AN ABSTRACT OF THE THESIS OF

Reid P. Elam for the degree of Doctor of Philosophy in Education presented on May 3, 1985.

Title: The Relationship Between Tibial Nerve Conduction Velocity and Selected Strength and Power Variables in College Football Linemen.

Redacted for privacy

Abstract approved: ____________________
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Twenty-seven male college football linemen from the Oregon State University football team served as subjects for the study to determine which variables in strength and power would be best suited for use in regression analysis with tibial nerve conduction velocity (TNCV). The purpose of the investigation was to determine whether or not a significant linear relationship existed between TNCV and levels of strength and power in college football linemen. Stepwise regression search methods selected vertical jump power (VJP) as the best variable according to the predetermined F value of 4.22. Linear regression analysis showed that a significant linear relationship existed between TNCV and VJP ($p < .01$). The slope of the regression line was negative and the relationship between TNCV and VJP was an inverse one where higher rates of TNCV were associated with lower outputs in VJP. Explanations for this relationship centered on muscle function and adaptive abilities by individual subjects to compensate for physiological limitations.

The Relationship Between Tibial Nerve Conduction Velocity and Selected Strength and Power Variables in College Football Linemen

by

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A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

Completed May 3, 1985

Commencement June 1985

APPROVED:

Redacted for privacy

Professor of Physical Education in charge of major

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Date thesis is presented May 3, 1985

Typed by Express Typing Service for Reid P. Elam

ACKNOWLEDGEMENTS

I wish to thank the individuals who have been instrumental in the completion of this investigation:

Dr. John P. O'Shea, major advisor, for his assistance and encouragement throughout the study;

Dr. Carvell Wood, minor advisor, School of Education;

Dr. Forest Gathercoal, representative from the School of Eduction;

Dr. Richard Irvin, representative from the School of Health and Physical Education;

Dr. Berle Barth, OSU Athletic Department team physician, for his help, expertise and equipment;

OSU football team whose support made this study possible;

Susie Elam, my wife, and Jodi, Matthew, and Amy, my children, for their love and continued support;

Irene Elam, my mother, for her support and generosity during my matriculation.

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The Relationship Between Tibial Nerve Conduction Velocity and Selected Strength and Power Variables in College Football Linemen

CHAPTER 1

INTRODUCTION

American-style football is a sport involving many complex movements with hard physical contact being the most prominent feature of the game. To be able to initiate contact, and withstand the consequences, players must possess a high level of strength, speed and power (30).

A comprehensive definition for the attributes of strength, speed and power, and their interrelationships, is illustrated in the following equation:

$$\text{Power} = \text{Strength} \times \text{Speed}$$

By combining the factors of strength and speed, a resultant force, power, is produced. Should an increase in either strength or speed occur, a corresponding increase in power will occur. To develop these components of football fitness, conditioning techniques must emphasize forms of training that enhance power production.

Westcott (63) stated that speed is not easily developed as it is a complex neuromuscular phenomenon and is probably enhanced through the grooming of more efficient neural pathways. This same author conceded that speed of movement is benefitted through strength training as a result of increased athletic power. His concession is supported by research that showed increased movement speed resulted from increased muscular strength (8,10,53).

Strength is the ability of the neuromuscular system to produce forces that initiate and sustain movement and is enhanced through weight training. Thus it is apparent that weight training directly benefits athletic power, and is a necessary requisite for football conditioning.

The ingredients for football success is, to a great degree, dependent on the attributes of strength and power. This is especially evident in the play of opposing linemen at the line of scrimmage. Whoever can execute the movements of charging, blocking and tackling with greater force and greater speed of execution will have an advantage over his opponent (65).

At higher levels of proficiency, as in collegiate and professional football, players are capable of producing tremendous contact forces. This combined with greater collision speed compound the problems found at impact. These problems are twofold: (1) strategic--controlling or offsetting the momentum of an opposing lineman--and (2) injury related. For this reason weight training for strength and power development is essential for the football lineman and is highly endorsed at these levels of play (24,65).

To design a resistance exercise program that develops optimal levels of strength and power for the football lineman, an understanding of the muscle actions and physical demands of the position is important. This aids in determining what body regions are to be emphasized and what modes of training are most conducive to producing desired results.

Everson et al. (17) stated that in line play, the explosive phase of contact initiation, involved vigorous hip, knee and trunk extension, along with plantar flexion. Table 1.1 describes the muscle action of the trunk, hip, knee and ankle during contact initiation.

Hay (26) presented a description of a head-on tackle that also cited vigorous extension of the hip, knee and ankle joints. This is illustrated in Figure 1.1.

High impact forces in the basic contact skills of the football lineman are generated in the lower regions of the body. It is here, in the "power zone" of the body, where strength and power development is focused (54).

To affect all the muscular actions and joint movements in a synchronized manner, free weights are the preferred training modality for affecting athletic power (22, 24, 54). Dynamic weight training movements that have carryover value to charging, blocking and tackling are the Olympic weightlifting exercises, the snatch and clean.

In describing the rotary action of the legs and hips in the snatch, Miller (41) stated that the sequence emulated the charge of a football lineman. He noted that the rotary action was a multi-directional one that utilized the big muscles of the legs and hips to bring the hips forward and up, down, and forward again to start athletic motion. The development of these muscles and muscle actions are facilitated by training in the Olympic weightlifting exercises to increase leg and hip power.

Table 1.1

Muscle action analysis of offensive blocking techniques: explosive phase (17).

	Main Action	Muscles Involved
Trunk	Extension and general stabilization	Splenius, Erector Spinae, Semispinalis, Deep Posterior Spinal Group, Abdominal Group
Hip Joint	Extension	Gluteus Maximus, Medius, Minimus, Hamstring Group
Knee Joint	Extension	Quadricep Group
Ankle Joint	Plantar Flexion	Gastrocnemius, Plantaris, Soleus Posterior Tibialis, Peroneus Longus

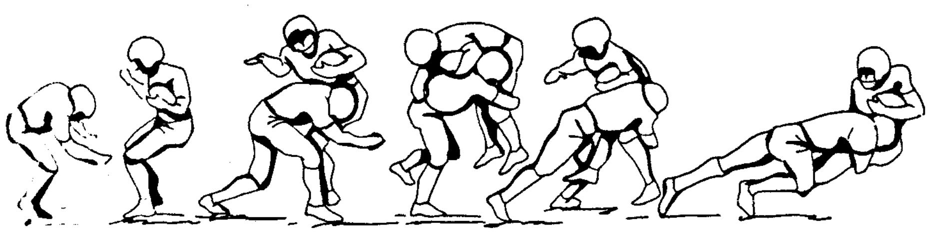


Figure 1.1

Executing a head-on tackle (26).

Meyers (40) listed three important factors in training to increase explosive power:

1. Increase leg strength.
2. Increase range of movement (crouch) to apply force over a greater distance.
3. Decrease time of transition from eccentric to concentric (explosive) contraction.

These factors are all realized through the employment of Olympic weightlifting movements in training.

To maximize the development of leg, hip and trunk strength, the squat is another important exercise for the football lineman (45,54). Studies have shown that free weight squats are beneficial in affecting leg and hip power (51,57,62). The importance of the squat exercise in conjunction with Olympic lifts is described in the following statement by Morris et al. (45):

> Two of the most basic and important exercises for the football player are the squat and power clean. Both exercises develop total body strength, coordination and explosiveness.... They also directly develop the two muscle groups that are used in lifting and driving an opponent: the legs and lower back.... Movements like these are also movements which imitate those on the field.

Because of the preponderance of leg, hip and trunk involvement in the lineman's skills, the resistance exercise program focuses on these anatomical regions and employs the use of free weights which include Olympic weightlifting movements and squats.

Specificity of movement in the lineman's training regimen suggests that neurophysiological benefits can be derived. Positive benefits to the neuromuscular system in strength training are substantiated by studies that showed that applied stress provided in sufficient amounts of intensity and duration increased motor unit activity (28,55).

Research has indicated that strength training, employing the use of isotonic and isometric muscular contractions, was able to affect the neuromuscular system in its ability to recruit additional motor units in forceful contractions (4,6,27).

Muscle training or strength-related activities, such as weightlifting, has been shown to affect the conduction characteristics of nerve fibers. Higher conduction velocities of the tibial nerve were found in power-trained athletes as compared to athletes trained for endurance (34,61). Lastovka (36) was able to demonstrate that physical training would increase the conduction velocity of the tibial nerve showing the effects of muscular hypertrophy on the nervous system.

These studies validate the need for training for strength and power for football lineman as physiological benefits that affect the neuromuscular system are derived.

Because the propagation of action and the display of instantaneous strength are deemed important in the football lineman's movements, the speed at which the nerve impulse travels in the lower body could be a determining factor as to what capacity the athlete possesses in the areas of leg, hip and trunk strength and power. The premise of this assertion is based on the logic that the faster the impulse (neural message to the muscle), the faster the muscle responds, and therefore the more critical the actuation of force to generate an explosive movement. It is this aspect, nerve conduction velocity in relation to strength and power, that this study was proposed.

Purpose of the Study

The purpose of this study was to determine whether or not a significant relationship existed between the tibial nerve conduction velocity and selected strength and power variables in college football linemen.

Hypothesis

The hypothesis was that no significant relationship would exist between tibial nerve conduction velocity in college football lineman and selected strength and power variables determined by stepwise regression techniques.

Delimitations

Delimiting factors on the scope of this study were:

1. Subjects were college football offensive and defensive linemen from the 1984 varsity football team at Oregon State University.

2. Observations were focused on the relationship between tibial nerve conduction velocity and strength and power measurements exclusively.

Limitations

The limitations were that:

1. Subjects were male college athletes from one university and members of the same team.

2. Only the right leg was used for measuring tibial nerve conduction velocity.

3. Ambient temperature was the only means to control environmental factors which may affect nerve conduction velocity.

4. Lack of uniform anatomical site due to individual differences for biopolar stimulation.

5. Lack of instrumentation to assess kinetic parameters in force and power production.

Definition of Terms

For the purpose of this study, the following definitions of terms are provided.

Action Potential--An electrical wave of excitation transmitted along the nerve or muscle fiber due to the potential difference of ions across the membrane.

Alpha Motoneuron--A large, fast conducting nerve that carries a neural impulse (action potential) from the spinal cord to the skeletal muscles.

Bipedal Locomotion--Human movement in the form of walking and running.

Bipolar Stimulation--Percutaneous electrical signals applied to a nerve by an instrument with two electrical poles (cathode and annode).

Conduction Velocity--The rate or speed of a neural impulse (action potential), determined from the latency of stimulation to muscle activation over the distance from the stimulation site to the site where muscle activation is detected.

Electromyography (EMG)--EMG indicates when the muscles are electrically active through the use of special instrumentation. An electromyogram is a record of the fluctuations of potential that occur between two conducting (metal) surfaces that are placed on the surface of the body or within it (1).

Football Lineman--An athlete who plays the position of guard, tackle, center or light end on offense, or the position of tackle, end or linebacker on defense. The lineman usually operates out of a down position (three or four point stance). Due to the physical demands of the position, the football lineman possesses an adequate level of strength.

Lewis Formula--Calculation which converts vertical jump measurements into units of power.

Muscle Twitch--A single muscle contraction lasting for a fraction of a second as a result of passing a short electrical stimulus through the muscle itself, or exciting the nerve to a muscle (23).

One Repetition Maximum (1-RM)--The maximum load that an individual can lift in a particular weight-training exercise in one attempt.

Relative Strength--An expression of the amount of force produced by an individual (as measured by a 1-RM) divided by that individual's bodyweight.

Weight Training--The form of resistance exercise that primariy employs the use of barbells, dumbbells and machine apparatus.

CHAPTER 2

REVIEW OF LITERATURE

Strength development through weight training has been validified through research. Scientifically based methods for athletic conditioning are in practice through the sports world.

