes like jumpers and throwers, although considered power-athletes, are more difficult to categorize. Although there is a tendency for these athletes to have a high proportion of FT fibres, wide variation is found (Costill et al., 1976 b; Gollnick et al., 1972).

Sex Related Differences in Fibre Area

Sedentary males have larger FT fibres than ST fibres, whereas the opposite is true for females (Nygaard, 1981; Thorstensson, et al., 1975). Both FT and ST fibres are larger in males than in females. (Costill et al., 1976b; Gollnick et al., 1972). Among male and female athletes event specialization is evident. Sprinters and endurance runners, both male and female, are characterized by larger FT and ST fibres respectively, (Gregor et al., 1979; Costill et al., 1976b).

Sex Related Differences in Skeletal Muscle Enzymes

Bass et al. (1975) reported that the activity of lactate dehydrogenase, glycerophosphate dehydrogenase and hexokinase were lower in the vastus lateralis of women. Komi and Karlsson (1978) found that the levels of Ca activated ATPase, CPK and phosphorylase are considerably lower in the vastus lateralis of women than in men.

Haralambie (1979) performed muscle biopsies on several different muscles in females of various ages and checked the activity of sixteen different enzymes. In muscle groups such as the deltoids there was no difference in enzymatic activity between males and females. Haralambie claimed that the reported differences in the literature for the vastus lateralis can be explained on the basis of the difference in activity patterns between males and females.

Studies such as one done by Costill et al. (1976b), which have looked at enzymatic activity in male and female athletes, have found both similarities and differences which can be accounted for by looking at the training status of the athletes.

Training and its Effect Upon Muscle

The degree and kind of changes that training can bring about in the muscle depend upon the type, intensity and duration of the training program. Training can induce changes in enzymes, metabolites or fibre composition.

Anaerobic Training. Strength training has been shown to increase the FTa percent fibre area and the FT/ST area ratio (Costill et al, 1979; Thorstensson et al., 1976a). Jansson et al. (1978) found that intense anaerobic training (running) could decrease the percentage of ST fibres and increase the FT fibre population, whereas the majority of studies failed to report any change in fibre type due to this type of training (Fournier et al., 1982; Thorstensson et al., 1975).

Anaerobic training must be of a certain type or intensity to effect enzymatic activity. Costill et al. (1979) demonstrated this, noting that that a 30-second protocol produced increased activities in PFK, CPK, MK, malatedehydrogenase (MDH) and SDH. Several researchers have employed sprint training and have found increases in Mg ATPase, MK,

CPK and PFK (Fournier et al., 1982; Thorstensson et al., 1975). Strength training, on the other hand, increased MK significantly but not Mg ATPase, PFK and CPK (Thorstensson et al., 1976 b). McDougall et al. (1977) showed that strength training increased the levels of CP, creatine, ATP and glycogen. Thorstensson et al. (1975) reported that sprint training did not change the concentrations of ATP and CP, but that the total amount of phosphagens did increase.

Aerobic Training. Several studies have demonstrated that the area of the ST fibres is increased with aerobic training (Gollnick et al., 1973b; Fournier et al., 1982). Such training also has been reported to affect the FT fibre population, possibly by decreasing the FT fibre area or increasing the percentage, and the fibre area, of FTa fibres while decreasing the same parameters in FTb fibres (Anderson & Henrikson, 1977; Fournier et al., 1982; Gollnick et al., 1973b). Enzymatic activity is specifically affected by the type of aerobic training. Gollnick et al. (1973b) and Fournier et al. (1982) demonstrated that SDH activity is increased significantly by endurance training. Henrikson and Reitman (1976) found that SDH activity was susceptible to continuous, as opposed to interval training. Substrates, such as glycogen, also have been reported to increase with endurance training (Gollnick et al., 1973b).

Muscle Fibre Composition and Performance

Cycle-ergometre Studies. Average power and PP on the WT were found to correlate with both the percentage of FT fibres and the percent area occupied by FT fibres, when either trained males or male physical education students were used as subjects (Bar-Or et al., 1980; Inbar et al., 1981; Kaczkowski et al., 1982). When females (Jacobs & Tesch, 1981) and untrained males (Inbar et al., 1981) were used as subjects, AP and PP did not correlate with either the percentage of FT fibres or the percent area occupied by FT fibres. Jacobs and Tesch (1981) did report a significant negative relationship between level of fatigue, as expressed by the relative power decrease during the WT, and intramuscular lactate concentration.

Campbell et al. (1979) attempted to describe the relationship between muscle fibre type and performance in 24 female subjects. Tests included a maximum oxygen uptake test, Sargeant jump test and two anaerobic power tests on the cycle- ergometre. Resistance settings for the anaerobic tests were individually set and were related to performance on the maximum oxygen uptake test. No significant correlations were found between any of the tests and the percentage of FT muscle fibres. Twenty of the subjects then underwent six weeks of anaerobic training on the cycle-ergometre. The tests were repeated and significant improvements were reported for the Sargeant jump and the two anaerobic cycling

tests. Again, no significant correlations were found between the percentage of FT fibres and performance on any of the tests, nor was any correlation found to exist between change in performance and the percentage of FT fibres.

