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Forty-five subjects were given 30 trials of isometric elbow flexion and 30 trials of elbow extension. Each trial consisted of maximum exertion followed by a short rest in 10 second cycles. Subjects were ranked on the basis of the addition of the median flexion and extension scores and were divided into three groups of 15 subjects each representing high, middle, and low levels of strength. A two by three factorial analysis of variance suggested that: (a) no significant difference exists between the fatigue patterns of elbow flexors and extensors, and (b) different levels of strength possess significantly similar fatigue patterns in the muscles around the elbow.

Isometric Fatigue Curves of Elbow Flexors and Extensors

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ISOMETRIC FATIGUE CURVES OF ELBOW FLEXORS AND EXTENSORS

CHAPTER I

INTRODUCTION

Fatigue, strength and endurance have been topics of interest and concern for many years. Teen-age boys trying to make the varsity team, coaches developing strong athletes, and doctors and therapists working on cures and rehabilitation have all been students of fatigue, strength and endurance. Capacities, characteristics, and expected outcomes of specific programs must be established for the different body systems in order to develop worthwhile training and rehabilitative programs. Many studies have been conducted to answer the questions raised by interested persons but controversies and unknowns in the areas of strength, fatigue and endurance still exist. More research is needed to determine the validity of currently accepted theories and to analyze results for possible applications.

Isometric fatigue curve studies have been conducted, but these studies have usually been limited to one group of muscles at a time, and the muscle groups studied this way have usually been wrist flexors or hand muscles. Kroll (37,38) studied the fatigue curves of the wrist flexors in subjects of different levels of strength. Similar studies have not been conducted to test the fatigue curves of the elbow flexors or extensors to determine if they follow the same trends that the wrist flexors do. The review of literature indicated a need to determine if the elbow flexors and extensors have the same relationship as do flexors and extensors in other muscle groups of the body.

Purpose of the Study

The purpose of this study was to determine if elbow extensors have the same isometric fatigue patterns as elbow flexors. A second purpose was to compare the fatigue curves of elbow flexors and extensors at three levels of strength. The above two purposes would then provide possible answers to the following two questions: (a) Is the relationship between flexors and extensors at the elbow joint the same as the general relationship between extensors and flexors in other areas of the body? (b) Do the fatigue trends at the three levels of strength show the same relationship between high, middle and low as do the patterns of wrist flexors at the same three levels of strength?

To accomplish these purposes several hypotheses were tested.

1. A significant amount of fatigue occurs during the conditions of this test.

After testing the first hypothesis to be true, the following null hypotheses were tested.

2. No significant strength differences exist between the strength levels tested.

3. No significant difference exists between the fatigue patterns in the elbow flexors of individuals from three levels of strength.

4. No significant difference exists between the fatigue patterns in the elbow extensors of individuals from three levels of strength.

5. No significant strength difference exists between elbow flexors and extensors.

6. No significant difference exists between the fatigue patterns of elbow flexors and extensors.

7. In the elbow flexor and extensor muscle groups, no significant fatigue pattern difference exists between high, middle and low levels of strength.

Definitions

Pertinent operational definitions of terms used in this study are presented below.

Endurance is the ability to maintain a relative high level of strength.

Extensors are those muscles which ordinarily increase the angle at a joint.

Fatigue curves are lines drawn through the scores obtained from 30 isometric contractions.

Flexors are those muscles which ordinarily decrease the angle at a joint.

Isometric contractions in this study are maximum contractions made against a cable with very little movement and technically no accomplished work. The amount of effort exerted is calculated by measuring tension in the cable.

Isotonic contractions are those in which the contracting muscle either shortens or increases in length.

Relative fatigue in this study is that shown by the strength decrement index which is a score indicating the per cent of decrease.

Strength in this test is that measured in tension pounds by a cable tensiometer and converted to pounds pulled by a standard conversion table.

Limitations

Muscles differ from person to person in such ways as size, number of fibers, availability of blood supply, and number of mitochondria. The pounds of tension that can be exerted per square centimeter of muscle varies from person to person. But the fact that all people do not approach the same degree of closeness to the maximum amount of force possible to exert makes the possibility of comparing the effects of physiological differences very difficult. Such things as inhibitions, state of mind, verbal motivation, and noises can cause subjects to achieve different scores on strength tests (34). Therefore, disturbances such as basketball players on the gym above the laboratory and people entering and leaving the lab, although kept to a minimum, caused a small variance in conditions and must be considered as limitations in this study. The most serious limitation was the impossibility of knowing how near physiological maximum potential each subject was approaching throughout the testing.

Delimitations

The subjects were male college students at the Oregon State University whose ages ranged from 18 to 30 years. The subjects all seemed to be physically normal with no noticeable defects. Elbow flexors and extensors were tested in 45 different subjects. Efforts were made by the tester to obtain very strong, moderately strong, and weak subjects.

CHAPTER II

REVIEW OF THE LITERATURE

The review of literature that follows will basically explain the structure and properties of muscle, muscle contraction, blood supply, strength, endurance, fatigue, flexors and extensors, and testing methods. This material will be presented to aid in the understanding and explanation of the phenomenon of fatigue curves, and more specifically to answer the question of why the muscles of the individuals of this study responded the way they did.

Structure and Properties of Muscle

The mobilizing power throughout the animal kingdom with few exceptions is muscle. The paramount virtue of muscle is its contractility (9, Vol. 1, p. 1). Muscles make up forty to forty-five per cent of the adult body weight. Two hundred and fifty million individual striated muscle fibers are found in the human body, with 434 muscles being voluntary and 75 pairs of muscle involved in the general posture and movement of the body. The two basic types of muscle tissue in the human body are smooth muscles and skeletal or voluntary muscles. The two basic types of muscle structure are fusiform, or longitudinal, and penniform, or diagonal. The fusiform muscles are the simplest type, and they run parallel to each other and the length of the muscle. Penniform muscles are subdivided into three categories; unipenate (muscle to one side of the tendon), bipenate (muscle to both sides of the tendon), and multipenate (muscles that converge to several tendons (52). This study is primarily concerned with the voluntary muscles. The following section is a compilation of ideas obtained from King and Showers (36) and Bourne (9). These authors agree on most points, but King and Showers give a more straight forward account of muscular structure and function therefore most of the discussion that follows is from King and Showers.

Muscle tissue contracts only in the direction corresponding to the long axis of the muscle cells. Skeletal muscle fibers are very long, ranging from 4 to 12 cm. in length, with a width of 10 to 100 microns. In addition to contractility, the properties of irritability, elasticity, and conductivity are well developed in skeletal muscle tissue. Individual cells are like long cylinders enclosed in an elastic sheath, the sarcolemma, in much the same manner that a link of sausage is enclosed in its casing- isolated and yet connected to adjacent muscle cells. Each cell has many nuclei that are in the sarcoplasm, under the sarcolemma, and near the periphery of the fiber. Numerous mitochondria, glycogen, fat, and pigment granules are among inclusions found in the sarcoplasm.

Myofibrils marked by alternate light and dark striations are oriented along the long axis of the muscle cells. Each myofibril possesses two types of myofilaments. The thicker myofilaments are rich in the protein myosin. Actin, another protein, is found in the thinner myofilaments. A complex system of cross-bridges links the myofilaments in an orderly, helical pattern, joining one thick filament to each of six adjacent thin filaments every 400 angstroms. This arrangement of myofilaments correlates with the striations of the myofibril (36).

The sarcomere extends from Z to Z intersecting half of two I bands or light striations, and including one A band or dark striation. A bands appear to be a zone of overlapping of thick and thin myofilaments, and I bands represent only the thin myofilaments. In consideration of this arrangement, contractility seems to be based upon the sliding together of the myofilaments in a sarcomere. The Z line is currently thought to be a membrane running transversely through the myofibrils, attached to the sarcolemma, and related to irritability of the muscle tissue (36; 9, Vol. 1, p. 35).

Each striated muscle consists of a body and two attachments. The body contains the muscular tissue; the attachments are composed of white fibrous tissue. The attachment of muscle to bone may be one of three types: direct to the periosteum, by means of a tendon, or by means of an aponeurosis. In a direct attachment the white fibers of the connective tissue framework of the muscle fuse with the fibrous layers of the periosteum of the bone. A tendon is a band or cord of white fibrous tissue serving to connect a muscle to a bone. The sarcolemma and the connective tissue surrounding the muscle bundles fuse with the collagenous fibers of the tendon. An aponeurosis is a heavy sheet of white fibrous tissue serving to connect a muscle to a bone, or in some instances, to connect muscles (36; 9, Vol. 1, p. 24-25).

The more fixed attachment of a muscle which serves as a basis of action is called the origin. The movable attachment where the effects of movement are produced is the insertion. Generally the origin is near the spinal axis of the body, while the insertion is peripheral (36).

Some of the properties of muscle are elasticity, distensibility, plasticity, and viscosity. Elasticity is the tendency of a material to return to its original unstressed condition when it has been deformed by the application of a force. Distensibility is actually the reciprocal of elasticity. A material which can be stretched out of shape by the application of a small deforming force would be exhibiting a small degree of elasticity, but a large degree of distensibility.

Upon removal of the deforming force, an elastic material will return to its original length by virtue of the attractive counterforces present. However, some materials are composed of molecules which are not held so strongly by cohesive forces. The application of a distorting force to these materials will cause the molecules to slide over each other, and the material will be permanently deformed. In other words, when the deforming force is removed the molecules do not return to their original position. Such materials exhibit the property of plasticity (41,36).

Measurements of viscosity describe the relative resistance to flow of molecules past one another. Viscosity is a property most commonly associated with liquids, but many solids also exhibit viscosity. In the sliding filament theory of muscle contraction the muscles demonstrate a degree of viscosity as molecules slide past one another.

Lehmkuhl (41) suggests that the soft tissues of the body have mechanical properties which are quite different from those of the usual solid. Their properties are more nearly like those of a group or material called elastomers. Compared with the properties of solids, elastomers (a) have a smaller modulus of elasticity and therefore exhibit greater distensibility, (b) have a sigmoidal relation between strain and stress rather than a linear one, and (c) may be stretched to considerably greater lengths before the breaking point is reached.

Experiments with the isolated muscles of frogs reveal that the tension developed in muscle is seen to be a function of muscle length, and that muscle consists of two components in series. The contractile component is the part which is altered by stimulation and is capable of active tension development and shortening. In series with the contractile component is an undamped passive elastic element through which the contractile component has to transfer its force to the muscle tendon (61).

The series elastic component has an important effect on the mechanical properties of the whole muscle, for it smooths out rapid changes in tendon. Thus it often makes a nuisance of itself in experiments which are examining the mechanical properties of the contractile component; for, whenever the tension is changing, the length of the elastic component must be changing too. This change in length can be calculated from the change in length of the whole muscle in order to find the length change in the contractile component. The need to correct for the series elastic component is largely eliminated by isotonic testing (61). The presence of a series elastic component in muscle is indeed very strongly implied by a variety of experiments, although its structural whereabouts and chemical nature are unknown. From a theoretical viewpoint, this component is of great significance, since the mechanical properties of muscle, as currently visualized, depend on it. The elastic component is supposed to provide a buffering action in muscle against the consequence of rapid changes in physical state. This elastic component possibly is not a structural entity but may be part of the contractile machinery left in the elastic "resting" state when other portions are already activated. If the contractile system is not activated at the same instant along the whole length of the fiber, the elastic portion not yet activated can indeed fulfill the buffering function (61).

Muscle Contraction

Resting muscle is plastic and freely extensible. During excitation it passes into a new physical state; it becomes hard, develops tension, lifts load, and resists stretching. This is the active state, and is characteristic of all voluntary muscles (9, Vol. 1, p. 245).

The physical state in muscle is the same during the early part of a twitch and in a tetanus, activity being maximal in both cases. A single stimulating pulse sets off the active state fully without maintaining it. Thus the active state declines before maximum tension is reached. The results is a twitch. If a series of pulses are placed close enough to one another, the active state is maintained and individual twitches fuse into a smooth contraction (9, Vol. 1, p. 246).

Types and Degrees of Muscle Contraction

All-or-none principle

When an individual muscle fiber is stimulated under laboratory conditions it contracts maximally or not at all. This is the so called "all-or-none" principle. In intact muscle, however, an increased stimulus results in an increased mechanical response. This has been used as a basis for arguments that the all-or-none law does not apply to striated muscle. However, any tissue having a definite threshold for excitation and known to be refractory after excitation must be considered to behave according to this principle.

Serious difficulties in interpreting the evidence from skeletal muscle studies arise because individual muscle fibers respond differently. Their response is a complex series of events liable to vary considerably according to conditions existing in the fibers. A weak stimulus excites only the most irritable fibers, whereas a strong stimulus may affect even the least irritable fibers. The more fibers are excited, the greater the force of the contraction. Rasch (52) postulated that one of the benefits of training with near maximal weights in progressive resistance exercise is that this brings some of the high threshold neurons within the orbit of voluntary activity.

Twitch. When an electrical stimulus of sufficient size is applied to the motor nerve, the muscle responds with a spasmodic contraction known as a muscle twitch. A delay is noticed between the time the stimulus is applied and when a response can be detected. This is known as the latent period, and in a frog gastrocnemius is about 0.01 seconds. The muscle takes about 0.04 seconds to contract and about 0.05 seconds for the subsequent relaxation. After an impulse has been produced, an absolute refractory period lasting approximately 0.4 to 1.0 milliseconds takes place during which a nerve fiber will not respond to stimulation. This period is followed by a relative refractory period of approximately 3 milliseconds, during which the fiber regains its irritability and will respond to a relatively intense stimulus (52).

Treppe. When a muscle is stimulated in such a way that complete single twitches rapidly follow each other, the first few contractions progressively increase in height. This is known as treppe, or the staircase effect. This successive increase in the extent of the contraction has led some authors to cite treppe as the mechanism responsible for the benefits of warm-up in sports (52).

