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Effects of warm-up on isokinetic measures at the knee

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Effects of Warm-up on Isokinetic Measures at the Knee

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Effects of Warm-up on Isokinetic Measures

at the Knee

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ABSTRACT

Effects of Warm-up on Isokinetic Measures

at the Knee

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This study was undertaken to determine the effects of warm-up on peak torque and on torque accelerated energy of the muscles at the knee. Twenty-two male subjects participated in this study and had the following characteristics (standard deviations in parentheses): age, M = 23.22 years (2.50); height, M = 68.48 inches (9.95); and weight, M = 199.90 pounds (44.90). Subjects were habitually active and had no history of joint disease or acute joint trauma. Prior to testing, subjects attended an orientation session where they became familiar with the testing instrument and procedures. Each subject was tested twice on a Cybex 340 Extremity Testing System: (1) control condition involving measurement with no warm-up and (2) experimental condition involving measurement following warm-up. All warm-up was completed on a stationary bicycle ergometer. Subjects pedaled for five minutes at a cadence of 50 RPM with a resistance sufficient to elicit 50% heart rate reserve. Subjects were tested at 60 degrees per second and at 180 degrees per second. Peak torque and torque accelerated energy measures were obtained for both legs, and test results were gravity corrected as per manufacturer's

recommendations. The data were analyzed using multivariate analysis to determine if a significant difference existed between peak torque with no warm-up and peak torque following warm-up and between torque accelerated energy with no warm-up and torque accelerated energy measured following warm-up. The results of the analysis indicated there were no significant differences in peak torque or in torque accelerated energy measures as a result of warm-up.

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CHAPTER 1

Introduction

The concept of warm-up as it relates to exercise and rehabilitation has been widely accepted by many physical educators as a vital and indispensable adjunct of physical activity, exercise, or a training program. In theory, warm-up results in an increase of intramuscular temperatures and in elevation of metabolism by increasing heart rate, respiratory rate, and oxygen uptake. Increased temperatures within the muscle result in increased muscle viscosity, which reduces the friction and internal work associated with a given movement. Thus, the mechanical efficiency of the exercise or movement is improved.

A general warm-up also results in an increase in cardiac output. Furthermore, warm-up results in a systemic responsive mechanism that results in a shunting of the flow of blood to the working muscles, providing them with nutrients and assisting in thermoregulation.

This study was intended to examine the effects of non-specific warm-up on the development of peak torque and on torque accelerated energy of the muscles at the knee.

Delimitations

All subjects who participated in this study were officially enrolled as students at Middle Tennessee State

University. Participation in the study was voluntary and was limited to 22 healthy male students.

The research instrument used was a Cybex 340 Extremity Testing System located in the Human Performance Laboratory on the Middle Tennessee State University campus. Subjects completed warm-up procedures by pedaling a predetermined number of revolutions per minute on a Monarch bicycle ergometer. Warm-up lasted five minutes, and the resistance offered by the bicycle ergometer was sufficient to elicit approximately 50% heart rate reserve.

Definition of Terms

1. Accommodating resistance--variable resistance offered by the lever arm of a dynamometer in order to accommodate the force applied by an exercising limb.

2. Active warm-up--the use of physical activities, such as pedaling a bicycle ergometer at 50 revolutions per minute at a resistance sufficient to elicit 50% heart rate reserve in order to increase internal temperatures of the body.

3. Gravity effect torque--the effect of gravity on torque produced by the limb and the input adapter of the dynamometer.

4. Isokinetic movement--a process in which a body segment accelerates to achieve a preselected and fixed angular velocity against an accommodating resistance.

5. Torque--a force that acts to produce rotation of a body or a segment around an axis. Torque is the product of the force times its perpendicular distance from the axis of rotation.

6. Torque accelerated energy--the amount of power a muscle, or a group of muscles, generates during the first one-eight second of a contraction.

7. Warm-up decrement--the level of performance lost following rest prior to subsequent trials.

8. Work--the amount of energy expended during a specified number of repetitions.

Hypotheses

For the purposes of this study the following hypotheses were statistically tested:

HO_1: No significant difference will exist between peak torque developed during work at 60 degrees per second following warm-up and peak torque developed during work at 60 degrees per second with no warm-up.

HO_2: No significant difference will exist between peak torque developed during work at 180 degrees per second following warm-up and peak torque developed during work at 180 degrees per second with no warm-up.

HO_3: No significant difference will exist between torque accelerated energy developed during work at 60 degrees per second following warm-up and torque accelerated energy developed during work at 60 degrees per second with no warm-up.

HO_4: No significant difference will exist between torque accelerated energy developed during work at 180 degrees per second following warm-up and torque accelerated energy developed during work at 180 degrees per second with no warm-up.

Significance of the Study

The effects of warm-up on peak muscle torque production have not been adequately studied. To date, investigations of the effects of warm-up generally have been limited to endurance and efficiency of movement. A review of related literature has revealed a lack of recent investigations into the relationship of warm-up to various strength parameters (e.g., peak torque and torque accelerated energy).

The effectiveness of muscle testing, with and without its antecedent warm-up, has been a point of contention among physical educators, as well as athletic trainers. In practice, there are long-standing assumptions that warm-up is necessary for reliable testing, rehabilitation, and training when using isokinetic testing and exercise. This study was undertaken as a challenge to the assumption that a non-specific warm-up is essential to reliable measurement of muscle function and is necessary for optimal benefit of therapeutic exercise protocols. In addition, this study attempts to quantify the value of non-specific warm-up to muscle testing and to exercise, whether as part of a conditioning program or as part of a rehabilitation program.

Students who are studying and developing skills as athletic trainers need to develop the ability to test and evaluate muscle function around a joint. Accurate testing is critical to establishing: (1) training programs for athletes, (2) rehabilitation programs for athletes who have suffered injuries, and (3) identification of potential injuries and development of injury prevention programs.

CHAPTER 2

Review of Related Literature

The review of literature was divided into two sections. Presented first was a historical perspective on research into the effects of warm-up. The second section was a review of the use of isokinetic devices in exercise and in the evaluation of muscle function.

A Historical Perspective of Warm-up

The foundation textbook for many students of athletic training is Modern Principles of Athletic Training by Arnheim (1989). The textbook lists "Ten Cardinal Conditioning Principles," the first one of which is "See that proper and adequate warm-up procedures precede all activities." The literature is proliferate with suggestions of adequate warm-up, the benefits of warm-up, and the consequences of failure to adequately warm up.

Warm-up has been defined as the gradual preparation of muscles, the cardiovascular system, and the respiratory system for exercise or activity. Coaches, athletes, and physical education teachers have been confident that the practice of warm-up would enhance performance (Anshel, 1985; Arnheim, 1987; Barnard, Gardener, Diaco, MacAlpin, & Kattus, 1973; Binkhorst, Hoofd, & Vissers, 1977; De Bruyn-Prevost & Lefebvre, 1980; Fahey, 1986; Freischlag, 1987; High, Howley & Franks, 1989; Karpovich & Hale, 1956; Massey, Johnson, &

Kramer, 1960; Robergs et al., 1991; Roy & Irvin, 1983; Sedgwick & Whalen, 1963; Stamford, 1987) and reduce the chance of injury (Arnheim, 1987; Fahey, 1986; High et al., 1989; Hoyle & Smith, 1989; Karpovich & Hale, 1956; Mathews & Fox, 1976; Roy & Irvin, 1983; Safran, Garrett, Seaber, Glisson, & Ribbeck, 1988; Stamford, 1987; Wiktorsson-Moller, Oberg, Ekstrand, & Gillquist, 1983). Perhaps no other area of exercise science was so thoroughly studied yet remained so controversial as the area of warm-up.

Experimentally, it has been difficult to prove that warm-up aids performance. Traditionally, athletes have believed that warm-up was necessary. As a result, a difficulty has been to convince a control group to give a maximal effort without warming up (Stamford, 1987).

Noble (1986) contended that warm-up was a component of exercise and not an exercise principle. According to Lamb (1978), the effectiveness of warm-up was thought to be due to an activation of appropriate neural pathways. This activation facilitated more motor units being recruited which resulted in increased strength of contraction. Lamb (1978) also stated that psychological aspects of warm-up were considerations as most individuals have been taught to believe in the value of warm-up.

While warm-up was widely accepted as essential to proper preparation for physical activity, little reference to the effects of warm-up on muscular strength or on segmental acceleration were found in the literature. The effects of warm-up prior to exercise or activity included increased core temperature (Asmussen & Boje, 1945; Freischlag, 1987; High et al., 1989) increased subcutaneous blood flow (Nielsen, Staberg, Nielsen, & Sejrsen, 1988), increased temperature of blood and muscle which made the dissociation of oxyhemoglobin faster and more complete (Barcroft & King, 1909), increased muscle temperature (Asmussen & Boje, 1945; Binkhorst et al., 1977; Freischlag, 1987; Karpovich & Hale, 1956; Lamb, 1978; Robergs et al., 1991; Safran et al., 1988; Saltin, Gagge, & Stolwijk, 1968; Wiktorsson-Moller et al., 1983), increased speed of contraction and relaxation (Lamb, 1978), prevention of damage to the myocardium during the first few seconds of intense activity (Barnard et al., 1973; Lamb, 1978), prevention of delayed-onset muscle soreness (High et al., 1989), and increased range of motion (Safran et al., 1988).

Asmussen and Boje (1945) published one of the first works which suggested that higher intramuscular temperatures increased the capacity for work. They proposed that higher temperatures might decrease the reaction time of the motor unit and thus increase the capacity for work.

Although warm-up was credited with diminishing the chance of injury, Karpovich and Hale (1956) reported that no objective evidence was substantiated that warming-up reduced the incidence of athletic injuries. The assumption that a warm-up affected the chance of injury resulting from participation in activities or in athletics was not supported by research findings, but was an empirical suggestion based on experiences of many athletes and coaches.

Stone and Kroll (1986) classified warm-up as either passive or as active. Lamb (1978) contended that most research suggested that a passive warm-up was not particularly useful in the expression of muscular strength. The research of Neuberger (1969) indicated that non-specific and passive techniques had not effectively improved performance. Neuberger further stated that specific and vigorous forms of actual practice of a motor skill as a warm-up generally had a positive effect on performance.

DeVries (1986) reported that when a muscle was cooled the speed of contraction and relaxation was decreased, while application of heat increased the speed of contraction and relaxation. Nerves conducted impulses more rapidly when heated, and tendons and ligaments became more resilient. According to Lamb (1978), these enhanced functions probably resulted from increased enzyme activity, less resistance to change in length, or lower viscosity in the heated tissues. In consideration of these effects, maximal strength should be somewhat improved by warming the muscle prior to the exertion of muscular force.

An investigation by deVries (1986) found that immersion of the arm in hot water (120 degrees Fahrenheit) for eight minutes caused small but significant gains in strength. Using the same subjects, immersion of the arm in cold water (50 degrees Fahrenheit) resulted in a highly significant 11% decrease of grip strength.

Saltin et al. (1968) investigated variations in temperature due to exercising muscles. They found that exercising muscles produced a great deal of heat and that during exercise the body maintained a higher core temperature than during rest. The magnitude of the increase in temperature was proportional to the work performed by the individual.

Using copper-constantan thermocouples placed at different levels and at different locations within muscles, Saltin et al. (1968) found that muscle temperatures at all depths and at all locations increased rapidly with the onset of exercise. Within 10 to 22 minutes after exercise had begun, internal temperatures reached a relative plateau. Their research also suggested the temperature of a resting muscle was generally lower than was the rectal temperature.

While it was generally accepted that elevated temperatures resulting from warm-up enhanced various parameters of muscle function, research by Bergh and Ekblom (1979) and by Blomstrand, Bergh, Essen-Gustavsson and Ekblom (1984) showed that depressed temperatures resulted in reduced physical performance. They found that at low body temperatures the decrease in physical performance coincided with a reduction in peak aerobic power and with a decreased maximal muscle strength.

DeVries (1986) postulated that the intensity and the duration of warm-up must be modified to accommodate the individual athlete. An increase of rectal temperature of one to two degrees Fahrenheit was desirable, and signs of development of heat from within (e.g., perspiration) may be used as an indicator of an effective warm-up. His research showed that intensities of 75% maximal oxygen consumption or more can impair rather than enhance performance. Investigations by Stone and Kroll (1986) suggested that for events which require more strength, power, aerobic, or anaerobic effort than skill, the vigor of the warm-up seemed to be important.

