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Effects of various rest intervals on isokinetic knee extension and flexion strength

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EFFECTS OF VARIOUS REST INTERVALS ON ISOKINETIC KNEE EXTENSION AND FLEXION STRENGTH

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EFFECTS OF VARIOUS REST INTERVALS

ON ISOKINETIC KNEE EXTENSION

AND FLEXION STRENGTH

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ABSTRACT

EFFECTS OF VARIOUS REST INTERVALS ON ISOKINETIC KNEE EXTENSION AND FLEXION STRENGTH

Timothy Ross Johnson

This study investigated the effects of various rest intervals on isokinetic knee extension and flexion strength. Thirty male subjects, age 24.23 $\pm$ 4.80 years, height 181.74 $\pm$ 7.44 centimeters, weight 88.4 $\pm$ 16.05 kilograms, and body fat 18.07 $\pm$ 7.66 percent, were tested on a Cybex isokinetic dynamometer under three different rest interval treatments. The treatments consisted of a one-, three-, or five-minute rest interval administered between four sets of five maximal repetitions of isokinetic extension and flexion exercise at a controlled velocity of sixty degrees per second. All subjects visited the Human Performance Laboratory on four separate occasions. The initial visit was to measure physical characteristics and acquaint each subject with the Cybex by a bilateral comparison of knee extension and flexion strength. This bilateral test was used to determine the dominant limb. All successive visits were conducted on non-consecutive days with the rest interval treatment being randomly assigned and the dominate limb used for all further testing. Multivariate, univariate, and pair-wise contrasts were conducted to analyze the data. A significant difference ($p < .05$) was obtained between the one-minute and three-minute treatments and between the one-minute and five-minute treatments. There were no differences between the three-minute and five-minute treatments. The Pearson Correlation Coefficients for fat-free body weight and the strength measurements revealed significant relationships ($p < .05$). Fat-free body weight was significantly correlated with 47 of 48 strength measurements. It is concluded that a three-minute rest interval allowed the muscle sufficient time for recovery after five isokinetic knee extension and flexion repetitions.

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CHAPTER I

Introduction

Throughout history, man has always seemed to be intrigued by strength and by the men who demonstrated great strength. Samson, Hercules, and others are remembered for their great strength. Strength training principles and practices have also been used by athletes since antiquity. The first recorded progressive resistance training was practiced by a Greek named Milo of Crotona in the sixth century B.C. However, the Romans were credited with actually defining and organizing strength training practices and principles which have changed very little over the last 2000 years. Atha (1981) reported that some of the principles and variables of strength training had not been objectively examined. He noted that the rest interval had received very little attention and needed to be examined objectively.

The rest interval is very important to strength training and to the cellular adaptations derived from the training program. Kraemer, Fleck, and Deschenes (1988) noted that a reduction of the rest period may impair the maximal torque production capability because of physiological alterations in the muscle. This was important since tension was the stimulus for strength development, not fatigue. The "fatigued muscle cannot generate enough tension to reap the benefits of a maximum adaptive response" (Atha, 1981, p. 15). Therefore, the rate of fatigue and the training stress and adaptations were determined not only by the frequency, load, and duration of training, but also by the rest interval. Atha suggested that "the dependency of the training stress upon the rest interval thus demands quantification" (p. 27). The purpose of this study was to provide some needed quantification by examination of various rest intervals and their effects on isokinetic knee extension and flexion strength. A secondary purpose was to examine the relationship among isokinetic strength measures and the subjects' fat-free body weight.

Limitations

The limitations of the study were:

1. Subjects were 30 male students at Middle Tennessee State University who were enrolled in Health, Physical Education, and Recreation Department classes.

2. Peak torque was measured to the nearest foot-pound, using a Cybex 340.

3. Residual volume was predicted, based on the vital capacity.

Definition of Terms

For the purpose of this study, the following terms are defined:

Muscular strength--the maximum force generated by a muscle or muscle group (Powers & Howley, 1990).

Isokinetic dynamometer--a device used to measure force at a constant velocity through the range of motion (Osternig, 1986).

Maximum voluntary contraction--the greatest force a muscle or a muscle group can generate at a given position (Cafarelli, 1988).

Rest interval--the recovery time period between sets of an exercise.

Torque--the force produced at an axis of rotation.

Peak extension--the maximal torque generated by the knee extensors over five repetitions.

Peak flexion--the maximal torque generated by the knee flexors over five repetitions.