Isometric tension. When force is exerted by a muscle against an object which it cannot move, the muscle remains at the same length and technically accomplishes no work. The energy that would normally be displayed as mechanical work is dissipated as heat. In such a case the muscle is said to develop isometric tension. Actually no muscle action is perfectly isometric. Even under the most rigid conditions, the contractile elements shorten by five to ten per cent of their length by stretching the elastic components. Good evidence is available to establish that the muscle fibers are not of uniform strength; some of the heat produced may result from the extending of the weaker fibers by the stronger ones. The development of isometric tension may be analyzed as a gradual internal shortening of a contractile substance of the muscle against an elastic passively extending portion. Posture is largely maintained by isometric contractions of certain muscles of the back and legs, where muscular tension is required to offset the effects of gravity upon the body. Isometrics are also employed for muscle setting exercises in physical medicine (61).

When a muscle performs a strictly isometric contraction, the pH change is alkaline (55, p. 27). The review of literature on physiology of muscular contraction points out that the maximum eccentric force is greater than the maximum isometric and maximum concentric forces, although the reasons for this are not yet clearly understood (55, p. 32).

Isotonic Contractions. Muscle shortening during contraction is known as isotonic or dynamic or phasic contraction (36). Strictly speaking, no purely isotonic contractions occur in the human body. This misnomer is used probably in order to avoid such a cumbersome term as hetero-tonic-metric contraction, which indicates a change in both length and tension. When a contracting muscle lengthens, this state is referred to as eccentric contraction; whereas when a muscle shortens, it is called concentric contraction.

Chemistry and Mechanics of Muscle Contraction

Athletes train by alternating periods of strenuous activity with rest pauses, the latter being fully as important as the former in the contraction cycle. Rasch (52) reports that among the chemical changes in the muscles after contraction are the following: (a) ATP and phosophocreatine are completely re-synthesized, effectively reconstituting the energy-rich substances at the site of contraction, (b) all residual lactic acid, including that which has diffused into inactive parts of the body, is oxidized or re-synthesized, (c) muscle glycogen stores are replenished and, under the stimulus of a training regimen, may be increased, (d) liver glycogen stores are replenished and increased, provided that adequate carbohydrate food is ingested and digested, (e) the end products of the neutralizing activity of the body buffers undergo reverse chemical reactions, freeing lactic acid and other acids for oxidation or elimination, (f) muscle protein and other tissue proteins which were destroyed during the activity are replaced.

For muscle to do work, chemical energy must ultimately be transformed into mechanical work; but how and at what stage this transformation is accomplished remains controversial. Observations which have been made indicate that when a muscle contracts, its actin filaments slide past its myosin filaments. The extent of this sliding movement is much greater than the separation of the lateral projections on the myosin filaments, and therefore these projections cannot remain attached to the same points on the actin filaments for more than a very small fraction of the total contraction. In a contracting muscle there is a repetitive cyclic process that goes on at each actin-myosin crosslinkage site, the link being connected for one part of the cycle and discontinued for the rest. The discussion of actomyosin systems given above suggests that the opening and closing of the links corresponds to the binding and the dephosphorylation of ATP. Each time one cycle of operation of the links takes place, the actin filaments are forced to slide a short distance past the myosin filaments in the direction of the center of the sarcomere. When a load on the muscle opposes this movement, tension is exerted. Each link will act many times while the muscle is active (9, Vol. 1, p. 216-218).

Two ways in which such a system might work can be suggested. The more obvious one is by a repetitive change in the positions of the lateral projections on the myosin filaments, in such a way that while they are attached to the actin filaments, they exert a tension and draw these filaments along in the direction of the center of the sarcomere. While they are detached from the actin filament, they return to their original position; then they attach themselves to the actin filaments at new points. The cycle is then repeated. Change in position of the lateral projections might occur as a result of the binding of ATP to the protein, or as a result of the dephosphorylation of ATP to the protein, or as a result of a combination between myosin and actin. The essence of the system is that each link can exert a tension while moving along a certain distance during one phase of each cycle of operation, and that these tensions, generated at many links in the muscle, add together in parallel. The distance of movement will necessarily be controlled by the exact spatial arrangement of the cross-links. The total movement of the actin filament while the muscle is shortening is related to the sum of all the movements of any one link while it is connected to the actin filament, and the total tension at any particular time is the sum of the tensions generated at all the links in operation.

The general theory goes on to suggest that a muscle remains active for as long as ATP is being split, each of the cross-links going through one cycle of operation each time it captures a quantum of ATP and splits it. If the supply of ATP fails, the links lock and remain locked (rigor). If the dephosphorylation of ATP ceases while the supplies of ATP are still maintained the muscle relaxes (9, Vol. 1, p. 216-218).

Contraction and heat. In testing muscles, Harbach (29, p. 20) reported that there is a statistically significant increase in temperature from the normal temperature and that measured after one maximum isometric contraction.

Some effects of heat or increased internal muscle temperature on the contractile strength and muscle endurance of the elbow flexor muscle group were found by Michielli (46, p. 44). He found that when internal muscle tissue was increased by microwave diathermy between 0.2 and 8.2 degrees F, the contractile strength of the elbow flexor muscle group did not differ significantly. When the internal muscle temperatures of the biceps brachii was raised between 1.6 to 9.8 degrees F, the work-performance of the elbow flexors was not significantly affected. So the physiological responses that may have resulted from an increase in internal muscle temperature were not of sufficient magnitude to cause significant changes in the contractile strength and work performance of the elbow flexor muscle group. Daily variation in the control of internal muscle temperature is slight. Therefore, a single control muscle temperature measurement any day, on any given subject, can be regarded as a representative muscle temperature.

A related study was done by Harbach (29, p. 20). He reports that fatty tissue is a poor conductor of heat. Therefore, the experiment indicates that those individuals with a low measurement of fat and girth would have the greatest temperature change. Harbach found other studies that contradicted each other on this point. In his study he found a significant increase in the temperature that was found to exist between normal temperature and heat measured after one maximum isometric contraction. He also found that the amount of temperature change is not affected by arm girth, adipose tissue or strength, although there was a tendency in this direction (29, p. 20).

Blood Supply

Importance and Availability of Blood

Each muscle receives its supply of oxygen, sugar, and other food stuffs from the circulatory system and is therefore necessarily supplied with one or several arteries. Each artery divides into smaller arterioles, and they in turn finally divide into a large number of small capillaries which lie in the endomysium. The walls of the capillaries are extremely thin and provide for an easy transfer of needed substances from the blood to the fiber itself (52). An intermittent ebb and flow of blood takes place through the capillary network due to the opening and closing of capillaries and arterioles in response to local tissue changes. If the fiber is inactive its metabolic needs are slight and little or no blood flows through its capillaries. Upon commencing exercise the acid metabolites resulting from muscular contraction cause the capillaries to dilate, thus permitting an influx of needed blood.

Faster vasomotor changes are probably due to the sympathetic vasoconstriction and vasodilation. These independent unsynchronized contractility changes are believed responsible for the basal vasomotor tone and are probably more important in the vasodilation accompanying muscular exercise than are the local metabolites. The principal regulation of the blood vessels for homeostatic purposes is probably through the sympathetic innervation, although humeral factors also play a role. Proof of the sympathetic innervation of blood vessels is seen when the vessels dilate even before exercise when the individual is anticipating exercise (52).

Experimental evidence by Barcroft (4) indicates that the body responds to meet the need for a greater blood supply in the heavily exercised muscle by the development of additional new capillaries within the muscle. One of Barcroft's reported studies reported that this increase was about 45 per cent.

During a strong sustained muscular contraction the circulation is temporarily arrested. Within a short time, however, the limb volume begins to rise, indicating that while strong muscular contraction does compress the vessels, this compression is insufficient to prevent them from dilating to a certain extent under the influence of dilator substances released from the muscle fibers. Static contractions, such as standing at attention, weight training and gymnastics may thus hinder the venous return to the heart. In dynamic exercise the pumping action pushes blood back to the heart (52, 4).

Internal Pressure and Blood Flow

In the maximal contraction of a frog's gastrocnemius an internal pressure is developed of the order of 100-300 mm. Hg. The muscles contract resulting in a compression of the liquids found in the muscle. This phenomenon is also true in human muscle and explains the cessation of blood flow during strong contraction. This pressure is sufficient to account for the reversible changes of volume accompanying contraction and relaxation which can be regarded as due to mechanical compression and decompression. This does not affect the accepted view that the decreases of volume remaining after relaxation, and its subsequent changes, are due to chemical breakdown (33).

Muscle Contraction and Increased Blood Flow

With the use of a strain-gauge plethysmograph, the effect of brief (0.3 sec.) contraction of the forearm muscles on forearm blood flow has been studied in healthy adults. An increase in flow due to dilation of the blood vessels of muscle could be detected within a second after the completion of the contraction. The blood flow was maximal immediately and decreased rapidly. A second contraction of the same magnitude made during the period of increased flow caused an additional increase in flow. The maximal increase in flow caused by a strong brief contraction was only about 25 per cent of that recorded after strong repeated rhythmic contractions or a sustained contraction. Cervical sympathectomy did not change these findings, indicating the local nature of the response (22). Since breathing oxygen failed to reduce the dilation for a given strength of contraction, oxygen lack was probably not the stimulus for vasodilation. The oxygen saturation of blood that drained the muscles could not be determined accurately immediately after contraction because at this time muscle venous blood was contaminated by venous blood from the skin.

Vasodilation in skeletal muscles have been produced in animals by stimulation of the brain stem, and in many humans by emotional stress and by fainting. The dilation is due to the activation of sympathetic vasodilator fibers. Abrahams and his colleagues, (22) concluded from studies on the cat that reflex muscle vasodilation is one component of a coordinated defense reaction. The reflex may be activated whenever a sudden increase in blood flow of the muscle is required for muscle effort. If this is true, sympathetic vasodilator fibers could reinforce and even precede the dilation mediated locally in the active muscles.

The speed of onset of the dilation from the local mechanism makes it unnecessary to postulate a reflex adjustment of blood flow to the muscles to meet immediate demands at the onset of exercise. Although vasodilator fibers may be excited during exercise and perhaps as a consequence of emotional stress, they are not an intergal part of the general vasomotor response to exercise (22).

Strength

The absolute strength of a muscle describes the maximum contractile tension that a muscle of given cross-section can develop. Values of approximately three to four kg/cm^2 of cross section have been reported for normal skeletal muscle (41). Strength as measured in this study was the amount of pulling force exerted on a 3/16 inch aircraft cable, measured in tension pounds by a cable tensiometer and converted to pounds pulled by a standard conversion table (29, p. 17; 45, p. 44).

Importance of Strength

Man's existence and effectiveness depend upon his muscle. Volitional movements of the body or any of its parts are impossible without action by skeletal muscles. Thus, obviously, one cannot stand, walk, run, jump, climb, or swim without the contraction of many muscles throughout the body. Smaller muscles perform intricate functions including writing manuscripts, playing musical instruments, singing, using hand tools, catching and throwing balls, and the like. Muscles perform vital functions of the body. The heart is a muscle; death occurs instantly when it ceases to contract. Breathing, digestion, and elimination would be impossible without muscular contractions (20).

The good condition of muscles, their strength and endurance, is essential to man. Too frequently, this fact is ignored in an automated society, as only minimum muscular strength and endurance are needed functionally to perform many tasks. However, a sedentary society, in which the muscles are used only mildly, seldom vigorously, is conducive to physical degeneration. Hypokinetic disease is defined as the whole spectrum of inactivity. Lack of activity is thought to be partly responsible for some diseases and the lack of exercise constitutes a cause for a deficiency state comparable to avitaminosis (20). In fact, a relatively new medical specialty, physical medicine and rehabilitation, makes extensive use of exercise as the therapeutic modality.

A number of researchers support the contention that physical vigor is related to mental accomplishments, especially as affecting mental alertness. Thus, a person's general learning potential for a given level of intelligence is increased or decreased in accordance with his physical vitality. A similar relationship is evident between strength, an essential component of physical fitness, and social adjustment. Clarke (20) reported that boys high in strength show tendencies toward social difficulties, feelings of inferiority, and other personal maladjustments. Studies conducted at the United States Military Academy by Appleton (as reported by Clarke) indicate that physical proficiency measures are useful predictors of nonacademic aspects of military success (20).

Numerous studies show that muscular strength and endurance are essential factors in athletic success. This fact is now accepted by many champion athletes in various sports who train regularly on weights to reach and maintain high levels of muscular condition. Thus, the strength and endurance of muscles is prerequisite to human effectiveness in many ways (20).

Strength and Training

Penman (50) did a study on the effects of training and strength increases using humans. He examined the ultrastructural changes in human striated muscle brought about by three different methods of training (running, isometric exercises, and isotonic training). The training period was eight weeks. The muscle tissue was immediately processed for electron microscope examination. Sarcomere length, sarcomere width, A band length, I band length, intracellular fat globule quantity and diameter, mitochondria length, mitochondria quantity, and Z band width were the parameters measured. These measurements were compared with similar ones taken before the training period. Penman's findings suggest that the following changes were found after increasing strength during a training program: between seven and eleven actin fibers in orbit around each myosin fiber; increased glycogen and intracellular fats; greater mitochondria length, decreased myosin density, and an increase in myosin fiber diameter.

DeLorme (24) has discussed different training programs. He has concluded that low repetition- high resistance exercises produce power. High-repetition, low resistance exercise produces endurance. Each of these two types of exercise is incapable of producing results obtained by the other (24).

DeLorme's findings (24) suggest that strong, stronger and weak people exist and the methods of attaining strength are about as varied as people are varied. Strength obtained in different training programs (planned or otherwise) might cause individuals of the same level of strength to respond differently to certain strength tests. For example one very strong person could be a mason and another a business man who worked out with high resistance- low repetition weight programs. Both might be equal in absolute strength but the mason would undoubtedly have more muscular endurance.