The means for gauging the success of any training concept is ultimately derived from performance outcomes. Although physical training can enhance the attributes that contribute to success in a sport, it is the adaptive response of the human organism that is the underlying key to optimum athletic performance.

This review of literature focused on presenting studies that examined the operation of the neuromuscular system and its response to training. In particular, a case for further investigation in the relationship of nerve conduction velocity, and strength and power was made.

Bipedal Locomotion

Human or bipedal locomotion is initiated by contraction of the ankle plantar flexors. This provides the means to offset the body's center of gravity to begin to propel the body forward as in walking or running.

In athletic movements where strength and power are evident, as in the charge of a football lineman, strong ankle plantar flexion is of paramount importance. Garhammer (21) alluded to this when he mentioned the role of the ankle plantar flexors in contributing significant amounts of energy to parts of Olympic lifting movements.

In connection with the role of the gastrocnemius muscle (a major ankle plantar flexor) in football, it was cited by Starr (54) to be most useful as it was one of the primary muscles used in running and jumping.

In a study to observe the patterns of muscular action in human locomotion, Cavanaugh (7) noted that the intensity of EMG increased dramatically as the speed of walking increased. He noted that the gastrocnemius, in assisting extensor thrust, was of little importance in slow walking, but that great muscular tension was exerted at higher speeds of walking.

The gastrocnemius and soleus muscles contribute to ankle plantar flexion or extensor thrust in bipedal locomotion. These muscles are innervated by the posterior tibial nerve, with synergistic ankle flexors innervated by its branches (2). To determine the role of the tibial nerve in human locomotion, Dietz et al. (15) looked at EMG of the gastrocnemius while stimulating the tibial nerve at different rates and produced maximum isometric forces 30 to 40 percent higher than maximum voluntary contraction. When gastrocnemius EMG was stimulated to emulate EMG profile during running, it was found that a greater mechanical impulse, facilitated by the spinal stretch reflex, became effective in phases of a fast sprint.

To assess the role of the ankle plantar flexors in walking, Sutherland et al. (60) used a tibial nerve block and observed that subjects were unable to transfer weight to the forward part of the foot on the blocked side, and that maximum step length was unachievable.

These observations imply that the initiation of quick, forceful movements in bipedal locomotion originates with strong ankle plantar flexion. The role of the neural mechanisms to achieve fast impulse conduction via the tibial nerve tract to the plantar flexors may be related to the force producing capabilities of the muscular system.

Nerve Conduction Velocity

Propagation of human movement results from the basic function of the motor unit. The motor unit is the physiologic unit of the neuromuscular system consisting of the anterior horn cell, its axon and terminal branchings, and all the muscle fibers it innervates (38).

The motor unit is activated by an electrical disturbance which passes from the anterior horn cell (located in the spinal cord) down the axon and its branches to the myoneural junction, where the liberation of chemical substances, known as neurotransmitters, initiate a wave of excitation along each muscle fiber (31).

The source of the nerve impulse stems from an electrochemical phenomenon of reversed polarization of endogenous ions. The resting membrane potential (difference of positive and negative ions across the membrane) of a neuron is approximately -90 millivolts (31). This is the value of the homeostatic status of the sodium differential across the semipermeable membrane of the neuron. Once small quantities of sodium pass from the extracellular compartment into the cell to reduce the resting membrane potential difference to -55 millivolts, an action potential is elicited. This process of depolarization causes the action potential to travel down the nerve fiber.

The speed at which the nerve impulse travels down the axon can be viewed as the time it takes to depolarize a corresponding segment of the nerve fiber (32). The quotient of these factors, distance over time, equals the nerve conduction rate or velocity.

Skeletal muscles are innervated by alpha motoneurons. These fibers are rapid conducting fibers due to their insulative properties. A myelin sheath wrapped around the axon provides the insulation which affects nerve conduction velocity. Basically, the greater the amount of myelination, the greater the velocity at which nerve impulses travel. Nerve conduction velocity is directly related to the diameter of the axon because the diameter is inversely related to the internal electrical resistance of the nerve fiber (1). The relationship of axonal diameter and conduction velocity is shown in Table 2.1.

Schwann cells, which are myelin-based cytoplasm, adhere to alpha motoneurons in a manner which makes the neuron appear to have beads (Figure 2.1). It is at the open spaces, between the beads of Schwann cells, known as the Nodes of Ranvier, where transmission of neural impluses receive their conduction characteristics. This small, uninsulated area is 500 times as permeable as some unmyelinated fibers (30). The Nodes of Ranvier interrupt the myelin sheath of the alpha motoneuron at intervals of about 1 to 2 millimeters. When one node is generating an action potential, a neighboring node becomes depolarized, and this is relayed from node to node (1). This

Table 2.1

Electrophysiological classification of nerve fibers on the basis of conduction velocity (1).

Group	Fiber Diameters (μ)	Conduction Velocity (m/sec)	Anatomical Features
A	1-22	5-120	myelinated afferent and efferent
B	less than 3	3-15	myelinated efferent
sC	0.3-1.3	0.7-2.3	unmyelinated efferent
drD	0.4-1.2	0.6-2.0	unmyelinated afferent

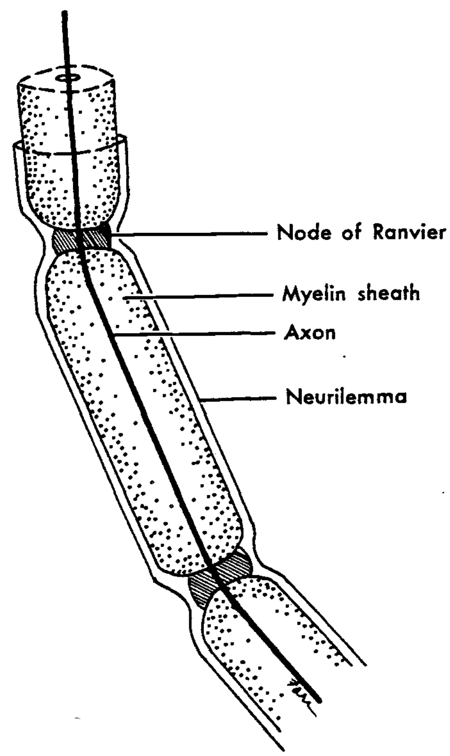


Figure 2.1

Alpha motoneuron and its coverings (2).

process of neural transmission is called saltatory conduction and is responsible for rapid rates of nerve conduction.

Distances between the Nodes of Ranvier have an effect on conduction velocity. The greater the distance between nodes, the greater the conduction rate (30).

Large-diametered and fast-conducting alpha motoneurons will affect the characteristics of its motor unit. Weurker et al. (64) in diagnosing the properties of motor units found that a direct relationship existed between the tension generated by a motor unit and the size of its motoneuron as inferred from axonal conduction measurements. Skeletal muscles innervated by slower conducting alpha motoneurons responded with contractions that exhibited low, sustained tensions, whereas muscles innervated by faster conducting alpha motoneurons contracted with high, short-duration tensions. These characteristics were measured electrophysiologically as muscle twitches, and were termed slow-twitch and fast-twitch muscle response, respectively. Figure 2.2 graphically depicts the difference between slow-twitch and fast-twitch muscle responses.

Studies that investigated nerve conduction velocity had values that referred only to the most rapidly conducting fibers in the nerve (1). These values cannot be considered absolute, however, as percutaneous nerve stimulation (the EMG technique used to measure conduction velocity) involved stimulation of a nerve bundle and not an individualized nerve fiber. Therefore, the duration of a muscle action potential in response to nerve stimulation was related

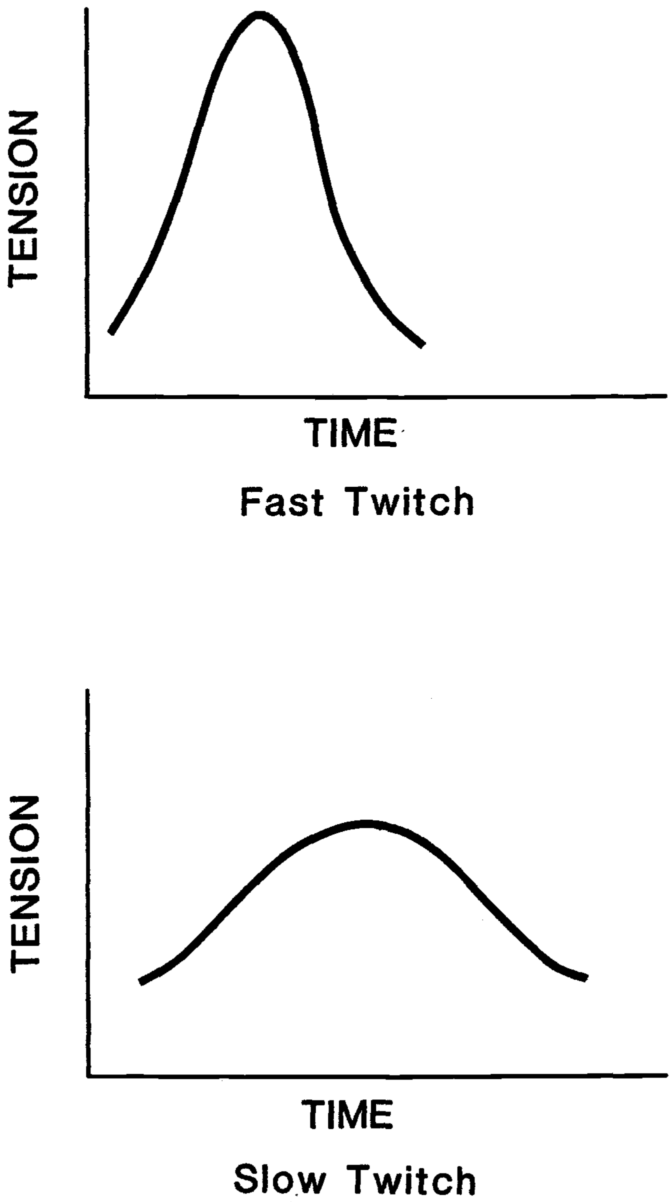


Figure 2.2

Graphs of tension and temporal characteristics for fast-twitch and slow-twitch muscles.

in part to the range of conduction velocities in the fibers constituting the nerve (1).

Le Quesne (37) found in his observations that dispersion of the action potential may have resulted from the slowing of conduction rates of some of the innervating fibers. Therefore, muscle action potential, determined by EMG analysis, is recorded as a compound action potential, or the muscle action potential of a group of muscle fibers resulting from the stimulation of a nerve bundle which contains nerve fibers of varying conduction properties.

A unitized muscle action propagated by an electrical charge (of an external or volitional source) directed to a particular nerve tract or bundle responds in a fast, high tension-producing way. This implies that faster-conducting nerves enhance the strength of the action potential; hence, athletic movements that require quick and forceful muscle actions benefit from the instantaenous response of fast motor units.

Kamen et al. (34) noted that, among males, weightlifters had markedly higher tibial nerve conduction velocities than did sprinters, middle distance runner, marathoners, or untrained individuals. The researchers concluded that there seemed to be a difference in nerve conduction velocity between athletes trained for power and those trained for endurance activities. Their findings are summarized in Table 2.2.

Upton (61) compared the tibial nerve conduction in athletes and untrained college males. His subjects were trained in endurance, strength, and some were untrained. No significant difference was found between the mean conduction velocity of the endurance-trained

Table 2.2

Nerve conduction velocity (meters/sec) from Kamen et al. (34).

	Ulnar	Tibial
<u>Females</u>		
Sprinters (N = 10)	59.8±4.24	47.0±7.94
Middle distance runners (N = 9)	61.9±6.00	48.2±5.19
<u>Males</u>		
Sprinters (N = 8)	59.1±4.93	46.3±2.58
Middle distance runners (N = 13)	57.6±7.15	46.1±3.71
Marathoners (N = 7)	59.3±10.21	45.6±1.99
Weightlifters (N = 7)	64.9±4.11	52.9±6.94
Untrained (N = 9)	61.9±5.18	43.9±4.10

group and the untrained group. The same was true between the strength-trained group and the untrained group. There was a highly significant difference between the strength-trained and endurance-trained groups. Because of the reliance on recruitment of fast motor units for strength-related events and slow motor units for endurance events, the training for each may have influenced tibial nerve conduction velocity.