Average peak extension--the average maximal torque generated by the knee extensors over five repetitions.

Average peak flexion--the average maximal torque generated by the knee flexors over five repetitions.

Set--a series of repetitions performed without a rest interval.

Recovery--return of the ability to produce initial torque values measured during the first set.

Hypotheses

The following hypotheses were submitted for statistical treatments:

1. There will be no difference in peak extension torque among the rest interval treatments.

2. There will be no difference in peak flexion torque among the rest interval treatments.

3. There will be no difference in average peak extension torque among the rest interval treatments.

4. There will be no difference in average peak flexion torque among the rest interval treatments.

5. There will be no relationship between strength measures and fat-free body weight.

Need for the Study

The study provided useful information related to the time needed for muscle recovery following maximal voluntary isokinetic exercise. The study was unique since a basic strength training program of four sets of five repetitions were examined and repeated for three different rest intervals. Previous researchers have examined the effects of frequency, load, and duration on strength training, but few have attempted to examine the rest interval as a dependent variable. This study attempted to provide needed quantification of the rest intervals and the time needed between sets for recovery of initial strength.

CHAPTER II

Review of Related Literature

The following articles were examined to provide depth of information and support for the present study. The articles are arranged in chronological order under three main headings: (1) Isokinetics, (2) Muscle Strength and Training, and (3) Muscle Fatigue and Recovery.

Isokinetics

Moffroid, Whipple, Hofkosh, Lowman, and Thistle (1969) investigated the reliability of a Cybex isokinetic dynamometer on 10 test-retest sessions. Based on their research, a reliability coefficient (r = .995) was obtained using inert weights. A correlation (r = .946) was obtained using the mechanical computation and the measured value for work performed. A correlation coefficient (r = .999) was obtained for power, and a value (r = .985) was obtained between predicted and obtained speed.

Molnar and Alexander (1977) tested the reliability of the Cybex II by test-retest comparisons on children. They examined the elbow and knee flexors and extensors one week apart. They found no significant differences on the reliability of the Cybex II.

According to Hinson, Smith, and Funk (1979), confusion existed in the literature regarding the term "isokinetics" which needed clarification. The confusion was due to the change of the speed of the muscle contraction and acceleration. Hinson et al. concluded that the term "isokinetics" referred to contractions which accompany a constant angular velocity of a limb.

Beam, Bartel, and Ward (1982) examined the relationship of isokinetic torque to body weight and lean body weight in athletes. They used 178 subjects and measured torque output at 60, 180, and 300 degrees per second for the knee, shoulder, elbow, and ankle extensors and flexors. Lean body weight was found to have a significant relationship with isokinetic extension and flexion strength for all joints tested.

Mawdsley and Knapik (1982) examined the reliability of the Cybex II. They obtained a correlation coefficient ($\underline{r}$ = .993) for test-retest reliability of the isokinetic dynamometer using inert weights. They also examined the peak torque of maximal knee extension on three different test sessions which were separated by two weeks. No significant differences were found between the tests.

Fillyaw, Bevin, and Fernandez (1986) investigated the importance of correcting for gravity when measuring isokinetic peak torque to calculate flexor and extensor ratios. Twenty-five female soccer players were tested on an isokinetic device at 60 and 240 degrees per second. Fillyaw et al. concluded that a failure to consider the effect of gravity resulted in an underestimation of quadriceps muscle torque and an overestimation in hamstring muscle torque. They suggested that

> Clinicians must remember the importance of making the gravity correction in patients with reduced torque output where the gravitational torque is a greater percentage of the measured torque to ascertain correctly the relative strength of antagonists inversely affected by gravity. (p. 23)

Osternig (1986) reviewed the literature on isokinetic dynamometry. He postulated that safety was one of the major advantages to isokinetic exercise. This was because there was no external load to the limb, and the resistance encountered was simply due to the force applied to the dynamometer. Osternig noted that isokinetic exercise optimally loads the muscles throughout the range of motion, and thus minimized the risk of injury. The isokinetic dynamometry exercise was thus considered accommodating resistance, since "the resistance exerted by the dynamometer is proportionate to the amount of force exerted by the muscle and a maximal load can be applied at all points throughout the arc of motion" (p. 51). Another advantage of the isokinetic dynamometry was that torque was measured at all joint angles throughout the range of motion. Osternig concluded that certain types of isokinetic dynamometers such as the Cybex and Cybex II were safe and highly reliable.