Isokinetic Studies. Several studies have looked at isokinetic strength at high angular velocities and have demonstrated, quite conclusively, that a relationship exists between performance on these tests and the percentage of FT fibres or FT fibre area (Coyle et al, 1979; Nilsson et al, 1977; Thorstensson & Karlsson, 1976). Only Clarkson et al. (1982) failed to find a significant relationship between peak torque, at any angular velocity, and the percentage of FT fibres. They did report, however, that body weight and thigh circumference correlated significantly with peak torque and fatigue. Unfortunately, the studies which reported that the percentage of FT fibres correlated significantly with peak torque did not report the correlation between body weight and thigh circumference, and peak torque.

The Influence of Body Dimensions on Anaerobic Power and Capacity

The relationship between anaerobic power and body dimensions has not been examined systematically. In children, Cumming (1973) found that vertical velocity as computed from the stair test of Margaria et al. (1966) did not correlate with weight in either boys or girls. Cumming did find that total work performed during a 30-second anaerobic sprint on a cy-

cle-ergometre correlated r=0.68 and r=0.37 with body weight in boys and girls, respectively. Davies et al. (1972) used the same stair test and found that when power was computed in kgm/sec, it correlated r=0.88, r=0.89, r=0.91, r=0.90 with height, weight, leg volume (LV), and lean body mass (LBM), respectively.

In men under 35, Davies (1971) found that power computed on the stair test in kgm/sec correlated 0.53, 0.79 and 0.86 with height, weight and LBM, respectively. For men over 35, the corrrelations with weight and LBM were 0.56 and 0.58 respectively. Davies also computed power on the force platform and found that for men under 35, power correlated 0.43, 0.58, and 0.68 with height, weight and LBM.

Katch (1974) reasoned that work output on the cycle ergometre should be weight independent since body weight is not involved in the computation. Katch had his male subjects cycle for 2 minutes at a workload of 5.6 kp and initially at 97 rpms. During the early part of the test, when work output was similar for all subjects, LV, body weight and leg density were of little predictive importance. During the latter stages of the test, as performance differences became more significant, body weight and LV become more important as determinants of performance. Total work correlated r=0.64 and r=0.60 with body weight and LV respectively. Leg density did not correlate with total work.

Katch and Weltman (1979) had male subjects ride a cycle-ergometre for 2 minutes at 34 kpm/rev with an all-out cadence. Anaerobic capacity was taken as the total work on the test while anaerobic power was the 6 second period with the highest work output. Body weight accounted for 50%, while leg density and LV accounted for slightly less than 35% of the variance in total work. Anaerobic power correlated 0.40 and 0.29 with body weight and leg volume respectively.

Body weight and thigh circumferance have also been found to correlate significantly with peak torque and fatigue during isokinetic testing (Clarkson et al., 1982).

Anaerobic Testing on the Cycle Ergometre

Several researchers have carried out studies to determine optimum resistance and pedal frequencies for anaerobic testing on the cycle-ergometre. Katch et al. (1976) determined that all-out cycling produced higher power output during the first 30 seconds of a power test on the cycle-ergometre. Katch et al. (1977) reported that the optimal characteristics for a test of maximal work on the cycle-ergometre would be: a duration of 40 seconds, a resistance of 5-6 KP and an all-out cadence. Seabury et al. (1977) indicated that there was an optimal pedalling frequency for each power output.

Wingate Test

The Wingate Test (WT) is based on a 30 second cycle-ergometre test which Cumming (1973) used to evaluate fitness in youths participating in a training camp. Resistance was 4.5 KP for males and 4.0 KP for females. Test-retest correlation was r=0.86, and body weight correlated highly with performance.

Bar-Or (1978), working at the Wingate Institute, used the same 30-second format as Cumming(1973) but varied the resistance according to body weight (.075 KP/kg. for the Monark bike and .40 KP/Kg. using the Fleisch ergometre). Reliability varied from r=0.95 to r=0.97 when children, youths and adults were used as subjects. The validity of the test was demonstrated as it correlated with 300 metre run times (r=-0.85), oxygen debt (r=-0.86), and 25 metre swim time (r=-0.87 to -0.90).

Many studies have been concerned with correlating work out-put on the WT with fibre type (Bar-Or et al., 1980; Jacobs & Tesch, 1980). Therefore, it is important that the test allows for the subjects to achieve maximum performances. Evans and Quinney (1981) considered this problem in relation to the WT. The authors reported that there was a significant difference between the optimum resistance settings that elicited maximum power, and capacity and those that the WT would indicate. The authors offered three methods for choosing resistance settings which were superior to

the WT protocol. The power curve for each subject could be determined, which could take from 5-10 trials. One of two regression equations could also be used. The first uses the subject's weight and leg volume (r=0.87), while the second utilizes a pre-test score (r=0.77). Subjects in this study were healthy, athletic males, and, thus far, the validity of these regression equations for other populations has yet to be established.

METHODS AND PROCEDURES

Subjects

Eighteen females volunteered to be subjects in this experiment and were subsequently divided into two groups. Group A consisted of 4 intercollegiate basketball and 4 intercollegiate volleyball players while group B was made up of 10 physical education students. Among the physical education students were several provincial calibre athletes. These included a cross-country skier, cyclist, and speed skater. Prior to participating in the study subjects were fully informed of the procedures to be used and signed an informed consent form (Appendix A).

Design

Subjects reported to the laboratory on four separate occasions during a two week period. During session one, the subjects' height,weight and lean body mass were determined. The subjects also performed the first WT. The second WT was conducted during the second session. The third session involved the determination of maximum oxygen uptake. During session four, a single muscle biopsy was taken from the muscle vastus lateralis of each subject.