Noble (1986) suggested that in exercise testing, the test protocol should include a warm-up period. According to Noble, using the early minutes of a test was a prudent procedure. Using a treadmill exercise test as an example, the first stage of the protocol, zero degrees elevation, was considered a warm-up which was specific to the task.

Neuberger (1969) and McDavid (1991) agree with Noble in that specific and vigorous forms of actual practice of a motor skill as warm-up generally had a positive effect on performance. McDavid further states that practicing a skill as a specific warm-up may be beneficial to the actual performance of that skill and that the effects garnered by such warm-up may be due more to psychological aspects of warm-up than to elevated temperatures.

Lamb (1978) suggested that active warm-up should precede the event by no more than 15 minutes and that warm-up appeared to be most effective when its duration was between 5 and 30 minutes. Recent investigations by De Bruyn-Prevost and Lefebvre (1980) found evidence that a rest period between warm-up and the event eliminated any warm-up effects. Studies by Muido (1946) and Nukada (1955) contended that the effects of warm-up lasted for 45 to 80 minutes, and Stamford (1987) contended that the elevated temperature resulting from warm-up lasted for an hour or more.

Warm-up decrement, defined as the phenomenon where there was a loss in the level of physical performance after a rest and before subsequent trials, was established by Schmidt (1988). The loss of the effects of warm-up was discussed by Anshel (1985). An athlete or student was often expected to resume performance at optimal efficiency after a break. However, because of warm-up decrement, the athlete or student may not have been prepared to compete at optimal levels.

Anshel (1985) listed the following possible explanations for warm-up decrement: (1) an aspect of forgetting, (2) a result of the extinction of conditioned inhibition, (3) the dissipation of arousal during a rest period, (4) the set hypothesis or a loss of set, such as physical and/or cognitive adjustments that are associated with the desired response, and (5) the loss of an internal state during the rest period, or the activity-set hypothesis.

Schmidt (1988) contended that if warm-up decrement resulted from the loss of internal adjustments as suggested by the set and the activity-set hypotheses, it was not clear what those adjustments were. If the adjustments are physiological in nature, the cooling of the muscles and internal structures may have explained, at least partially, warm-up decrement.

Investigations by Binkhorst et al. (1977) into temperature and force velocity relationships of muscles of the upper extremity found that maximal muscle velocity, maximal force, and maximal power were affected by variations in temperature. According to deVries (1986), two investigators found that a whole body warm-up significantly increased muscular strength, while three others who applied only local heat found no improvement.

This data seemed to suggest that changes in strength recordings were due to changes in the central nervous system that were brought about by temperature change, circulatory change, or a combination of a change in temperature and in circulation. On the basis of this evidence, measurement of strength seemed to be improved when preceded by a general body warm-up.

Measurement of Muscle Function

When measuring strength parameters of muscle function, three methods are available: (1) isometric measures, (2) isotonic measures, and (3) isokinetic measures. Isometric (derived from the Greek term isometros; isos is translated equal or same, and metron means measure) means the length of the muscle does not change (Kroemer & Howard, 1970). In physiology, the term has been used to denote a condition where the origin and the insertion of a contracting muscle are held fixed so that the contraction produces increased tension at a constant, overall muscle length (Stedman, 1982). An isometric muscle contraction is a contraction against an accommodating resistance or a resistance that is equal to or greater than the force applied. An isometric contraction involves no perceptible movement of the joint acted on. The term isometric contraction has been used interchangeably with static contraction.

Isotonic is a combining-form word derived from the Greek terms isos (equal) and tonos (tension). In physiology, an isotonic contraction denotes a condition where a contracting muscle shortens under a constant load (Stedman, 1982). During isotonic work, movement is divided into two components: (1) concentric contractions, where the length of the muscle decreases as a result of the muscle contraction and (2) eccentric contractions, where the muscle lengthens under tension. A frequently used example of an isotonic contraction has been a movement with a weight, such as a barbell. The resistance offered by the barbell does not change; and as the muscle contracts, it develops a constant tension.

Isokinetic (equal movement, motion, or rate of change) has been used to refer to a movement that is limited to a constant angular velocity (Stedman, 1982). Isokinetic strength measurement has proven to be an objective method for quantifying a muscle group's dynamic strength at each point throughout a joint's range of motion. Isometric strength testing, however, is used to determine static strength. One central limitation of isometric testing is that it measures strength at only one angle in the range of motion. Theoretically, strength output should be the same at any joint angle, but measurement throughout the range of motion often shows this to be untrue (Gleim, Nicholas, & Webb, 1978).

Isotonic testing is a dynamic measure of strength. It often uses a one repetition maximum method, which is the maximum amount of weight that can be moved one time through a full range of motion. The limitation in this method of strength testing is the sticking point--the weakest point in a joint's range of motion.

The most effective way to measure muscular strength, muscular power, and muscular endurance is through the use of an isokinetic dynamometer. Isokinetic testing and exercise are based on the concept of accommodating resistance. This means that when the subject exerts maximum force against the resistance offered by the lever arm of the dynamometer, maximum resistance will be supplied throughout the range of motion by the dynamometer (Gould & Davies, 1985).

When a load is applied to a dynamically contracting muscle, the contracting velocity of the muscle decreases as the load increases. When the load has increased to the point that it equals the maximum force of contraction the muscle can exert, the velocity of contraction becomes zero degrees per second, and an isometric contraction results. In an isokinetic contraction, the speed of rotation of a moving segment can be predetermined and held constant despite the changes in the amount of tension developed by the muscles affecting that movement (Osternig, Bates, & James, 1977).

Thistle, Hislop, Moffroid, and Lowman (1967) published one of the first studies relative to isokinetic muscle testing. The following year, Perrine (1968), a consulting engineer to the Institute of Rehabilitative Medicine in New York, discussed the concept of accommodating resistance which was limited to a constant angular velocity throughout the range of motion. He patented the first isokinetic dynamometer in 1968, and Lumex, Incorporated bought the patent and license rights in 1970. Currently, isokinetic dynamometers are used widely, with most of the data collected being either in the area of rehabilitation or in research of various strength parameters (Rankin & Thompson, 1983).

The use of isokinetic measures in research has included investigations of the relationship of muscle strength to fiber type, the effects of training and performance on muscular strength and endurance (Kelly, Gorney, & Kalm, 1978), the influence of limb speed on torque production (Osternig, Sawhill, Bates, & Hamill, 1981), and the relationship of peak torque to age, sex, performance, and body weight (Campbell & Glenn, 1979; Gleim et al., 1978; Perrin, 1986).

Investigations by deVries (1986) and Astrand and Rodahl (1970) showed that strength was closely related to size and height. Rankin and Thompson (1983) suggested that development of normative data based only on raw data derived from isokinetic testing did not account for variations in strength that were due to differences in size and in height. For this reason, the expression of strength as a ratio to the individual's body weight was proposed by Davies et al. (1981); Parker, Holt, Bauman, Drayna, and Ruhling (1982); and Beam, Bartels, and Ward (1982).

The use of isokinetic exercises has become commonplace in muscle training programs and in rehabilitation of athletic injuries. The ability to test and evaluate muscle function has been critical to establishing: (1) training programs for athletes, (2) rehabilitation programs following an athletic injury, and (3) injury prevention programs (Thigpen, Blanke, & Lang, 1990). The usefulness of isokinetic dynamometers in the rehabilitation of injuries, according to DeLateur et al. (1979), was due to the fact that isokinetic dynamometers allowed the muscle to exert the maximum force of which it was capable throughout its range of motion.

In addition to the applications of isokinetic dynamometers in exercise and rehabilitation, they have been used to measure muscle function precisely. Since exercises that involve lifting weights have been difficult to standardize with accuracy, Thistle et al. (1967) suggested that a torque measure was the best index of strength.

Kroemer and Howard (1970) related that there was no safe method of assessing an individual's greatest absolute strength. They contended that, in the context of strength testing, the term maximum strength only indicated a relative magnitude--the quantity possible or observed under the prevailing conditions of testing. A major variable in strength measurement was the method of muscular contraction (e.g., isometric, isotonic, or isokinetic) the subject used to generate force or torque.

Another key consideration was the criteria chosen to measure strength. Some investigators used the highest point in the strength curve as the chosen measure. This method was appropriate for studies of instantaneous strength, but not for sustained measurements of strength. A sustained measure required an average or time-integrated score.

A literature search by Kroemer and Howard (1970) of 50 publications revealed that only 34% of randomly selected reports clearly stated the method subjects used to generate force. They asserted that since no standard method of strength measurement was accepted, each investigator must develop and follow his or her own protocol of measure. An athletic trainer's ability to accurately test and evaluate muscle function about a joint is essential to identifying potential injuries, as well as to establishing rehabilitation protocols. Consequently, the reliability and the validity of devices that have been used to measure parameters of muscle function is significant.

Isokinetic dynamometers have been used to record the joint moment of force as the contracting muscles cause the joint to rotate at a predetermined rate. A great deal of research that has employed isokinetic dynamometers has been conducted with the subject seated and extending his or her knee against the force of gravity and flexing the knee with the assistance of gravity.

If, during a measurement, the subject stopped extending his or her knee, the dynamometer would register a velocity of zero degrees per second. The extensor muscles of the knee would have maintained that point of extension with an isometric contraction. Although there were forces generated by the extensors of the knee, the dynamometer would have registered a flexor movement due to the effects of gravity on the input adapter and resistance arm of the dynamometer. As the extensor muscles increased the rate of contraction, the flexor moment decreased to zero, but did not register as an extensor moment until the muscles generated enough force to overcome the gravitational moment created by the subject's extremity and the dynamometer's input lever arm.

Gravity does not affect moments in the horizontal plane so there are no errors due to gravity. When movements are in the vertical plane, however, the muscles are not only working against the dynamometer, but are either aided or assisted by gravity. Winter, Wells, and Orr (1981) have contended that most researchers have not made corrections for the effects of gravity. They have stated that when Moffroid, Whipple, Hofkosh, Lowman, and Thistle (1969) determined the validity of the Cybex dynamometer, they compared predicted and obtained moments, work, and powers for a motion in a vertical plane. The research of Moffroid et al. (1969) revealed a high correlation for the predicted and for the obtained values.

Winter et al.'s (1981) dispute was based upon the fact that in Moffroid et al.'s (1969) validation study there were no extremities secured to the lever arm of the dynamometer which minimized the effects of the gravitational moment. By neglecting the gravitational forces acting on the leg, an investigator could have arrived at an erroneous conclusion about muscle biomechanics. If research has supported significant relationships and the study did not utilize a gravitational correction, the use of gravity-corrected torques could have substantially altered the correlation coefficients. Research by Winter et al. (1981) showed that knee extension (opposed by gravity) and knee flexion (assisted by gravity) revealed an error in mechanical work that varied from 26% to 43% in extension and from 55% to 510% in flexion. They devised a relatively simple solution to compensate for errors due to effects of gravity.

Before any measurements were recorded, the subject's leg and the input adapter of the dynamometer were weighed. This measurement, recorded as foot-pounds, was obtained by allowing the leg to move through its range of motion at 12 degrees per second. The Cybex 340 system's computer multiplies the gravity effect torque by the cosine of each degree in the range of motion of the joint tested (Cybex 340 System, 1989).

Kroemer and Howard (1970) proposed that a standardized protocol be adopted for testing and evaluating muscular strength. They concluded that results of muscular strength testing, which, during the late 1960s and early 1970s, consisted primarily of isotonic and isometric protocols had low validity and reliability. Additionally, methods and results seemed to vary from researcher to researcher as they developed and followed their own methods and procedures. Consequently, results of strength tests by different researchers cannot be easily compared.

CHAPTER 3

Methods

Subjects

Twenty-two male subjects voluntarily participated in this study. All subjects were officially enrolled in selected courses at Middle Tennessee State University during the spring semester of 1990. Informed consent was obtained from all subjects according to procedures adapted from Guidelines for Exercise Testing and Prescription (1986) (see Appendix B).

Subjects were randomly divided into a control group and an experimental group. Prior to testing, subjects attended an orientation session with the Cybex 340 Extremity Testing System in order to become familiar with the testing process and facilitate accurate measurement during testing sessions. Each subject participated in the testing process on two separate occasions. A 48-hour time lapse separated testing sessions. All tests were administered under laboratory conditions in the Human Performance Laboratory on the Middle Tennessee State University campus.