Different Levels of Strength

McGlynn (44) did a study with individuals of different strength levels. He reports that during a maximum isometric contraction the intramuscular pressure rises above the arterial pressure in the muscle. The exerted force results in the occlusion of blood to the muscle. As a result a major part of the energy for sustained contraction depends upon the amount of aerobic energy reserves in the muscle. Studies indicate that the region of the fatigue level asymptote, where the depletion and replenishment mechanism balance each other and when circulation is unimpaired is at a contraction of 60 per cent maximal force. Until this point is reached, the energy for the sustained contraction is dependent on whatever oxygen may exist in the muscle tissue and the immediate energy available. Thus the factors determining endurance are the energy available and the demands made upon it. In such a situation, endurance becomes a function of strength and should be related to it. This means that the individuals with greater strength can maintain a higher level of strength for an effort. The build-up of biochemical fatigue products in an isometric contraction is then related to the amount of force exerted by the muscle. Individuals exerting high levels of maximum strength therefore would produce more fatigue elements than those of a weaker group. In the case of the stronger group one could expect an earlier onset of fatigue as a result of the larger amount of fatigue products present in the muscle (44).

Kroll (38) suggests that higher levels of strength possess a superior physiological apparatus designed to maintain higher absolute levels of strength in situations where recovery periods are allowed. Kroll's data suggest that (a) no biologically fixed and constant absolute critical intensity level (reported by McGlynn (44) as being 60 per cent of maximum) of isometric muscular tension which occludes intramuscular and (b) different levels of strength possess dissimilar local circulatory efficiency and/or tolerance to fatigue products (38).

Many people have been interested in finding out the differences in the local muscle tissue among individuals of different levels of strength. Williams (62) made a study of the effects of training on the basal concentration of ATP in muscle tissue. She used rats in her study, trained them by having them swim, and then examined their muscles at various stages. Williams found no significant change in the base concentrations of ATP in the experimental rats as compared to the control rats. The control animals on the average ate more and weighted more than the experimental ones. A definite trend of an increased basal concentration of ATP was found in the exercised animals. Since 88 per cent of the exercised rats had a higher ATP concentration per gram of tissue, Williams suggested that further study in this area be conducted.

Another attempt to find possible differences in the muscle of people at different levels of strength was made by Etemadi and Hosseini (27). They studies the biceps muscle of a strong lumberjack (deceased) and two other less athletic persons. The strong man had 30 per cent greater numbers of muscle fibers in his biceps in comparison to the other two of similar age but less strength. The lumberjack's individual fibers composing the muscle had a cross sectional area about three times that of the other two. In the human biceps, fibers extend from origin to insertion and that no fibers end free within the muscle. So a possible different level of extracted cross-section taken from the specimens should not have made any difference. The number of muscle fibers do not increase in the post natal period, and therefore this particular strong person must have been endowed from birth with this one-third higher number of fibers, and no doubt their individual size was related to his occupation as a lumberjack.

Endurance

Muscular endurance is the ability to maintain sustained contractions over a period of time. A complicated relationship exists between strength, endurance, relative endurance and fatigue. The following discussion reveals some of the research that has been done in this area.

Hettinger (31) reported that only 15 per cent of the maximum strength can be exerted throughout the day without muscle fatigue. The mass of nuclei decreases in proportion to the mass of muscle fibers. The muscle works more economically when the relative mass of nuclei is lower. Capillarization increases in trained muscles. Muscle fat decreased in trained muscles. The percentage of glycogen glutathione also changes. The muscles get larger and the effect of enzymes and coenzymes in the decomposition of the reverse nutrients in the muscle also increases, thus freeing more energy for mechanical work. Trained muscles produce less lactic acid during a certain work-load than untrained muscles.

A study by Stuart (57) on the local muscular isometric endurance with occluded blood supply gives insight into possible reasons for different people reacting differently on a fatigue routine. He reported that when the blood supply to a muscle is interrupted the amount of energy would be required for the minimal metabolic process of the resting muscle and the remainder would be available for producing external work. The external work which a muscle can perform in such circumstances would appear to depend on the amount of available local energy and the product of the muscless basic metabolic requirements, and the time during which the work is to be done. An alternative description of the situation would be that the rate of dissipation of the available energy would be the algebraic sum of the work output and basal metabolic rate of the muscle. When the amount of external work produced by a muscle is large, the energy required for the basal metabolism would be insignificant in comparison and effectively, the dissipation of the energy reserve would be proportional to work output. The higher the work output the shorter is the period during which output can be maintained, i.e., the lower is the endurance. This would give an exponential relation where endurance (F)= energy reserves (R)/energy output per second (E). The extremes of the exponential curve might appear linear which would account for the linearity of the data in this study. The data from trained athletes were atypical in comparison with the untrained individuals because the trained do not follow the above formula very well.

Strength and Endurance

Strength and endurance are closely related according to much of the literature. Carlson (15) writes that muscular strength is an important factor in muscular endurance. Individuals with a high level of strength are usually able to achieve better scores on tests of muscular endurance than individuals with less strength.

However, Carlson concluded that little or no relationship exists between strength and relative muscular endurance. In a test of relative isometric endurance, a weak individual is usually able to do better than an individual with more strength. His study included a wider range of percentage used for the test of relative muscular endurance than had been used previously. Strength does not have an effect upon the performance on a test of relative isotonic endurance (15, p. 110). This test seems to achieve the purpose of the relative loading procedure more adequately than does the test of relative isometric endurance. The substitution of a test of isometric strength, for a test of isotonic strength will not yield identical results while the same individual will score high on both tests, the absolute value of the raw scores will be significantly different (15, p. 110).

Bartz (7, p. 21) did a study on training and endurance, and he reported that the training of a muscle group increases its isometric endurance under conditions of circulatory occlusion and that a positive relationship is apparent between isometric strength and isometric endurance under conditions of circulatory occlusion.

Fatigue

Fatigue is a natural phenomenon that happens to everyone and even though it is associated with feelings of discomfort, the mechanism of fatigue is necessary and should be desired rather than feared. The following section explains the meaning and importance of fatigue.

Rationale of Fatigue

Many researchers have studied and attempted to understand fatigue. The following studies are examples of some of these attempts.

Caldwell performed some tests attempting to measure pain and endurance and he concluded that a pain scaling procedure may prove useful as a device to assess reserve strength well in advance of task termination (12). According to Hastings other ways to measure and study fatigue are by obtaining three types of biological material: the seat of activity, the muscles; the excretions and respiratory gases; and the medium of transportation, the blood (30, p. 40).

By taking samples of the materials that Hastings suggested, much can be learned about the chemistry of the body during fatigue. Chemistry helps answer questions about the body process, and it helps answer what chemical substances, if any, may be used to prevent or alleviate fatigue (6).

The chemistry of the body may become altered in any one of several ways; (a) by body activity itself; (b) by changes in the environment such as temperature or humidity extremes; (c) by substances that are ingested or injected; or by deprivation of substances needed by the organisms, such as oxygen, sugar, water, etc. All of these changes in the body's chemistry are related to the feeling of fatigue.

The chemistry that is called the chemistry of fatigue refers to several things: (a) the chemistry of metabolism, primarily that of foods, in which the ability to metabolize at sufficient rates during exertion is crucial; (b) the chemistry that has to do with mood; (c) the chemistry of the hormonal system which is a part of the chemistry involved in the maintenance of health; (d) the chemistry involved in activation of interoceptors which relay tissue condition to the sensory-cognitive center of the brain (6).

Bartley's (6) definition of fatigue implies that fatigue is a whole symptom felt throughout the body, not confined to special regions or specific functions, emanating from the whole body and mind. Natural fatigue is a protective phenomenon that helps maintain the equilibrium of the organism by stimulating the desire for natural restoratives - food and rest. The purpose of fatigue is self-preservation of self-esteem not merely protection against physical injury.

Bartley and Chute (5) define fatigue as the sensory-cognitive syndrome which includes tiredness, aversion to work, body discomfort, ineffectiveness in performance, etc. Fatigue then is an experienced self-evaluation. Fatigue is the aversion to activity, a condition of existence expressed in bodily feelings, a self-felt assessment of inadequacy, and the experience of futility with the desire to escape. It is the impairment, disorganization, discomfort, largely localized in muscles and work decrement (6).

Fatigue has many aspects but this study will emphasize muscular fatigue or impairment and other factors that are closely related to it. The failure of muscle to perform (muscular fatigue or impairment) lies in changes within the muscle itself and is referred to as contractile fatigue by Bartley and Chute (5). In their book entitled Fatigue and Impairment in Man, Bartley and Chute (5) give a good basic understanding of what fatigue is and why it is studied. They say that the concept of fatigue pertains to organization. What the organism does or fails to do can be largely accounted for on the basis of the principles of its organization. Fatigue is a kind of behavior of the organism which is to be understood primarily in terms of organization. One purpose of the analysis of fatigue is to further the understanding of the relations of different organismic functions to each other and to the environment. The factor of organization is particularly critical in the study of fatigue, since this stance always involves internal contradiction (5).

Fatigue does not crucially depend upon energy expenditure. Confusion of fatigue with impairment and the common practice of comparing men and machines have contributed to the perpetuation of the energy idea of fatigue. Fatigue, contrary to the usual understanding of it, is not to be considered in terms of energy. Energy of course is involved, but the crucial determinant of fatigue is organization (5).

Performance may be thought of as being limited by the specific conditions under which it occurs. For normal performance certain ranges of conditions are required. If the conditions are altered toward the extremes of lack of supply, behavior changes accordingly. Common examples of these extremes are lack of oxygen, heat, carbohydrate, water, salt, etc., and oversupply of heat and carbon dioxide. Many extreme conditions have been studied intensively owing both to their frequent occurence and to their spectacular effects (5).

Bartley and Chute (5) made a summary list of what fatigue is. The list includes: physiological depletion, diminished capacity for work, conscious inability, gradual work decrement, rate drop during the work day, task beyond capacity of worker due to exhaustive character of work, derived from expenditure of considerable proportion of energy. Fatigue is measurable with definite physiological accompaniments and an urge for rest.

Sites of Fatigue

Another author, Hill (32), made some good observations regarding lactic acid and fatigue. He said that lactic acid itself was the most obvious cause of the showing of fatigue and of the stiffening or rigor mortis.

When a muscle is excited and fatigued, or sent into rigor by heat, chloroform or other similar agencies, or allowed to undergo a prolonged process of anaerobic survival, definite changes are recognizable:
(a) glycogen disappears, (b) lactic acid appears in an equivalent amount (32).

Langley (40) reports that fatigue is a common experience. If a muscle is worked for a long period of time, a point is reached at which it is truly impossible for the muscle to continue to perform. When people complain of being tired, the muscles are probably fatigued. What has been written about the chemistry of muscular contraction indicates that if the primary constituents are utilized more rapidly than they are resynthesized, contraction must ultimately cease. At this point the muscles have a shortage of the phosphate compounds and of glycogen and an abundance of lactic acid. Until the basic substances can be replenished the muscle must remain in this completely exhausted state.

Still another factor is present in muscle fatigue. The impluse which traverses the motor nerve must cross the neuro muscular junction in order to activate the myons. The mechanism by which this is brought about is thought to be similar to the mechanism by which the impulse passes across the synapse. Whatever the true facts, it has been established that the mechanism by which the impulse is transmitted becomes exhausted so that even though the muscle is still willing to respond, the impulse is not transmitted across the motor end-plate and, hence, no muscular contraction (40).

Reid (53) supported the nervous fatigue theory by reporting that muscles completely fatigued by voluntary effort can be made to contract by electrical stimulation of the nerves. Reid explained this phenomenon by proposing the idea that inhibitory impulses were set up in the muscles to prevent further voluntary contraction and to protect the muscles from the supposedly dangerous effects of complete fatigue. Merton (45) implied that if Reid's test results were true, the simplest explanation would be that not all the motor units were at the command of the will, so that in a voluntary contraction some would escape fatigue.

In an experiment similar to Reid's (53), Merton (45) suggested that fatigue is peripheral and due to failure of the muscle to contract when impulses reach it. Merton's experiment also shows that the failure of the muscle to respond is not due to blockage of impulses at the neuromuscular junction.

Catton (16) wrote of the nervous system in fatigue. He reports that receptor fatigue is defined as the rise of threshold that occurs during repetitive stimulation with brief mechanical pulses. Receptor fatigue is distinguished from adaptation, which is a diminution in impulse frequency during a sustained deflection. Fatigue reveals itself as a cumulative rise of threshold. This limits the maximum number of responses to a train of fixed amplitude stimuli. The rate of fatigue is a function of the frequency of stimulation. Recovery of excitability to the resting level may take as long as two seconds after a single impulse and several minutes after a receptor has been driven by stimuli at high frequency. These times are far longer than the recovery of excitability of the mylenated sensory axon and probably reflect behavior of the terminal itself or the first Ranvier node.

Most of the material perused in the review of literature suggests that the muscle and not the nervous system is the site of fatigue. For example an air cuff when applied to stop the circulation in a limb exhausted by heavy exercise prevents the recovery of strength until the circulation recommences. And the act of writing, an intricate and skilled but light exercise, becomes difficult within two minutes when the circulation is prevented, and within another minute impossible (9).

Perception of Fatigue

Two possible channels exist through which the condition of muscles is relayed to the central nervous system so as to have an effect upon how the individual senses fatigue. The one channel would be the kinesthetic pathway. The other would involve the circulatory system. If the latter were involved, then substances put into the blood stream from the muscle as it is exercised would find their way to some chemoreceptor upstream or would affect certain brain centers directly. This, of course, is not in line with prevailing thought. However, Bartz (6) reports that Selye has demonstrated to his satisfaction that all tissues when insulted produce some chemical that the blood carries to the pituitary gland and starts a chain of consequences which he calls the General Adaptation Syndrome.

More recently investigators have shown that stimulation of the vagus afferents to the brain in an animal in which the vagus supply to the stomach is severed, produces gastric contractions suggesting that the avenue for inducing seemed to be carried in the circulation. Regardless of whether the state of muscles is made known through a neural or a chemical channel it is certainly made known (6).

The metabolic state of muscle in being a chemical state is also very possibly expressed in mechanical terms. The chemical state effects the mechanical properties of muscle, and the kinesthetic receptors in being mechanical receptors are able to discriminate certain mechanical differences in muscle in addition to the ones that have to do with the ordinary forms of muscle contraction. These mechanical activities may be unsteady or step-wise contractile patterns when muscles are in subnormal states, as in contrast to finely graded contraction patterns under normal circumstances. This difference in muscle activity could be the basis for sending differently distributed nerve impulse groupings to the brain, where they would be the basis for the individual's feeling firm, strong, steady, and comfortable, or on the other hand weak, shaky, unsteady, and uncomfortable (6).