Davies (1987) suggested a velocity spectrum testing for standard orthopedic tests. This included a slow contractile velocity of 60 degrees, a medium contractile velocity of 180 degrees, and a fast contractile velocity of 300 degrees per second. He recommended that five test repetitions be performed at each speed. Davies also provided normative data on peak isokinetic torque values. His data indicated that, at an angular velocity of 60 degrees per second, male subjects 15 to 40 years old were able to produce peak knee extension torque equal to their body weight. He also suggested for males, a hamstring strength between 60 to 69 percent of the quadriceps strength.

Muscle Strength and Training

Various researchers have investigated strength training programs. Capen (1956) examined the effects of various loads, frequencies, and repetitions on strength. He concluded that three sets of five repetitions, three days per week were the most effective to produce increases in strength. Berger (1963) compared training loads of two-, six-, and ten-repetition maximums. Strength increased in all groups, but the six-repetition maximum group showed the greatest increase. O'Shea (1966) compared training loads of two-, five-, and ten-repetition maximums. Although all groups showed an increase in strength, the two-repetition maximum group showed the greater increase. Berger and Hardage (1967) investigated strength gain over an eight-week period comparing a constant load with an ever-lightening load. They concluded the ever-lightening load, which decreased weight as the sets progressed, was more effective than the constant but heavier load. Withers (1970) examined three-, five-, and seven-repetition maximum strength training programs for nine weeks. He concluded that a five-repetition maximum, utilizing only four repetitions, was better than the three- or seven-repetition maximum exercise program, although differences were not significant.

Morehouse and Miller (1976) presented a theoretical model of weight training for specific muscular adaptations. They suggested a muscular endurance training protocol of two to four sets of 40 to 50 repetitions with one to two minutes of rest between sets. For strength training they recommended three to four sets of one to five repetitions with three to four minutes' rest between sets. For muscular hypertrophy they recommended four to six sets of 15 to 20 repetitions with four to five minutes' rest between sets.

Rogozkin (1976) examined the effect of swim training on male albino rats. The treatments consisted of either one or three weighted swimming exercise sessions per day, six days per week, for a 10-week period. The total exercise time was gradually increased to 60 minutes for each group. One group exercised once each day for the training program while the other group exercised three times per day for the same duration. The quadriceps and gastrocnemius muscles were used for analysis. The results showed that the group which exercised three times per day with a rest period between sessions increased content and intensity of skeletal muscle proteins as evidenced by an increase in amino acid content in the muscle. This group also showed an increased synthesis of ribosomal and microsomal RNA, and increased skeletal muscle protein fractions. These results indicated an advantage of distributed exercise over massed exercise for increased protein synthesis.

Davies (1977) compared a heavier but constant load and an ever-lightening load of equal sets and repetitions. Although the constant load showed the higher gains, the differences were not significant.

Lesmes, Costill, Coyle, and Fink (1978) examined five males during an isokinetic training program. The subjects trained four times per week for seven weeks. The training bouts consisted of maximal extensions and flexions at the knee at a constant velocity of 180 degrees per second. The leg traveled a distance of 90 degrees for all subjects. One leg was trained with a six-second work bout repeated 10 times with 114 seconds of relief between each bout. The other leg was trained for 30 seconds with a rest of 20 minutes between bouts. The total work time was 60 seconds. No significant differences were obtained between the two methods, as both had similar increases in strength.

Atha (1981) examined research articles investigating muscular strength. He concluded that four to eight repetitions were best for producing strength gains and considered that five to six repetitions were ideal. Atha also noted that the primary strengthening stimulus was tension, not fatigue. As mentioned earlier, he concluded that "a fatigued muscle cannot generate enough tension to reap the benefits of a maximum adaptive response" (p. 15).

Kraemer, Fleck, and Deschenes (1988) suggested an effective range of exercise repetitions between two and ten and recommended six repetitions. They recommended a minimum of three repetitions for isokinetic exercise. Kraemer et al. suggested that the rest period was often overlooked in strength training research and noted that the amount of rest determined the metabolic reliance upon glycolytic energy systems. The reduction of the rest interval impaired the maximal force production capability due to physiological alterations in the muscle which may not be desirable when typical strength programs were utilized. They also suggested that from three to six sets be utilized for optimal gains in strength.

Corbin and Lindsey (1991) reported that strength training programs for isotonic training should include three sets of three to eight repetitions with one minute of rest between sets. They also noted that isokinetic training programs should include three to five sets of three to eight repetitions with one minute of rest between sets.