Instrumentation and Procedures

All isokinetic measures were obtained with a Cybex 340 Extremity System. The Cybex system was calibrated daily, using calibration weights certified by the United States Bureau of Standards, supplied by Lumex, Incorporated. The damping factor was maintained at manufacturer's recommendations throughout the study (Isolated Joint Testing, 1983).

Warm-up Procedures

During testing sessions that involved a warm-up prior to measurement, subjects engaged in exercise for five minutes on a Monarch bicycle ergometer. Pedal cadence was 50 revolutions per minute, with a resistance sufficient to maintain the subject's heart rate at 50% heart rate reserve, as calculated according to the methods of Karvonen, Kentala, and Mustala (1957).

The bicycle ergometer was individually adjusted to accommodate each subject. Adjustments to the bicycle and instructions were as follows:

1. The height of the saddle was adjusted so that the knees were flexed approximately five degrees with the ball of the foot resting on the pedal while at its lowest position.

2. Subjects were instructed not to grip the handlebars tightly.

3. Subjects were instructed to maintain a constant pedal cadence during the five-minute warm-up period. A metronome with an audible click was used to provide a cadence for the subjects during testing sessions that involved warm-up. The metronome was set at 100 beats per minute, and each subject was instructed that each time a

click was heard one foot should be at the bottom of the pedal stroke. This provided a rate of 50 revolutions per minute.

A two-minute transition period was allowed to enable each subject time to move from the bicycle ergometer to the Cybex. This transition period allowed the researcher time to isolate and stabilize the subject's leg to be tested, isolate the knee joint, and program the testing protocol into the Cybex's computer.

Measurement Procedures

The resistance arm of the Cybex 340 was secured to the anterior lower leg immediately proximal to the malleoli by a pad and velcro strap arrangement. The mean length of the resistance arm, as measured from the crown of the anterior tibial tuberosity to the center of the shin pad, was 26.70 (+/- 5.37) centimeters. Subjects were strapped onto the testing bench with straps across the waist and across the pectoral region of the torso. This procedure isolated the subject's quadriceps muscle and eliminated the possibility of using hip flexors in a closed kinematic chain to add torque to the force generated by the quadriceps.

A kinematic chain is created by a combination of several joints. Successively, the more distal segments will have higher degrees of freedom than do the proximal ones. In an open kinematic chain, the distal segments terminate in free space, while in a closed kinematic chain the distal segment is fixed (Lehmkuhl & Smith, 1986).

When considering the application of the kinematic chain concept to isokinetic exercise and testing, the distal segment would be the lower leg and resistance arm apparatus of the dynamometer. The proximal segment would be the subject's trunk. Unrestricted movement of the trunk would allow the hip flexors to aid in the extension of the knee by adding leverage and torque to extension.

According to methods outlined by Goslin and Charteris (1979), three fundamental concepts of positioning subjects and limb segments were firmly adhered to. The principles were:

1. All moving limb segments were aligned parallel with the input arm of the dynamometer.

2. The axis of rotation of the joint was assigned so that it coincided with the axis of rotation of the dynamometer.

3. All limb segments were firmly strapped to the dynamometer and stabilized on the testing seat. Trunk position was maintained relative to the axis of rotation.

The Johnson and Siegel (1978) protocol of specific warm-up in preparation for immediate isokinetic measurement was adapted for this study. Each subject was allowed three sub-maximal trials and one maximal warm-up effort in order to manifest the most reliable measurements.

Subjects were instructed to grip the handgrips that are located at each side of the testing seat. This procedure was employed in order to further reduce the possibility of muscle substitution. All subjects were familiar with the Cybex dynamometer and with the principles of its operation.

Subjects were tested in knee extension and in knee flexion at two speeds: 4 repetitions at 60 degrees per second and 20 repetitions at 180 degrees per second. The testing progression from slowest to fastest speeds was according to the manufacturer's recommendations (Isolated Joint Testing, 1983).

Each subject's dominant leg was tested first, then the non-dominant leg. Determination of the dominant leg was according to the methods employed by Nutter and Thorland (1987). The dominant leg was determined by the subject's preferred leg in kicking skills.

Order of testing was as follows: (1) the dominant leg was tested at 60 degrees per second, (2) the dominant leg was tested at 180 degrees per second, (3) the non-dominant leg was tested at 60 degrees per second, and (4) the non-dominant leg was tested at 180 degrees per second (Isolated Joint Testing, 1983).

Statistical Analysis

Descriptive statistics were used to analyze physical characteristics of the subjects. Multivariate analysis was used to analyze the data and determine differences in group means. The .05 level was used to determine significance.

CHAPTER 4

Results and Discussion

In this chapter, the results of the study are examined and discussed. The discussion was divided into two sections. Discussed first were effects of warm-up on peak torque measures. The second section discussed the effects of warm-up on torque acceleration energy.

Peak Torque

Table 1 shows the means, standard deviations, and results of the multivariate analysis of peak torque measures for extension of the dominant leg at 60 degrees per second. Mean peak torque developed by the dominant leg of the experimental group was 177.59 foot-pounds, and the standard deviation was 48.72. The group that did not warm up recorded a mean of 184.50 foot-pounds with a standard deviation of 46.22. The mean for extension of the dominant knee of the control group was 6.91 foot-pounds of torque higher than the means for the experimental group. The univariate analysis yielded an F-ratio of 0.23 and a probability of .63. This analysis provided evidence that a significant difference did not exist between the control group and the experimental group.

The means and standard deviations for data relative to extension of the non-dominant knee at 60 degrees per second are shown in Table 2. The experimental group developed a

Table 1

Peak Torque for Extension of the Dominant Leg at 60 Degrees Per Second

	Means and Standard Deviations		
Condition	N	Mean	S. D.
Warm-up	22	177.59	48.72
No warm-up	22	184.50	46.22
Entire sample	44	181.05	47.06

	Univariate Analysis				
Source	DF	SS	MS	F	Sig.
Condition	1	525.09	525.09	0.23	.63
Error	42	94,716.81	2,255.16		

Table 2

Peak Torque for Extension of the Non-dominant
Leg at 60 Degrees Per Second

	Means and Standard Deviations		
Condition	N	Mean	S. D.
Warm-up	22	175.40	44.20
No warm-up	22	175.00	48.92
Entire sample	44	175.20	46.07

	Univariate Analysis				
Source	DF	SS	MS	F	Sig.
Condition	1	1.84	1.84	0.01	.97
Error	42	91,301.31	2,173.84		

mean of 175.40 foot-pounds of torque with a standard deviation of 44.20. The control group showed a mean peak torque of 175.00 foot-pounds with a standard deviation of 48.92. The univariate analysis resulted in an F-ratio of 0.01 and probability of 0.97 which indicated that warm-up had no significant effect on knee extension of the non-dominant knee at 60 degrees per second. Figure 1 graphs the differences in peak torque produced during extension of the knees under the control and the experimental conditions.

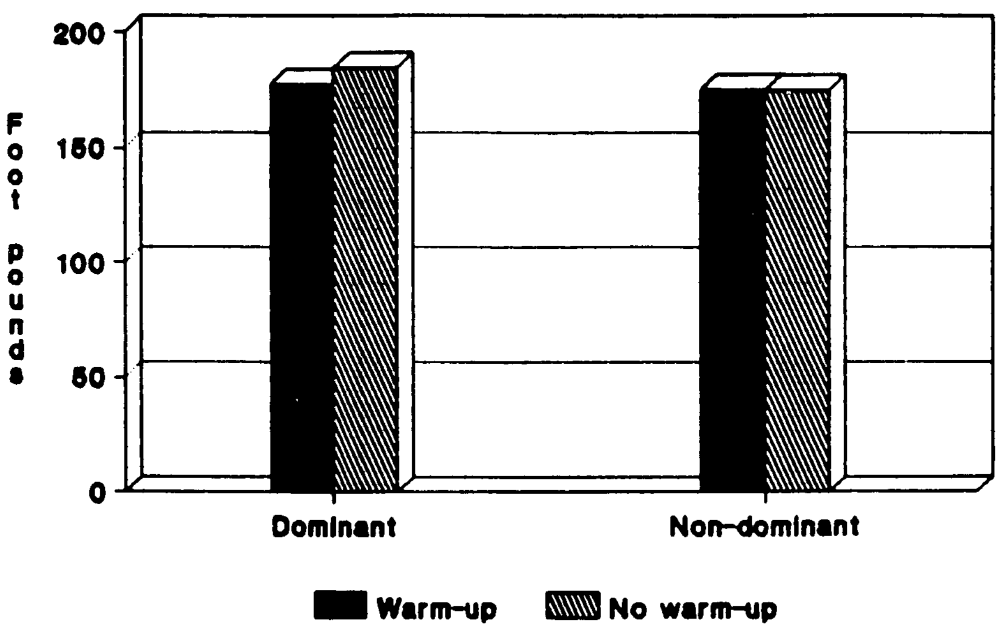

Figure 1. Peak Torque for Extension at 60 Degrees Per Second

The mean peak torque of extension of the dominant knee at 60 degrees per second obtained by this research was below the norms as established by Davies (1987), but agreed with the normative data presented by Trundle (1984). Davies suggested that for males between the ages of 15 and 40 years of age, normative values for peak torque developed by the quadriceps at 60 degrees per second should be 100% of body weight, while Trundle contended that peak torque generated at 60 degrees per second should be 90% of body weight.

Under the experimental condition the mean peak torque of 184.5 foot-pounds was 92.29% of the mean body weight, while the experimental condition resulted in a mean peak torque of 177.59 foot-pounds, which was 88.80% of mean body weight. Differences in peak torque means developed by the non-dominant leg between conditions were not as great as differences in means developed by the dominant leg. Peak torque developed by the non-dominant leg was 175.00 foot-pounds for the control condition and 175.40 foot-pounds for the experimental condition. These figures respectively represented 87.54% and 87.74% of the mean body weight.

The present study also agreed with norms for peak torque of extension at 60 degrees per second as established by the research of Thorstensson, Grimby, and Karlsson (1976). They suggested that college-age students should develop a peak torque of 172.00 foot-pounds. Other researchers (Baltzopoulos, Williams, & Brodie, 1991; Wyatt &

Edwards, 1981) obtained values that were lower than the values of the present study. The research of Baltzopoulos et al. (1991) established a mean peak torque of 153.20 foot-pounds, and Wyatt and Edwards (1981) found a mean peak torque of 137.00 foot-pounds for the dominant leg and 132.00 foot-pounds for the non-dominant leg.

Tables 3 and 4 deal with peak torque of extension generated by the dominant and the non-dominant knees at 180 degrees per second. Table 3 contains the data for peak torque for extension of the dominant knee at 180 degrees per second. The mean peak torque of the experimental group was depressed when compared to the mean peak torque developed by the control group. The depression of means obtained following warm-up is evident in Figure 2.

The control group developed 133.13 foot-pounds of peak torque with a standard deviation of 37.27. After warm-up, the experimental group posted a mean peak torque of 131.45 foot-pounds with a standard deviation of 37.27. The univariate analysis revealed an F-ratio of 0.02 and a probability of 0.88. The results of the univariate analysis suggested that warm-up had no significant effect on the development of peak torque of extension generated by the non-dominant knee at 180 degrees per second.