By studying the effects of physical training on the conduction velocity of the posterior tibial nerve, Lastovka (36) was able to demonstrate an increase in conduction velocity. He concluded that where muscle hypertrophy resulted from various forms of training activities, there would be a corresponding increase in nerve conduction velocity.

Singh and Maini (52) took measurements of the conduction velocities of the motor nerve fibers constituting the peroneal and posterior tibial nerves. Their subjects were rickshaw pullers. They found that the mean values for nerve conduction velocity were greater for rickshaw pullers than for the control subjects. A significant difference in peroneal nerve conduction velocity was found between the two groups. That a statistically significant difference was not found in the case of the posterior tibial nerve was explained in their conclusion:

> The variability can be explained by the observed fact that the increased muscular development in rickshaw pullers is far from uniform, and is influenced by factors like body build, nutrition and quantum of exertion. But for this variability, it is highly likely that the difference in conduction velocity would have been significant in the case of [posterior tibial nerve] also, and that failure to demonstrate statistical significance difference is due to small size of the sample.

Neuromuscular Factors in Strength and Power

Muscular force production is associated with the cross-sectional area of muscle tissue. Guyton (23) cited a relationship of 3.5 kilograms of force produced per one centimeter-squared of cross-sectional area of muscle tissue. This concurred with the premise that increased muscle fiber girth will enhance the force-producing capabilities of that fiber. Hence, muscle hypertrophy is a valid objective for athletes training for strength and power.

In repeated strength measurements there may be an increase in strength-related performance without accompanying hypertrophy. This would indicate that factors other than muscle growth are involved in strength.

Ikai and Fukunaga (29) showed a 91.7 percent increase in isometric elbow flexion strength in subjects who concomitantly showed only a 23 percent increase in cross-sectional area as determined by ultrasonography, following a training period of 100 days. The results implied that increases in muscular strength were due to neural factors which accompanied specific resistance exercise training.

Moritani (44) observed the neural aspects of muscle strength by quantifying muscle activation levels by use of EMG instrumentation. This researcher observed the changes that occurred over an 8-week training period and found that early changes in strength were due largely to neural factors. The results suggested that increased levels of muscle activation may be induced by greater facilitation and greater disinhibition occurring at various levels within the neural system.

Hakkinen and Komi (25) used 14 subjects to study the changes in EMG during a 16-week weight training period and a subsequent 8-week training period. The training program focused on developing the leg extensor muscles. Significant increases were observed in early training, although maximal forces were limited in later stages. Marked improvements in muscle strength were accompanied by increased neural activation as measured by integrated EMG techniques. It was concluded that early changes in muscular strength were accounted for by neural factors with a gradually increasing contribution of hypertrophic factors in later stages of training. During detraining, the decrease in muscle force was accompanied by neural and muscular adaptations caused by the inactivity.

Explosive strength or power has great reliance on neural factors. Concerning the power-producing capabilities of Olympic weightlifters, Garhammer (20) said that power capacity was clearly dependent on factors such as fast/slow fiber area ratios and motor unit recruitment capabilities.

Synchronization of motor unit firing is essential to power production. Milner-Brown et al. (42) reported synchronization of motor units in individuals involved in manual occupations that require the development of large, short-duration forces. They reported a significantly greater incidence of synchronization in weightlifters as compared to control subjects. Their findings indicate that greater synchronization of EMG activity is related to higher short-duration forces and that synchronization may be the result of regularly using muscles to exert large, brief forces. Thus, this study gives credence to weight training for athletic strength and power as a means to prompt desirable physiological adaptations.

The pattern of motor unit firing has an effect on power production in that the sequence of muscle (and subsequently, joint) actions culminated in a summation of torques that allowed an individual to move with great force and speed. Kuzenow (35) explained that the physiological mechanism for the development of explosive strength chiefly resided in the adequate stimulation of the essential neuromuscular process--intermuscular coordination and among-muscles coordination.

Stone (56) listed the following determinants as having great bearing on strength and power movements:

1. The number of motor units involved will determine the strength of a muscular contraction. Greater force is produced with increasing motor unit--more likely fast-twitch units--involvement.

2. The frequency of motor unit firing, if increased, will cause muscle tension output to increase. This becomes more crucial as maximum tension is approached and the number of motor available units decreases.

3. Synchronization of motor units will produce forceful muscular contractions as large numbers of motor units contract simultaneously.

4. The pattern of motor unit and whole muscle contraction can lead to more efficient mechanics in performance.

5. The muscle fiber type plays an important role in producing movements as fast-twitch motor units produce greater forces in comparison to slow-twitch motor units.

Neural factors play a major role in strength and power development as do the muscular factors hypertrophy and muscle fiber type. It is important to understand the influence of the nervous system on muscle function and the influence of muscle training on the nervous system to determine the integrative processes of these two systems and how they relate to developing conditioning procedures for the strength athlete.

Neural Influence on Muscle Function

The integration of the nervous system and musculo-skeletal system is evident in movement. The nerve action potential is relayed along the alpha motoneuron and elicits a muscle action potential. Thus, neural mechanisms influence the function of muscles to prompt movement.

Burke et al. (5) used glycogen depletion methods to determine the histochemical properties of muscle fibers in individual motor units. They found that the fibers of an individual motor unit were all of the same histochemical type. Fast motor units had muscle fibers that exhibited high rates of glycolytic metabolism and slow motor units had muscle fibers that possessed high propensities to carry on oxidative metabolism. These histochemical characteristics were directly related to muscle twitch characteristics of fast and slow motor units. Their conclusion was that the alpha motoneuron exerted some influence over the histochemical makeup of respondent muscle fibers.

Edington and Edgerton (16) stated that motoneurons have a great deal of control over the proteins synthesized in muscle fibers and that the characteristics of the motoneuron determine the speed of contraction and predominant form of metabolism.

Close (12) showed the effects of cross-union of nerves to muscles by sectioning nerves from fast-twitch and slow-twitch muscles and cross-uniting them. When innervation was switched, the mechanical response of the two muscle types were reversed.

To investigate the metabolic characteristics of muscle fibers after cross-innervation, Romanul and Van der Meulen (49) found that partial reversal of the histochemical profile of constituent muscle fibers occurred.

The metabolic properties and mechanical function of muscle fibers are related. Fast-twitch muscles, which respond in quick, forceful contractions, have glycolytic mechanisms as their basis for metabolism. Slow-twitch muscles respond with a longer, less forceful contraction due to their reliance on oxidative metabolism. For these reasons, muscle fibers are categorized into two basic types: (1) fast-glycolytic or FG fibers, and (2) slow-oxidative or SO fibers.

Because FG fibers are the predominant ones selected in movements requiring strength and power, their activation is crucial to assure success in a required task. FG fibers are innervated by fast-conducting nerves, and, thus, activation is dependent upon the ability of the alpha motoneuron to transmit the impulse to enable the motor unit to respond in an explosive manner. The speed at which the neural impulse travels may influence the desired outcome in strength movements.

The Influence of Weight Training on the Neuromuscular System

In assessing changes in neuromuscular performance in voluntary and reflex muscular contractions, Hakkinen and Komi (25) found, through a combination of experimental techniques involving EMG, muscle biopsy and computerized force analysis, that the mechanical response of individual muscle fibers of a respective motor unit was improved following 16 weeks of weight training. They found significant increases in maximal isometric force of the leg extensors, a more economical activation of the knee extensor muscles, improvements in isometric force-time parameters and increase in the fast-twitch/slow-twitch muscle fiber area ratio for the trained group.

O'Shea (48) listed the following adaptations of the neuromuscular system as a result of isotonic, full-range, multiple-joint weight training movements:

1. An increase in the nerve fiber diameter.

2. An increase in the length of the motoneuron, providing greater synaptic area for the effective release of neurotransmitters.

3. An increase in the size of the neuromuscular junction in proportion to muscle fiber type.

4. An increase in the number of functional synapses which allow an athlete to utilize a greater percentage of motor units in a group of synergistic muscles at any one time.

5. An increase in neuronal facilitation and spatial summation. Voluntary motoneuron recruitment patterns are enhanced and modified--selective facilitation is developed.

6. A "learning process" in the motor cortex that makes possible smoothness and accuracy of full-range muscular movement that is acquired only by practice. Dynamic strength is increased by more efficiently synchronizing motor units. The mechanisms of the process of learning how to time nerve impulses and how to make a highly complex motor action effortless and automatic are unknown.

Hellebrandt and Horitz (28) found that the manner in which the overload principle in muscle training was applied would determine the effect it would have on the neuromuscular system. They mentioned that an exercise in strength training would need to be done in a manner that the amount of repetitions would cause sufficient neuromuscular stress to enhance the functional capacity of the skeletal muscle employed.

Kabat (33) noted that heavy resistance is the most effective means to activate the greatest number of motor units and produce maximum activation of the entire neuromuscular pathway. The benefits of training with maximal weights were shown by an EMG study by Stepanov (55) in which high threshold neurons were brought into "range" through voluntary activity in progressive resistance exercise.

Sale et al. (50) used EMG techniques to measure motoneuron excitability in the extensor digitorum brevis, soleus, brachioradialis and hypothenar muscles. The excitability of a motoneuron was measured by the degree to which the reflex response was potentiated by voluntary effort. It was found that strength training may have caused an increase in ability to raise motoneuron excitability during voluntary effort. This would imply that the action potential is more easily propagated as the motoneuron becomes conditioned through strength training.

Considerations for influencing the strength and power capacities of the neuromuscular system would include selection of modalities used and the manner in which the athlete trains.

Stone (57) showed that positive changes occurred in the force-velocity relationship of muscular action of individuals who trained with free weights. He concluded that exercises needed to emphasize high force and high speed movements. These methods are considered essential in power training as fast-twitch motor units are more selectively recruited (6).

With the use of free weights, an individual utilizes his own pattern of motor unit firing and this greatly contributes to a carrying-over into athletic skill from the point of mechanical specificity (56). Garhammer (22) stated that free-standing total body lifts, employing free weights, trained the neuromuscular system and resulted in excellent transfer to the neuromuscular demands of athletic competition. In defining free-standing total body lifting movements, Garhammer mentioned multiple-joint and muscle actions similar to the block and tackle in football. These actions are best developed through strength and power training by the use of Olympic lifts (22,40,41,45,54) and squats (45,47,54,62) which are free-weight exercises.

Summary

Ankle plantar flexor muscles contribute greatly to human locomotion. These muscles are innervated by branches of the posterior tibial nerve, and the speed at which the action potential travels down this motoneuron affects the response of these muscles in explosive movements.

Fast-conducting nerves supply fast-twitch muscles. Various nerve fibers constitute a nerve bundle; therefore, the rate of conduction is really an average of the velocities of the range of fibers. This is recorded as a compound action potential in EMG analysis.

Studies have revealed that tibial nerve conduction velocities in power-trained individuals are markedly faster than in endurance-trained individuals (34,61), and faster in the trained over the untrained (36,52).

The nervous system influences the muscular system in two ways: (1) metabolically and (2) mechanically. Each is related to the conduction characteristics of the innervating motoneuron. Fast-conducting nerves supply muscles that are glycolytic, slow-conducting nerves serve muscles that are oxidative in their metabolic design. These are respectively termed fast-glycolytic (FG) and slow-oxidative (SO) muscle fibers. Muscle fibers respond according in their twitch characteristics: FG fibers have a fast, high tension response; SO fibers have a slow, low tension response. It is critical in explosive movements that the FG fibers respond in a synchronized manner; the speed of the neural impulse, therefore, may be critical in affecting this action.