Muscle Fatigue and Recovery

Davis (1954) examined strength before and following a 200-yard swim for time. The mean results of the strength decrements for all muscle groups tested were 14.34 percent decrease for the unconditioned and a 12.46 percent decrease for the conditioned. Davis examined shoulder, hip, and knee extensors and flexors. The knee extensors had the least decrements of 6.97 and 7.54 percent for unconditioned and conditioned. The knee flexors showed decrements of 12.99 and 12.46 percent, respectively, for unconditioned and conditioned.

Clarke, Shay, and Mathews (1954) examined the strength decrement of the elbow flexor muscles following exhaustive exercise. They examined this because "no objective evidence was available relative to the effects of exhaustive muscular efforts upon strength and strength recovery rate" (p. 376). The subjects, male students from Springfield College, exercised their elbow flexor muscles on a Kelso-Hellebrandt ergograph. The exercise consisted of a resistance equal to 3/8 of each subject's elbow flexion strength at a cadence of one second each for flexion and extension. The exercise was continued until the subjects were unable to move the ergograph load the distance necessary to register on the cumulative distance meter. The elbow flexor muscles were tested for cable tension strength before and at several intervals after exercise. The study was divided into three phases: (1) effect on untrained subjects, week one and two; (2) effect on trained subjects, weeks three, four, and five; and (3) effect on trained subjects followed for two hours after exercise, week six. All groups showed a decrement 30 seconds after exercise between 29 and 33 percent and showed a decrement between 11 and 29 percent after seven and one-half minutes of recovery.

Clarke, Shay, and Mathews (1955) proposed a test of muscle fatigue called the Strength Decrement Index (SDI). The test was based on the concept that an immediate effect of muscular fatigue was to reduce the muscle's capability to develop tension. The Strength Decrement Index was equal to the percent loss of strength in a given muscle or muscle group. The formula for calculating the SDI was, SDI = [(Si-Sf)/Si]100, with Si equal to initial strength which was taken before exercise and Sf equal to final strength taken after exercise. They also examined the strength decrement after a 7.5-mile march with a rucksack and a 61-pound military load. The mean strength decrement index revealed a loss in strength of all muscle groups tested with the exception of the knee extensors which was not significantly different. They estimated that the mean loss of strength 30 seconds after the marching exercise was 20 percent.

Gross (1958) examined the effects of heat and cold on the measurement of strength and fatigue. The results showed that immersion of the forearm in hot water (48° Celsius for eight minutes) did not have an effect on initial strength or steady-state fatigue level. However, the heat treatment did cause a 34 percent increase in the rapidity of fatigue. The cold treatment (10° Celsius for eight minutes) decreased initial strength 11 percent without altering the observed fatigue level.

Pastor (1959) investigated the rate of strength recovery following various amounts of exercise of the elbow flexor muscles. The subjects exercised at a cadence of 38 contractions per minute on a Kelso-Hellebrandt ergograph at one-fourth the strength of each subject's elbow flexor muscles. The subjects were 210 male students between 17 and 21 years of age. The subjects were divided into 14 groups of 15 subjects per group. Each group was tested for muscular strength under 14 different exercise treatments. One group served as a control group and performed zero repetitions of the exercise. The other groups were tested for strength prior to exercise and then performed various repetitions. All groups were then tested post exercise at 30 seconds, 2 1/2 minutes, 7 1/2 minutes, and 12 1/2 minutes. The results through six repetitions were as follows:

Repetitions	Pre-Ex	30 s.	2.5 m.	7.5 m.	12.5 m.
0	137.87	137.93	133.53	133.27	126.67
3	130.60	126.40	123.20	120.20	122.13
4	135.93	131.27	127.60	126.87	133.20
5	121.87	118.80	116.00	116.00	116.73
6	137.00	132.47	131.80	127.53	129.87

Clarke (1962) tested 30 subjects for static and dynamic strength, using a spring loaded hand ergograph. The dynamic exercise consisted of six minutes of dynamic contractions at the rate of 30 per minute. The mean strength was initially measured at 45.7 kg, but fell to a steady state value of 27.6 kg. The rate of decline (half-time) was 89 seconds. The static work consisted of two minutes of continuous exercise. The initial mean static strength of 46.9 kg fell to 15.8 kg. The rate of decline was 38 seconds. Following these exercise treatments, the recovery of strength was examined for ten minutes. The recovery process was examined and a two-component exponential equation was derived to account for the observed progressive return of strength. Clarke concluded that recovery from static exercise was faster than the recovery for dynamic exercise. Clarke did not attempt to explain the physiological process and noted that more research is needed to explain why the dynamic recovery process takes longer than the static recovery process.