Table 4 discloses the analysis of data for peak torque of extension developed by the non-dominant leg at 180 degrees per second. With no warm-up, the mean peak torque

Table 3

Peak Torque for Extension of the Dominant
Leg at 180 Degrees Per Second

	Means and Standard Deviations		
Condition	N	Mean	S. D.
Warm-up	22	131.45	37.27
No warm-up	22	133.13	37.27
Entire sample	44	132.29	36.84

	Univariate Analysis				
Source	DF	SS	MS	F	Sig.
Condition	1	31.11	31.11	0.02	.88
Error	42	58,352.04	1,389.33		

Table 4

Peak Torque for Extension of the Non-dominant Leg at 180 Degrees Per Second

	Means and Standard Deviations		
Condition	N	Mean	S. D.
Warm-up	22	127.09	33.38
No warm-up	22	129.18	35.36
Entire sample	44	128.13	34.00

	Univariate Analysis				
Source	DF	SS	MS	F	Sig.
Condition	1	48.09	48.09	0.04	.84
Error	42	49,669.09	1,182.59		

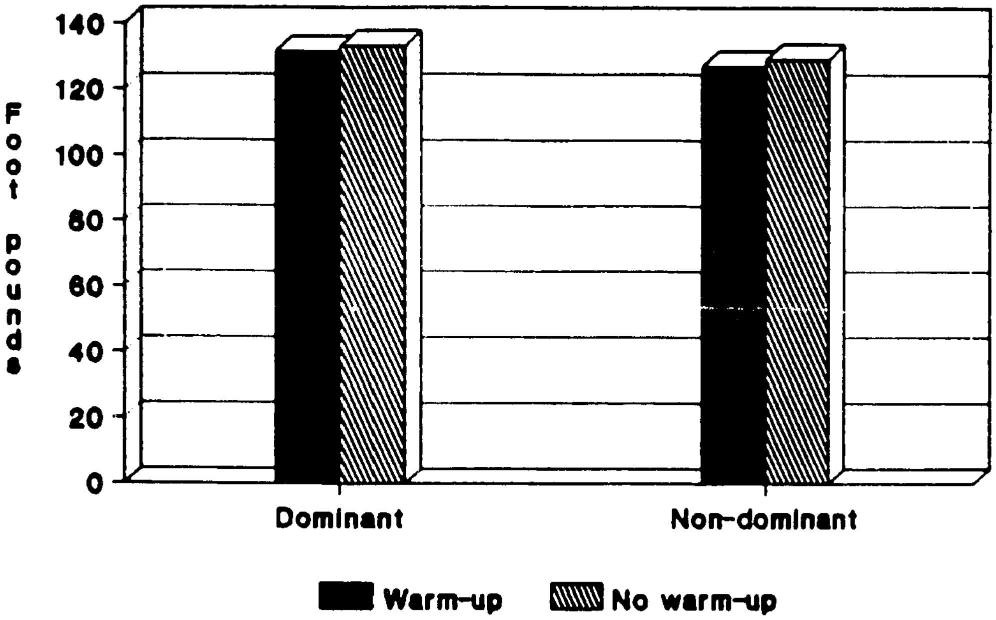

Figure 2. Peak Torque for Extension at 180 Degrees Per Second

was 129.18 foot-pounds with a standard deviation of 35.36. Following warm-up, the mean peak torque was depressed to 127.09 foot-pounds with a standard deviation of 33.38. The univariate analysis revealed an F-ratio of 0.04 and a probability of 0.84. A significant difference in peak torque production during extension of the non-dominant knee at 180 degrees per second did not exist between conditions. Figure 2 illustrates the differences between conditions for the dominant and the non-dominant knees.

The peak torque values for extension of the knee at 180 degrees per second obtained by this research were higher than norms as suggested by Davies (1987), Wyatt and Edwards (1981), Thorstensson et al. (1976), and Baltzopoulos et al. (1991). Davies proposed that males, within the age group that participated in this study, should develop a peak torque between 50% and 59% of their body weight. Subjects in this study developed 63% and 65% of their body weight with the non-dominant and the dominant legs, respectively.

Investigations by Wyatt and Edwards (1981) found that males should develop 97.00 foot-pounds, while Baltzopoulos et al. (1991) established 110.20 foot-pounds of torque as a norm for knee extension at 180 degrees per second. Thorstensson et al. (1976) proposed a mean peak torque of 119.60 foot-pounds. The deviations of the means of the present study may be attributed to the habitually active tendencies of the subjects.

Table 5 presents means, standard deviations, and univariate analysis of peak torque of flexion of the dominant knee at 60 degrees per second. The mean peak torque of the control condition was 108.09 foot-pounds, while warm-up slightly depressed the mean peak torque to 107.50 foot-pounds. Standard deviations were 28.20 and 24.29, respectively. Univariate analysis of peak torque for flexion at 60 degrees per second disclosed an F-ratio of 0.01 with a probability of 0.94. According to the results of the univariate analysis of peak torque for flexion at 60

Table 5

Peak Torque for Flexion of the Dominant
Leg at 60 Degrees Per Second

	Means and Standard Deviations		
Condition	N	Mean	S. D.
Warm-up	22	107.50	24.29
No warm-up	22	108.09	28.20
Entire sample	44	107.79	26.01

	Univariate Analysis				
Source	DF	SS	MS	F	Sig.
Condition	1	3.84	3.84	0.01	.94
Error	42	29,097.31	692.79		

degrees per second, no significant difference exists between conditions.

Table 6 contains the analysis of data for peak torque for flexion of the non-dominant knee at 60 degrees per second. The group that participated in the warm-up condition produced a peak torque of 104.40 foot-pounds with a standard deviation of 24.91 foot-pounds. The peak torque of the group that did not warm up was 107.50 foot-pounds, and the standard deviation was 27.87 foot-pounds. Differences in peak torque of flexion at 60 degrees per second between conditions can be seen in Figure 3.

The univariate analysis for significance between conditions manifested an F-ratio or 0.15 with a probability of 0.70. These results implied no significant difference in peak torque of flexion of the non-dominant knee at 60 degrees per second between conditions. Figure 3 graphs the means for peak torque of flexion at 60 degrees per second for the dominant and the non-dominant legs under both conditions.

According to Davies (1987), normative data for peak torque of knee flexion at 60 degrees per second should be between 120 and 138 foot-pounds. These figures represent a range of 60% to 69% of the mean body weight. The present study resulted in means that were below Davies' norms, but above the norms suggested by other investigators.

Table 6

Peak Torque for Flexion of the Non-dominant
Leg at 60 Degrees Per Second

	Means and Standard Deviations		
Condition	N	Mean	S. D.
Warm-up	22	104.40	24.91
No warm-up	22	107.50	27.87
Entire sample	44	105.95	26.17

	Univariate Analysis				
Source	DF	SS	MS	F	Sig.
Condition	1	105.09	105.09	0.15	.70
Error	42	29,344.81	698.68		

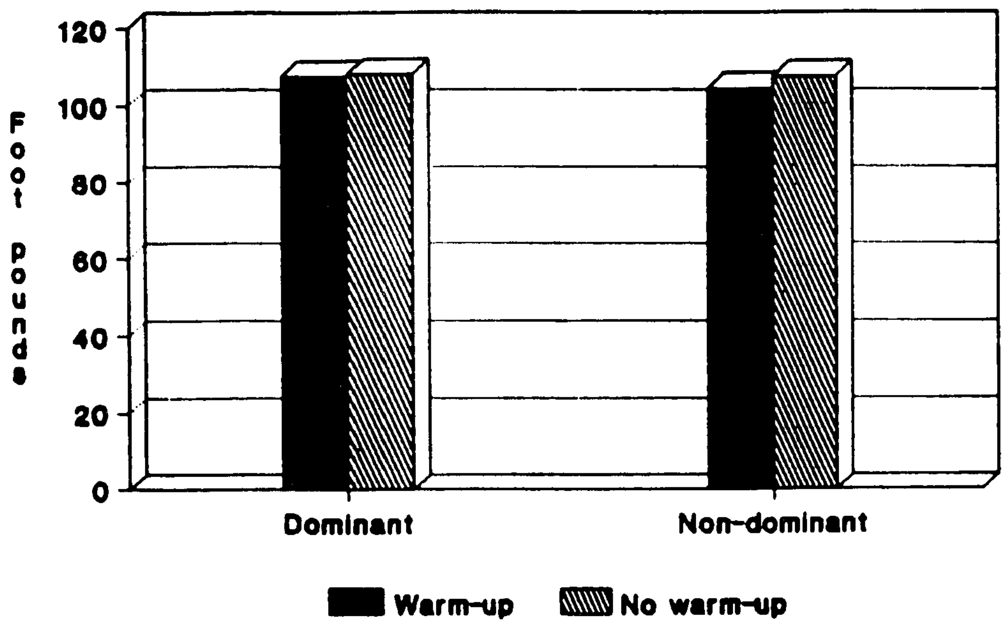

Figure 3. Peak Torque for Flexion at 60 Degrees Per Second

The analysis of data for knee flexion of the dominant leg at 180 degrees per second is presented in Table 7. The mean peak torque production of the control group was 85.36 foot-pounds with a standard deviation of 21.41, while the experimental group developed a mean peak torque of 86.22 foot-pounds with a standard deviation of 19.64. Univariate analysis of the data pertaining to peak torque of extension of the dominant knee at 180 degrees per second produced an F-ratio of 0.02 and a probability of 0.89. The results of the analysis suggested that warm-up did not make a significant difference in peak torque produced during flexion of the dominant leg at 180 degrees per second.

Table 7

Peak Torque for Flexion of the Dominant
Leg at 180 Degrees Per Second

	Means and Standard Deviations		
Condition	N	Mean	S. D.
Warm-up	22	86.22	19.64
No warm-up	22	85.36	21.41
Entire sample	44	85.79	20.31

	Univariate Analysis				
Source	DF	SS	MS	F	Sig.
Condition	1	8.20	8.20	0.02	.89
Error	42	17,732.95	422.21		

Means and standard deviations for peak torque of flexion of the non-dominant knee at 180 degrees per second are listed in Table 8. Under the control condition subjects developed a mean peak torque of 83.31 foot-pounds with a standard deviation of 21.03. The non-specific warm-up used in this study resulted in a depressed mean peak torque of 81.09 foot-pounds. The standard deviation for peak torque generated under the experimental condition was 18.26.

The univariate analysis for significance between conditions resulted in an F-ratio of 0.14 and probability of 0.71. These results inferred that warm-up did not make a significant difference in flexion of the non-dominant knee at 180 degrees per second. Figure 4 projects the differences in mean torque for the control condition and for the experimental condition. Although warm-up elicited a slightly elevated mean peak torque, there was not a significant difference between conditions.

The mean peak torque of flexion of the dominant and the non-dominant knees at 180 degrees per second that were found in this investigation agrees with the suggested norms of Davies (1987). The present means are above the norms suggested by Wyatt and Edwards (1981) and others.

Lamb's (1978) thesis that maximal strength should be improved by warming the muscle prior to maximal exertion was not consistent with this research. The present study, however, agreed with Neuberger's (1969) contentions that a

Table 8

Peak Torque for Flexion of the Non-dominant Leg at 180 Degrees Per Second

	Means and Standard Deviations		
Condition	N	Mean	S. D.
Warm-up	22	81.09	18.26
No warm-up	22	83.31	21.03
Entire sample	44	82.20	19.50

	Univariate Analysis				
Source	DF	SS	MS	F	Sig.
Condition	1	54.56	54.56	0.14	.71
Error	42	16,296.59	388.01		

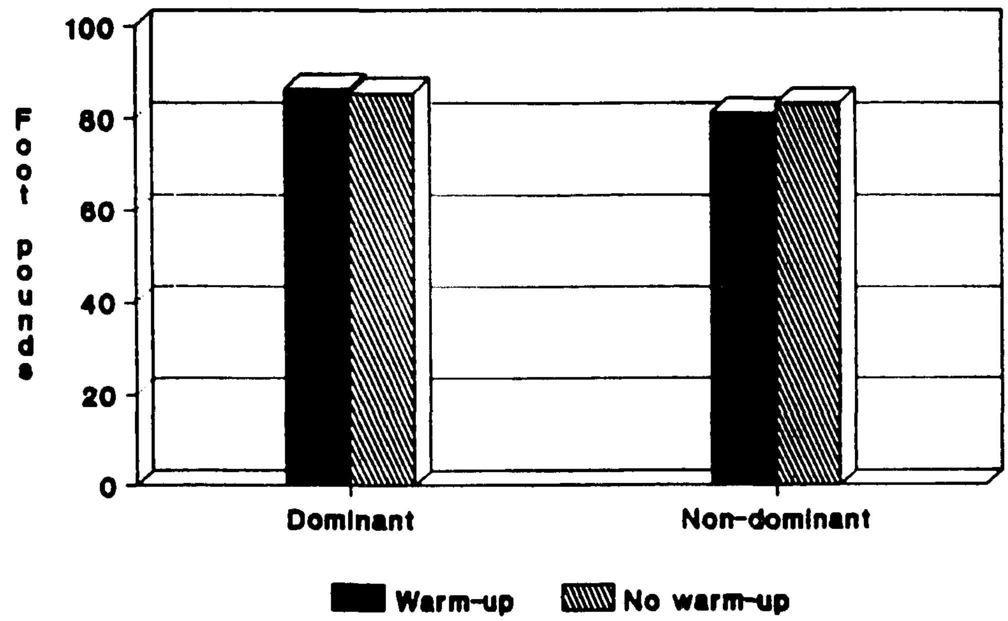

Figure 4. Peak Torque for Flexion at 180 Degrees per Second

passive or a non-specific warm-up was not particularly useful in the expression of muscular strength. There was no evidence in the results of this investigation that elevated temperatures induced by a non-specific warm-up will result in enhanced muscle function.