Test Protocols

Lean Body Mass

Total body fat was determined from body density as determined by underwater weighing. The volume of the gas in the gastrointestinal tract was assumed to be 100 ml for all subjects. Residual volume of the lungs was assumed to be 30% of the vital capacity, which was determined using a spirometer. Percent body fat was estimated from body density using the formula of Keys and Brozek (1953). Height and weight were determined by standard procedures.

Wingate Test

The protocol was similar to that described by Evans and Quinney (1981). The saddle height was adjusted so that the leg was almost at full extension when the pedal was down. The position was noted for the second trial. Subjects completed a two minute warmup at 50 watts. The subject was then instructed to pedal at maximum velocity, at which time a resistance equal to .075 KP/kg body weight was set. After the resistance was set, subjects pedalled all-out for 30 seconds. Strong verbal encouragement was given.

An electrically operated recording device was started simultaneously with the setting of the resistance. Three scores were obtained: peak power (PP);average power (AP); and power decrease (PD).

For the WT, the Monark bike was adapted so that revolutions and speed could be recorded. Total revolutions were counted by means of an impulse counter (Lafeyette), which received signals from a magnetic sensor on the pedal crank. To monitor speed, a cable was attached from the gearbox on the ergometre to an electrical speedo (voltage generator). The voltage was used to drive a chart recorder (Linear Instruments), from which the revolutions per minute could be determined at any point of the 30 second test.

Maximum Oxygen Uptake Test

A progressive continuous treadmill protocol was used. Subjects ran at 7.0 mph at 0% grade. The grade was then increased 2% every 2 minutes until the subject reached her maximum oxygen uptake. Criteria for subjects attaining maximum oxygen uptake were: a higher workload caused no increase or a slight decrease in maximum oxygen uptake from the previous workload; the subject could no longer keep up with the treadmill; heart rate had reached its predicted maximum.

The Beckman MMC Horizon System (MMC) was used to measure gas concentrations and volumes. This system is operated by an INTEL 8085A microprocessor in a Multibus configuration. Oxygen is measured with a temperature controlled, fast response, polarographic sensor. The signal conditioning for the oxygen measurement is based on that in the Beck-

man OM-11 Oxygen Analyzer. Carbon dioxide is measured with a dual beam non dispersive infrared optical system with a pneumatic detector. The signal conditioning is based on that in the Beckman LB-2 Medical Gas Analyzer. The MMC was calibrated before and after each test using known calibration gases. The volume transducer was calibrated daily and checked between tests.

Muscle Biopsy

Muscle biopsies were taken from the vastus lateralis by a physician according to the technique of Bergstrom (1962). The vastus lateralis was used because it has been shown that glycogen breakdown, blood flow and muscle temperature in this muscle are related to workload on the cycle-ergometre (Karlsson et al., 1971). Serial cuts were taken and were stained for actomyosin ATPase to identify ST and FT muscle fibres. All surface areas and percentages of fibres were calculated from micrographs. (see Appendix B for biopsy procedure, tissue cutting and staining procedure)

Statistical Analysis

A two tailed t-test was used to determine the significance of the differences between groups for the following dependent variables: age, weight (Wt), % body fat, lean body mass (LBM), average power, peak power, power decrease (PD), average power/kilogram body weight (APKG), peak power/kilogram body weight (PPKG), power decrease/ kilogram body

weight (PDKG), average power/kilogram lean body mass (APLB), peak power/kilogram lean body mass (PPLB), power decrease/ kilogram lean body mass (PDLB), % ST muscle fibres (% ST), % FT muscle fibres (% FT), % area ST (% STAR), % area FT (% FTAR), average area of ST muscle fibres (STAV), average area of FT muscle fibres (FTAV) and the ratio of FTAV/STAV (FT/ST).

Prior to analysis the level of statistical significance was set at $p<0.05$. No significant differences in physical characteristics, fibre characteristics or performance on the WT were found, therefore the groups were merged. The Pearson product moment correlation was then used to determine the relationship between the above variables for the entire sample.

RESULTS

The average physical and muscle fibre characteristics of the subjects are reported in tables 1 and 2, respectively.

TABLE 1

Physical characteristics

	Age (yrs)	Height (cm)	Weight (kg)	Fat (%)	LeanBody Mass (kg)
Mean	21.10	168.00	60.50	19.90	48.50
SD	2.25	8.01	5.30	4.02	3.43

TABLE 2

Muscle characteristics

	% ST	% FT	% ST Area	% FT Area	FT/ST
Mean	55.3	44.7	57.4	42.6	0.93
SD	12.97	12.97	16.03	16.11	0.24

Wingate Test Results

Performance on the WT was calculated in absolute terms and relative to body weight and lean body mass (Table 3). Performance scores on the WT were higher than those reported

by Jacobs and Tesch (1981) for females but were lower than those reported for males (Kaczkowski et al., 1982; Inbar et al., 1981).

TABLE 3

Wingate test results

		AP (w)	PP (w)	PD (w)
Absolute	Mean	483.20	630.90	281.90
	SD	43.23	67.05	51.05
KG	Mean	8.01	10.45	4.68
	SD	0.66	0.92	0.85
LB	Mean	9.98	13.00	5.80
	SD	0.74	1.04	0.99

KG = power per kilogram body weight
LB = power per kilogram lean body weight

Maximum Oxygen Uptake

The mean maximum oxygen uptake of the 15 subjects who performed the progressive test was 52.8 ml/kg/min (SD 4.49). Three subjects were not able to take the test due to illness. Mean maximum oxygen uptake was 52.8 ml/kg/min. (SD 4.49). The correlation between maximum oxygen uptake and fibre type was non significant.