Training and Fatigue

Bartley and Chute (5) have, among many other things, also discussed training and how it affects strength, endurance and fatigue. They report that a number of changes occur in muscle tissue as a result of exercise repeated over extended periods of time. Muscle girth increases, but the fiber length, number of nuclei, and size and number of fibrils remain unchanged. Since no new fibers appear to develop and only the sarcoplasm increases in the original ones, the increased girth seems to be the result of the hypertrophy of individual fibers.

Alkali reserves have also been reported to increase with training (5). Alkali reserves act as a buffer for the lactic acid and thereby increase the body's tolerance to fatigue.

Apparently the resting blood-sugar level is uninfluenced by training, although less fluctuation levels occur during vigorous exercise. Initial hyperglycemia and terminal hypoglycemia tend to be eliminated, and certain experimental findings (5) show that with training no shifts occur in the relative amounts of the kinds of fuel used.

Bartley and Chute (5) reported on a man who, over a period of four and one-half years, measured the changes in endurance in his forearm on a Mosso type ergograph. By the end of this tine, he had multiplied his initial endurance five-fold. Another investigation found a better than eight-fold increase in a 50 day training period of the arms. A two-thirds drop in the capacity following cessation of training was reported.

Various investigations have found that the percentage of glycogen is higher in trained than in untrained muscles (5). Bartley and Chute report that controversy exists over whether or not the glycogen level stays up in trained muscles and they therefore conclude that glycogen supply in muscle is not an essential characteristic of the trained state (5).

Strenuous training appears to increase total blood hemoglobin and blood volume. The count of red blood cells is often increased in the early stages of exertion. This may be due to hemoconcentration, i.e., the transfer of fluid from the circulatory system to the tissues. After longer exercise, net fluid exchange reverses, providing a dilution which would naturally lower the cell count per unit volume. Extreme exertion may increase the rate of red cell destruction from capillary compression by muscles and from increased velocity of blood flow. These effects would be more likely in sporadic bouts in sedentary individuals than in the more completely trained individual. Evidence suggests that while extra-cellular fluids remain constant, intra-cellular water and total body water increases with the training. Apparently levels of blood lactate following sub-maximal exercise, tend to be inversely proportional to the degree of fitness of the individual. The ability of the individual to tolerate higher concentrations of blood lactate before exhaustion increases with fitness.

Evidence suggests that training reduces the amount of oxygen required by working muscles (6). But the ability to consume more oxygen during strenuous exercises is increased and the ability to utilize anaerobic energy reserves is greater (6).

Undoubtedly the greatest and most permanent changes induced by training occur in the nervous system. Improved coordination and less expensive ways of doing things seem to be the outcome of practice.

A large factor in the trained state is the existence of a number of conditioned reflexes involving adjustments through the automatic nervous system. In other words, training reorganizes the nervous functions of the individual so as to utilize the resources of the supporting organs more efficiently (5). Therefore fatigue rate varies depending on many of these mentioned factors.

Individuality of Fatigue

McGlynn (43) did a study that helps explain why different people have different fatigue curves. He said that one of the consequences of an increase in maximum strength is that more muscle fibers will be brought into play since the muscles contrast more forcefully, resulting in the accumulation of more biochemical fatigue products. This in turn may have a limiting effect upon the endurance of the muscles and show up as a faster deterioration of force during a maximally held contraction.

Individual performers in a fatigue test are very likely to show very different results. Alderman (1) concluded from a test that motor fatigue, like motor learning and motor coordination, is probably characterized by high task specificity of individual difference. Even a large amount of intra-task specificity is found when the work load is altered (1).

Another related reason for unique fatigue rates in different individuals is that people have varying capacities to recover from fatigue. The recovery process not only differs under different conditions such as the weight of the load but it also differs from individual to individual depending on their ability to carry out the recovery process.

Caldwell (13) wrote of the recovery from the effects of isometric contractions that it was found to follow a negatively acclerated growth function with endurance recovery being faster for the heavy load than for the lighter one. Since the after affects of strong isometric contractions are primarily within the muscles, the recovery functions may reflect the removal of acid metabolites from the muscle following restoration of the capacity of the contractile tissue. If it may be assumed, then, that the rate of removal of the metabolites is directly proportional to their concentration in the muscle, the mechanism involved in recovery may be viewed as follows: (a) the partial or complete occlusion of the blood supply produced by the internal pressure in the active muscle produces a pooling of the acid metabolites, (b) some of the metabolites such as lactic acid produce local dilation of the arteriole; (c) with the relaxation of the muscle comes a restoration of circulation, and (d) as the vasodilators are removed the blood vessels gradually return toward their normal state with a reduced rate of removal of the remaining waste products. The faster recovery from the effects of the heavier load (at least for the 80 per cent as compared to the 30 per cent load) suggests that with the higher internal pressure in the muscle and a greater degree of ischemia a larger accumulation of metabolites are available to stimulate the recovery process.

Flexors and Extensors

Different muscle groups respond differently to training and therefore give different results on tests (31). Muscles are of different sizes, fiber arrangements, lengths, and they have varying degrees of mechanical advantages in the closing and extending of joints.

The inside portion of the muscle cell is composed of a specialized but undifferentiated protoplasm termed sacroplasm. This is a portion sol (a liquid solution of colloids) of relatively low viscosity. In some fibers the sarcoplasm contains relatively large amounts of myohemglobin and much granular material, which gives them a much darker and redder appearance than other fibers which have less sarcoplasm, few granules, very little myohemoglobin. These two types of muscle fibers are known as red and pale muscle respectively. In red fibers the pigment may serve as a means of storage of oxygen. Hence these muscles should be better adapted to long sustained contraction, such as is required in maintaining posture, which has a tendency to produce ischemia. Pale fibers on the other hand are better adapted to perform fast contractions. Domestic fowl legs, which are in continuous use, are largely composed of red fibers, whereas the wings and breast, which are of little use, are largely composed of pale fibers. In contrast, wild fowl which engage in long flights, have red fibers in the wings and breast as well. In man the common type of muscle is a mixed one, containing varying amounts of red and pale fibers, depending on its task. Leg muscles such as the soleus and extensors, which are engaged in the ardous task of posture maintenance have high proportions of red fibers, while the flexors, which do not have to be used continually, have relatively higher proportions of pale fibers. Experimental findings led Rasch to conclude that if red muscle is transplanted to do the work of a pale muscle, it develops characteristics typical of a pale muscle (52).

As already implied, a muscle can do only two things; develop tension within itself or relax. The size, shape, and number of fibers of a muscle, the type of joint traversed, the nature of the tendinuous or flexhy origin and insertion, the angle and place of insertion, the mechanical advantage of the bone muscle levers, and other factors may affect its actions. In addition, muscles may function singly or as members of a team in various combinations and patterns of movement. The various roles which a muscle may play are designated by technical terms.

If a muscle contracts concentrically, it is said to be a mover or agonist for the joint actions which result. For example, the movers for more than one action in a given joint; may have single or multiple actions on each or two or more joints which they happen to traverse. The biceps brachii, for instance, is a mover for both elbow flexion and radioulnar supination, and in addition it is a mover for several shoulder joint actions. An axiom states that a muscle, when it contracts, tends to perform all of the actions for which it is a mover, although some or all of these actions may be prevented from occuring, in specific situations, by contraction of other muscles, or by some external force, such as gravity.

An antogonist is a muscle whose contraction tends to produce a joint action exactly opposite to some given joint action of another specified muscle. An extensor muscle is antagonistic, potentially, to a flexor muscle. Thus, the biceps brachii is an antagonist of the triceps brachii with respect to elbow extension, and to the pronator teres with respect to radioulnar pronation. The biceps is not an antagonist of the brachialis, because it cannot oppose any motion for which the brachialis is a mover. Muscles also play other roles but for this study a definition of agonists and antagonists is sufficient.

This study is concerned primarily with the flexors and extensors of the elbow joint. The elbow is a true hinge joint in that the only actions possible are flexion and extension. Analysis of the joint reveals that action takes place at the articulation of the ulna with the humerus. The radius does not articulate directly with the humerus. The structure of this joint with the olecranon process of the ulna fitting between the condyles of the humerus makes impossible any motions other than flexion and extension. Elbow flexion is accomplished mainly by the Biceps Brachii, Brachialis and Brachioradialis. These muscles are assisted by the Extensor Carpi Radialis Longus, Palmaris Longus, Flexor Carpi Ulnaris, Flexor Digitorum Sublimis and Pronator Teres. The muscles that accomplish elbow extension are the Triceps and Anconeus. They are assisted by the Extensor Carpi Ulnaris, Extensor Digitorum Communis, Extensor Digiti Quinti, and the Extensor Carpi Radialis Brevis (26).

Steindler (56) adds further understanding to the mechanism of elbow movements stating that in the elbow, the combination of bi- and uniarticular muscles results in release of tension stress of the humerus on contraction of the biceps, where as in contrast, the contraction of the brachio-radialis relieves only the tension stress on the upper radius and ulna and on the lower humerus. Steindler also stated that, expressed in kilogrammetrical values, the flexors are one and one-half times stronger than the extensors. The flexory effect is greater when the forearm is in pronation than when it is in supination because in the former position the distance of the muscle axes from the center of motion is greater. The maximum work of the elbow flexors with the forearm in mid-position is 5.185 kgm., while that of the extensors is 3.345 kgm.

Bowen (10) discussed the two main muscles concerned with elbow flexion and extension: the Triceps and Biceps. He explained that the long head of the Triceps has a short tendon or origin; the fibers of the other two parts arise directly from the humerus. The tendon of insertion is flat, and as it leaves the ulna it broadens into a thin sheet that extends far up the external surface of the muscle and the muscular fibers attach obliquely to its deeper surface. The long head passes up between the Teres Major, lying in front, and the Teres Minor behind it.

Biceps. The tendon of the long head is long and slendor and lies in the bicipital groove of the humerus, becoming muscular at the lower end of the groove. The tendon of the inner head is shorter, the muscular fibers of the two parts being of equal length. The tendon of insertion is flattened as it joins the muscle and passes up as a septum between the two parts and receives the fibers in a penniform manner at both sides.

As for reaction time in the triceps and biceps, a comparison of reaction time latencies of the voluntarily produced single motor unit dischanges in biceps and triceps reveals stable differences. Triceps units usually have shorter reaction time latencies than do biceps units.

Variability of single unit reaction time is less for triceps units than for biceps units. Comparison with gross EMG performance shows consistently greater unit reaction time latency regardless of muscle origin. Intermittent loss of control over motor unit occurs in the reaction time task (57).

Precedence

Kroll (38) did some research and experimentation of the fatigue curves of the wrist flexors that stimulated thought and ideas for this present study. In 1966 Kroll performed some tests and concluded that higher levels of strength possess a superior physiological apparatus designed to maintain higher absolute levels of strength in situations where recovery periods are allowed. His data suggests no biologically fixed and constant absolute critical intensity level of isometric muscular tension exists which occludes intra-muscular circulation. Kroll concluded that different levels of strength possess dissimilar local circulatory efficiency and/or tolerance to fatigue products.

Work by Kroll in 1968 indicated that analysis of a fatigue curve, which is an average or composite for a large experimental group, seldom legitimately represents the fatigue pattern of low levels of strength. He found that low level strength groups demonstrated significant linear fatigue patterns under five and ten second recuperation period conditions, indicating the absence of a steady state. Yet high and middle levels of strength subjects were able to demonstrate quadratic curve components indicating a steady state while operating at higher levels of absolute strength. This evidence indicates that stronger muscles fatigue faster than weaker muscles under certain conditions. Even though high and middle levels of strength differed with regard to absolute amounts, their fatigue patterns were similar (37). Kroll's work agrees with other work done in this area (15) but in the cases cited, flexors only were tested.

Equipment

The choice of equipment for the testing procedures in this study was made on the basis of preview of literature of previously reported studies and material on tests and test measurement. The equipment used included a tensiometer, goniometer, testing table, attachments, stop-watch, strap, aircraft 1/16 inch cable, and recording supplies. The use of this equipment, positions for testing and precautions were obtained from Clarke's Cable-Tension Strength Tests, and his book entitled Muscular Strength and Endurance in Man (19,20). Clarke's cable-tension strength tests are used as a basis for determining strength by many researchers because of their high objectivity and ease of administration (29, p. 17).

Methods and Considerations

The equipment, precautions, and general procedures used for this investigation were decided upon because of their success and objectivity as shown in previous tests (19;20;29, p. 17). Baer says that it is possible that too great a tension development during exercise (or an isometric contraction) might be undesirable because of the danger of exceeding the elastic limit of the passively stretched elements in muscle (3).

Through a series of tests, Schenck (54) concluded that in strength testing a period be provided to subjects and patients during which tine procedures should be repeated sufficient numbers of times so that a quantitative leveling of the behavior tested may be reached before an experimental period is begun. Should this not be feasible, she suggests that a control group which is tested according to the identical testing schedule as an experimental group should be employed. In the event that neither a pre-testing period nor a control group is part of the research design, the results should be interpreted with full knowledge that score increases can occur without the addition of an exercise program.

Fishel observed various testing situations and found that the verbal encouragement motivating situation was influential in contributing to improved muscular strength scores (28, p. 63). Berger (8) found that a knowledge of muscular strength scores during an isometric strength test results in a greater score than when this information is not known.

Ikai and Steinhaus (34) did some experimenting on some of the factors that modify the expression of human strength. They found that the maximal pull of forearm flexors was increased and, in some instances, decreased in predictable fashion by a loud noise, by the subject's own outcry, by certain pharmacologic agents (alcohol, adrenaline, and amphetamine), and by hypnosis. Significant average changes ranging from 26.5 per cent to -31 per cent were observed by them. An analysis of their data and that of others lead them to regard all performances short of the maximum limit, which is always imposed by the structure and prevailing physiologic state of the performing muscles, to be manifestations of acquired inhibitions that in turn are subject to disinhibition by pure Pavlovian procedures, by anesthetization of inhibitory mechanisms, or by pharmacologically induced symptoms serving as stimuli for disinhibition.