DeVries (1986) suggested that warm-up intensities greater than 75% maximal oxygen consumption impaired performance. The current research suggested that for activities requiring strength, a warm-up intensity of 50% maximal oxygen consumption impaired performance up to 4%.

Torque Accelerated Energy

The analysis of data for torque accelerated energy for extension of the dominant knee at 60 degrees per second is presented in Table 9. The control group developed a mean torque accelerated energy of 4.63 foot-pounds, while following warm-up the mean torque accelerated energy increased to 5.50 foot-pounds. The standard deviations were 1.43 and 3.08, respectively. Although this difference in means represented the greatest disparity found in this study and approached significance, the difference was not statistically significant. The univariate analysis revealed an F-ratio of 1.42 and a probability of 0.24.

Measures of torque accelerated energy for extension of the non-dominant knee at 60 degrees per second, as seen in Table 10, did not display as great a difference between conditions as did measures of the dominant knee. Torque accelerated energy of extension at 60 degrees per second is displayed in Figure 5. The control group established a mean torque accelerated energy of 4.72 foot-pounds with a standard deviation of 1.77. Following warm-up, the mean torque accelerated energy was slightly depressed to 4.63 foot-pounds, and the standard deviation was 1.94. The univariate analysis for differences between conditions revealed an F-ratio of 0.03 and a probability of 0.87. The implications of this univariate analysis of differences

Table 9

Torque Accelerated Energy for Extension of the Dominant Leg at 60 Degrees per Second

	Means and Standard Deviations		
Condition	N	Mean	S. D.
Warm-up	22	5.50	3.08
No warm-up	22	4.63	1.43
Entire sample	44	5.06	2.41

	Univariate Analysis				
Source	DF	SS	MS	F	Sig.
Condition	1	8.20	8.20	1.42	.24
Error	42	242.59	5.77		

Table 10

Torque Accelerated Energy for Extension of the Non-dominant Leg at 60 Degrees per Second

	Means and Standard Deviations		
Condition	N	Mean	S. D.
Warm-up	22	4.63	1.94
No warm-up	22	4.72	1.77
Entire sample	44	4.68	1.83

	Univariate Analysis				
Source	DF	SS	MS	F	Sig.
Condition	1	0.09	0.09	0.03	.87
Error	42	145.45	3.46		

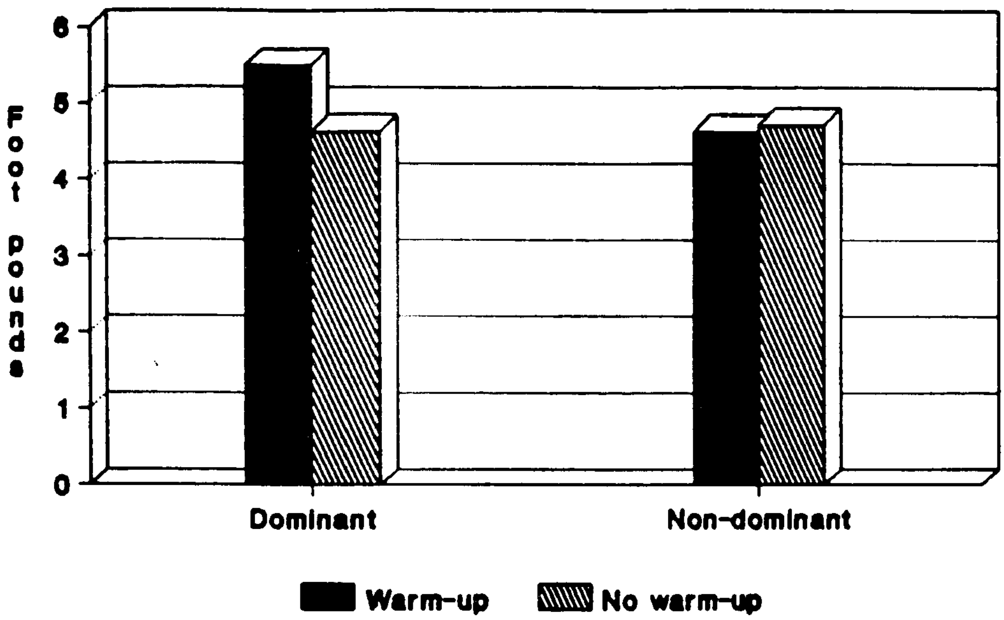

Figure 5. Torque Accelerated Energy for Extension at 60 Degrees per Second

between conditions indicated that no significant difference existed between conditions.

The means for torque accelerated energy for extension of the dominant knee at 60 degrees per second were lower than the norms suggested by Davies (1987). Measurements taken with no warm-up resulted in a mean torque accelerated energy of 4.63 foot-pounds, which represented 64.61% of Davies' (1987) norms. Following warm-up, the mean torque accelerated energy was 76.81% of the norms that were suggested by Davies (1987).

Measurements that were taken during extension of the non-dominant knee at 60 degrees per second also resulted in depressed means. Measurement under the control condition resulted in a mean torque accelerated energy which was 65.92% of the norms established by Davies (1987), while warm-up elicited a mean that was 64.66% of the norms. Specificity of training may account for the deviation of norms suggested by Davies. The athletic tendencies of the subjects may foster changes in muscular function that are specific to fast angular velocities.

Table 11 contains information pertaining to the analysis of data for torque accelerated energy for extension of the dominant knee at the velocity of 180 degrees per second. Subjects who were measured under the control condition produced a mean of 21.13 foot-pounds of torque accelerated energy. Following warm-up, the mean torque accelerated energy was depressed to 20.50 foot-pounds. Standard deviations were 7.25 for the control group and 7.24 for the experimental group. The results of the analysis, an F-ratio of 0.08 and a probability of 0.77, supported the hypothesis that a significant difference did not exist between torque accelerated energy of the dominant leg with no warm-up and torque accelerated energy following warm-up.

The mean torque accelerated energy of extension of the non-dominant knee at 180 degrees per second and under the control condition was 20.86 foot-pounds of energy, and the

Table 11

Torque Accelerated Energy for Extension of the Dominant Leg at 180 Degrees per Second

	Means and Standard Deviations		
Condition	N	Mean	S. D.
Warm-up	22	20.50	7.24
No warm-up	22	21.13	7.25
Entire sample	44	20.81	7.17

	Univariate Analysis				
Source	DF	SS	MS	F	Sig.
Condition	1	4.45	4.45	0.08	.77
Error	42	2,208.09	52.57		

standard deviation was 1.77. These data are depicted in Table 12. Following warm-up, the mean torque accelerated energy of the non-dominant knee was 20.00 foot-pounds with a standard deviation of 6.56.

The univariate analysis revealed an F-ratio of 0.19 with a probability of 0.66, indicating warm-up had no effect on torque accelerated energy for extension of the non-dominant knee at 180 degrees per second. Figure 6 displays the mean torque accelerated energy of knee extension at 180 degrees per second for dominant and for non-dominant knees, with no warm-up and following warm-up.

The means for torque accelerated energy of extension at 180 degrees per second were below the norms of Davies (1987). With no warm-up, the dominant leg posted a mean that was 86.99% of the norms. After warm-up, the ratio dropped to 84.39% of the norms. Under the control condition, the non-dominant leg had a torque accelerated energy measurement that was 85.87% of the norms, and following warm-up the torque accelerated energy fell to 82.33% of Davies' norms.

Table 13 refers to the torque accelerated energy of knee flexion developed by the dominant leg at a velocity of 60 degrees per second. Measurement of the dominant leg under the control condition resulted in a mean torque accelerated energy of 4.63 foot-pounds, while the control group registered 4.36 foot-pounds of energy. A standard

Table 12

Torque Accelerated Energy for Extension of the Non-dominant Leg at 180 Degrees per Second

	Means and Standard Deviations		
Condition	N	Mean	S. D.
Warm-up	22	20.00	6.56
No warm-up	22	20.86	6.43
Entire sample	44	20.43	6.43

	Univariate Analysis				
Source	DF	SS	MS	F	Sig.
Condition	1	8.20	8.20	0.19	.66
Error	42	1,774.59	42.25		

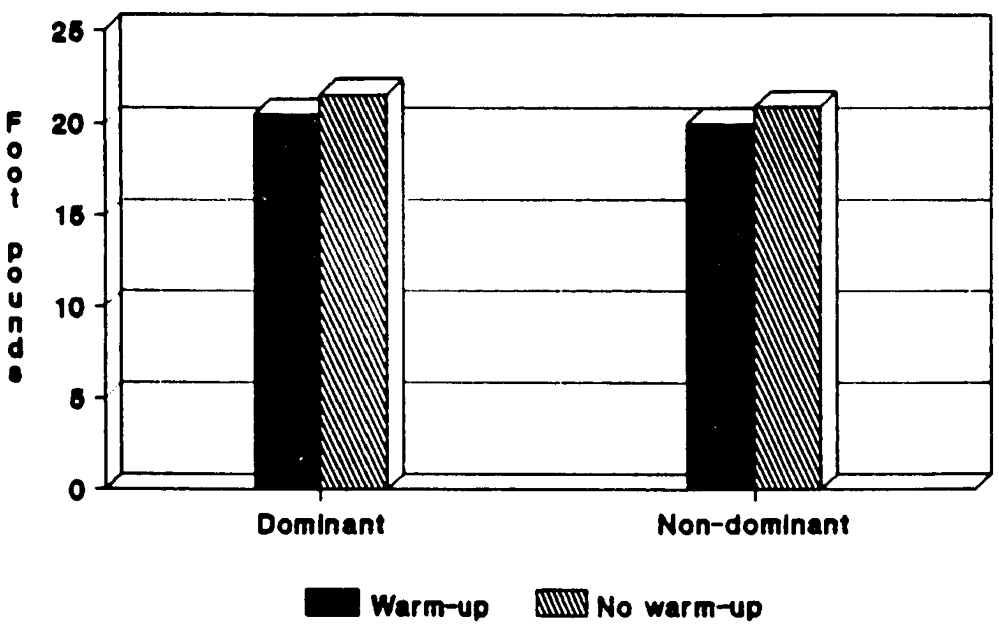

Figure 6. Torque Accelerated Energy for Extension at 180 Degrees Per Second

Table 13

Torque Accelerated Energy for Flexion of the Dominant Leg at 60 Degrees per Second

	Means and Standard Deviations		
Condition	N	Mean	S. D.
Warm-up	22	4.36	1.52
No warm-up	22	4.63	1.43
Entire sample	44	4.50	1.47

Univariate Analysis

Source	DF	SS	MS	F	Sig.
Condition	1	0.81	0.81	0.37	.54
Error	42	92.18	2.19		

deviation of 1.43 was obtained by the subjects in the control group, while the experimental group established a standard deviation of 1.52. Univariate analysis of measures of torque accelerated energy developed during flexion of the dominant knee resulted in an F-ratio of 0.37 and a probability of 0.54. These results suggested that there was no significant difference between conditions.

Table 14 presents data regarding measurement of torque accelerated energy of flexion of the non-dominant knee at 60 degrees per second. Measurement of subject's dominant leg under the control condition resulted in mean torque accelerated energy of 4.72 foot-pounds and a standard deviation of 1.77. Following warm-up, subjects established a slightly depressed mean torque accelerated energy of 4.59 foot-pounds with a standard deviation of 1.86. A univariate analysis of the data pertaining to torque accelerated energy of flexion of the non-dominant knee found an F-ratio of 0.06 and a probability of 0.80. Differences in torque accelerated energy of knee flexion for dominant and non-dominant knees can be seen in Figure 7. These results offer the suggestion that a significant difference did not exist between the torque accelerated energy of the control group and of the experimental group.