Kroll (1968) examined isometric fatigue curves on 135 male college students. Kroll used three experimental groups and provided intertrial recovery periods of 5, 10, or 20 seconds between the 30 five-second isometric contractions. This provides a work/rest ratio of 1/1, 1/2, and 1/4, respectively, for the groups. Kroll also subdivided the groups into high-, middle-, and low-strength levels based on their first two trials. The data were analyzed by an analysis of variance of trends. All groups exhibited a significant reduction of fatigue or decreased performance except the low strength level subgroups. The low strength level subgroups did not show a significant decline in performance over the 30 trials. According to Kroll, this subgroup exhibited a steady state, which implies a balance between the metabolic requirements for contraction and recovery under the imposed conditions.

Stull and Clarke (1970) examined the effects of a six-week strength training program. Twenty male students performed three sets of 10 repetitions using 1/2, 3/4, and 100 percent of the 10-repetition maximum, three times per week for the six-week period. A pre- and posttest was used; and subjects showed an increase in initial strength, final strength, and total work. However, no significant difference was observed in the amount of fatigable work accomplished. The time between the sets of each workout session was not noted.

Stull and Clarke (1971) examined recovery following isometric and isotonic strength decrements. They studied 31 male subjects in two experiments involving handgripping exercise. Experiment one involved maintaining a maximal isometric contraction for one minute, while experiment two consisted of maximal dynamic contractions at a rate of 30 per minute for three minutes. Following both experiments, the researchers measured strength at either 10, 35, 70, 115, 170, or 235 seconds after exercise. Each subject was tested on six different days for both isometric and isotonic recovery. One recovery measurement was taken on each day. The study indicated an initial rapid recovery period for both isometric and isotonic exercise. Recovery from the isometric exercise was complete after 235 seconds, while the isotonic exercise recovery had actually surpassed the value recorded at the initiation of exercise.

Funderburk, Hipskind, Welton, and Lind (1974) examined three male subjects during five successive, isometric handgrip contractions at 20 percent, 40 percent, and 60 percent of the maximum voluntary contraction to the point of fatigue. The contractions were performed with five different rest intervals between contractions. These were kept constant at 3, 7, 11, 20, and 40 minutes. At all tensions, the duration of successive contractions fell and reached a steady state by the fourth or fifth contraction. This steady state value was the shortest when the rest interval was the shortest, but even after 40 minutes of recovery, it reached only 85-90 percent of the original duration. Funderburk et al. concluded that the endurance recovery was rapid at first and was then slower after 10 minutes. It was 85-90 percent complete only after the longest recovery interval examined. However, the ability of the muscle to exert maximum voluntary contraction was complete in about 10 minutes.

Karlsson, Funderburk, Essen, and Lind (1975) examined isometric muscle fatigue. Three subjects were used for the study. Each performed five successive isometric contractions to fatigue at constant tensions varying from 20 to 80 percent of the maximum voluntary contraction. The rest interval between contractions was held constant at 11 minutes. Muscle biopsy samples were obtained at the start and after the first, fourth, and fifth contractions, and before the second and fifth of the successive contractions. Adenosine triphosphate (ATP), creatine phosphate (CP), glycogen, and lactate were examined for each muscle biopsy sample. The levels of ATP and glycogen did not vary a great deal. The CP and lactate were great after fatigue at intermediate tensions, but Karlsson et al. considered the CP to be an unlikely cause of fatigue. They concluded that at tensions between 30 to 50 percent of the maximum voluntary contraction, lactate may cause fatigue. They did not suggest a cause for fatigue at the higher and lower intensities.

Rogozkin (1976) held the load and total exercise duration constant. Rogozkin's group one exercised for one hour, while group two exercised for three 20-minute sessions. He concluded that increasing the number of sets and adding rest intervals significantly increased both the content and intensity of protein synthesis in all muscle protein functions. Thus, the rest interval allowed the muscle to be worked harder.