One of the subjects in the Ikai, Steinhaus study (34) was an experienced weight lifter. He set a record for forearm flexion in a control pre-hypnotic state and was not able to reach that level of effort during hypnosis. His case points out that some people can overcome inhibitions and perform near their physiological maximum but with this one exception the tests very strongly point out that most people do not reach their maximum under normal testing conditions.

In his book of the Physiology of Strength, Hettinger (31) gives some interesting facts about strength that help define the delimitations, limitations and explanations of outcome in the present study. He said that muscle strength per cm^2 is 4 kg., and that that figure is true for both women and men. However in the muscles of forearm flexion and extension the women only reach about 55 per cent of the total over all strength that men do. Also trainability is less for women than it is for men. In other words strength is determined by the actual size of the muscle. Hettinger reports that the maximum physiological strength is greater than our measurements of voluntary isometric muscle contraction indicates. The increase of muscle strength in hypnosis is much higher in untrained people than in athletes.

Controversy exists over whether or not there are differences between the results of isometric and isotonic strength tests. Carlson (15, p. 40) reports that the results of strength and relative endurance can be influenced by factors such as motivation and blood flow. Control of these factors is difficult, if not impossible. Consequently, consideration must be given to these factors in order that meaning be given to the results. Carlson indicates that the ability of the individual to continue performing a task of muscular endurance is dependent upon the removal of waste products of contraction and furnishing energy for continuing the contraction. This exchange necessitates a functional blood flow through the contracting muscle groups. Consequently, the amount of occlusion produced by the muscular contraction is of considerable importance in determining the length of time a task can be continued.

In testing muscle strength, isometric contractions must be used because movement changes muscle length which causes changes in strength. The angle position is directly related to the muscle length and muscle insertion and the lever arm play an important role. But in general the strength of a muscle increases as its length increases. On strength tests if the subject is willing to make a maximum muscle contraction results are accurate, but if the subject is not interested in showing his maximum strength, the result of this measurement is wrong.

Test Analysis

Many investigations have been made of muscular fatigue. The approach used by many of these investigators has been a technique historically useful in the sciences for describing certain relationships in nature. The scientist related empirical observations with suitable mathematical systems to describe apparent uniformities with greater simplicity and accuracy. Inherent in this approach to mathematical definition of muscular fatigue curves is the theoretical problem involved in the selection of a conceptual basis for seeking a suitable mathematical system for description. Some view mathematics as being abstract with no direct intent of aligning its conceptual operations upon symbols with any real ties in the world. The scientist is the one who must link empirical constructs with some intact system of mathematics. Investigators studying muscular fatigue curves have had difficulties in the past in attempting to find suitable mathematical systems for alignment with empirical observations. Kroll (39) has pointed out that some of the difficulties encountered afford the basis for consideration of a second- a statistical- approach to the problem of identifying components in fatigue curves.

The testing analysis used in the present study were statistical. Mean scores and an analysis of variance of a 2 X 3 factorial model were used to analyze the data.

Summary

The review of literature has covered the structure and properties of muscle, muscle contraction, blood supply, strength, endurance, fatigue, flexors and extensors, and testing methods. The purpose of the review of literature was to facilitate an understanding of the fatigue curves obtained in the present study and to help explain the results of the test.

CHAPTER III

METHODS AND PROCEDURE

The purpose of the present study was to examine and compare fatigue curves made by executing sets of maximum, isometric contractions with the elbow flexors and extensors. A review of the literature indicated a need for such a study.

The research, testing, analysis and reporting were accomplished at the Oregon State University during the 1970-71 school year.

Subjects

The subject requirement for the study was 45 physically normal college males of three general levels of strength: low, medium and high. A letter was written and duplicated for the purpose of explaining the nature of the study to prospective subjects with spaces for name, address, telephone number and periods of free time (Appendix A). The instructors of an intermediate weight-lifting class, a beginning weight-lifting class and a corrective physical education class were approached and were very helpful in soliciting subjects. Also members of the weight lifting team, the coach of the wrestling team and friends were contacted to help provide subjects.

The initial criteria used to enable the screening and categorizing of subjects into the low, medium and high strength groups was the individual's current physical activity, nature of activity, history of physical activity and the number of push-ups and pull-ups that each could do.

The 45 subjects varied in size, training experience and strength. The ranges of some of the subject differences are indicated in Table I.

One participant was the 1970 NCAA hammer throw champion however some of the subjects had neither been members of an athletic team nor had ever followed an exercise program nor even worked hard physically. The members of the very strong group were competitive weight lifters, varsity wrestlers, gymnasts, track and field athletes and football players. Most of the middle group came from an intermediate weight lifting class and most had had high school athletic experience. The weak group members were either enrolled in a beginning weight lifting class or had no physical education classes at the time of testing. The low group, for the most part, also lacked athletic experience. Forty-five subjects were used with 15 in each of the three strength categories.

Experimental Design

In order to fullfill the purpose of this study, the data were analyzed in terms of a double classification analysis of variance, (see Figures 1 & 2), a single classification analysis of variance, and descriptive analysis and comparison of the data. The double classification analysis of variance included the strength decrement index score for each individual tested in each level of strength for both flexion and extension (see Figure 1). This model indicated whether or not there was a fatigue pattern difference between elbow flexors and extensors and whether or not there was a difference between the fatigue patterns of subjects in the three strength levels (hypotheses 6 & 7). The single classification analysis of variance only explained

TABLE 1.

RANGES OF SUBJECT DIFFERENCES

	AGE	HEIGHT	WEIGHT	PUSH-UPS	PULL-UPS
Low	18	5' 3"	126 lbs.	10	0
High	29	6' 3"	250 lbs.	100	30

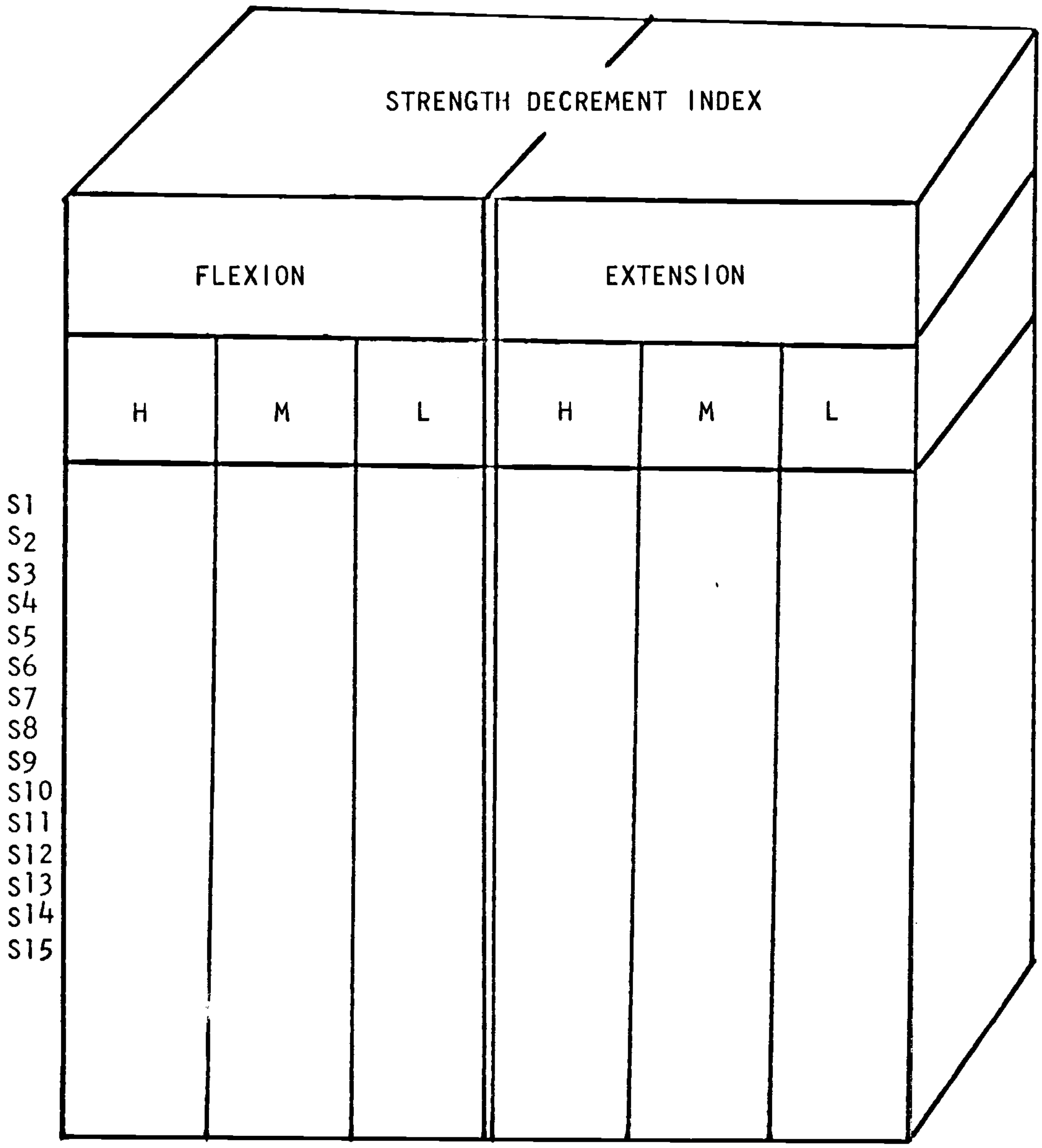

FIGURE 1. Experimental Model of Analysis of Variance of a 2 X 3 Factorial.

Source	DF	Mean Square	F
A Initial-Final or Flexion-Extension	1	-	-
B Levels of Strength	2	-	-
AXB Interaction of A and B	3	-	-
Total	89	-	-

FIGURE 2. Double classification analysis of variance print out form.

the data in one muscle group at a time. The mean of the initial five and the mean of the final five score for each of the 45 subjects were put into the model. The operation was performed twice; once for the flexion scores and once for the extension scores. This data indicated whether or not there were significant strength differences in the three levels tested, whether or not significant fatigue took place in each individual and whether or not the fatigue patterns were different at each level of strength for both flexor and extensor muscle groups (hypotheses 1,2,3,4). The descriptive statistics included the means, standard deviations and ranges of the six average fatigue patterns (one pattern for each strength level for flexion and for extension). The t-values were calculated for the comparison of flexor and extensor strength at each level of strength (hypothesis 5).

Equipment

The equipment used in the study consisted of a testing table, goniometer, cable tensiometer, strap and chain, 1/16 inch aircraft cable, stopwatch and recording supplies (see Figures 3 and Appendix B).

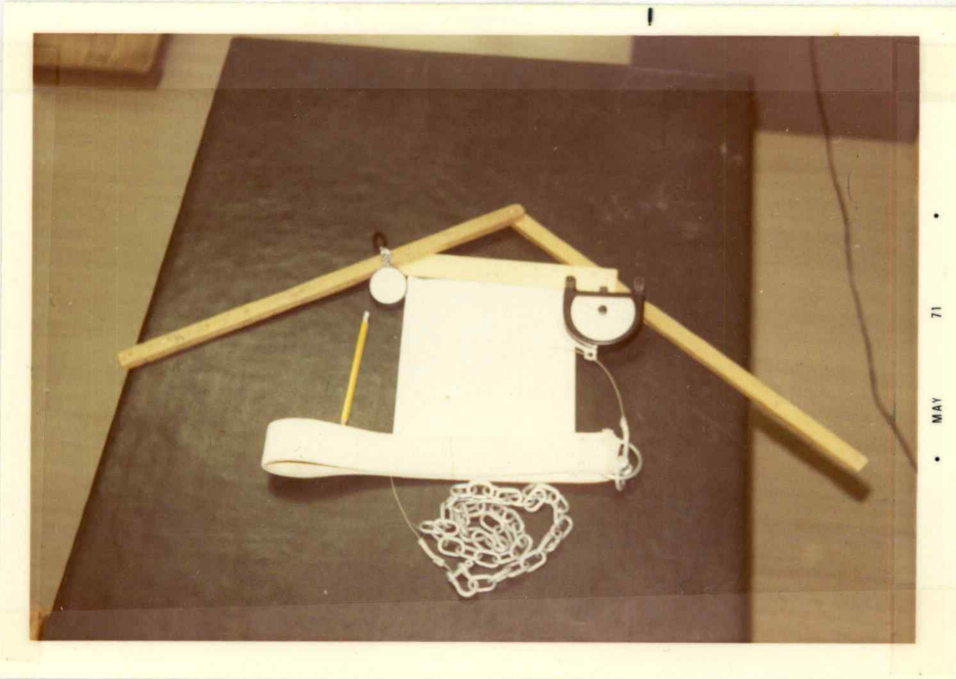

FIGURE 3. Test equipment

Test Description and Procedure

The procedures followed for this study are well outlined by Clarke (19,21). The procedures were simple but time consuming and many careful precautions were required on the part of the tester.

The subjects came to the lab one at a time to be tested. Each subject was shown the equipment, and some basic information was given regarding the nature of the test. The age, weight, athletic history, current training activities and number of pull-ups and push-ups that each could do were recorded.

The subject was then told to lie on the testing table in a supine position as close to the edge of the table as possible while allowing room for the elbow to be supported on the table. The hips and knees were flexed with feet resting on the table, free hand on the chest and head straight with the body. The upper arm on the side tested (dominant side) was adducted and extended at the shoulder to 180 degrees; elbow in 115 degrees flexion; and the forearm in a mid-prone, supine position. A regulation cuff was placed around the forearm midway between the ulna process and olecranon process. The pulling assembly was attached to a hook at the base of the table.

The subject was then instructed to contract with maximal effort on command. He was not allowed to arch the back nor to pry with the body and he was asked to concentrate on the elbow flexors as much as possible. The subject's arm was watched and supported at the elbow when necessary to prevent the upper arm from abducting. Each individual was also supported so that he would not slide on the table and thus change the angle of the elbow. Frequent checks of the angle were made

FIGURE 4. The testing position of elbow flexion.

and when necessary, corrections were made to keep the elbow flexed at 115 degrees.