The means for torque accelerated energy of flexion that were set by this research seemed to depart from the trend of depressed means that other parameter measurements

Table 14

Torque Accelerated Energy for Flexion of the Non-dominant Leg at 60 Degrees per Second

Condition	N	Mean	S. D.
	Means and Standard Deviations		
Warm-up	22	4.59	1.86
No warm-up	22	4.72	1.77
Entire sample	44	4.65	1.80

Source	DF	SS	MS	F	Sig.
	Univariate Analysis				
Condition	1	0.20	0.20	0.06	.80
Error	42	139.68	3.32		

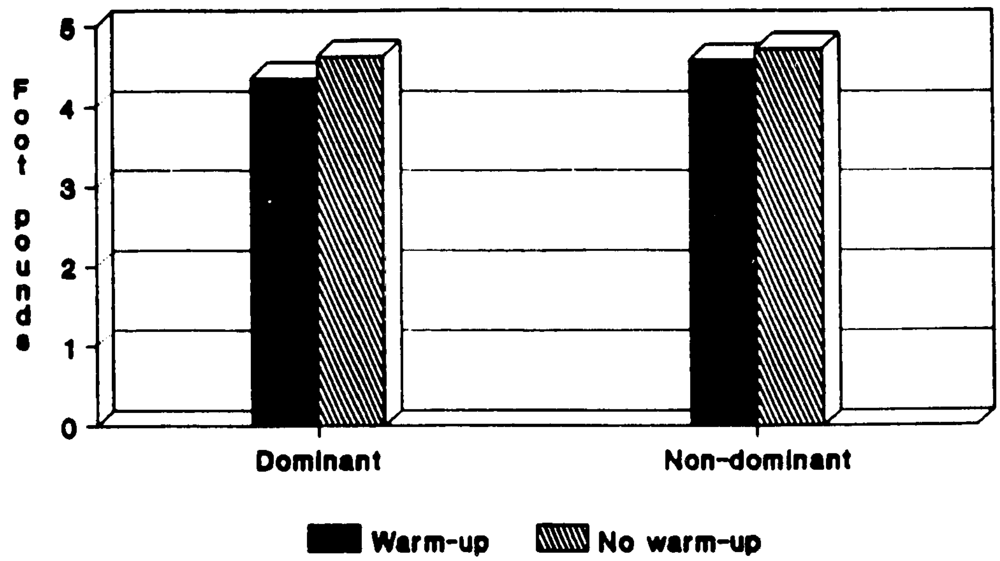

Figure 7. Torque Accelerated Energy for Flexion
at 60 Degrees per Second

established. With no warm-up, the dominant leg had a torque accelerated energy that was 119.94% of Davies' (1987) norms, and measurement following warm-up resulted in a torque accelerated energy mean that was 112.95% of the norms. Measurement of the non-dominant leg posted means that were 122.27% with no warm-up and 118.91% following warm-up. This departure may be attributed to athletic tendencies of the habitually active subjects.

An analysis of data relating to torque accelerated energy for flexion of the dominant knee at 180 degrees per second is given in Table 15. The control group produced a

Table 15

Torque Accelerated Energy for Flexion of the Dominant Leg at 180 Degrees per Second

	Means and Standard Deviations		
Condition	N	Mean	S. D.
Warm-up	22	15.50	3.51
No warm-up	22	16.36	3.74
Entire sample	44	15.93	3.61

	Univariate Analysis				
Source	DF	SS	MS	F	Sig.
Condition	1	8.20	8.20	.62	.45
Error	42	554.59	13.20		

mean torque accelerated energy of 16.36 foot-pounds with a standard deviation of 3.74. Following warm-up, a mean of 15.50 foot-pounds of torque accelerated energy was developed. A univariate analysis of the data pertaining to torque accelerated energy resulted in an F-ratio of .62 and a probability of 0.45. Interpretation of these results implied warm-up produced no significant difference in torque accelerated energy of flexion of the dominant knee at 180 degrees per second.

Table 16 refers to the analysis of data for torque accelerated energy for flexion of the non-dominant knee at 180 degrees per second. With no warm-up, subjects produced a mean torque accelerated energy of 15.13 foot-pounds. Following warm-up, the mean torque accelerated energy of 14.77 foot-pounds was slightly depressed. The standard deviation for the control group was 4.59, and the experimental condition established a standard deviation of 4.08.

The univariate analysis of the data for torque accelerated energy of the non-dominant leg at 180 degrees per second revealed an F-ratio of 0.77 and a probability of 0.78. These results implied that there was no significant difference in torque accelerated energy between conditions. Differences between conditions are reflected in Figure 8.

Although warm-up made no significant difference between conditions in torque accelerated energy of flexion at 180

Table 16

Torque Accelerated Energy for Flexion of the Non-dominant Leg at 180 Degrees per Second

	Means and Standard Deviations		
Condition	N	Mean	S. D.
Warm-up	22	14.77	4.08
No warm-up	22	15.13	4.59
Entire sample	44	14.95	4.29

	Univariate Analysis				
Source	DF	SS	MS	F	Sig.
Condition	1	1.45	1.45	0.77	.78
Error	42	792.45	18.86		

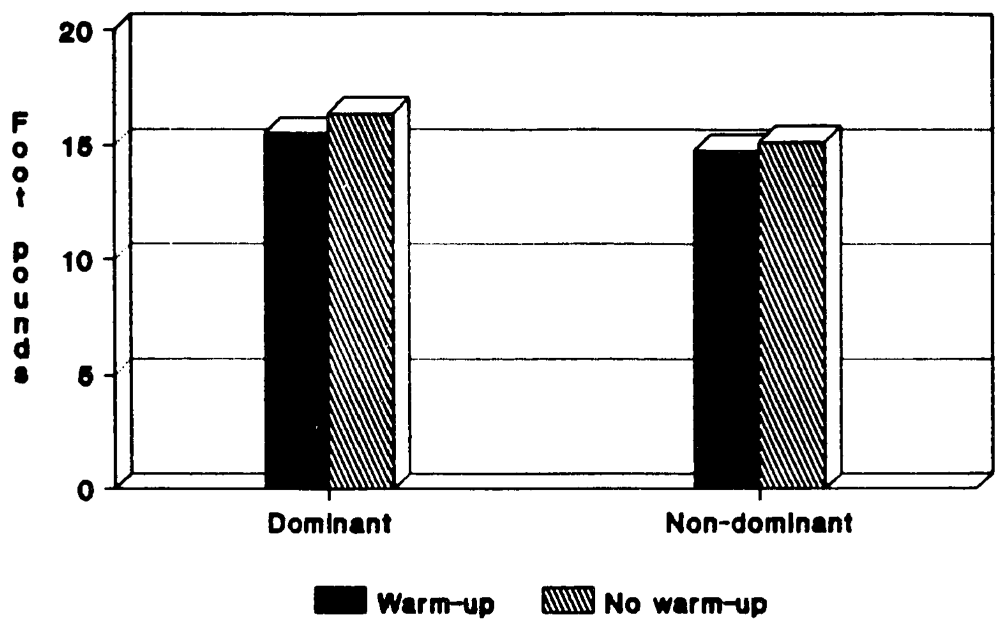

Figure 8. Torque Accelerated Energy for Flexion at 180 Degrees Per Second

degrees per second, the means for the dominant and the non-dominant legs were elevated when compared to the norms suggested by Davies (1987). The mean torque accelerated energy of the dominant leg was 111.67% of the norms, and warm-up resulted in a mean that was 105.80% of the norms. Testing the non-dominant leg with no warm-up resulted in a mean torque accelerated energy that was 103.27% of the norms, and measurement under the experimental condition established a mean that was .81% higher than the norms of Davies (1987). The tendencies of the habitually active subjects may account for the elevated means.

When considering the effects of warm-up, the pathway that is to supply the energy for the type of task at hand seems to be a prime consideration. At the onset of exercise during warm-up, adenosinetriphosphate (ATP) is converted to adenosinediphosphate (ADP) and free phosphate at the cross-bridges in order to develop tension within the muscle. The increase in the ADP in the cytoplasm of the myofibrils brings into action the ATP producing systems in order to meet the ATP demands of the cross-bridges.

Creatine phosphate responds immediately to the ATP demand. Glycolysis and oxidative phosphorylation provides all ATP aerobically during steady state. In the present study, subjects who underwent warm-up established the steady state between two and three minutes after commencement of exercise.

Maximal performances of 10 to 60 seconds duration during isokinetic testing are predominantly anaerobic. The intensity of the muscular contractions during test sessions elicits a progression of muscle fiber recruitment from Type I to Type IIa to Type IIb. The ATP supply needed for contraction is dependent on anaerobic sources of ATP. Thus, fatigue is specific to the type of task undertaken.

If a task requires recruitment of Type I muscle fibers, factors that limit performance will be different than factors that limit performance that utilized Type II muscle fibers. According to the research of Sale (1987), exercise intensities up to about 40% maximal oxygen consumption recruit the Type I slow-twitch muscle fiber to provide tension development. Type IIa fast-twitch fatigue resistant fibers are recruited between 40% to 75% maximal oxygen consumption. Type IIa fibers have many mitochondria and depend on the delivery of oxygen for contraction. Type IIb muscle fibers, which are recruited at about 75% maximal oxygen consumption, have few mitochondria. Type IIb fibers generate a great deal of tension through anaerobic energy sources, but fatigue quickly.

The non-specific warm-up used in this study may be equated to an endurance event, and isokinetic testing may be considered a power event. The number and ratios of fiber types are genetically determined and may play a role in endurance and power events.

According to Sale's data, the exercise intensity that was used for warm-up in this study, 50% maximal oxygen consumption, would result in Type IIa muscle fibers being recruited. It appears that a non-specific warm-up of the type and intensity used in this study tends to utilize the aerobic energy pathway where isotonic testing depends on anaerobic energy pathways. Therefore, if fatigue is specific to the type of task undertaken and fatigue was a limiting factor during warm-up, it seems that fatigue cannot be responsible for the depressed means of muscle function.

On the other hand, peripheral fatigue may have contributed to the observed depressed means. One of the sites that seems to be related to peripheral fatigue is the cross-bridge. The action of the cross-bridge depends on two conditions: (1) the availability of calcium for binding with troponin allowing the cross-bridge to bind with the actin and (2) the availability of ATP which is needed for activation of the cross-bridge and for the dissociation of the cross-bridge from actin.

A high hydrogen ion concentration resulting from a high rate of lactate formation may interfere with calcium binding to troponin, thus, reducing the tension developed by the muscle. This may explain the impairment of muscle function during strength measurement. The results of this study revealed that non-specific warm-up did not significantly enhance peak torque or torque accelerated energy as measured isokineticly.

CHAPTER 5

Summary, Conclusions, and Implications for Teaching

Summary

This study was undertaken to determine the effect of warm-up on peak torque and on torque accelerated energy of the muscles of the knee. Twenty-two male subjects who were habitually active and had no history of joint disease or acute joint trauma participated in this study.

Prior to testing, each subject attended an orientation session where he became familiar with the testing instrument and procedures. Each subject was tested twice on a Cybex 340 Extremity Testing System: (1) control condition involving measurement with no warm-up and (2) experimental condition involving measurement following warm-up.

All warm-up procedures were completed on a stationary bicycle ergometer. Subjects were tested isokineticly at 60 degrees per second and at 180 degrees per second. Peak torque and torque accelerated energy measures were obtained for both legs of each subject.

Multivariate analysis of variance was used to determine if there was a significant difference in measures with and without warm-up. The results of the multivariate analysis suggested that no significant differences existed between conditions.

Conclusions

A conclusion was drawn for each of the four hypotheses tested. HO_1 stated that no significant difference will exist between peak torque developed during work at 60 degrees per second following warm-up and peak torque developed during work at 60 degrees per second with no warm-up.

While warm-up resulted in depressed means in all measurements of peak torque developed during work performed at 60 degrees per second, no significant difference between conditions was found. Therefore, HO_1 is accepted. There was no significant difference between peak torque developed during work performed at 60 degrees per second following warm-up and peak torque developed during work performed at 60 degrees per second with no warm-up.

HO_2 stated no significant difference will exist between peak torque developed during work at 180 degrees per second following warm-up and peak torque developed during work at 180 degrees per second with no warm-up. During work at 180 degrees per second under the experimental condition, one mean was elevated, while the remaining three means were depressed. These differences were slight and were not significant at the chosen level of significance. As there were no significant differences in peak torque developed during work at 180 degrees per second following warm-up and peak torque developed during work with no warm-up, HO_2 is accepted.

The third hypothesis tested proposed that no significant difference will exist between torque accelerated energy developed during work at 60 degrees per second following warm-up and torque accelerated energy developed during work at 60 degrees per second with no warm-up. The measure that closest approached significance was the mean torque accelerated energy of extension at 60 degrees per second. This was the only measure of torque accelerated energy that was elevated following warm-up. No significant differences existed between torque accelerated energy developed during work performed following warm-up and torque accelerated energy developed during work performed with no warm-up. Therefore, HO_3 is accepted.