Relationship Between Performance, Muscle Characteristics and Body Composition

Table 4 contains the significant correlations between body composition, and performance scores and muscle characteristics. Both weight and lean body mass were signifcantly correlated with AP and PP. A significant correlation was also evident between weight and FT/ST.

TABLE 4

Correlations between body composition, and performance scores and muscle characteristics

	AP	PP	FT/ST
Wt	0.58 *	0.62 **	0.57 *
FFW	0.59 **	0.68 **	0.36

* significant at the 0.05 level
** significant at the 0.01 level

The correlation coefficients between performance scores and FT fibre characteristics are given in Tables 5-7. Average power and PP correlated significantly with FT/ST. All other correlations between performance scores and muscle characteristics were non significant.

TABLE 5

Correlations between peak power and muscle characteristics

	FT	FTAR	FT/ST
PP	0.02	0.05	0.51 *
PPKG	-0.33	-0.24	0.01
PPLB	-0.33	-0.18	0.30

* significant at the 0.05 level

TABLE 6

Correlations between average power and muscle characteristics

	FT	FTAR	FT/ST
AP	0.25	0.33	0.62 **
APKG	-0.07	-0.07	0.08
APLB	-0.04	0.15	0.40

** significant at the 0.01 level

TABLE 7

Correlations between power decrease and muscle characteristics

	FT	FTAR	FT/ST
PD	-0.10	-0.09	0.26
PDKG	-0.29	-0.24	-0.04
PDLB	-0.04	0.15	0.12

DISCUSSION

Population

Studies which find a positive relationship between %FT, %FTAR and performance on the WT generally have a high proportion of male endurance and strength athletes as subjects (Kaczkowski et al., 1982; Inbar et al., 1981). When female physical education students or untrained males are studied, these correlations are not observed (Jacobs & Tesch, 1981; Inbar et al. 1981). In this study an attempt was made to recruit female athletes from various teams at the University of Manitoba. Four basketball and four volleyball players and 10 female physical education students volunteered to take part in the study.

Subjects were initially divided into two groups: Group A (basketball and volleyball players) and Group B (physical education students). The data on the height, weight, age, WT scores and muscle characteriscs of the subjects indicated that the volleyball and basketball players were significantly taller than the physical education students. The difference in height can be explained by the selection process, as it is advantageous for basketball and volleyball players to be tall. There were no other significant differences between the groups. The finding that neither WT scores nor

muscle characteristics were significantly different between the groups could reflect a lack of intensity or specificity in the training of the basketball and volleyball players. As the groups differed on only one of the measured variables, the data were subsequently merged. Subjects in this study were taller and heavier and had higher levels of aerobic and anaerobic fitness than subjects in similar studies (Jacobs & Tesch, 1981; Campbell et al., 1979). This was largely due to the presence of the intercollegiate volleyball and basketball players and to the presence of provincial calibre athletes among the physical education students.

Fibre Distribution

Subjects in this study had a greater percentage of ST fibres, as well as larger ST fibres than FT fibres, in the vastus lateralis (Table 2). Both fibre distribution and area are consistent with the range of values reported in the literature (Komi & Karlssson, 1978; Nygaard, 1981).

Test Protocols

Wingate Test. A major difference between the WT protocol employed here and similar studies was the method used to compute PP. Peak power is generally computed from the 5 second period with the highest power output (Bar-Or et al., 1980). The apparatus employed in the present study allowed for the measurement of power at any point during the test.

Therefore the measurement of PP in this study was a true PP and not a five second average.

Body Composition and Performance

Weight correlated significantly with AP and PP: $r=0.58$ ($p<0.05$) and $r=0.62$ ($p<0.01$), respectively. Correlations were slightly greater when LBM was the independent variable: $r=0.59$ ($p<0.01$) and $r=0.68$ ($p<0.01$) for AP and PP, respectively. This relationship is to be expected, since it has been shown that body weight accounts for 41% of the common variance in a high intensity cycle-ergometre test (Katch, 1974). Also, the workload setting for the WT is not designed to noramalize power output among subjects but to optimize it. As has been shown on Margaria et al's (1966) test, larger individuals generate more power (Kitagawa, 1980). The data from the present study indicate that subjects with a larger muscle mass generate more power in absolute terms than do subjects with a smaller muscle mass. Valid comparisons can only be made among subjects by dividing performance scores by body weight or by lean body mass.

Muscle Characteristics and Performance

Results from the present study failed to demonstrate a consistent relationship between performance on the WT and muscle fibre characteristics. A significant correlation between these variables depends on the muscle sample being truly representative of the whole muscle, and on the results

of the WT reflecting the true AP and PP of each subject. Single biopsies have been the accepted practice in this type of study, but some investigators feel that as many as four biopsies are needed to establish the true fibre type profile of the muscle (Elder, 1982). Evans and Quinney (1981) determined that the WT does not provide an optimal measure of either PP or AP in males. To date, their work has not been replicated in females, but it seems likely that the test does not provide optimal power scores for this population either. As the workload on the WT is determined by the body weight of the subject, females could be at a disadvantage since on average they have proportionally less lean body mass than males.