Specific weight training movements with free weights have a positive effect on the neuromuscular system. These movements must be done in a high force, high speed manner. Olympic lifts and squats condition the neuromuscular system in a way that emulates the demands made upon the neuromuscular system in athletic competition.

The college football lineman is a strength athlete who must employ free weight training to develop leg, hip and trunk strength and power to enhance his performance. The degree of strength and power that the lineman possesses may determine the nerve conduction characteristics of his nervous system, thus indicating a positive physiological adaptation that muscle training has on the nervous system.

CHAPTER 3

METHODS AND PROCEDURES

Experimentation was conducted at Oregon State University, Corvallis, Oregon in the Spring of 1984. All testing was done within the confines of the Oregon State University Athletic Complex.

Subjects

Twenty-seven male athletes from the Oregon State University football team of 1984 served as subjects. All represented either offensive or defensive lineman positions.

Prior to testing, all subjects participated in an intensive eight-week strength training program. This training was required for all members of the Oregon State University football team (see Appendix B).

A summary of the physical characteristics of the subjects is contained in Table 3.1.

Instrumentation and Equipment

The EMG unit used in this study was a TECA model B-2, manufactured by TECA Corporation, White Plains, New York (Figure 3.1).

An isometric table and cable tensiometer was used to test static leg strength. A goniometer was employed to set the angle of the knee joint in the static leg strength test.

Table 3.1

Physical characteristics of subjects.

Variable	Mean	Standard Deviation	Minimum	Maximum
Age (yr)	20.67	1.84	18.00	26.00
Height (cm)	190.22	4.74	180.30	203.20
Weight (kg)	112.84	9.75	97.25	136.50

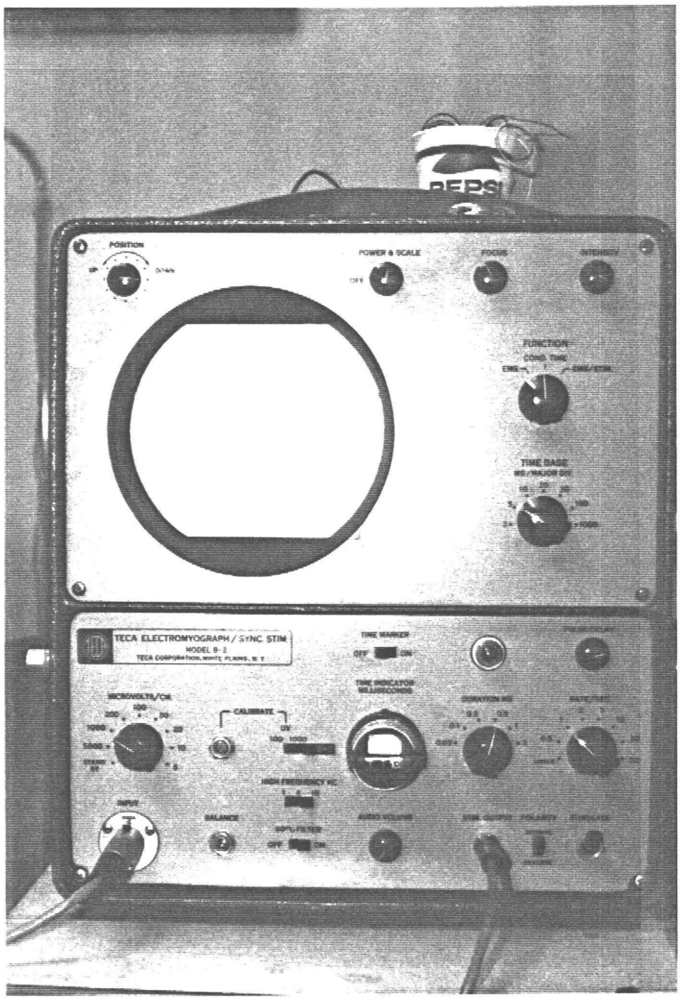


Figure 3.1

TECA model B-2 electromyograph.

Standard Olympic barbell weight sets, consisting of 20.4 kilogram bar and assorted plates, were used to evaluate dynamic strength.

Equipment needs for other tests were met by use of metric measurements (meter stick and tape measure) and a stopwatch.

EMG Testing Procedures

For measuring tibial nerve conduction velocity, the following instrument settings were used:

Time base = 5 msec
Impulse frequency = 1/sec
Impulse charge = 1000 microvolts
Impulse duration = 0.5 msec
Filter setting = 60 cycles
Polarity = normal
Function = conduction time

The procedures for measuring tibial nerve conduction velocity as outlined by Aminoff (1) were followed:

1. Subjects laid prone on an insulted table. The right leg was used for testing.

2. The recording electrode was placed over the adductor hallucis muscle (located on the medial side of the plantar surface of the foot) and held in place by a rubber strap (Figure 3.2).

3. The ground lead and electrode was affixed to the lateral side of the dorsal surface of the same foot by the rubber strap holding the recording electrode (Figure 3.3).

4. A bipolar prod (Figure 3.4) was used to deliver percutaneous electrical stimulus to the tibial nerve.

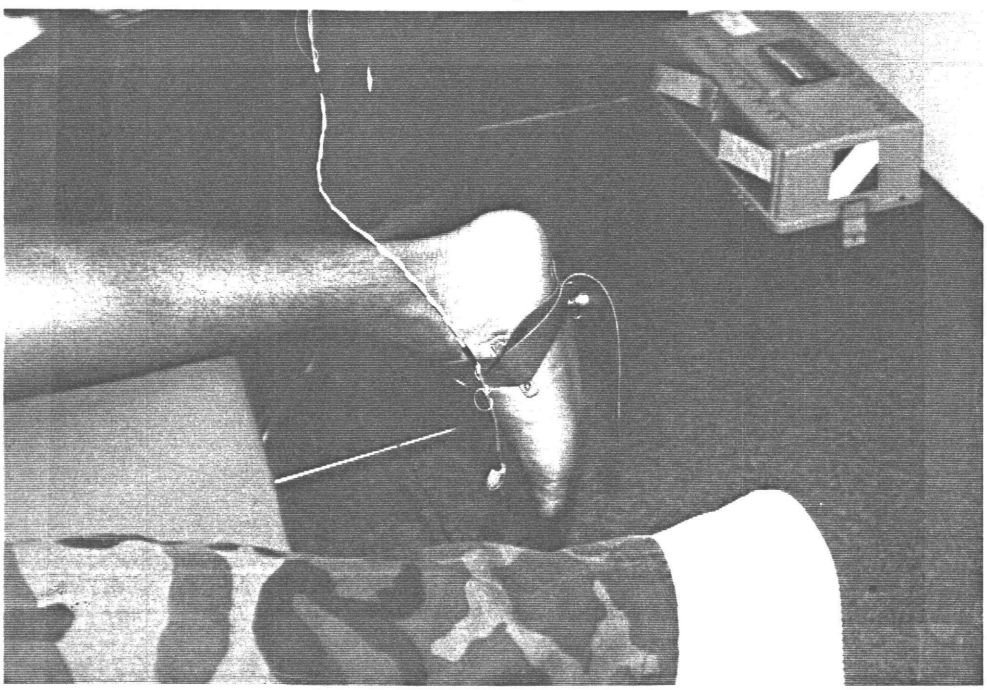


Figure 3.2

The recording electrode placed over the adductor hallucis muscle.

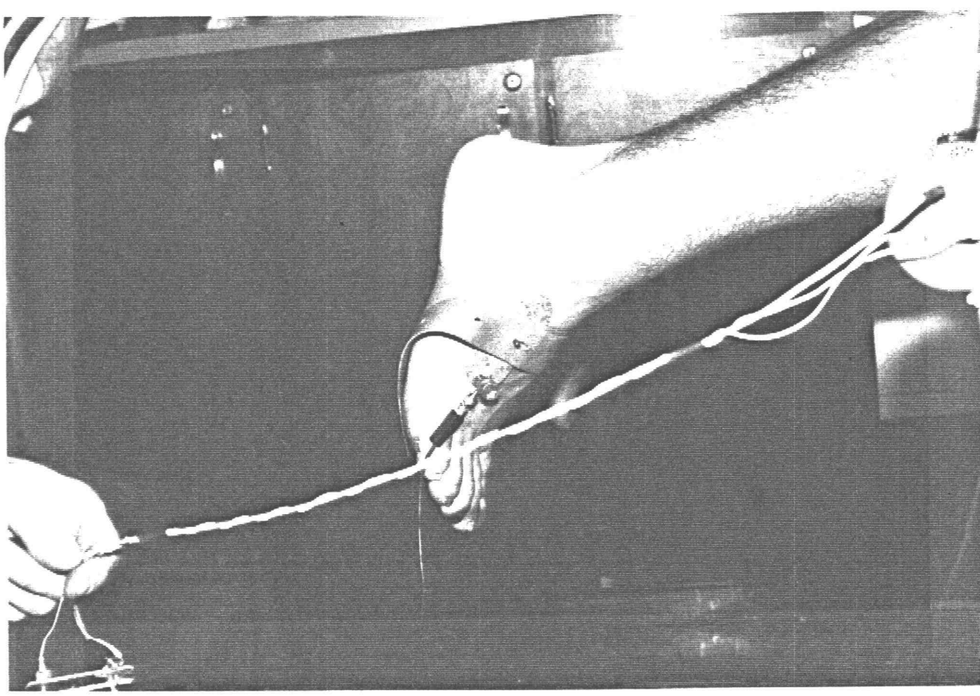


Figure 3.3

The ground lead and electrode attached to the dorsal suface of the foot.

Figure 3.4

TECA electromyograph bipolar stimulator.

5. The site of stimulation was located at the popliteal fossa over the path of the descending nerve tract (Figure 3.5).

6. The muscular response (contracture of the adductor hallucis muscle) was displayed as a compound action potential on the cathode ray oscilloscope. By adjusting the baseline time-mark indicator to the foot of the spike, a latency reading was obtained on the central time indicator dial. Figure 3.6 illustrates the graphic display of the compound action potential.

7. The length of the tibial nerve tract and its medial branch was measured from the proximal site of the recording electrode to the site of stimulation by a metric tape measure.

8. The recorded latency period was divided into the distance of the tibial nerve tract to obtain the nerve conduction velocity of the tibial nerve.

To enhance recording, the ambient temperature was maintained at 72^{O}F by thermostatic regulation, and EKG solution was applied to all electrode surfaces.

Selection and Administration of Strength Tests

Isometric testing for static strength of the leg extensor muscles of the right leg was done in accordance to the testing protocal established by Clarke (11):

1. The subjects were seated on the edge of an isometric testing table in a back lean position. Their arms were extended to the rear and they were allowed to grasp the table for support.

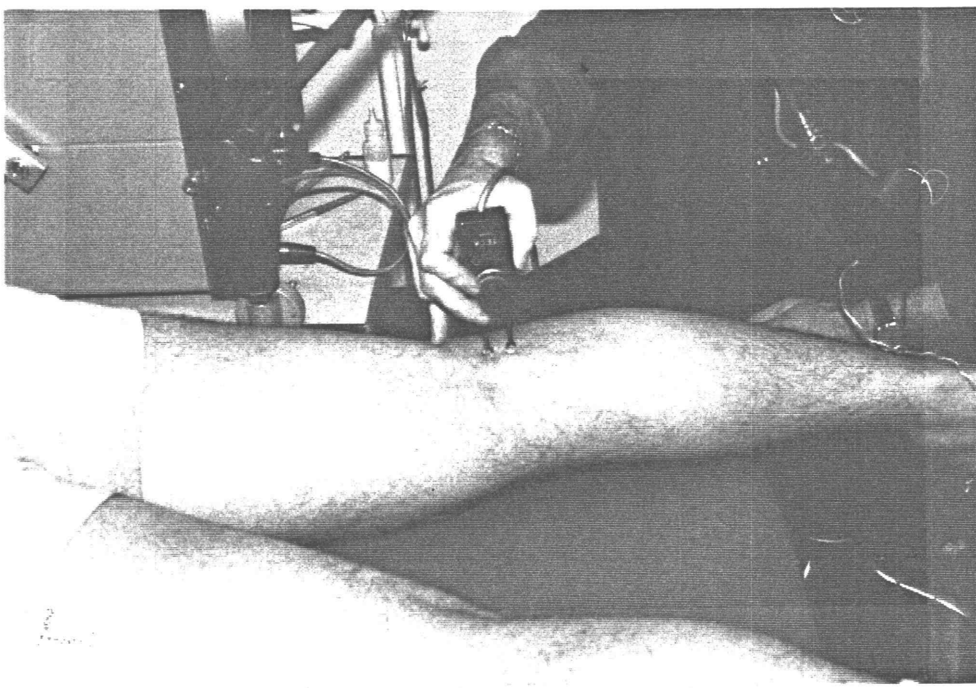


Figure 3.5

Applying percutaneous nerve stimulation to tibial nerve at the politeal fossa.