HO_4 stated that no significant difference will exist between torque accelerated energy developed during work at 180 degrees per second following warm-up and torque accelerated energy developed during work at 180 degrees per second with no warm-up. Torque accelerated energy of flexion at 180 degrees per second developed by the non-dominant leg following warm-up was elevated, although the elevation was not significant.

All other measures of torque accelerated energy during work at 180 degrees per second after warm-up had depressed means. Since there were no significant differences in torque accelerated energy developed during work following warm-up and torque accelerated energy developed during work with no warm-up, HO_4 is accepted.

In conclusion, warm-up had no effect on isokinetic measures at the knee. It is further concluded that an aerobic warm-up does not enhance performance that utilizes anaerobic energy systems.

Implications for Teaching

This section will address implications of this research for teaching within the broader area of physical education and for teaching within the narrower field of athletic training. Professionals in education are accountable for what they teach. Knowledge acquired by students should be based on fact founded on investigation, wherever possible, and not on empirical opinions.

Literature is proliferate with claims of the value and benefits of warm-up. Physical educators, classroom educators, and clinical educators have instilled into students the concept that an adequate warm-up must precede any physical activity. Definitions of adequate warm-up have been vague and have tended to accommodate the aims and philosophies of investigators who have studied the effects of warm-up.

It has been suggested that elevated temperatures resulting from warm-up are responsible for the effects of warm-up. The results of this research indicate that the elevated temperatures following a non-specific warm-up do not significantly enhance muscular strength or acceleration.

Physical educators should foster the conviction that warm-up should be kept as specific to the task as possible. Students in a weight training class, for example, would use the first set of a resistive exercise for a specific warm-up. In clinical athletic training, Knight (1979) employs a resistive exercise protocol that uses the first two of four sets of resistive exercise as a specific warm-up.

Many athletic training education programs embrace the concept that warming up on a stationary bicycle prior to testing or training is essential for quantitative results. The results of this research suggest that a non-specific warm-up does not provide the results that are asserted by many athletic training programs. A warm-up that is specific to isokinetic testing and training would involve the use of a specified number of repetitions at the same speed that would be used during the test. If more than one speed is to be used for the test, each speed should employ its own warm-up set.

Warm-up, as used in this study and in many testing and rehabilitation protocols, does not enhance muscle function as believed by many educators and clinicians. The results of this research suggest that a non-specific warm-up (e.g., pedaling a stationary bicycle ergometer prior to testing or training on an isokinetic device) results in a slight depression of some parameters of muscle function. Certainly, more research is warranted to investigate an appropriate warm-up for isokinetic testing and rehabilitation protocols.

APPENDICES

APPENDIX A

RESEARCH ETHICS COMMITTEE APPROVAL LETTER

APPENDIX A

RESEARCH ETHICS COMMITTEE APPROVAL LETTER

TO: Steve Rathbone and Powell P. McClellan
HPERS

FROM: Peter Heller ph
Chair, MTSU Research Ethics Committee

RE: Review: Use of Human Subjects

Date: January 31, 1991

The purpose of this memo is to inform you that the MTSU Research Ethics Committee has favorably evaluated your research proposal in terms of its ethical utilization of human subjects. Best of luck on the successful completion of your project.

APPENDIX B

INFORMED CONSENT FORM

APPENDIX B

INFORMED CONSENT FORM

1. Explanation of Testing Protocol

You have been asked to participate in an investigation of the effects of warm-up on strength. The test you will be participating in consists of measurement of torque generated by the quadriceps muscles and the hamstring muscles. All measurements will be recorded on the Cybex 340 muscle testing system. Each subject will be tested twice on the Cybex system: (1) the control condition involving measurement with no warm-up and (2) the experimental condition involving measurement following warm-up on a bicycle ergometer.

2. Risks and Discomforts

An acute or unrehabilitated injury to the knee (especially the anterior cruciate ligament) is a contraindication to participation in this investigation. Any discomfort you may experience should be limited to muscular discomfort associated with any intense exercise.

3. Freedom of Consent

Your permission to engage in this investigation is voluntary. You are free to deny any consent if you so desire, both now and at any point in the investigation.

4. Consent to Participate

I acknowledge that I have read this form in its entirety or it has been read to me and that I understand the investigation in which I will be engaged. I consent to participate in this investigation.

Signature   Date

APPENDIX C

PHYSICAL CHARACTERISTICS OF SUBJECTS

APPENDIX C

PHYSICAL CHARACTERISTICS OF SUBJECTS

Subject Number	Age (Years)	Length	RHR	HRR	Height (Inches)	Weight (Pounds)
1	22	28.25	60	129	68.75	160
2	25	27.50	56	126	68.50	156
3	27	28.75	72	133	73.25	215
4	22	30.25	74	136	74.25	197
5	25	25.00	60	128	72.50	184
6	22	31.00	70	134	73.50	245
7	29	24.20	78	135	66.50	163
8	23	22.00	58	128	71.50	187
9	23	25.50	60	129	72.00	248
10	23	27.50	84	141	72.25	267
11	23	28.50	68	133	67.25	172
12	21	27.25	84	142	67.00	127
13	20	35.50	70	135	74.75	283
14	23	24.50	60	129	71.25	231
15	21	26.75	88	144	74.00	245
16	22	28.00	96	147	70.25	197
17	26	25.50	88	141	26.25	253
18	26	25.50	60	127	66.00	145
19	19	26.00	66	134	71.75	193
20	20	30.25	80	140	73.00	153
21	23	25.50	56	127	69.75	231
22	26	23.25	92	143	62.50	146

Means: Age (Years) = 23.22, Length = 27.11, RHR = 71.81, HRR = 134.59, Height (Inches) = 68.48, Weight (Pounds) = 199.90.

S. D.: Age (Years) = 2.50, Length = 2.96, RHR = 12.66, HRR = 6.38, Height (Inches) = 9.95, Weight (Pounds) = 44.90.

APPENDIX D

CALIBRATION DATA

APPENDIX D

CYBEX CALIBRATION DATA

Date	Uncalibrated 70 pounds	Calibrated 70 pounds	Uncalibrated 5 pounds	Calibrated 5 pounds
1/28	220	180	22	20
1/29	215	180	23	20
1/30	209	180	23	20
1/31	213	180	23	20

APPENDIX E

RAW DATA

APPENDIX E

RAW DATA

Peak Torque of Knee Extension at 60 Degrees per Second

Subject Number	Dominant Knee Warm-up	Dominant Knee No Warm-up	Non-dominant Knee Warm-up	Non-dominant Knee No Warm-up
1	137	158	147	152
2	149	160	147	129
3	217	212	219	199
4	207	251	232	224
5	214	199	212	197
6	257	266	249	276
7	149	150	149	134
8	198	175	200	184
9	163	210	150	180
10	184	209	172	220
11	142	156	149	150
12	99	95	108	94
13	268	256	237	214
14	198	203	186	196
15	254	242	225	230
16	194	181	185	166
17	113	135	114	114
18	119	125	107	95
19	210	203	199	215
20	154	166	167	169
21	170	191	196	208
22	111	116	109	104
Means:	177.59	184.50	175.40	175.00
S. D:	48.72	46.22	44.20	48.92

Peak Torque of Knee Flexion at 60 Degrees per Second

	Dominant Knee		Non-dominant Knee	
	Warm-up	No Warm-up	Warm-up	No Warm-up
Subject Number				
1	113	105	123	120
2	94	87	99	102
3	141	126	122	121
4	128	139	150	133
5	137	142	139	147
6	137	144	119	140
7	116	99	99	90
8	87	88	96	65
9	107	124	80	97
10	112	118	87	103
11	95	97	96	101
12	61	52	62	52
13	131	160	120	142
14	95	108	112	122
15	146	138	146	143
16	115	106	118	120
17	78	75	81	82
18	81	89	77	66
19	114	113	98	110
20	119	120	119	136
21	94	95	96	101
22	64	53	58	72
Means:	107.50	108.09	104.40	107.50
S. D.:	24.29	28.20	24.91	27.87

Peak Torque of Knee Extension at 180 Degrees per Second

	Dominant Knee		Non-dominant Knee	
	Warm-up	No Warm-up	Warm-up	No Warm-up
Subject Number				
1	113	125	111	118
2	93	103	85	91
3	178	158	142	145
4	173	182	163	182
5	165	166	162	170
6	186	195	182	190
7	102	96	99	102
8	116	115	125	126
9	132	134	142	137
10	128	156	136	157
11	97	85	99	89
12	79	75	79	75
13	185	185	183	166
14	140	141	125	136
15	175	171	169	151
16	134	121	124	115
17	87	91	87	87
18	80	91	89	88
19	161	150	145	153
20	118	126	118	112
21	168	177	153	169
22	82	86	78	83
Means:	131.45	133.13	127.09	129.18
S. D.:	37.27	37.27	33.38	35.36

Peak Torque of Knee Flexion at 180 Degrees per Second

	Dominant Knee		Non-dominant Knee	
	Warm-up	No Warm-up	Warm-up	No Warm-up
Subject Number				
1	94	88	95	88
2	61	60	60	64
3	115	89	74	81
4	106	117	100	113
5	100	101	108	113
6	101	99	88	101
7	82	64	72	51
8	62	56	74	55
9	81	94	75	72
10	92	115	70	95
11	81	72	77	72
12	58	57	53	50
13	122	127	117	113
14	85	93	87	92
15	121	106	115	105
16	82	80	87	90
17	73	71	70	69
18	72	70	64	64
19	84	86	77	86
20	86	94	94	101
21	90	92	77	102
22	49	47	50	56
Means:	86.22	85.36	81.09	83.31
S. D.:	19.64	21.41	18.26	21.03

Torque Accelerated Energy During Knee Extension
at 60 Degrees per Second

	Dominant Knee		Non-dominant Knee	
	Warm-up	No Warm-up	Warm-up	No Warm-up
Subject Number				
1	4	6	6	6
2	2	4	3	4
3	7	6	4	5
4	4	6	6	5
5	11	6	6	6
6	4	8	7	8
7	3	4	4	4
8	4	3	4	3
9	4	4	2	3
10	6	6	3	5
11	5	5	6	5
12	2	3	2	2
13	9	5	7	7
14	10	4	7	7
15	12	6	7	7
16	4	3	4	4
17	6	5	3	3
18	1	2	2	1
19	5	4	5	5
20	5	5	4	5
21	10	4	8	6
22	3	3	2	3
Means:	5.50	4.63	4.63	4.72
S. D.:	3.08	1.43	1.94	1.77

Torque Accelerated Energy During Knee Flexion
at 60 Degrees per Second

	Dominant Knee		Non-dominant Knee	
	Warm-up	No Warm-up	Warm-up	No Warm-up
Subject Number				
1	5	6	6	6
2	3	4	3	4
3	6	6	4	5
4	6	6	6	5
5	7	6	6	6
6	5	8	7	8
7	5	4	4	4
8	4	3	4	3
9	2	4	2	3
10	4	6	3	5
11	5	5	6	5
12	3	3	2	2
13	6	5	7	7
14	6	4	7	7
15	7	6	7	7
16	4	3	4	4
17	3	5	3	3
18	3	2	2	1
19	4	4	5	5
20	3	5	4	5
21	3	4	7	6
22	2	3	2	3
Means:	4.36	4.63	4.59	4.72
S. D.:	1.52	1.43	1.86	1.77

Torque Accelerated Energy During Knee Extension
at 180 Degrees per Second

	Dominant Knee		Non-dominant Knee	
	Warm-up	No Warm-up	Warm-up	No Warm-up
Subject Number				
1	16	16	17	21
2	12	15	11	16
3	26	24	21	20
4	24	23	21	24
5	23	22	21	26
6	25	29	27	29
7	18	15	18	15
8	17	19	14	18
9	18	25	21	20
10	19	26	18	27
11	17	15	19	17
12	11	11	11	10
13	29	27	29	23
14	28	34	28	32
15	34	29	32	29
16	21	16	18	19
17	11	15	14	15
18	11	11	11	11
19	26	22	23	22
20	18	21	20	17
21	35	37	33	33
22	12	13	13	15
Means:	20.50	21.13	20.00	20.86
S. D.:	7.24	7.25	6.56	6.43

Torque Accelerated Energy During Knee Flexion
at 180 Degrees per Second

	Dominant Knee		Non-dominant Knee	
	Warm-up	No Warm-up	Warm-up	No Warm-up
Subject Number				
1	20	18	15	15
2	12	12	11	12
3	17	16	9	10
4	16	20	18	18
5	18	22	21	20
6	18	22	21	26
7	12	13	13	11
8	12	12	15	9
9	11	13	11	12
10	11	16	9	10
11	17	18	15	15
12	14	13	12	14
13	20	20	15	23
14	19	21	20	18
15	22	22	21	20
16	13	14	12	12
17	16	14	13	13
18	14	12	11	9
19	17	16	18	18
20	14	15	12	16
21	19	20	21	18
22	9	11	12	14
Means:	15.50	16.36	14.77	15.13
S. D.:	3.51	3.74	4.08	4.59

BIBLIOGRAPHY

BIBLIOGRAPHY

Anshel, M. H. (1985). The effect of arousal on warm-up decrement. Research Quarterly for Exercise and Sport, 56, 1-9.