Despite these potential pitfalls, studies which have used trained males have demonstrated a consistent relationship between performance on the WT and %FT, %FTAR and FT/ST (Kaczkowski et al., 1982; Inbar et al., 1981). This is the expected relationship since the energy demands of the WT have been reported to be 87% anaerobic and it has been shown that athletes whose sport is predominantly anaerobic have a predominance of FT fibres (Costill et al., 1976b; Edstrom et al., 1972; Inbar et al., 1976). The activities of ATPase, MK and CPK are higher in FT fibres than in ST fibres, providing FT fibres with a greater ability to use and generate ATP via the ATP-PC system (Taylor et al., 1974; Thorstensson, 1976). The glycolytic profile is more enhanced in FT

fibres and it has been shown that glycogen is preferentially depleted from FT fibres during supramaximal work (Gollnick et al., 1973a; Sjodin, 1976). Fast twitch fibres have been found to produce more initial force but to fatigue faster than ST fibres (Burke et al., 1971). Taken together this evidence suggests a positive relationship between FT fibres and performance of a predominantly anaerobic event such as the WT.

Although the studies that used males reported significant correlations between performance and fibre type, results were not reported in the same fashion for each study. Tables 8-10 provide the results from these studies as well as a comparison to the present study.

TABLE 8

Comparison of the relationship between muscle characteristics and performance on the WT in trained males and trained females

	Average Power		Peak Power	
	Males **	Females +	Males	Females
% FT	0.81 *	0.25	0.59 *	0.02
% FTAR	0.83 *	0.33	0.84 *	0.05

* significant at the 0.05 level
** Kaczkowski et al., 1982
\+ Paquin, 1985

TABLE 9

Comparison of the relationship between muscle characteristics and performance on the WT in trained and untrained males +

	% Fast Twitch		
	All	Trained	Sedentary
PP	0.27	0.72 ***	-0.71 ***
AP	0.04	0.57 **	-0.71 ***
PD	0.52 **	0.59 ***	0.04
PPKG	0.42 *	0.68 ***	-0.16
APKG	0.16	0.49 **	-0.28

* significant at the 0.05 level
** significant at the 0.01 level
*** significant at the 0.001 level
+ Inbar et al., 1981

Absolute power scores (Kaczkowski et al., 1982; Inbar et al., 1981), performance scores computed relative to body weight (Inbar et al., 1981) and power scores based on fat free weight (Bar-Or et al., 1980) have all been used to calculate the correlation between performance on the WT and muscle characteristics. Results from the present study indicate that AP and PP are influenced by body weight. Because the force setting on the WT is determined by body weight, heavier subjects can achieve potentially higher pow-

TABLE 10

Comparison of the relationship between muscle charateristics and performance on the WT in male physical education students and in trained females

	APLB		PPLB		PDLB	
	Males++	Females+	Males	Females	Males	Females
% FT	0.29	-0.04	0.54 *	-0.33	0.20	-0.10
% FTAR	0.42	0.15	0.60 **	-0.18	0.38	-0.09
FT/ST	0.63 **	0.40	0.41	0.30	0.75 ***	0.12

* significant at the 0.05 level
** significant at the 0.01 level
*** significant at the 0.001 level
++ Bar-Or et al., 1980
+ Paquin, 1985

er scores. Therefore, the method of reporting results can influence the strength of the correlations, especially when the subjects used in these studies are predominantly sprinters, weightlifters and endurance runners. Distance runners tend to be slight and have been reported to have larger and greater numbers of ST fibres than FT fibres (Costill et al., 1976b). Conversely, sprinters have significantly more and larger FT fibres while weightlifters have a greater FT fibre area (Costill et al., 1976a; Prince et al., 1976). The high correlations reported by Kaczkowski et al. (1982) and Inbar et al. (1981), based on absolute scores, were influenced by the fact that their larger subjects, either sprinters or weightlifters, had more and larger FT fibres than the smaller, distance runners who had a predominance of ST fibres in the vastus lateralis.

Correlations between muscle charcteristics and performance were lower when Inbar et al. (1981) computed power relative to body weight (Table 9). Although direct comparisons are difficult to make, Bar-Or et al. (1980) reported fewer and lower correlations when power was computed relative to fat-free weight (Table 10). These lower correlations might be related to the method of computing power or might be related to the type of subjects used in the study.

Trained versus Untrained

When untrained subjects were used significant negative correlations were found between %FT and AP or PP (Inbar et al., 1981). These correlations became insignificant when AP and PP were computed on the basis of body weight. The high negative correlations could have been due to a coincidental relationship between weight and the percentage of ST fibres. The non significant correlations are consistent with studies that have looked at the relationship between maximal oxygen uptake and %ST in untrained and trained populations. In untrained males Orlander (1977) could find no relationship between maximum oxygen uptake and %ST, while Berg et al. (1978) reported significant correlations between %ST and maximum oxygen uptake of r=0.72 for endurance and strength athletes.

Sex Related Differences

The present study as well as the investigations of Jacobs and Tesch (1981) and Campbell et al. (1979) failed to find a significant relationship between anaerobic performance and %FT or %FTAR in females. Studies that have used trained males, however, have consistently found a relationship. One obvious difference between the male and female studies is that the studies that used trained males had a predominance of either power or endurance athletes. Choice of population is a key factor in this type of investigation. In a similar type of investigation Gregor et al. (1979) used elite female athletes (sprinters and long distance runners) and found a significant positive correlation between peak torque and %FT fibres. The non significant correlations reported in the present study and Jacobs and Tesch (1981) might be expected in females, but there is a consistent pattern of negative correlations (in two cases these correlations were significant) between performance on the WT and %FT or %FTAR (Table 11). These results indicate a preferential recruitment of ST fibres, possibly related to fibre size. It has been demonstrated that ST fibres are larger than FT fibres in females (Nygaard, 1981 and Thorstensson, 1975).