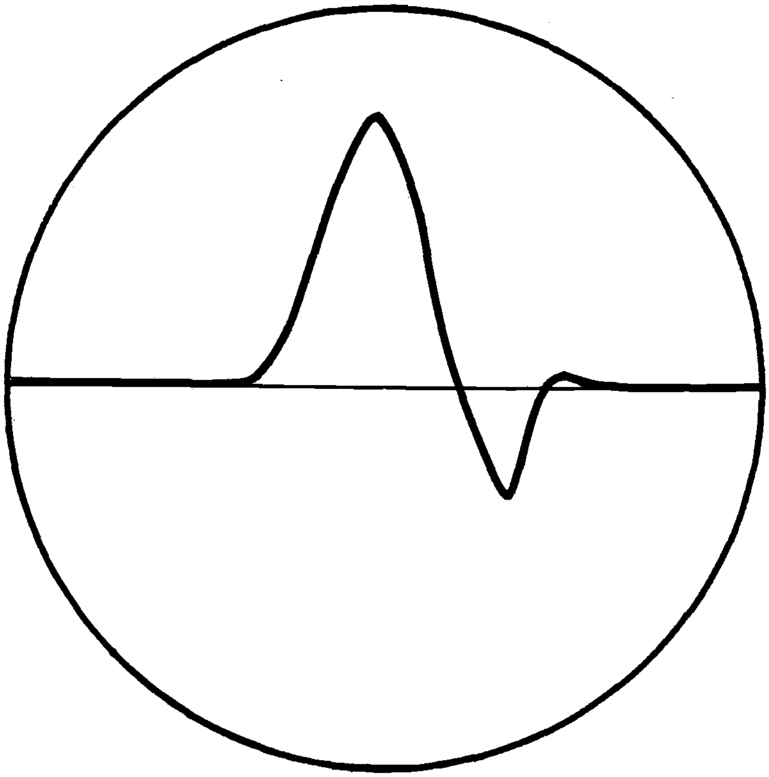


Figure 3.6

Muscle contraction response to percutaneous nerve stimulation recorded on electromyograph oscilloscope.

2. The right leg was tested.

3. The angle of the knee was positioned at 115 degrees of extension.

4. The strap, with cable attached, was placed around the lower leg, midway between the ankle and knee joints.

5. The opposite end of the cable was fastened to the testing table.

6. During testing, the arms were not allowed to flex nor were the subjects allowed to raise their buttocks off the table.

7. The cable tensiometer was placed on a taut cable, and subjects were exhorted to exert maximum effort against the cable strap.

8. Special attention was given to gradual tension development as any jerking movement would make the needle on the tensiometer jump, invalidating any reading.

Isometric testing for static leg strength is shown in Figure 3.7.

For testing dynamic strength in the leg, hip and trunk regions, the squat and power clean were used (see Appendix C). These lifts corresponded with ones used in training during the eight-week off-season schedule.

The sequence for proper execution of the 1-RM squat was as follows (47):

1. The bar was placed across the back of the shoulders in a horizontal position, not more than one inch below the top of the deltoids.

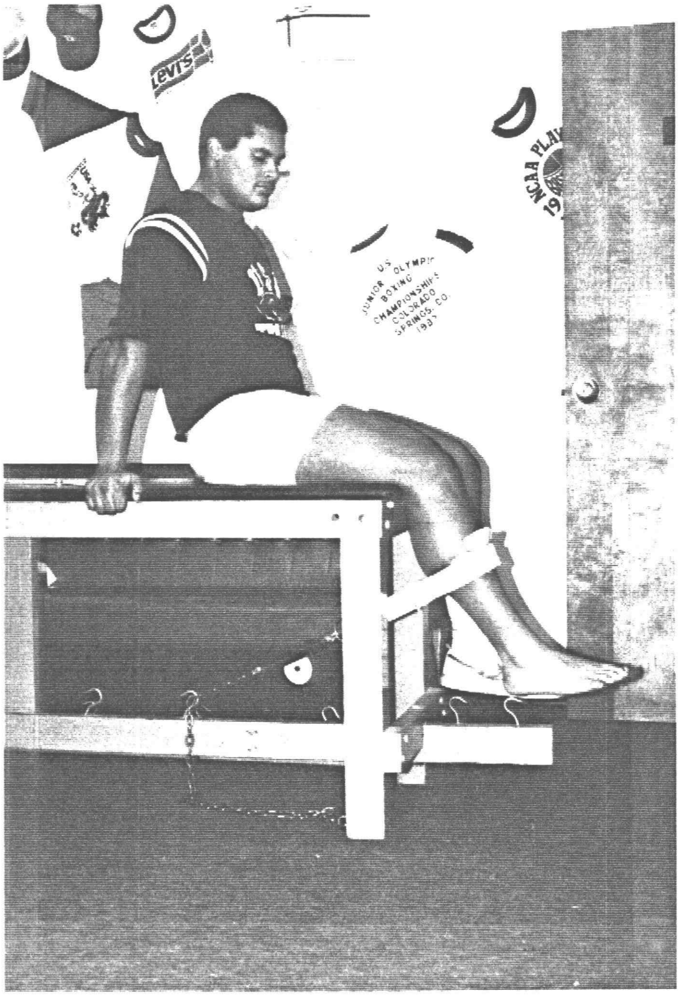


Figure 3.7

Isometric leg extension strength test.

2. The subject squatted with the barbell until the top levels of the thighs were below parallel with the platform.

3. Once the low position was achieved, the ascent to the standing position commenced.

4. Upon completion of the upward stroke in the squatting movement, the subject was to maintain an upright, controlled position with the knees locked for two seconds.

5. Compliance with all the above constituted a valid measurement.

The 1-RM test for the power clean was performed according to the following procedures (47):

1. The barbell was placed horizontally in front of the subject's legs.

2. The bar was gripped with the palms downward, and brought in a single movement from the ground to the shoulders, while either splitting or bending the legs.

3. Once the barbell was pulled from the floor and caught on the shoulders, the subject's feet returned to the same line, legs straight, to assume a controlled standing position.

4. The controlled standing position with the barbell "racked" at the shoulders was held until the subject was signalled by the tester to put the barbell down to the floor.

5. Compliance with all the above constituted a valid measurement.

Selection and Administration of Power Tests

Leg and hip power were assessed by use of the vertical jump, standing long jump and 10-yard dash tests.

In testing the vertical jump, the following method was used (13):

1. Two feet were placed together to start.

2. The subject jumped upward to attain a maximum reach-height with one hand.

3. The measurement was derived by taking the difference between jump reach-height and standing reach-height.

The standing long jump was administered in the following manner:

1. Both feet of the subject were placed together with the toes behind the restraining line.

2. The subject jumped forward as far as possible and landed on both feet simultaneously.

3. The measurement was taken from the back edge of the restraining line to the placement of the heel or body part contacting the landing surface closest to the restraining (starting) line.

The 10-yard dash was administered as follows:

1. The subject assumed a crouching stance to start, with one hand down behind the starting line.

2. A stopwatch was started on the commencement of movement by the subject and stopped as the subject crossed the line denoting a 10-yard displacement.

Data Collection

Measurements for 27 subjects were taken for all variables.

In all strength and power tests, the best result of three trials was recorded as the measurement used for analysis.

To examine all possible expressions of variables, the following transformations were made:

1. Ratios of 1-RM values in the squat and power clean to bodyweight to assess relative strength levels (9).

2. Use of the Lewis Formula to convert vertical jump scores into units of power (59):

$$P = \sqrt{4.9} \times BW_{kg} \times \sqrt{VJ_m}$$

where P = power;

BW_{kg} = bodyweight in kilograms; and

VJ_m = vertical jump reach height in meters.

3. Use of Newtonian physics to convert standing long jump measurements into units of power (3,26):

$$P = BW_{kg} \times LJ_m/2t\text{sec}$$

where $t = \sqrt{LJ_m/0.5g}$ and $g = 9.8\text{m/sec}^2$.

Test Design

The ten independent variables for this study were:

1. 1-RM isometric leg extension
2. 1-RM squat
3. 1-RM power clean
4. Relative strength, squat = 1 RM/bodyweight
5. Relative strength, power clean = 1 RM/bodyweight
6. Vertical jump

7. Vertical jump power (Lewis Formula)
8. Standing long jump
9. Standing long jump power (formula)
10. 10-yard dash

The one dependent variable was tibial nerve conduction.

Test Design Model

Subject	Y	X_1	X_2	X_3	. . . X_{10}
1	Y_1	X_{11}	X_{21}	X_{31}	. . . X_{101}
2	Y_2	X_{12}	X_{22}	X_{32}	. . . X_{102}
3	Y_3	X_{13}	X_{32}	X_{33}	. . . X_{103}
4	Y_4	X_{14}	X_{42}	X_{44}	. . . X_{104}
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
27	Y_{27}	X_{127}	X_{227}	X_{327}	. . . X_{1027}

Y = dependent variable

X_1, X_2, X_3 . . . X_{10} = independent variables

Analysis of Data

Descriptive statistics and regression techniques were used for obtaining information from test results.

The mean, minimum and maximum values and standard deviations of all performed tests provided a descriptive overview of sample characteristics.

In regression analysis, the number of independent variables used in studying the relationship between tibial nerve conduction velocity and strength and power was limited. This was done by stepwise regression search methods to select the best variable(s) to analyze the regression function. Stepwise regression methods computed a sequence of regression equations, at each step adding or deleting an independent variable (46). The criterion for inclusion of an independent variable was derived from use of the F value table provided by McCall (39). The critical level for inclusion of an independent variable used for the stepwise regression search methods in this study was $F^* = 4.22$, where $F^* = MSR(X_K)/MSE(X_k)$ and F^* is denoted F statistic (46). An F value of 4.22 was the equivalent of $F(.95; 1, 26) = 4.22$ so that specified F limits of 4.22 would correspond to a level of significance of .05 for any single test based on 26 degrees of freedom (39,46).

If stepwise regression methods failed to find a suitable variable, or set of variables, all possible regressions would be employed based on R^2_p criterion, where R^2 is the coefficient of multiple determination and p indicates the number of parameters (46).

After selecting the best variable or set of variables, linear regression determined the estimated regression function.

$$\hat{Y} = b_0 + b_1X_1 + b_2X_2 + \ldots + b_{p-1}X_{p-1}$$

where there are p - 1 independent variables $X_1, X_2, \ldots, X_{p-1}$ (46).

Examination for the aptness of the regression model with individual variables $X_1, X_2, \ldots, X_{p-1}$, was made by plotting the residuals of each independent variable (46).