Arnheim, D. D. (1989). Modern principles of athletic training (6th ed.). St. Louis: Times/Mirror Mosby College.

Arnheim, D. D. (1987). Essentials of athletic training. St. Louis: Times Mirror/Mosby College.

Asmussen, E., & Boje, O. (1945). Body temperature and capacity for work. Acta Physiologica Scandinavia, 10, 1-22.

Astrand, P. O., & Rodahl, K. (1970). Textbook of work physiology (2nd ed.). New York: McGraw-Hill.

Baltzopoulos, V., Williams, J. G., & Brodie, D. A. (1991). Sources of errors in isokinetic dynamometry: Effects of visual feedback on maximum torque measurements. The Journal of Orthopaedic and Sports Physical Therapy, 13(3), 138-142.

Barcroft, J., & King, W. O. R. (1909). The effect of temperature on the dissociation curve of blood. Journal of Physiology, 39, 374-384.

Barnard, R. J., Gardener, G. W., Diaco, N. V., MacAlpin, R. N., & Kattus, A. A. (1973). Cardiovascular responses to sudden strenuous exercise--Heart rate, blood pressure, and EKG. Journal of Applied Physiology, 34, 833-837.

Beam, W. C., Bartels, R. L., & Ward, R. W. (1982). The relationship of isokinetic torque to body weight and to lean body weight in athletes. Medicine and Science in Sport and Exercise, 14, 178.

Bergh, U., & Ekblom, B. (1979). Physical performance and peak aerobic power at different body temperatures. Journal of Applied Physiology, 46, 885-889.

Binkhorst, R. A., Hoofd, L., & Vissers, A. C. A. (1977). Temperature and force/velocity relationship of human muscle. Journal of Applied Physiology, 42, 471-475.

Blomstrand, E., Bergh, U., Essen-Gustavsson, B., & Ekblom, E. (1984). Influence of low muscle temperature on muscle metabolism during intense dynamic exercise. Acta Physiologica Scandinavia, 120, 229-236.

Campbell, D. E., & Glenn, W. (1979). Foot pounds of torque of the normal knee and the rehabilitated post-menescetomy knee. Physical Therapy, 59(4), 418-421.

Cybex 340 system user's manual. (1989). Ronkonkoma, NY: Lumex.

Davies, G. J. (1987). A compendium of isokinetics in clinical usage and rehabilitation techniques (3rd ed.). Onalaska, WI: S & S.

Davies, G. J., Kirkendall, D. T., Leigh, D. H., Lui, M. L., Reinbold, T. R., & Wilson, P. K. (1981). Isokinetic characteristics of professional football players: Normative relationships between quadriceps and hamstring muscle groups and relative to body weight. Medicine and Science in Sport and Exercise, 13, 76.

De Bruyn-Prevost, P., & Lefebvre, F. (1980). The effects of various warming-up intensities and durations during a short maximal anaerobic exercise. European Journal of Applied Physiological Occupational Physiology, 43, 101-107.

DeLateur, B., Lehmann, J. F., Warren, C. G., Stonebridge, J., Furnita, G., Cokelet, K., & Egbert, H. (1979). Comparison of the effectiveness of isokinetic and isotonic exercise in quadriceps strengthening. Archives of Physical Medicine and Rehabilitation, 53, 60-64.

deVries, H. A. (1986). Physiology of exercise for physical education and athletics. Dubuque: William C. Brown.

Fahey, T. D. (1986). Athletic training: Principles and practice. Palo Alto, CA: Mayfield.

Freischlag, J. (1987). Total warm-ups. Physical Educator, 44, 278-280.

Gleim, G. W., Nicholas, J. A., & Webb, J. N. (1978). Isokinetic evaluation following leg injuries. The Physician and Sportsmedicine, 6(8), 75-82.

Goslin, B. R., & Charteris, J. (1979). Isokinetic dynamometry: Normative data for clinical use in lower extremity (knee) cases. Scandinavian Journal of Rehabilitative Medicine, 11, 105-109.

Gould, J. A., & Davies, G. J. (1985). Orthopaedic and sports physical therapy. St. Louis: C. V. Mosby.

Guidelines for exercise testing and prescription (3rd ed.). (1986). American College of Sports Medicine. Philadelphia: Lea & Febiger.

High, D. M., Howley, D. T., & Franks, B. D. (1989). The effects of static stretching and warm-up on prevention of delayed-onset muscle soreness. Research Quarterly for Exercise and Sport, 60, 357-361.

Hoyle, R. J., & Smith, R. F. (1989). Warm-up with skill. Journal of Physical Education, Recreation and Dance. 60(9), 15-16.

Isolated joint testing: A handbook for using Cybex II and the U.B.X.T. (1983). Ronkonkoma, NY: Cybex.

Johnson, J., & Siegel, D. (1978). Reliability of an isokinetic movement of the knee extensors. The Research Quarterly, 49(1), 88-90.

Karpovich, P. V., & Hale, C. J. (1956). Effect of warming-up upon physical performance. Journal of the American Medical Association, 162, 1117-1119.

Karvonen, M. J., Kentala, E., & Mustala, O. (1957). The effects of training on heart rate. Anals of Medical Exper. Fenn., 35, 307-315.

Kelly, J. M., Gorney, B. A., & Kalm, K. K. (1978). The effects of a collegiate wrestling season on body composition, cardiovascular fitness, and muscular strength and endurance. Medicine and Science in Sports, 10, 119-124.

Knight, K. L. (1979). Knee rehabilitation by the daily adjustable progressive resistive technique. The American Journal of Sports Medicine, 7(6), 336-337.

Kroemer, K. H. E., & Howard, J. M. (1970). Towards standardization of muscle strength testing. Medicine and Science in Sports, 2(4), 224-230.

Lamb, D. R. (1978). Physiology of exercise: Responses and adaptions. New York: MacMillan.

Lehmkuhl, L. D., & Smith, L. K. (1986). Brunnstrom's clinical kinesiology. Philadelphia: F. A. Davis.

Massey, B. H., Johnson, W. R., & Kramer, G. F. (1960). Effect of warm-up exercise upon muscular performance using hypnosis to control the psychological variable. The Research Quarterly, 32(1), 63-71.

Mathews, D. K., & Fox, E. L. (1976). The physiological basis of physical education and athletics (2nd ed.). Philadelphia: W. B. Saunders.

McDavid, R. S. (1991, June 5). Telephone interview.

Moffroid, M. A., Whipple, R., Hofkosh, J., Lowman, J., & Thistle, H. (1969). A study of isokinetic exercise. Physical Therapy, 49(7), 735-744.

Muido, L. (1946). The influence of body temperature on performances in swimming. Acta Physiologica Scandinavia, 12, 102-109.

Neuberger, T. (1969, October). What the Research Quarterly says about warm-up. JOHPER, 75-77.

Nielsen, H. V., Staberg, B., Nielsen, K., & Sejrsen, P. (1988). Effects of dynamic leg exercise on subcutaneous blood flow rate in the lower limb of man. Acta Physiologica Scandinavia, 134, 513-518.

Noble, B. J. (1986). Physiology of exercise and sport. St. Louis: Times Mirror/Mosby College.

Nukada, A. (1955). Hauttemperatur and leistungsfahigkeit in extremitaten bei statischer haltearbeit. Arbeitsphysiologie, 16, 74-80.

Nutter, J., & Thorland, W. G. (1987). Body composition and anthropometric correlates of isokinetic leg extension strength of young adult males. Research Quarterly for Exercise and Sport, 58(1), 47-51.

Osternig, L. R., Bates, B. T., & James, S. L. (1977). Isokinetic and isometric torque force relationships. Archives of Physical Medicine and Rehabilitation, 58, 254-257.

Osternig, L. R., Sawhill, J. A., Bates, B. T., & Hamill, J. (1981). Function of limb speed on torque ratios of antagonist muscles and peak torque joint position. Medicine and Science in Sport and Exercise, 13(2), 7.

Parker, M. G., Holt, D., Bauman, E., Drayna, M., & Ruhling, R. O. (1982). Descriptive analysis of bilateral quadriceps and hamstring muscle torque in high school football players. Medicine and Science in Sports and Exercise, 14, 152.

Perrin, D. H. (1986). Reliability of isokinetic measures. Athletic Training, 21, 319-321.

Perrine, J. J. (1968). Isokinetic exercise and the mechanical energy potentials of muscles. Journal of Health, Physical Education and Recreation, 39, 40-43.

Rankin, J. M., & Thompson, C. B. (1983). Isokinetic evaluation of quadriceps and hamstring function: Normative data concerning body weight and sport. Athletic Training, 18, 110-114.

Robergs, R. A., Pascoe, D. D., Costill, D. L., Fink, W. J., Chwalbinska-Moneta, J., Davis, J. A., & Hickner, R. (1991). Effects of warm-up on muscle glycogenolysis during intense exercise. Medicine and Science in Sport and Exercise, 23(1), 37-43.

Roy, S., & Irvin, R. (1983). Sports medicine: Prevention, evaluation, management, & rehabilitation. Englewood Cliffs, NJ: Prentice-Hall.

Safran, M. R., Garrett, W. G., Seaber, A. V., Glisson, R. R., & Ribbeck, B. M. (1988). The role of warm-up in muscular injury prevention. The American Journal of Sports Medicine, 16, 123-129.

Sale, D. G. (1987). Influence of exercise and training on motor unit activation. In K. B. Pandolf (Ed.), Exercise and sport sciences reviews 15, 95-151. New York: MacMillan.

Saltin, B., Gagge, A. P., & Stolwijk, J. A. J. (1968). Muscle temperature during submaximal exercise in man. Journal of Applied Physiology, 25, 679-688.

Schmidt, R. A. (1988). Motor control and learning. Champaign, IL: Human Kinetics.

Sedgwick, A. W., & Whalen, H. R. (1963). Effect of passive warm-up on muscular strength and endurance. The Research Quarterly, 35(1), 45-59.

Stamford, B. (1987). Warming-up. The physician and sportsmedicine, 15(11), 168.

Stedman, T. L. (1982). Stedman's medical dictionary. Baltimore: Williams & Wilkins.

Stone, W. J., & Kroll, W. A. (1986). Sports conditioning and weight training (2nd ed.). Newton, MA: Allyn & Bacon.

Thigpen, L. K., Blanke, D., & Lang, P. (1990). The reliability of two different Cybex isokinetic systems. The Journal of Orthopaedic and Sports Physical Therapy, 12(4), 157-162.

Thistle, H. G., Hislop, H. J., Moffroid, M., & Lowman, E. W. (1967). Isokinetic contraction: A new concept of resistive exercise. Archives of Physical Medicine and Rehabilitation, 40, 279-282.

Thorstensson, A., Grimby, G., & Karlsson, J. (1976). Force velocity relations and fiber composition in human knee extensor muscles. Journal of Applied Physiology, 40(1), 12-15.

Trundle, T. L. (1984). Cybex isokinetic testing and rehabilitation. Greenville: Institute for Exercise and Sports Medicine.

Wiktorsson-Moller, M., Oberg, B., Ekstrand, J., & Gillquist, J. (1983). Effects of warming-up, massage, and stretching on range of motion and muscle strength in the lower extremity. The American Journal of Sports Medicine, 11, 249-252.

Winter, D. A., Wells, R. P., & Orr, G. W. (1981). Errors in the use of isokinetic dynamometers. European Journal of Applied Physiology, 46, 397-408.

Wyatt, M. P., & Edwards, A. M. (1981). Comparison of quadriceps and hamstring torque values during isokinetic exercise. The Journal of Orthopaedic and Sports Physical Therapy, 3(2), 48-56.