Each subject executed a maximum contraction and when the needle on the tensiometer reached its highest point and stopped the subject was told to relax and the achieved tensiometer scale reading was recorded.

A stop watch was used and the subject was told to contract every 10 seconds. The time limit of ten seconds was arrived at because it would allow short recuperation periods between each effort and it would help make the test similar for each subject and thus make the comparisons more valid. The contraction usually lasted three seconds so there was about a seven second rest between each contraction. This procedure was continued for 30 contractions. The objectivity coefficient for this test was reported by Clarke (17), as being .95.

After the 30 contractions of the elbow flexors the strap was taken from the arm and the subject was allowed to rest for a few minutes. Each subject was then told to assume the test position for elbow extension which was the same as that for elbow flexion with the modifications of the elbow being in 40 degrees of flexion, and the strap being placed at the head end of the table so that the angle of the extending arm to the cable would be 90 degrees as it was during the flexion contractions.

The same precautions were followed for the extension series except that pressure was now applied on the shoulder from the direction of the head of the table to keep the shoulder from elevating. Again 30 maximum contractions were executed with each one being recorded.

Clarke (17) reports the objectivity coefficient of the elbow extension test as being .94.

Each subject was thanked and his questions were answered after the test. Subjects usually wanted to know what their scores were and how they compared with other people.

Reduction and Analysis of Data

Thirty scores for flexion and thirty scores for extension contractions were recorded for all of the 45 subjects. The tensiometer indicated a certain value and then with the use of a conversion table, the numbers were converted to pounds of tension. (The tensiometers were calibrated by the Department of Engineers.)

The criteria for assigning people to strength levels was based on absolute scores. The median score of the flexors was added to the median score for the extensors to provide one absolute strength score for each individual. All subjects were then ranked from one to forty-five on the basis of these median scores. The top 15 were placed into the high strength group, the next 15 went into the medium group and the lowest 15 were placed in the low level strength group. Generally, the stronger individuals had much more athletic training experience than the weaker individuals.

The data were manipulated three ways to fit the three models in the experimental design. For the single classification analysis of variance model the scores were arranged according to muscle group (flexion or extension). The mean of the initial five scores and the mean of the final five scores for each individual were calculated. Then these scores were typed in the computer for the analysis of variance. The procedure was done exactly the same for flexion scores first and then for extension scores.

For the double classification analysis of variance a strength decrement index was calculated for each individual in each muscle group making a total of 90 strength decrement indexes. This information was typed into the computer and were analyzed in the form illustrated in Figure 1. The strength decrement indexes were calculated by using the following formula:

$$\text{S.D.I.} = \frac{\text{average of initial five scores} - \text{average of final five scores}}{\text{average of the initial five scores}} \times 100$$

Each subject executed 30 isometric contractions in both the flexor and the extensor muscle groups. In order to obtain a descriptive analysis of the scores, the mean score for all fifteen subjects in each of the three strength level groups, was calculated for each of the 30 trials. The results were six mean fatigue patterns (one pattern of 30 scores for each level of strength for both elbow flexion and extension).

All data scores were typed into the computer system at the Oregon State University. The *ANOVA12 program was utilized to obtain the double and single classification analysis of variance and the *SIPS program was used to acquire the descriptive statistics and t-values.

Level of Significance

The level of significance chosen by the investigator reflects what is hoped to be a reasonable balance between the probability of alpha and beta errors. An alpha or Type I error is the rejection of the null hypothesis when it is true, and a beta or Type II error occurs when the null hypothesis is false, but not rejected. The level of significance chosen should be dependent upon the nature of the study. A more stringent level is desirable if an application of the findings of the study could be potentially dangerous or damaging. The .05 level was selected for the rejection of the null hypotheses of this study. The .01 level was selected for the rejection of hypothesis number one because of its expected and important outcome of being accepted.

CHAPTER IV

ANALYSIS AND INTERPRETATION OF DATA

The major purposes of this investigation were to compare the fatigue patterns of the flexors and extensors at the elbow joint and to compare these fatigue patterns at different levels of strength. In this chapter the results of the statistical analyses used to test the hypotheses of this investigation are presented. Additionally, these results are interpreted and various trends are compared with similar studies reported in the literature.

Analysis

Flexors

Tables II and III and Figure 5 indicate the trends of the elbow flexors at each level of strength. The average scores of the initial and final five scores at each level of strength and an overall average of all groups are depicted in Table II. The table indicates that a decrement in strength occurred in every case.

Table III is the analysis of variance in a 2 by 3 arrangement of the average initial and final absolute scores. The *F* value in the initial-final (A) row of 43.21 is clearly significant, which suggests that significant decrements in strength occurred as a result of 30 contractions of the elbow flexors at every level of strength. The *F* value for the HML (B) row is 77.43 and is also significant at the .01 level of confidence. This *F* value illustrates the fact that a significant difference in strength of the elbow flexors was obtained at the three levels of strength. Finally the AB row has an _F_ value of .004 which is not significant. This between group comparison denotes that no significant difference exists between the fatigue patterns at each level of strength.

Figure 5 graphically illustrates the information of Tables II and III. Every fatigue pattern has a downward slope revealing that fatigue did take place. The patterns are widely spread apart indicating three distinct levels of strength and the lines appear to be very near to being parallel, as the _F_ value of the interaction term in Table III indicates they should be.

Extensors

Tables IV and V and Figure 6 illustrate the trends and nature of the elbow extensor muscles tested in this study. The results are similar to those obtained for the flexor muscles. The mean scores of the initial and final five scores appear in Table IV. In every level of strength the final mean is lower than the initial mean indicating that fatigue occured at all levels of strength in the extensor muscles. The significant _F_ value of 15.12 in the initial-final (A) row of Table V implies a significant decrement in strength of the extensor muscles at every level of strength. Table V lists an _F_ value of 70.97 which indicates a clearly significant difference between the strength at the three levels of strength. The interaction term in Table V illustrates that no significant difference exists between the fatigue patterns at each level of strength for the elbow extensor muscles. Figure 6 illustrates the data of Tables IV and V.

TABLE II. Initial and Final Elbow Flexion Scores for Three Levels of Strength.

LEVEL	INITIAL FIVE	FINAL FIVE
H	125.51	104.39
M	104.45	84.03
L	77.28	56.33
ALL LEVELS	102.41	81.58

TABLE III. A/V of the Means of Initial and Final Flexion Scores.

Source	DF	M.S.	F
A	1	9763.54	43.21[a]
B	2	17496.81	77.43[a]
A X B	2	1.00	0.004
TOTAL	89		

[a]Significant of the .01 level of confidence.

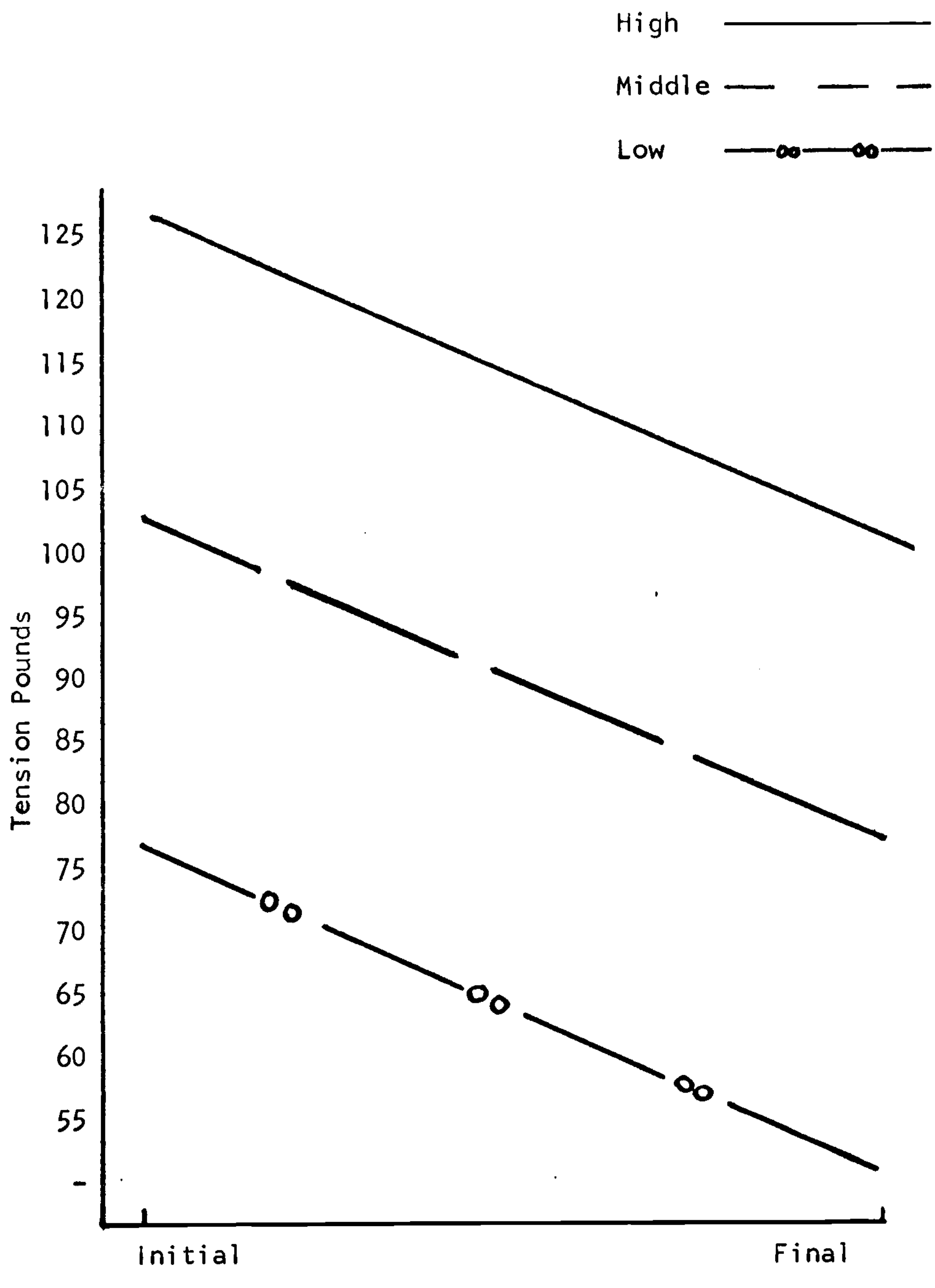

FIGURE 5. Flexion fatigue patterns from the mean of the initial 5 scores to the mean of the final 5 scores.

TABLE IV. Initial and Final Elbow Extension Scores for Three Levels of Strength

LEVEL	INITIAL FIVE	FINAL FIVE
H	90.49	79.34
M	64.54	52.89
L	49.64	39.83
ALL LEVELS	68.22	57.35

TABLE V. A/V of the Means of Initial and Final Extension Scores.

SOURCE	DF	M.S.	F
A	1	2659.07	15.12[a]
B	2	12483.36	70.97[a]
A X B	2	6.75	.04
TOTAL	89		

[a]Significant at the .01 level of confidence.

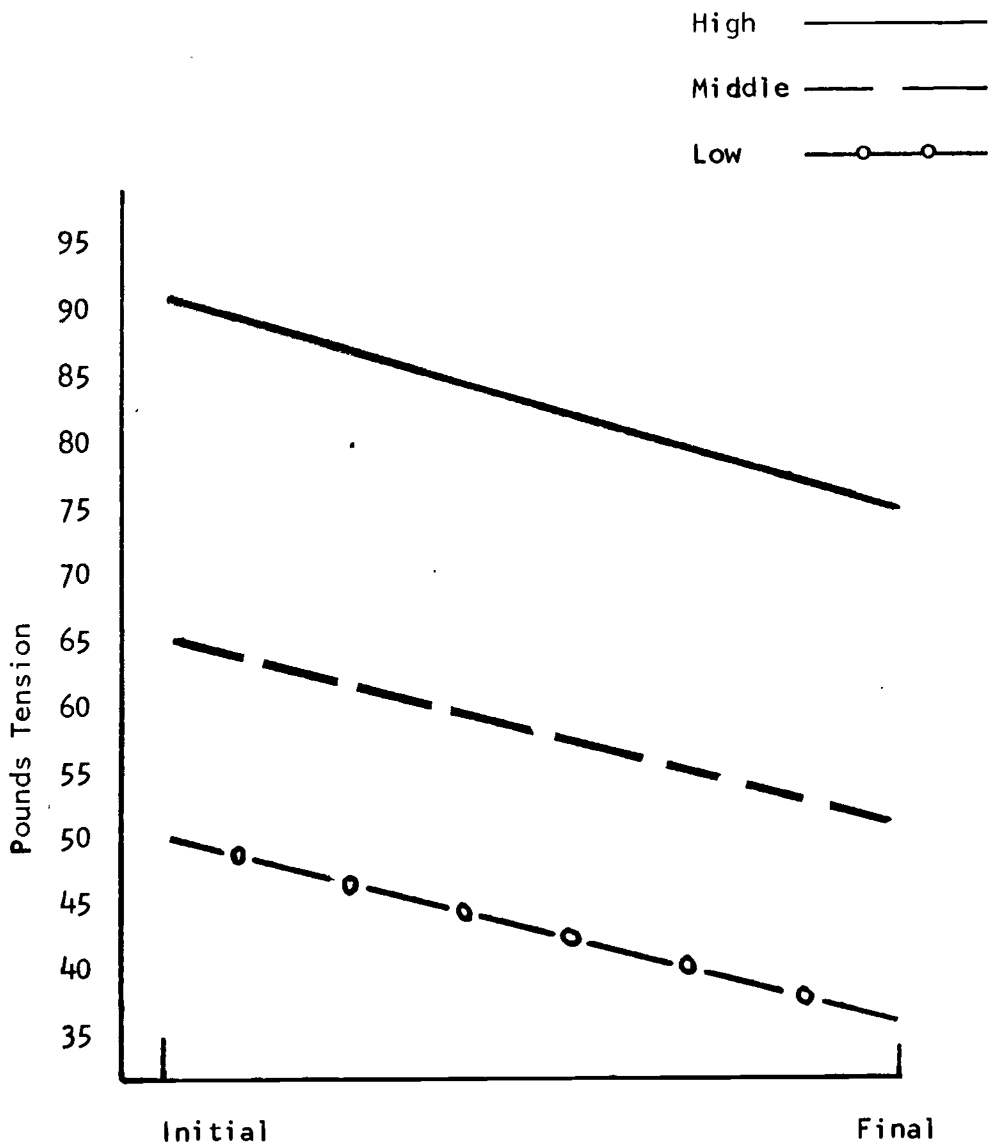

FIGURE 6. Extension fatigue patterns from the mean of the initial 5 scores to the mean of the final 5 scores.