TABLE 11

Comparison of the relationship between performance on WT and muscle characteristics in female subjects

	APKG		PPKG		PD	
	J&T	Paquin	J&T	Paquin	J&T	Paquin
% FT	-0.39	-0.07	0.21	-0.33	-0.48	-0.29
% FTAR	-0.53 *	-0.07	0.22	-0.24	-0.63 *	-0.24
FT/ST	-0.23	0.08	0.23	0.01	-0.22	0.04

* significant at the 0.05 level
** Jacobs & Tesch (1981)

The discrepency in the size of the ST and FT fibres in males and females is difficult to understand, since the studies of Colling- Saltin (1978) and Lundberg et al. (1979) indicate that these differences exist neither in new-borns nor in small children. These differences only become apparent when the child reaches adolescence (Nygard, 1981). Possibly these differences are the result of different levels of activity in males and females. Boys, from quite an early age, tend to enagage in more vigorous activities than girls. As a result, Nygaard (1981) states girls do not experience the training which involves the level of high tension necessary for FT fibres to develop.

An interesting exception is found in the mothers of severely handicapped children, where the FT fibres of the brachial biceps are thicker than the ST fibres. This is likely

due to the amount of lifting and carrying, which is a large component of the daily care of these children (Nygaard, 1981). Similarly, Saltin et al. (1977) indicate that the small-sized FT fibres in the thigh muscles of sedentary women may be related to the fact that only a few of their lives' daily activities involve the FT fibres.

There may be a difference in neuromotor control in females. Komi and Karlsson (1979) found that surface recorded electromyograph activity was significantly lower in women than in men, and that women took twice as long to reach a maximum voluntary contraction as men did. Karlsson (1980) indicate that women have a less positive attitude towards activity than do men which could have an effect upon technique or motor control.

There are also sex related differences in the enzymatic profile. Women have significantly less active ATPase, CK, phosphorylase, LDH, glycerophosphate dehydrogenase and hexokinase than men (Komi & Karlsson, 1978 & Bass et al., 1975). It is by no means clear whether this is the result of an innate difference or is the result of different activity levels as Haralambie, (1978) and Costill et al. (1976b) suggest. Harkonen et al. (1982) found significantly more CP in ST fibres than in FT fibres in women. This might be an indication of more ST fibre involvement during short-term maximal work in females.

The role of sex hormones is another factor in different fibre sizes between males and females. Inbar et al. (1981) mentioned a longitudinal study of prepubertal boys, which failed to confirm the relationship between fibre characteristics and performance. It is only later, when specific sex hormones are produced, that the relationship between performance and fibre distribution becomes evident. The authors suggest that the production of sex hormones, induced by training and maturation, affects the metabolic properties of the fibre types. Another possibility is that the subpopulations of type II fibres might be different in females due to the absence of testosterone. Testosterone has been shown to increase phosphorylase activity in type II fibres in rats (Krotkiewski et al., 1980).

Much of this evidence is highly speculative at best and fails to provide any hard facts to establish a difference in muscle physiology between males and females. Table 12 presents correlations from the present study and from the untrained male subjects of Inbar et al. (1981). Results are almost identical which might indicate that there is no fundamental difference between the muscle physiology of males and females, but rather a continuum with individuals falling along it at different places depending on factors such as fitness levels, fibre type, motivation and past history of physical involvement in sport.

TABLE 12

Comparison of the relationship between performance on WT and %FT in females and in untrained males

	APKG		PPKG	
	Males*	Females**	Males	Females
%FT	-0.28	-0.07	-0.16	-0.33

* Inbar et al., (1981)
** Paquin, 1985

SUMMARY AND CONCLUSIONS

The purpose of this investigation was to determine the relationship between performance on the WT with muscle fibre morphological profile and body composition. Within the delimitations noted, the results of this study suggest that a relationship does exist between weight or LBM, and performance on the WT.

Results from this investigation also suggest that a relationship does not exist between performance on the WT and muscle fibre types. This finding is consistent with studies that used either females (Jacobs & Tesch, 1981) or untrained males (Inbar et al., 1981), but is contrary to the studies that employed trained males as subjects (Kaczkowski et al., 1982; Inbar et al., 1981). Results from the present study and Jacobs and Tesch (1981) suggest a possible preferential recruitment of ST fibres in females on the WT. Sex-related differences in fibre size, neuromotor control, enzyme activity, interest and motivation have all been suggested as possible reasons for these findings. These are not absolute, genetically controlled differences, but are differences that are likely determined by environmental factors. The use of elite female athletes could possibly minimize the influence of these factors. Significant positive correlations were

reported between %FT and peak torque in elite female athletes (Gregor et al., 1979). Significant positive correlations between FT muscle characteristics and performance on the WT would most likely have been reported if a population similar to that used by Gregor et al. (1979) had been used in the present study.

Recommendations

In conclusion it is suggested that further research be conducted in this area with the following recommendations:

1. An attempt should be made to use higly trained female sprinters and endurance runners as subjects.
2. Two biopsy sites should be used to ensure that a truly representative muscle sample is obtained.
3. The individual power curve should be determined for each subject.

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Appendix A

INFORMED CONSENT

Explanation of the Tests

Wingate Test

This test involves 30-seconds of all-out pedalling on a cycle-ergometre. The resistance on the cycle-ergometre will be set according to your body weight. The physical sensation during the test will be like pedalling up a steep hill. You will be very short of breath at the end of the test but recovery will be virtually complete in a few minutes.