ANOVA was used to test whether or not tibial nerve conduction velocity was significantly related to lower body strength and power (46):

Source of Variation	SS	df	MS
Regression	SSR	p - 1	MSR
Error	SSE	n - p	MSE
Total	SSTO	n - 1	

The F statistic was used to test the significance of the regression relation:

$$F^* = MSR/MSE$$

The coefficient of multiple determination was used to measure the proportionate reduction of total variation in tibial nerve conduction velocity associated with the use of the selected set of independent variables:

$$R^2 = SSR/SSTO$$

Estimation of regression boundaries using simultaneous Bonferroni confidence intervals were computed (46):

$$b_k - t(1 - \alpha/2;\ n - p)\ s(b_k) \leq \beta_k \leq b_k + t(1 - \alpha/2;\ n - p)\ s(b_k)$$

where $\beta_k = 0 (k = 1, \ldots, p - 1)$. This determined the degree of confidence that the coefficient β_k for a given $X_1, \ldots, X_{p-1}$ will fall within certain limits.

Testing for multicollinearity on regression coefficients will determine if the X's are correlated.

In calculations for ANOVA, F test, and Bonferoni confidence intervals, the .05 level of confidence was used.

All statistical analyses were computed on an electronic computer.

CHAPTER 4

RESULTS

The results of testing in all variables are summarized in Table 4.1. Of the ten independent variables entered into stepwise regression search methods, only one was found suitable at the F level specified--vertical jump power. The data for the regression function with one independent variable (vertical jump power) are displayed in Table 4.2.

With one independent variable, the equation for the regression model was as follows:

$$\hat{Y} = b_0 + b_1X_1$$

where b_0 is the y intercept and b_1 is the slope of the regression line, and X_1 is the independent variable. By using the data from Table 4.2, the regression function studied was

$$\hat{Y} = 72.36 - 0.14X$$

The scatter plot of the regression line is shown in Figure 4.1. The slope of line, which was -0.14, showed that a negative relationship existed between tibial nerve conduction velocity and vertical jump power.

To assure the aptness of the regression model, a plot of the residuals (random error) against the independent variable was made (Figure 4.2). There appeared to be no systematic departure from zero (R = .00). The regression function was deemed appropriate for this study.

Table 4.1

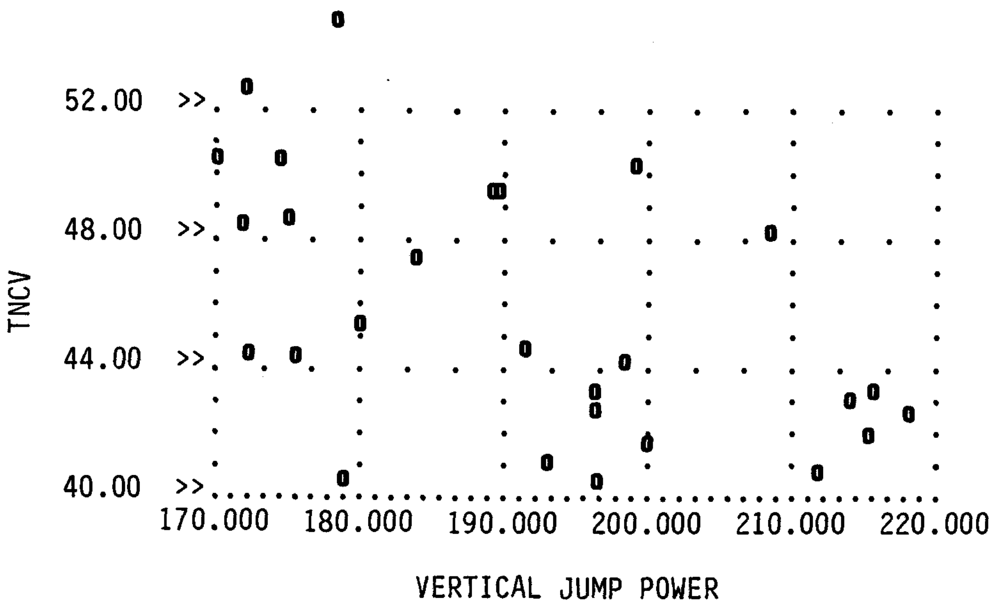
Results of all variables tested (N = 27).

Variable	Mean	Standard Deviation	Maximum Value	Minimum Value
Static leg (kg)	92.87	13.76	121.21	71.33
1-RM Squat (kg)	221.33	30.93	288.50	166.00
Squat/Bodyweight	1.98	0.28	2.50	1.43
1-RM Power clean (kg)	132.48	13.63	166.00	109.00
Clean/Bodyweight	1.18	0.13	1.54	0.92
Vertical jump (m)	0.59	0.08	0.76	0.48
VJ power (newtons)	190.97	14.95	215.35	170.33
Long jump (m)	2.51	0.20	3.20	2.24
LJ power (newtons)	202.73	33.67	353.60	167.10
10-yard dash (sec)	1.82	0.10	2.03	1.65
Tibial NCV (m/sec)	45.55	4.15	55.75	40.00

Table 4.2

Data on tibial nerve conduction velocity (TNCV) and vertical jump power (VJP).

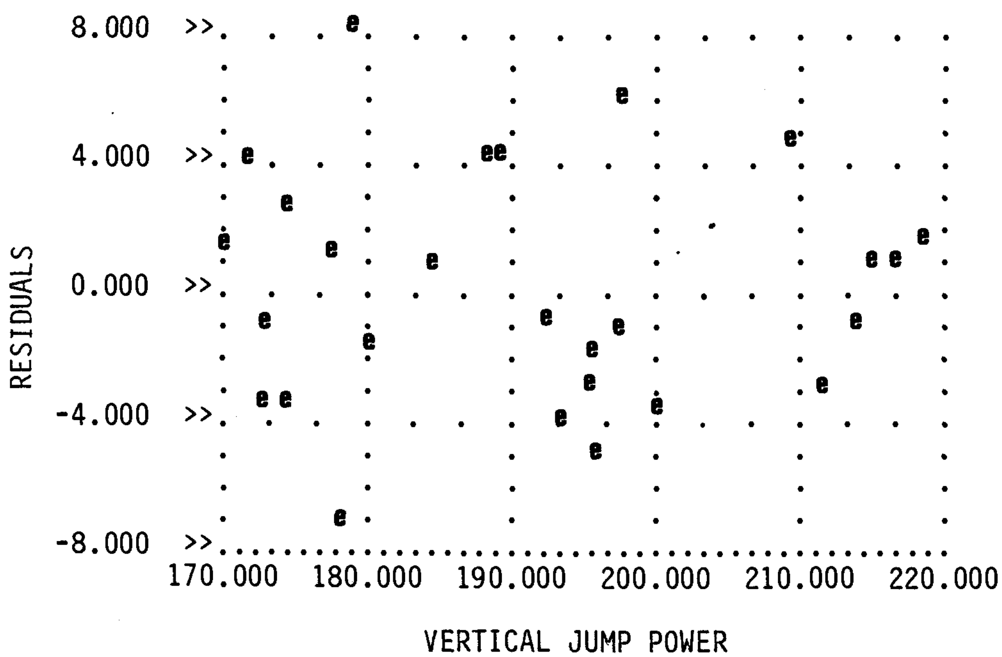
Subject	TNCV (Y) (m/sec)	VJP (X) (newtons)
1	41.67	213.24
2	43.20	214.20
3	43.22	196.40
4	47.41	184.03
5	41.43	199.77
6	40.00	196.30
7	49.61	189.23
8	43.80	176.17
9	52.17	172.28
10	47.90	209.34
11	44.83	190.97
12	50.00	196.92
13	50.00	170.33
14	50.45	173.75
15	42.50	195.85
16	55.75	179.05
17	48.15	176.46
18	47.62	172.22
19	42.74	215.35
20	40.43	211.35
21	44.78	197.01
22	40.15	177.64
23	43.90	172.38
24	49.54	189.04
25	40.78	193.91
26	45.45	179.96
27	42.86	213.12



Lower bound of X = 170.330
Lower bound of Y = 40.0000
Upper bound of X = 215.350
Upper bound of Y = 55.7500
R = -.5053

Figure 4.1

Scatter plot of regression of tibial nerve conduction velocity (m/sec) and vertical jump power (newtons).



Lower bound of X = 170.330
Lower bound of Y = -7.26818
Upper bound of X = 215.350
Upper bound of Y = 8.52983
R = -.0000

Figure 4.2

Scatter plot of residuals (e_i) for independent variable vertical jump power (newtons).

The results of ANOVA used to test for a significant linear relationship between tibial nerve conduction velocity and vertical jump power are shown in Table 4.3. The F statistic was 8.57, which was significant at the .01 level of confidence.

The coefficient of multiple determination, R^2 = SSR/SSTO or 114.52/448.44, was .26. This explained that the total variation in tibial nerve conduction velocity was reduced by 26 percent due to the use of vertical jump power in the regression function as the independent variable. This was deemed adequate for regression analysis and hypothesis testing.

The confidence intervals using Bonferroni technique were found to be $-0.19 \leq \beta_1 \leq 0.01$ at $p < .05$. This means that the mean value for the tibial nerve conduction velocity regression coefficient would fall within these limits for every one-unit increase in vertical jump power with 95 percent confidence.

The test for multicollinearity on regression coefficients was omitted because only one independent variable was selected by stepwise regression techniques.

The Pearson product moment correlation technique was used in assessing relationships between vertical jump power and all other independent variables deleted in stepwise regression procedures (39). The results are contained in Table 4.4.

Table 4.3

ANOVA table for test of linear relationship between tibial nerve conduction velocity and vertical jump power.

Source of Variation	SS	df	MS	F
Regression	1114.52	1	114.52	8.57
Error	333.92	25	13.36	
Total	448.44	26	17.25	

Table 4.4

Results of correlations between all independent variables not selected through stepwise regression and vertical jump power.

Variable	r
Static leg strength	.29
1-RM squat	.42
Squat/Bodyweight	- .12
1-RM Clean	.01
Clean/Bodyweight	- .52
Vertical Jump	.29
Long jump	.07
Long jump power	.61
10-yard dash	.16

CHAPTER 5

CONCLUSION

The results of this study indicated a highly significant ($p < .01$) statistical relationship between tibial nerve conduction velocity and vertical jump power in college football linemen. Thus, the null hypothesis was rejected.

In the review of literature, Kamen (34) and Upton (61) demonstrated that there were marked differences between power-trained athletes and endurance-trained athletes and non-athletes in tibial nerve conduction velocities. Singh and Maini (52) showed significant differences between rickshaw pullers and control subjects in lower limb nerve conduction velocities. These studies found faster conduction rates in the power-trained athletes and rickshaw pullers.

College football linemen are power-trained athletes. An expected outcome in this investigation, based on previous studies, was that higher nerve conduction velocities would be associated with higher levels of power. This was not the case. The results of this study showed an inverse relationship--higher rates of tibial nerve conduction were associated with lower levels of vertical jump power.

The findings supported the null hypothesis that no significant linear relationship existed between tibial nerve conduction velocity and leg and hip strength and power in college football lineman. This was based on the premise that observations came from within a homogenous sample whereas other studies observed differences between heterogenous samples (34,52,61). This position was taken on the basis of "natural selection" where football athletes who played lineman positions would be naturally suited to play at these positions because of their physical characteristics (19). This is especially true at higher levels of competition, as in major college football, where these physical attributes were honed in scholastic competition at the secondary school level. Strength and power would be an attribute that is intrinsic to the college football lineman, and neuromuscular abilities, including nerve conduction velocities, would have minimal variance.

That the stepwise regression search method failed to produce variables in strength, indicated that it was reasonable to conclude that significant linear relationships would not be found between tibial nerve conduction velocity and leg and hip strength after regression analysis.

Power output expressed in units of vertical jump power had been selected as the variable which was significantly associated with tibial nerve conduction velocity in college football linemen. This suggested that the ability to project and displace one's body mass in a vertical fashion was related to the speed of nerve conduction via the posterior tibial nerve tract. Projection of body mass in a horizontal direction through power generated in the standing long jump was a variable that did not have any significant bearing on the relationship between leg and hip power, and tibial nerve conduction velocity. This may be due to the coordinated muscle actions involved in the standing long jump, which has a higher degree of difficulty in performance than the vertical jump.