The data and graphs on the elbow flexors and extensors indicate that both muscle groups show significant strength decrements or fatigue over the 30 trials, significant differences exist between the strength of each strength level in both muscle groups and the flexor fatigue patterns were significantly the same for each level of strength as were the extensor fatigue patterns.

Extensors versus Flexors

Strength decrement index scores were calculated to facilitate a comparison of the flexors and extensors. Tables VI and VII and Figure 7 show the data used for this comparison. The strength decrement index for both the flexor and extensor muscles at each level of strength and overall are listed in Table VI. At every level of strength the flexor strength decrement index is higher than that for the extensors. However in the middle level the difference is only .07. This information implies that the flexors tend to fatigue more than do the extensors. Figure 7 graphically depicts the scores listed in Table VI. Table VI and Figure 7 both illustrate the already mentioned tendency for the elbow flexors to fatigue more or at a greater rate than the extensors and they depict a tendency for the low strength level flexors and extensors to fatigue more than the middle or low levels and the high strength flexors and extensors tend to fatigue least of all. The middle strength muscle groups fall in between the high and low level fatigue rates for both flexors and extensors.

The tendencies or trends implied in Table VI and Figure 7 are not significant however. The $\underline{F}$ values of 0.35 for the flexion-extension

TABLE VI. Means of Strength Decrement Indexes of Flexion and Extension Scores.

LEVEL	FLEXION	EXTENSION
H	14.81	11.84
M	17.89	17.82
L	22.93	20.41
ALL LEVELS	18.54	16.69

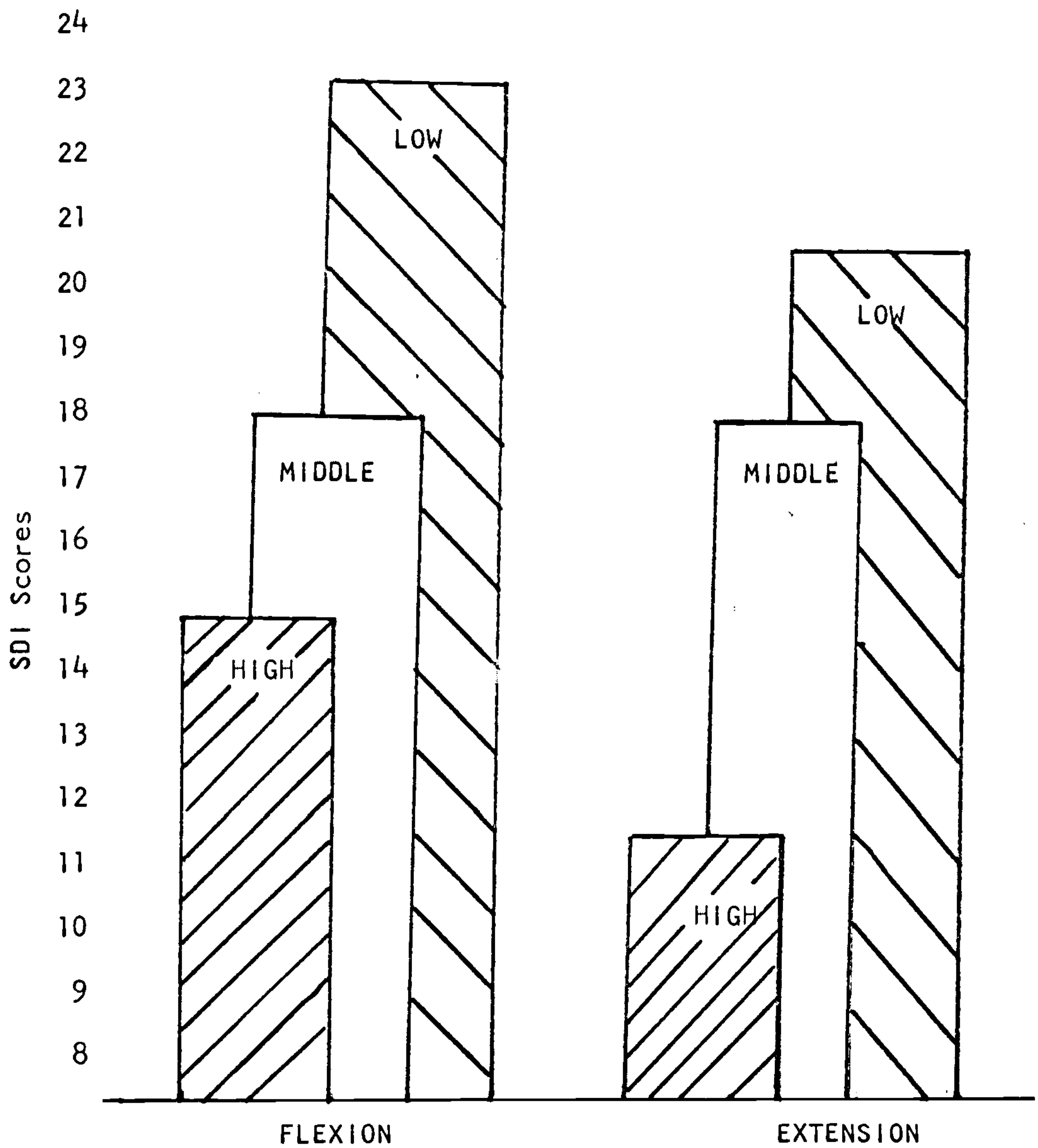

FIGURE 7. Strength decrement index scores of all groups for both flexion and extension.

TABLE VII. A/V of SDI Scores of Flexion and Extension.

SOURCE	DF	M.S.	F
A	1	77.28	0.35
B	2	522.94	2.36
A X B	2	18.34	0.08
TOTAL	89		

row (A), 2.36 for the HML (B) row and .08 for the interaction (AXB) row are listed in Table VII. These F values are not significant. In other words no significant difference exists between the "all levels" index scores of 18.54 for flexion and 16.69 for extension; no significant difference exists between the strength decrement indexes of high, middle and low strength levels; and no significant difference exists between the interaction of flexion-extension indexes and the three levels of strength.

The analysis of variance of the two by three factorial experimental model of strength index decrements therefore establishes that the fatigue patterns of flexors and extensors at all levels of strength tested are significantly the same.

Descriptive statistics of the absolute scores in Table VIII further illustrate the nature of the fatigue curves obtained in this study. The means of the flexion scores are significantly higher than those for extension at each level of strength. The standard deviation and range are also greater for the flexor muscles indicating a greater decrement in strength or more fatigue as was illustrated in Table VI and Figure 7. However, as was illustrated in Table VIII, the difference between fatigue patterns in the elbow flexors and extensors is not significant.

TABLE VIII. Descriptive Statistics of the Absolute Scores.

	HIGH 15 Flexion	HIGH 15 Extension	MIDDLE 15 Flexion	MIDDLE 15 Extension	LOW 15 Flexion	LOW 15 Extension
Mean	115.08	82.64	93.41	57.71	67.47	43.02
Std. Dev.	8.84	4.02	7.17	4.29	6.65	4.11
Range	31.8	16.5	23.5	15.8	24.5	17.4
t-value	18.30[a]		23.41[a]		17.14[a]	

[a]Significant at the .01 level of confidence.

Interpretation of Data

The results of this investigation are discussed both in terms of their application to the hypotheses stated in Chapter I, and in terms of their contribution to the current knowledge of fatigue patterns in flexors and extensors. The evidence supporting the rejection or non-rejection of each hypothesis will be presented along with a discussion of possible causes for insignificant trends in the data.

The first hypothesis, that a significant amount of fatigue occurs in all groups under the conditions of this test, is not rejected. The $\underline{F}$ values of 43.21 and 15.12 in Tables III and V respectively are both significant and therefore support the conclusion of non-rejection of the first hypothesis. This conclusion was assumed to be true at the outset of the study but it was not an assumption that could be ignored. If no significant fatigue had taken place in each muscle group of the three strength levels then further analysis would have been unnecessary and unappropriate.

Hypothesis number two, that no significant strength differences exist between the strength levels tested, is rejected. The $\underline{F}$ ratios for the B rows in Tables III and V are definitely significant and therefore support this conclusion of rejection. The outcome of hypothesis number two was controlled but could not be ignored either. The establishment of significantly different levels of strength was also necessary for a valid study.

The third hypothesis, that no significant difference exists between the fatigue patterns in the elbow flexors of individuals from three levels of strength, is not rejected. The $\underline{F}$ ratio for the interaction term in Table III supports this conclusion. In a comparison of elbow flexor and extensor fatigue curves, one pattern cannot be assumed to be dependent on the other therefore a regression analysis of the two patterns would not be a correct procedure for analysis in this study. But for interest a regression analysis was made on portions of the data. For example, the strongest ten subject's flexion scores, expressed as percentages of the maximum score, were regressed on the weakest ten subject's flexion scores, also expressed as percentages of the maximum. The correlation coefficient of that regression was .81. This very high correlation also supports the non- rejection of hypothesis number three. A discussion of these results will be included under the discussion of hypothesis number seven.

The fourth hypothesis, that no significant difference exists between the fatigue patterns in the elbow extensors of individuals from three levels of strength, is not rejected. Information in Table V supports this conclusion and the correlation coefficient of the strongest ten extension scores regressed on the weakest ten extension scores (expressed as percentages of maximum) was .80. The discussion for this conclusion also follows the discussion of hypothesis number seven.

Hypothesis number five, that no significant strength difference exists between elbow flexors and extensors, is rejected. This non-rejection is supported by the t-value in Table VIII.

Steindler (56) stated that, expressed in kilogrammetrical values the flexors are one and one-half times stronger than the extensors. The maximum work of the elbow flexors with the forearm in mid-position is 5.185 kgm. while that of the extensors is 3.345 kgm. In the current study in the high level of strength the flexors were 1.39 times stronger than the extensors in the middle group this ratio was 1 to 1.62 and in the low group it was 1 to 1.57 (mean scores). The results of this study therefore support the literature in stating that the elbow flexors are stronger than the elbow extensors.

Hypothesis number six, that no significant difference exists between the fatigue patterns of elbow flexors and extensors, is not rejected. The $\underline{F}$ values in Table VII indicate that the difference between the strength decrement index score of 18.54 for the flexors and the score of 16.69 for the extensors is not significant. This finding is not in complete agreement with the literature. However, Table VI establishes that at each level of strength, the flexors did tend to have a higher strength decrement index than did the extensors. The general role of extensors in the body is that of posture requiring an almost constant nervous impulse bombardment and therefore the extensors tend to fatigue less than do the flexors. Heavily worked muscles such as the wings in wild fowl are more red (contain more mitochondria) and less used muscles are pale. However this arrangement can change if the role of the muscle is changed. Rasch (52) reported that if a red muscle is transplanted to do the work of a pale muscle, it develops characteristics typical of a pale muscle. In man the common type of muscle is a mixed one but in certain parts of the body such as in the legs the flexors tend to have relatively higher proportions of pale fibers (52).

The current study indicated that the elbow extensors as compared to the flexors were probably not predominatly red or white fibers because the strength decrement index scores were not statistically different.

Even though this study indicates no significant difference between the fatigue patterns of flexors and extensors, Table VI depicts a somewhat different relationship of flexors to extensors at each level of strength. In each level the extensor scores were regressed on the flexion scores and the three correlation coefficients were different at each level of strength. The middle group's scores had the highest correlation, .96, the low group was second, .86, and the high strength level group's correlation was the lowest, .79. These trends and differences at each level support the point expressed by Rasch (52) that a muscle's characteristics can be changed by changing the amount of work or the role of that muscle. Since the well trained athletes had the lowest correlation between flexor and extensor fatigue curves, training programs (the high group were the ones who had been subjected to the most athletic training and weight lifting) can apparently change the muscle relationships that might exist in individuals who do not follow training programs. Athletes, however, often concentrate on developing the muscles in one particular area of the body and might cause muscle relationships considered abnormal, compared to the individuals who do not concentrate on developing specific muscles.

Again the statistically significant conclusion was that there is no difference between the flexors and extensors around the elbow joint. This would suggest that the 45 people tested used both muscle groups about the same. The conclusion for hypothesis number six is entirely logical upon considering that the elbow extensors are not responsible for body posture as the trunk and leg extensors are and therefore their relationship to the corresponding flexors would not functionally be the same as a flexor-extensor relationships might be elsewhere in the body.

Hypothesis number seven, that in the elbow flexor and extensor muscle groups no significant fatigue pattern difference exists between high, middle and low levels of strength, is not rejected. The *F* value of 2.36 in the B row of Table VII is not significant at the .05 level of confidence. The conclusion of non-rejection of the seventh hypothesis is consistent with the conclusions for the third, fourth and sixth hypotheses namely that all flexor patterns are significantly similar, all extensor muscles are similar and finally that no significant difference exists between the fatigue patterns of elbow flexors and extensors. This conclusion does not agree with the results of a similar study done on wrist flexors (37,38). The conclusion in this study is that the differences in fatigue patterns are not significant which is not consistent with the results of the wrist flexor studies. The trends depicted in Table VI and Figure 7 are in direct contrast to the fatigue rates found for the wrist flexors. The contradiction could be due to one or a combination of several variables. Such as the difference in subjects which includes many possible differences, the nature of the testing procedures or a difference between wrist flexors and elbow movers.

The SDI scores indicated that the low level strength subjects tended to fatigue more than either the high or middle levels in both the elbow flexor and extensor muscle groups. The following discussion helps explain the results.