Maximum Oxygen Uptake Test

The purpose of this test is to measure the maximal amount of oxygen you can utilize while running. You will be given instructions on running on the treadmill and breathing through the gas collection system and be allowed to practise. Prior to the test, three electrodes will be attached to your chest for recording your heart rate. During the test, you will run at 7 mph, and every 2 minutes the treadmill will be inclined upwards so that you will be running more and more uphill. You will be asked to keep running until you are unable to maintain the pace set by the treadmill. At that

point, grasp the safety rail, and the treadmill will be stopped. We expect your heart rate and oxygen consumption to reach maximum levels for your age and fitness level. You can anticipate feeling quite fatigued upon completion.

Muscle Biopsy

The skin over the mid-lateral right thigh will be swabbed with 70% alcohol and iodine. Approximately 1 cc of 2% xylocaine will be injected to anaesthetize the area. After ensuring that the skin is properly anaesthetized an incision will be made 15-20 cm above the knee. The biopsy needle will then be introduced into the muscle, via the incision, and a small sample of muscle wil be obtained. The incision will be closed with an adhesive strip dressing.

Risks and Discomforts

Maximum Oxygen Uptake Test

There exists the possility of certain changes occurring during the test. They include abnormal blood pressure, fainting, disorders of heart beat, and, in very rare instances, heart attack. These risks are minimal if you are a normal healthy individual. If you stumble or fall during the test, the treadmill will be stopped immediately , and the consequences would be similar to a fall on a running track.

Muscle Biopsy

During the biopsy procedure some subjects report a feeling of painful pressure. This pain subsides immediately, once the biopsy needle is withdrawn. In a few cases, subjects report a slight ache in the muscle for a day or two. No serious complications have been reported from the muscle biopsy procedure.

Inquiries

You are encouraged to ask questions about the procedures to be used in any of the tests. If you have any doubts as to what is expected of you, please ask for further explanation.

Freedom of Consent

Your agreement to take part in this study is voluntary. You are free to deny consent if you so desire. You are free to withdraw from the study at any time.

I have read this form and I understand the test procedures that I will perform, and I consent to participate in this study.

_____ _____

Date Signature of Participant

_____

Signature of Witness

Appendix B

HISTOCHEMICAL PROCEDURES

Biopsy Procedure

A licensed physician performed the biopsies. The mid-lateral thigh was initially draped and swabbed with Bridine. Approximately 1 cc. of 2% xylocaine was injected subcutaneously to anaesthetize the area. A stab incision was then made and a 5 mm. Stille needle was inserted and a muscle sample was obtained.

Handling and Cutting of Muscle Sample

The muscle sample was removed from the needle and placed under a dissecting microscope and then orientated. The sample was then placed on a cork, covered with OCT and then snap frozen in 2-methyl-butane, cooled to -160 degrees centrigrade in liquid nitrogen. The sample was then stored at -65 degrees centrigrade.

In preparation for sectioning, the sample was removed from the freezer and then frozen to a chuck with OCT. Serial sections were cut at -20 degrees centrigrade in an American Optical Cryostat. The slides used to pick up the sections had been dipped in a solution of gelatin (.05 g) and potassium chromium sulfide (.001 g) and then allowed to dry. The

sections were allowed to dry for three hours before being stained.

Preparation of Reagents and Histochemical Procedures

Basic Medium

Glycine	1.98 g
Calcium Chloride	2.10 g
NaCl	1.45 g
NaOH	0.95 g
Water (distilled)	500 ml

This solution was made up daily and from it 40 ml were drawn off for the incubation medium while a further 50 ml were set aside whose ph was adjusted to 10.3. The ph of the remaining 410 ml was adjusted to ph 9.4. Ph adjustments were made with NaOH (5N) and HCl (5N).

Acid Preincubation Medium

Sodium Acetate	3.23 g
Potassium Chloride	1.85 g
Water (distilled)	250 ml

The ph of this solution was adjusted to 4.37 with glacial ascetic acid.

Incubation Medium

ATP	0.068 g
Basic Medium	40 ml

The ph of this solution was adjusted to 9.4 with HCl (1 N).

Calcium Chloride Solution

Calcium Chloride	5 g
Water (distilled)	500 ml

Cobalt Chloride Solution

Cobalt Chloride	3.66 g
Water (distilled)	100 ml

Ammonium Sulfide Solution

Ammomium Sulfide 20%	5 ml
Water (distilled)	95 ml

Procedures

Preincubate: ph 10.30 8 minutes at 37 C water bath

ph 4.37 5 minutes at room temperature

Slides were then rinsed in the basic medium ph 9.4 twice for 30 seconds.

The slides were then placed in a water bath at 37 degrees in the incubation medium.

Slides were then rinsed in the Calcium Chloride solution as follows: 1 minute, then emptied, 2 minutes, then emptied and then 3 minutes.

Slides were then placed in the Cobalt Chloride solution for 3 minutes. Folowing this the slides were rinsed thoroughly in distilled water.

The slides were then placed in the Ammonium Sulfide solution for 1 minute. The slides were once again thoroughly rinsed in distilled water.

The slides were then dried and coverslipped.

Determination of Fibre Distribution

Pictures were taken of the 4.37 and 10.3 stains from each subject with a Zeiss photomicroscope. From the micrographs the number of ST and FT muscle fibres were determined. Numbers ranged from 81 to 458 with the average being about 250 fibres.