The selection of vertical jump power was satisfactory for use in the regression model as power output in vertical jump performance was found to be closely associated with power production by elite Olympic weightlifters in 1-RM clean pulls (21). This factor in selection of the variable corresponded to the specific demands in training as use of the Olypmic lifting movements has great mechanical carryover to the execution of skills of the college football lineman (40,41,45).

Discussion

That subjects with higher levels of power output in the vertical jump possessed reciprocal (lower) levels in tibial nerve conduction velocities suggested that muscle function played an important role in generating greater amounts of muscular power.

Proper use of resistance training has been shown to enhance muscle operation, as well as develop neural and histochemical characteristics to a degree that would enhance muscular force production(20,28,33,48,50,56,57). As a result of training, the contractile properties of muscle fibers may have developed speed-response characteristics, independent of the speed at which the nerve impulse or action potential was received. Therefore, the ability of the muscle filaments at the sarcomere level to react to neural impulses to cause instantaneous muscle contractions may have been a critical factor in power output, not how rapidly an action potential got to the muscle.

Garhammer (20) offered additional evidence to support the role of muscular components in power capacity by citing the following:

> Power capacity is dependent upon the factors of muscle mass, fast/slow fiber area ratios, high energy phosphate availability at the contractile filaments, motor unit recruitment capabilities and skeletal leverages.

The biochemical factors (myofibril constitution and muscle enzyme availability) and anatomical limitations (skeletal leverages) are genetic parameters that cannot be improved appreciably through training. Muscle mass and motor unit recruitment, however, can be enhanced through specific conditioning methods.

Muscular hypertrophy resulted in increased cross-sectional area of myofibrils and greater capacities to exert tension (23). Weight training that incorporated the principle of progressive overload techniques caused increases in muscle mass (30,47,63). Subjects who displayed higher power outputs were assumed to have greater potential in this capacity as a result of proper weight training and increased muscle mass. Motor unit activation was more easily achieved as a result of training and facilitated the production of power. This was supported by a moderately high correlation between vertical jump power and 1-RM squat ($r = .42$).

The use of specific weight training exercises warranted explosiveness in training (20,48,56). Specificity in training, including use of the squat and power clean lifts, accounted for efficient recruitment of motor units which possessed contractile filaments that were capable of producing quick and forceful muscle contractions to increase power output.

The ability of the neuromuscular system to coordinate components within its goverance in an efficient manner can be attributed to higher power capacities. As stated by Fischer and Merhautova (18):

> In trained athletes, individuals could increase contraction at decisive moments, develop more force, utilize fewer muscle fibers to perform submaximal activity, relax antagonistic muscles better during decisive movements and better employ supporting body structures.

Power production in this instance resulted from the integrating of motor unit activities, the coordination of various contracting muscle groups and muscle contractile characteristics. It was concluded that subjects who displayed higher levels of power capacity possessed high ratios of fast-twitch fibers, were able to synchronously recruit a great number of motor units and were capable of coordinating contracting muscles to culminate in a summation of forces to produce higher amounts of power.

The individual's ability to synchronously recruit motor units would have a great influence over the amounts of muscular forces that could be harnessed in a maximal display of power. Edington and Edgerton (16) stated that the maximum number of motor units recruited at one time was an important limiting factor in maximal power performances.

Coordinated muscle activity would also add to one's maximal power output. Anthony and Kolthoff (2) mentioned that motoneurons conducted impulses to provide a means for rapid control of separate structures and for integrating the activities of many different structures. The neuromuscular system's ability to integrate motor unit activity and exercise rapid control of component structures would comply with the concept of summation where torques would accumulate from contributing body segments to augment powerful body movement (3).

The higher centers of the nervous system may have an important role in muscular force production. The motor cortex may be capable of learning to increase strength by more effectively synchronizing motor units (16). Perhaps the cortex learns to time nerve impulses so that synchrony of motor unit firing and coordinated body-segment movements coincide to produce greater muscular torques (48).

The correlation between vertical jump power and relative strength in the power clean showed a fairly high relationship ($r = -.52$), as did the correlation between vertical jump power and standing long jump power ($r = .61$). These variables all included bodyweight in their computations, which may explain their close relationships. This fact and the selection of vertical jump power as the best variable implied that tibial nerve conduction velocity and body mass were related. Garhammer (20) noted this relationship in his observations of elite Olympic weightlifters where lifters in heavier weight categories consistently produced higher outputs in maximal power over lifters in lower weight categories, although relative strength levels may have been less. The high negative correlation found between vertical jump power and relative strength in the power clean ($r = -.52$) supported Garhammer's findings.

Increased abilities in muscle function to produce higher outputs in power, including body mass enhancement, may have preceded any specific adaptations of the neuromuscular system. This assertion would contradict the findings of researchers who have concluded that early changes in muscular strength are due to neural factors and precede such factors as muscular hypertrophy (25,29,44). However, as the results of this investigation showed, nerve conduction velocity has no positive relationship with variables entailing the athletic attributes of strength and power. Although neural factors such as synchronization, integration and coordination of motor units can account for initial muscle force producing abilities, nerve conduction improvement may lag behind these developments and may occur some time after muscle hypertrophy has made a significant contribution to power output potential. Therefore, once optimum neuromuscular efficiency is developed, changes in the speed of neural transmission may be negligible, or need not occur at all.

Anthropometric differences may affect nerve conduction as limb lengths could add to, or delete from, calculations of velocity. One's performance in strength and power events can be affected by variations in limb lengths as leverage positions determine to a great degree the amount of muscular force that can be generated in total body movements (3).

Relationship Between Tibial Nerve Conduction and Vertical Jump Power

It was concluded that the inverse relationship discovered in this study showed that slower tibial nerve conduction velocities were indicative of greater abilities in neuromuscular functioning to produce higher outputs in power in the vertical jump, and faster tibial nerve conduction velocities were indicative of a lack of neuromuscular abilities to produce higher levels of vertical jump power.

In connection with the inverse relationship between tibial nerve conduction velocity and vertical jump power, along with related neuromuscular characteristics involved in power production, perhaps there existed terminal branchings from the descending alpha motoneurons which called auxiliary motor units into play (2,38). The inclusion of additional motor units would enhance muscular force production. Greater numbers of terminal branchings would increase the myoneural synaptic area accumulated from a "pool" of available motor units, which would enhance myofibril recruitment (synchrony and pattern) and increase the strength of ensuing muscle contractions (48). The greater the number of terminal branchings of a motorneuron, the more dispersion of the action potention which can reduce the conduction velocity (1,37).

Subjects with slower conduction velocities possessed greater numbers of terminal branches, and through explosive weight training, had a higher propensity towards developing neuromuscular factors conducive to generating greater muscular forces and power.

Subjects with faster rates of tibial nerve conduction possessed smaller numbers of axonal terminal branchings, and training methods produced small increases in neuromuscular factors involved in power production. These individuals had a greater propensity toward developing neuromuscular efficiency in areas that affected quickness, agility and body control.

Players with faster conduction velocities used this attribute to their advantage. They were able to compensate for a lack in muscle mass and muscular force producing capabilities with alternate attributes, perhaps speed and reaction where the temporal aspect or actuation of instantaneous muscular forces to produce power may be critical. A wide variance among subjects, atypical of a homogenous group, indicated by standard deviations in the variables 1-RM squat ($\pm$30.93 kg), 1-RM power clean ($\pm$13.63 kg), standing long jump power ($\pm$33.67), and vertical jump power ($\pm$14.95) suggested that differences in tibial nerve conduction velocity, which had a standard deviation that showed a small range of variance ($\pm$4.15 m/sec), influenced performances in power in a compensatory manner that reflected individual limitations in physiologic capabilities.

Similar conclusions would be found in subsequent investigations of the relationship between the same variables. This was predictable to 95% accuracy as established by Bonferroni techniques to set confidence intervals on the tibial nerve conduction velocity regression coefficient. The confidence interval found ($-.19 \leq \beta_1 \leq .01$) in the regression analysis performed in this study implied that improvements in strength and power variables that reduce the variance (measureable by standard deviations) among subjects in the homogenous sample may produce regression slopes that approximate zero. Therefore, the possibility exists that the continued use of specific training methods over a period of time could equalize vertical jump power capacities and/or tibial nerve conduction velocities so that there would no longer be a significant linear relationship between these two variables. In either case, vertical jump power or tibial nerve conduction velocity improvement would push the slope of the regression function in the positive direction--toward zero.

Variances in strength and power measurements, implied by the standard deviations calculated, may have been attributed to the caliber, or level of proficiency, of each football lineman. Abilities in the areas of strength and power may be related to levels of expertise in football performance. For example, higher levels of power output may correspond to a player's status as starter, All-League, or All-American relevant to football playing ability. Subsequently, tibial nerve conduction velocity may be related to levels of proficiency. Perhaps players with slower rates of tibial nerve conduction but higher capacities in leg and hip power (co-characteristic of the findings discovered in this study) are more proficient in their assigned tasks as football linemen; or perhaps linemen with faster tibial nerve conduction velocities who were not capable of generating amounts of power as higher as their slower velocitied counterparts were considered more adept in football skills by having the physical attributes of quickness, agility and body control.

The classification or rank of subjects was a delimitation that was not considered by the researcher and, therefore, all conclusions and inferences were applicable to the sample population, college football linemen.

Summary

The results of this study implied the following:

1. Muscle function, including contractile properties, played a major role in vertical jump power. The role of tibial nerve conduction velocity was insignificant.

2. Muscle mass, properly developed by weight training methods, was related to higher power output.

3. Motor unit activation was more readily achieved by subjects with higher power capacities.

4. Specificity in explosive training technique increased power output without corresponding increases in nerve conduction velocity.

5. Subjects with higher power capacities were better able to synchronize, integrate and coordinate motor unit to produce greater amounts of vertical jump power.

6. The higher centers of the nervous system may learn to produce desired muscle actions more efficiently.

7. Changes in body mass and power output may have preceded changes in nerve conduction velocity, and developed neuromuscular operations may have advanced to a point where nerve conduction rates would not enhance power capacity appreciably.

8. Limb lengths correspond to muscular power as leverages may vary and affect power output. Limb lengths are factored into velocity calculations for nerve conduction rates and can add to, or detract from, speeds of neural transmission.

9. Slower tibial nerve conduction velocity was indicative of possession of greater neuromuscular abilities to produce power in the vertical jump.

10. Higher tibial nerve conduction velocity was indicative of a lack of neuromuscular characteristics to enhance power output.

11. Terminal branchings from alpha motoneurons may vary in number from many for individuals with slow nerve conduction rates to few for those with higher rates.

12. Subjects having faster rates of tibial nerve conduction velocity were able to use this attribute to their advantage to compensate for a lack in muscle mass and muscular capabilities in producing vertical jump power.

13. Variance in strength and power variables may have resulted from different levels of proficiency among subjects within the sample.

14. Classification in levels of proficiency may be necessary to determine which attributes, power capacity or nerve conduction velocity, is the best predictor of succesful line play in football.

Recommendations

Further investigation in several areas were indicated as results from this study unfolded. The following are recommendations:

1. Observe the kinetic parameters in vertical jump power by studying the temporal and spatial aspects through use of force plate analysis, high speed cinematography and EMG techniques.

2. Study the relationship between instantaneous force or ground-reaction forces in the actuation of power production in the vertical jump and tibial nerve conduction velocity.

3. Conduct a long-term study on the effects of resistance exercise training techniques on EMG characteristics, nerve conduction velocity and power production.

4. Investigate existing relationship between body mass and vertical jump power and tibial nerve conduction velocity. Body composition, including lean body mass and body fat measurements, could be investigated in relation to power capacity and nerve conduction.

5. Observe relationships between between limb lengths and power production and nerve conduction velocity.

6. Conduct a study that would investigate the presence of terminal branches off motoneurons in power athletes compared to endurance athletes or untrained individuals.