Muscular fatigue consists of two parts. One part consists of a shortage of the phosphate compounds and of glycogen and an abundance of lactic acid. The second part of fatigue has to do with the impulse. The impulse which traverses the motor nerve must cross the neuromuscular junction in order to activate the myons. The mechanism by which this is brought about is thought to be similar to the mechanism by which the impulse is transmitted becomes exhausted so that even though the muscle is still willing to respond, no transmission of the impulse crosses the motor end-plate and, hence, no muscular contraction (40).

Cotton (16) reports that the receptor fatigue is defined as the rise in threshold that occurs during repetitive stimulation with brief mechanical pulses. The rate of fatigue is a function of the frequency of stimulation. Recovery of excitability to the resting level may take as long as two seconds after a single impulse and several minutes after a receptor has been driven by stimuli at high frequency. These times are far longer than the recovery of excitability of the mylenated sensory axon and probably reflect behavior of the terminal itself or the first Ranvier node.

Individual striated muscle fibers respond differently. For example their threshold levels vary and the more fibers are excited, the more forcefully they contract. One of the postulated benefits of training with near maximal weights in progressive resistance exercise is that this brings some of the high threshold neurons within the orbit of voluntary activity (52).

Many of the subjects in the high strength group had worked out with weights or they had done some other form of heavy training. Therefore, they could, according to the above idea, call on more effort from the individual fibers. This would seem to cause them to fatigue more than they did. Apparently some of the other factors involved compensated for what would be the expected higher rate of fatigue for the high strength group.

As for neuromuscular fatigue- the short rests between each contraction should have allowed sufficient time for nervous recovery. Besides, most researchers (9) agree that the muscle and not the nervous system is the main site of fatigue.

When physical training associated with strength increases takes place many changes take place in the body. For example trained muscle has increased glycogen units and intracellular fats, greater mitochondria length, decreased myosin density, and an increase in myosin fiber (50,5). The mass of nuclei decreases in proportion to the mass of muscle fibers. The muscle works more economically when the relative mass of nuclei is lower. Capillarization increases in trained muscles. In addition to the mechanism of increase in muscular hypertrophy is the effect of enzymes and coenzymes in the decomposition of the reserve nutrients in the muscle which also increases, thus free in more energy for mechanical work. Trained muscles produce less lactic acid during a certain workload than untrained muscles (31).

With all of the changes that come about because of training the muscles are more efficient, and have larger supplies of energy reserves available so it seems not hard to believe that they would have better endurance also. McGlynn (43) reported that one of the consequences of an increase in maximum strength is that more muscle fibers will be brought into play since the muscles contrast more forcefully, resulting in the accumulation of more biochemical fatigue products. This in turn may have a limiting effect upon the endurance of the muscles and show up as a faster deterioration of force during a maximally held contraction.

Studies also indicate that muscle tension produces pressure which occludes the blood supply. When this happens the energy for contraction is dependent upon the amount of aerobic energy reserves in the muscle. The level at which the depletion and replenishment mechanism balance each other is thought by some to be at 60% maximal force. Contractions of more than 60% would therefore depend on oxygen reserves in the muscle. In such a case it may be assumed that endurance becomes a function of strength and that individuals with greater strength can maintain a higher level of strength for an effort. Then the build up of biochemical fatigue products would be higher in the strong individual and there would be an earlier onset of fatigue expected (44).

Kroll (38) disagrees with the idea of a biologically fixed and constant absolute critical intensity level of isometric muscular tension which occludes intra-muscular circulation. Kroll believes that different levels of strength possess dissimilar local circulatory efficiency and/or tolerance to fatigue.

The information just cited suggests that the trained individuals are indeed more efficient and stronger but that the extra effort that they are able to exert causes early fatigue in comparison to weaker subjects and it therefore does not wholly explain why the results of the current study came out as they did. But the author feels that the changes that came about in the subjects of this test because of training did cause them to have a smaller percentage of fatigue than the low level of strength group.

Evidence suggests that training reduces the amount of oxygen required by working muscles. Also the ability to consume more oxygen during strenuous exercise is increased as is a greater ability to utilize anaerobic energy reserves (6). This information could either support the idea that the strong muscles fatigue faster or that they endure longer. The answer depends upon whether or not the energy stores were used up in the 30 trials of required contractions.

Some researchers believe that muscular strength is an important factor in muscular endurance. Individuals with a high level of strength are usually able to achieve better scores on tests of muscular endurance than the individuals with less strength (15).

The ability of the individual to continue performing a task of muscular endurance is dependent upon the removal of waste products of contraction and furnishing energy for continuing the contraction. This exchange necessitates a functional blood flow through the contracting muscle group (15).

The literature indicates that under conditions of circulatory occlusion there is a positive relationship between isometric strength and isometric endurance (7). But in non-occluded (controlled occlusion) conditions, the weak individual is usually able to do better than an individual with more strength in terms of relative isometric endurance (15).

The implication of the study just mentioned, that weak do better in a test of relative isometric endurance, is because of the phenomenon that in the maximal isometric contraction an internal pressure is developed (100-300 mm. Hg. in the frog sartorius). This pressure is caused by the contracting muscles pushing mainly the water contained in the muscle into different areas. This pressure explains the cessation of blood flow during strong contractions (33). A higher degree of occlusion exists in the strong individual.

The muscle must receive blood because the circulatory system is the source of supply of oxygen, sugar and other food stuffs from the body and it is also the means of carrying away much of the waste materials. The circulatory system breaks down into millions of arterioles, capillaries and venules. Upon commencing exercises the supply needs of the muscles increase and the acid metabolites resulting from muscular contraction cause the capillaries to dilate, thus permitting an influx of needed blood (52).

Evidence also indicates that the body responds to meet the need for a greater blood supply in the heavily exercised muscle by the development of additional new capillaries within the muscle, as was already stated earlier in the discussion. This increase has been reported to be as much as 45% (52,4).

The strong contraction in this study then results in a temporary arrest of the blood but the developed pressure isn't enough to prevent the vessels from dilating to a certain extent and so perhaps partly during and after the contraction the strong muscle is well furnished with needed supplies. This might be another factor causing the strong individuals to have a smaller percentage of fatigue or strength decrement index. The short test between contractions allowed time for the muscle to be partially recuperated. One problem in this study however was that the static position of the arm doesn't facilitate venous return as much as a dynamic contraction would.

Caldwell wrote of the recovery from the effects of isometric contractions that it was found to follow a negatively acclerated growth function with endurance recovery being faster for the heavy load then for the lighter one because of increased vasodilation and resultant increased blood flow to the area after the contraction resulting in a faster recovery (13). Perhaps because of a greater maximum potential and a nearer to maximum contraction, the strong in this study recovered more during the rest periods and thus showed a smaller percentage of fatigue.

The types of training programs that the individuals in the study had would surely affect their muscular endurance. For example, DeLorme (24) found that low-repetition, high-resistance exercises produce power while high-repetition, low-resistance exercises produce endurance. Six wrestlers, four track and field athletes, one competitive weight lifter and two football players were in the high level strength group. The majority of these subjects would then be involved in many low-resistance, high-repetition exercises such as calisthenics, etc. According to DeLorme, this would help explain why they had a lower percentage of fatigue than did the other two groups.

Another possible consideration for the results of this test might be involved in the elastic component of muscles. In isometric contractions the rate of internal shortening of the contractile component is equal to the rate of internal lengthening of the elastic component. Researchers do not know exactly what the elastic component is nor where it is but its presence has been shown by such researchers as Wilkie and Hill (61). They said that one of the functions of the undamped passive elastic element is to transfer force to the muscle tendon and to act as a buffer to smooth out rapid changes in tension (61).

Ligaments are believed to increase in strength along with the muscle (52). It is only logical to then assume that the strength that the strength of the elastic component would also increase.

In the isometric conditions of this study the angle at the elbow joint was maintained. Therefore if the elastic components of the weaker subjects were weaker or more elastic than those in the strong individuals, then the weak people would have to contract the contractile components of their muscles further to create tension than would the stronger subjects. This extra lengthening might require more work and therefore, in part, account for the larger percentage of fatigue in the weaker persons that were in this study.

According to Caldwell (12), who performed some tests attempting to measure pain and endurance, a pain scaling procedure may prove useful as a device to assess reserve strength well in advance of task termination. In the present study, the high strength group seemed to try harder to make a maximum contraction on each trial than did the weaker subjects but people in the low group complained more about pain and discomfort during the test. Perhaps the weak group didn't really make maximum pulls because of unwanted pain. If the weak really did exert less than maximal effort to avoid pain then their decrease in scores might reflect more of a desire to avoid pain than a fatigue decrement. The people in the stronger group were no doubt more accustomed to the pain accompanying physical effort because of their training experience and they may therefore have pulled harder or nearer their maximum on each trial than did the other groups.

As can be seen from the discussion up to this point, many factors can affect strength and fatigue. Much of the literature points out the individually of people and the differences brought about in people's muscles because of different training programs, as well as different personal reactions to training stimulus. The evidence cited in this discussion, makes the non-significant difference found between the patterns of the different levels and the tendency for the weak group to fatigue more than the strong group clearly possible even though the studies on wrist flexors showed a tendency in the opposite direction.

CHAPTER V

SUMMARY AND RECOMMENDATIONS

Summary

Coaches, athletes, therapists, doctors, teachers and researchers have been studying and trying to understand fatigue, strength and endurance for many years. Even though many studies have been conducted in these areas, many questions remain to be answered. For example: How much does the relationship of flexors and extensors vary at different joints? and How do training programs affect flexor-extensor relationships and overall performances of the trained individuals? This study represents an effort to better understand and answer questions about the phenomenon of fatigue in different individuals.

The main goals of this study were to determine if elbow extensors have the same isometric fatigue patterns as elbow flexors and to compare the fatigue curves of elbow flexors and extensors at three levels of strength. The accomplishment of these purposes would then provide possible answers to questions such as: (1) Do the fatigue trends at the three levels of strength show the same relationship between high, middle and low as do the patterns of wrist flexors at the same three levels of strength? and (2) Is the relationship between flexors and extensors at the elbow joint the same as the general relationship between flexors and extensors in other areas of the body?

This investigation was conducted during the school year of 1970-71. Data were collected from students of Oregon State University.

Forty-five male college students from three levels of strength were tested one at a time by the investigator.

Testing consisted of each subject executing 30 isometric contractions with the elbow flexors and then the elbow extensors. Contractions were made at ten second intervals and the amount of effort exerted was calculated by measuring the tension in a cable with a cable tensiometer. The scores were recorded, converted to pounds of tension and analyzed.

Analysis consisted of single classification analysis of variance, double classification analysis of variance and descriptive statistics comparisons. Mean initial and final five scores, strength decrement indexes, and mean fatigue patterns for each level of strength and muscle group were calculated from the subject's scores to make the analysis possible. *F* ratios and t-values were utilized to test the hypotheses.

The .05 level of significance was chosen to test the null hypotheses that were presented in Chapter I and the .01 level of significance was chosen to test hypothesis number one. Based on the results of the design and analysis, the following conclusions seem justified.

1. A significant amount of fatigue occured in both flexor and extensor muscle groups of all groups tested.

2. A significant strength difference existed between the elbow flexors and extensors in all the levels of strength.

3. The fatigue patterns for both flexors and extensors were significantly similar in all three levels of strength.

4. Even though in absolute values the individual in the three significantly different strength levels possessed disimilar elbow, flexor-extensor fatigue patterns; no significant difference was found in the types of fatigue patterns exhibited. However a tendency for the low group to fatigue at a higher rate than either the middle or high groups was evident (Figure 7). This tendency is in contradiction to strength level fatigue patterns exhibited by wrist flexors reported in other studies (37,38). This study does not indicate if the contradiction was due to subject difference or something else.

Recommendations

1. Flexor-extensor relationships do not appear to be similar at each joint throughout the body. More research is needed to determine whether or not the muscle relationships at different joints do vary.

2. Studies similar to the present study should be made with subjects being grouped according to types of training or activity rather than levels of strength.

3. Replicated studies are needed to verify the conclusions of this study.

4. A similar study, including a wrist flexor fatigue test on the subjects is needed to determine if elbow and wrist muscles fatigue at similar rates in the same individual.

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APPENDICES

A P P E N D I X A

Letter to the Subjects

Dear Participant,

Your assistance is needed for an investigation of muscular fatigue patterns. This study will help determine whether or not a difference exists between the fatigue patterns of flexor and extensor muscles around the elbow joint and whether or not the patterns are different at various levels of strength.

Previous studies indicate that the fatigue patterns of the wrist flexors are different at different levels of strength. The study will test to see if the elbow muscles follow similar fatigue curves.

Your participation will require you to spend parts of two class periods in the exercise physiology research laboratory. The first session will be to familiarize you with the test by having a short practice run. The second period will be the actual test at which time you will make 30 isometric contractions of the elbow flexors and then 30 contractions of the elbow extensors.

Your help will be greatly appreciated. If you are willing to participate, complete the acknowledgement form.

Respectfully requested,

Donald E. Campbell   Wayne H. Glenn

Acknowledgement of Willingless to Participate:

The undersigned acknowledges that he will volunteer to take part in the "fatigue-pattern study" being conducted by the Department of Physical Education of Oregon State University.

Signed:______________________________

Date:__________________ Age:__________

Phone:__________________ Activity:________

Residence:________________ Hour:____Days:____

A P P E N D I X B

Data recording form

FATIGUE CURVES   By Wayne Glenn

AGE__________ HEIGHT__________ WEIGHT__________ PUSHUPS__________ PULLUPS__________

ACTIVITIES IN LAST 2 HOURS:

COMMENTS:

30	29	28	27	26	25	24	23	22	21	20
30	29	28	27	26	25	24	23	22	21	20

Prac.	10	9	8	7	6	5	4	3	2	1
Fl.										
Ext.										
	10	9	8	7	6	5	4	3	2	1

30	29	28	27	26	25	24	23	22	21	20

TEST		10	9	8	7	6	5	4	3	2	1
FLEXION	Reading Lbs. In										
EXTENSION	Reading Lbs. In										