Determination of Fibre Size

Fibre size was determined by using micrographs at magnification of 300x. Each micrograph contained approximately 15-20 fibres of each type (Thorstensson, 1976). The micrograph was placed on an Apple Graphics Tablet hooked up to an Apple II plus computer. The area of each fibre was obtained by tracing around its circumference with a stylus and then having the computer determine its area by using the Stereo Measurement Program (Scientific Microprograms).

Appendix C

PHYSICAL, MUSCLE AND WT DATA

TABLE 13

Physical characteristics of subjects

Subjects #	Age yrs	Height cm	Weight kg	%Fat %	Lean**ody Mass kg
1 *	20	177.1	60.3	16.9	50.1
2 *	19	170.3	70.0	27.0	51.1
3 *	22	160.8	57.3	14.3	49.1
4 *	20	173.0	62.0	21.7	48.6
5 **	21	164.0	57.2	16.5	47.8
6 **	21	173.1	57.3	21.9	48.2
7 **	21	188.0	77.3	23.9	58.8
8 **	22	169.0	57.9	16.4	48.4
9 +	29	177.5	58.5	20.2	46.7
10 +	20	166.3	60.5	21.1	47.7
11 +	23	157.5	58.4	25.0	43.8
12 +	21	162.0	58.2	15.8	49.0
13 +	20	162.6	62.5	25.0	46.2
14 +	20	163.7	56.3	15.6	47.5
15 +	19	165.1	61.1	18.4	49.9
16 +	20	173.9	56.9	23.9	42.7
17 +	20	164.9	56.5	18.9	45.8
18 +	20	156.0	60.0	14.5	51.3
Mean	21.1	168.0	60.5	19.9	48.5
SD	2.25	8.01	5.30	4.02	3.43

*= Volleyball Player **=Basketball Player
+ Physical Education Student

TABLE 14

Wingate Test results

Subj #	AP watts	PP watts	PD watts	APKG watts	PPKG watts	PDKG watts	APFF watts	PPFF watts	PDFF watts
1 *	467.5	635.0	299.8	7.75	10.53	4.97	9.33	12.67	5.98
2 *	560.6	728.7	300.7	8.00	10.41	4.30	10.98	14.26	5.88
3 *	539.4	640.5	248.6	9.41	11.18	4.34	10.98	13.04	5.06
4 *	45.7	583.3	223.3	7.35	9.41	3.60	9.38	12.00	4.60
5 **	479.3	681.1	395.2	8.38	11.91	6.91	10.03	14.25	8.27
6 **	495.9	649.2	333.6	8.65	11.33	5.82	10.23	13.47	6.92
7 **	568.4	801.4	369.5	7.35	10.37	4.78	9.67	13.62	6.28
8 **	463.6	588.1	261.9	8.00	10.16	4.52	9.58	12.15	5.11
9 +	396.7	500.2	211.3	6.78	8.55	3.61	8.49	10.70	4.52
10 +	489.4	596.2	258.0	8.09	9.85	4.26	10.26	12.50	5.40
11 +	437.8	532.3	197.5	7.49	9.11	3.38	10.00	12.15	4.51
12 +	529.8	632.3	247.7	9.10	10.86	4.26	10.81	12.90	5.06
13 +	479.0	608.0	276.3	7.65	9.73	4.42	10.37	12.88	5.98
14 +	485.7	668.8	282.0	8.63	11.88	5.01	10.23	14.08	5.94
15 +	458.6	613.0	273.0	7.51	10.03	4.48	9.19	12.28	5.48
16 +	477.5	626.7	289.9	8.39	11.01	5.09	11.18	14.68	6.79
17 +	455.1	649.0	320.3	8.06	11.47	5.67	9.94	14.17	7.00
18 +	458.6	621.8	286.6	7.64	10.36	4.78	8.94	12.12	5.59
Mean	483.2	630.9	281.9	8.01	10.45	4.68	9.98	13.00	5.80
SD	43.23	67.05	51.05	0.66	0.92	0.85	0.74	1.04	0.99

* Volleyball Player ** Basketball Player
+ Physical Education Student

TABLE 15

Subjects muscle characteristics

Subject	% ST	% FT	% ST Area	% FT Area	FT/ST
1 *	74.8	25.2	27.6	51.1	1.13
2 *	56.2	43.8	51.5	48.5	1.20
3 *	55.5	44.5	53.9	46.1	1.07
4 *	63.9	36.1	68.4	31.6	0.82
5 **	70.0	30.0	77.4	22.6	0.68
6 **	44.1	55.9	42.4	57.6	1.07
7 **	41.0	59.0	48.4	51.6	1.30
8 **	41.2	58.8	34.9	65.9	0.74
9 +	56.6	43.4	71.1	28.9	0.53
10 +	53.3	46.7	53.8	46.2	0.98
11 +	xxx	xxx	xxx	xxx	xxx
12 +	38.8	61.2	40.0	60.0	0.95
13 +	37.2	62.8	33.1	66.9	1.20
14 +	73.8	26.2	83.1	16.9	0.58
15 +	43.9	56.1	40.9	59.1	1.13
16 +	75.0	25.0	76.3	23.6	0.93
17 +	60.4	39.6	61.0	39.0	0.97
18 +	54.0	46.0	67.9	32.1	0.56
Mean	55.3	44.7	57.4	42.6	0.93
SD	12.97	12.97	16.03	16.11	0.24

* Volleyball Player ** Basketball Player
+ Physical Education Student