7. Analyze the regression of tibial nerve conduction velocity on speed, agility, reaction and coordination.

8. Compare tests of power and nerve conduction speeds between different positions or different levels of proficiency in the same positions in football.

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APPENDICES

Appendix A

Table A.1. NVC vs. strength and power.

Subject	Bdywt.	Y	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
1	110.50	41.67	83.84	227.5	2.06	136.5	1.24	0.76	213.24	3.20	353.60	1.67
2	111.00	43.20	109.95	220.5	1.99	120.5	1.09	0.76	214.20	2.44	191.90	1.85
3	116.50	43.22	102.02	227.5	1.95	138.5	1.19	0.58	196.40	2.52	204.69	1.76
4	120.00	47.41	109.09	195.5	1.63	145.5	1.21	0.48	184.03	2.31	201.86	1.87
5	118.50	41.43	104.52	288.5	2.43	161.5	1.36	0.58	199.77	2.46	205.71	1.88
6	118.50	40.00	112.12	220.5	1.86	127.5	1.08	0.56	196.30	2.41	203.61	1.84
7	112.25	49.61	78.79	193.0	1.72	129.5	1.15	0.58	189.23	2.39	192.07	1.77
8	104.50	43.80	90.40	241.0	2.31	143.0	1.37	0.58	176.17	2.64	187.93	1.68
9	104.00	52.17	82.83	197.5	1.90	120.5	1.16	0.56	172.68	2.59	185.25	1.88
10	136.50	47.90	83.84	195.5	1.43	125.0	0.92	0.48	209.34	2.24	226.11	2.03
11	118.50	44.83	121.21	207.0	1.75	118.0	1.00	0.53	190.97	2.41	203.61	1.84
12	109.50	50.00	82.83	202.5	1.85	125.0	1.14	0.66	196.92	2.59	195.04	1.87
13	107.75	50.00	104.04	220.5	2.50	166.0	1.54	0.51	170.33	2.49	188.19	1.79
14	100.50	50.45	71.33	211.5	2.10	122.5	1.22	0.61	173.75	2.84	187.45	1.65
15	100.00	42.50	75.84	184.0	1.75	109.0	1.04	0.71	195.85	2.72	191.66	1.68
16	116.75	55.75	87.86	220.5	1.89	143.0	1.22	0.48	179.05	2.34	197.67	1.86
17	109.50	48.15	91.66	207.0	1.89	143.0	1.31	0.53	176.46	2.26	182.19	1.89
18	97.25	47.62	78.79	227.5	2.34	127.5	1.31	0.64	172.22	2.41	167.10	1.84
19	130.00	42.74	88.89	284.0	2.19	136.5	1.05	0.56	215.35	2.41	223.37	1.67
20	122.25	40.43	105.05	284.0	2.32	136.5	1.12	0.61	211.35	2.54	215.64	1.85
21	122.25	44.78	91.92	207.0	1.69	127.5	1.04	0.53	197.01	2.31	205.65	1.92
22	102.75	40.15	108.08	166.0	1.62	109.0	1.06	0.61	177.64	2.46	178.37	1.71
23	102.25	43.90	72.85	238.5	2.33	125.0	1.22	0.58	172.38	2.59	182.13	1.73
24	106.75	49.54	90.90	243.0	2.28	138.5	1.30	0.64	189.04	2.54	188.30	1.80
25	109.50	40.78	84.85	220.5	2.01	129.5	1.18	0.64	193.91	2.46	190.09	1.97
26	106.75	45.45	82.83	184.0	1.72	125.0	1.17	0.58	179.96	2.62	191.24	1.83
27	132.25	42.86	111.11	261.5	1.98	147.5	1.12	0.53	213.12	2.54	233.28	1.89

Y = tibial NCV (msec); X1 = static leg strength (kg); X2 = 1-RM squat (kg); X3 = squat/bodyweight; X4 = 1-RM clean (kg); X5 = clean/bodyweight; X6 = vertical jump (m); X7 = VJ power; X8 = long jump (m); X9 = LJ power; X10 = 10-yard dash

Appendix B

OSU Football Off-Season Cycle for Strength Training

Duration: 8 weeks

Phase 1 = 2 weeks	Set x Reps = 5 x 10 @ 65% 1-RM
Phase 2 = 2 weeks	Set x Reps = 5 x 5 @ 85% 1-RM
Phase 3 = 3 weeks	Set x Reps = 3 x 3 @ 95% 1-RM

<u>Program for backs, receivers and kickers:</u>

Monday - Wednesday - Friday

Mandatory Lifts:
- Back squat
- Power clean (pulls for Phase 1)
- Bench press
- Leg extension
- Leg curl
- Situps*
- 4-way neck

Auxiliary Lifts:
- Phase 1 = 2 x 15
- Phase 2 = 3 x 10
- Phase 3 = 3 x 8

* All phases = 2 x 25 minimum

<u>Program for linemen, linebackers, and tight ends:</u>

Split Program: Monday - Tuesday - Thursday - Friday

Mandatory Lifts:

<u>Monday & Thursday</u>
- Power clean (pulls for Phase 1)
- Bench press
- 4-way neck

<u>Tuesday & Friday</u>
- Back squats
- AMF hip press
- Calf raises
- Leg extension
- Leg curl
- Situps

<u>Added-Day Program</u>:

Monday - Wednesday - Friday - Saturday

Mandatory Lifts: <u>Monday & Friday</u>
Power clean (pulls for Phase 1)
Bench press
4-way neck
Situps

<u>Wednesday</u>
Back squat
Incline press
Leg extension
Leg curl
Situps

<u>Saturday</u>
Back squat
Overhead press
Leg extension
Leg curl
Situps

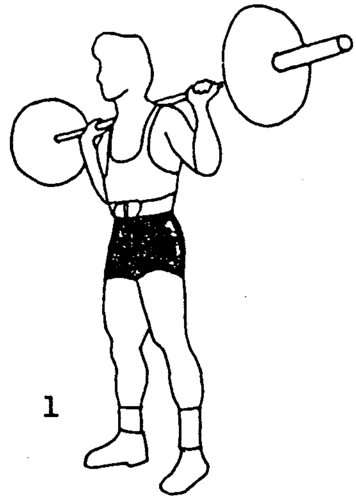
Appendix C

Procedure for Squat and Power Clean

SQUAT

Start/Finish (1)

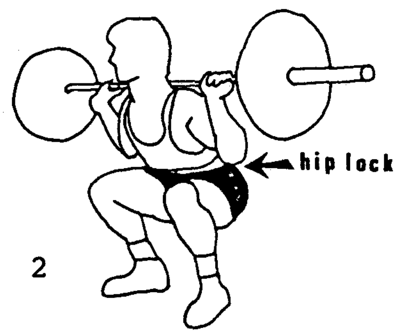
1. Feet spread slightly wider than hips.
2. Point toes out slightly for more quadricep involvement.
3. Bar across back either on the base of the neck or slid down to the "bubble" formed by the backshoulder muscles.
4. Head up, knees locked.
5. Keep back flat; stomach tensed.



1

Descent (2)

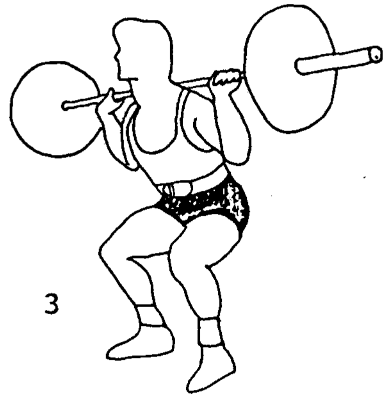
1. Inhale deeply and let knees move forward in line with toes.
2. Squat slowly to position where the top of the hip meets the thigh in a "locking" position. (Top of thighs near parallel with floor.)
3. DO NOT BOUNCE out of the bottom position. Doing so may result in serious knee injuries.
4. A board for a heel lift may be necessary so that the heels do not raise up off the floor.



2

Ascent (3)

1. Drive strongly upward utilizing a vigorous hip and leg thrust.
2. Keep back tight to avoid forward tilting. Forcing neck backwards on the upward drive helps to keep back in line.

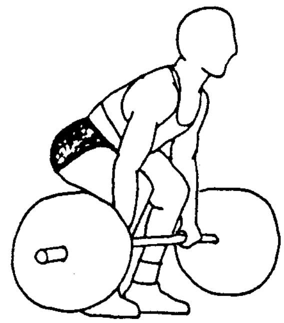


3

POWER CLEAN

Starting Position (1)

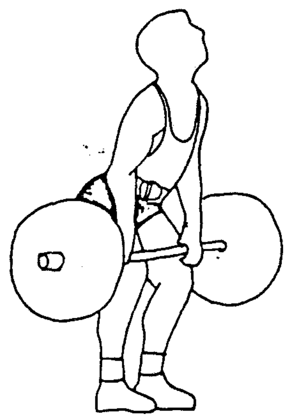
1. Feet positioned hip width apart with first eyelet of each shoe under the bar.
2. Toes pointed out slightly--not too far as bodyweight will tend to shift backwards on initial pull.
3. Weight should be forward over the insteps of each foot.
4. Body in semi-squat position.
5. Hands should be placed shoulder width apart--overhand grip.
6. Keep arms straight, elbows locked and shoulders tensed.
7. Keep back and shoulder flat and stomach tensed.



1

Initial Pull (2)

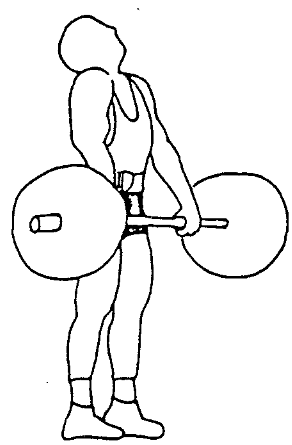
1. Keep shoulder over the bar.
2. Hips rise vertically from drive supplied by legs.
3. Pull strong and steady. (Do not jerk the bar off the floor by bending the arms.)
4. Keep the head up and back tight.
5. The initial pull should carry the bar above the knees.



2

"Scoop" and Second Pull (3)

1. As the bar passes the knees, bring it back slightly towards the thighs and <u>at the same time</u> dip the hips a few inches.
2. Accelerate the bar by driving the hips forward and upward ("scooping").
3. Keep the head up and the bar in close to the body.
4. Extend all the way up on to the toes.
5. Shrug and pull the bar with the elbows high and to the side.

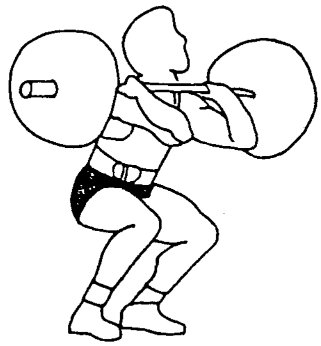


3

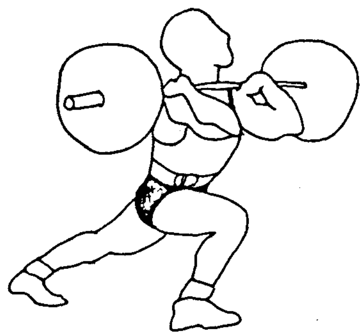
<u>"Rack"</u> (4)

1. When the bar is at its highest point, move under it by bending the legs and whipping the elbows forward.
2. Keep the elbows high and forward to rest or catch the bar on the front part of the shoulders.
3. Once the bar is racked, stand erect.
4. To lower the bar--Bring the weight down to the top of the thighs and take some of the "shock" by bending the legs. Lower the bar to the floor with the back in a good, flat position.

4



* An alternate method for "racking" a weight is known as the Split Style Clean (shown in 4a). In reacting to the weight (getting under the bar), one leg is brought forward while the other is split to the rear. It is important to react quickly, and to keep both feet together. The depth of the split depends on how high the bar has been pulled.



4a