MacDougall, Ward, Sale, and Sutton (1977) examined six subjects who were exercised on a cycle ergometer. The exercise consisted of one minute of maximum work intervals with three-minute recovery intervals. The work intensity was approximately 140 percent of the maximum aerobic power. The work intervals continued until the subjects could not maintain exercise for 30 seconds. The muscle glycogen levels were measured before, after, and at 2, 5, 12, and 24 hours post exercise. The glycogen level did not reach pre-exercise levels until the 24-hour measurement after exercise. The article suggested that a high intensity but brief exercise session resulted in a hyperglycemic condition. After exercise, glucose and insulin levels were higher than pre-exercise. These factors thus enabled glycogen resynthesis to occur.

According to McCafferty and Horvath (1977), high-energy phosphate stored in the muscle and nonoxidative glycolysis are the predominantly used sources of energy for short-term heavy exercise. ATP and CP thus appeared to be useful only for the first few seconds of heavy exercise. McCafferty and Horvath noted that these energy stores were insufficient for repeated bouts, unless sufficient rest periods were allowed. McCafferty and Horvath also noted that, following heavy exercise, ATP and CP levels did not return to pre-exercise levels until after several minutes of rest.

Atha (1981) noted that the rate of fatigue was determined by the rest interval, the load, and the duration of exercise. He indicated that "no attention at all has been paid to the relevance of the planned inter-repetition rest interval," and that "the recovery interval between repetitions has been allowed to vary in most studies without account being taken of whether or not such variance affects the results." He further stated that recovery periods were usually chosen arbitrarily and that "no real attention has been paid to the inter-repetition interval as a dependent variable" (p. 39).

Rasch (1982) noted that short, frequent rest pauses should be observed to prevent the muscle from becoming fatigued early in the training session. He suggested that a routine for isotonic weight training should use rest intervals of about three minutes.

According to Kraemer (1983), recovery from exercise was related to the body systems that were stressed by the exercise. These included energy systems, nervous systems, skeletal muscle tissue, soreness, and other physiological factors. Kraemer mentioned two recovery processes. These were the Alactacid (fast phase) and the Lactacid (slow phase). The ATP-PC turnover or recovery was very rapid and very difficult to measure. Kraemer noted that biopsy studies showed that 70 percent of the ATP-PC was restored in 30 seconds. Examination of the VO_2 curve showed that only 50 percent is restored in 30 seconds. The Lactacid phase involved the removal of lactic acid. This took approximately one hour. Kraemer also noted that active recovery periods enhanced the recovery process and aided in the removal of lactic acid at faster rates than inactive recovery. Kraemer further noted that the lactic acid was removed in four different ways: (1) excreted in urine and sweat, (2) converted to glycogen and glucose in muscle and liver, (3) converted to protein, and (4) 63 percent through oxidation of lactic acid to carbon dioxide and water.

According to Kraemer, recovery involved replenishment of the energy substrate and glycogen was the main concern. Endurance recovery may take a couple of days and was dependent on an adequate carbohydrate diet. Power activities required less total glycogen than did endurance activities, although glycogen was the main substrate used. Glycogen re-synthesis, therefore, started sooner after power activities than after endurance activities. Kraemer also noted that glycogen recovery was faster in white muscle fibers than in red muscle fibers.

Lamb (1984) suggested that the proper recovery or rest interval for maximal isometric contractions was two to three minutes. Lamb also recommended that a five- to ten-minute recovery interval between sets was needed for both isotonic and isokinetic exercise on the same muscle or muscle group. This recommendation was because isotonic and isokinetic exercises caused a greater depletion of energy reserves and a greater production of lactic acid.

Ariki, Davies, Siewert, and Rowinski (1985b) examined the optimum rest interval between isokinetic velocity spectrum speeds. Twelve subjects were tested on a Cybex II Isokinetic Dynamometer and Cybex Data Reduction Computer. Each subject performed 10 repetitions through three velocity spectrums of 180, 210, 240, 270, and 300 degrees per second, with rest intervals of 30, 60, or 90 seconds randomly administered. They concluded that the optimal rest period between speeds using this velocity spectrum protocol was 90 seconds.

Ariki, Davies, Siewert, and Rowinski (1985a) examined the optimum rest interval between isokinetic velocity spectrum rehabilitation sets. Twelve subjects were tested with a Cybex II Isokinetic Dynamometer and Cybex Data Reduction Computer. Each subject performed 10 repetitions through three velocity spectrums of 180, 210, 240, 270, and 300 degrees per second, with rest intervals of two, three, or four minutes randomly administered. They determined that the optimal rest time between sets using this velocity spectrum protocol was three minutes.

According to Guyton (1986), studies of athletes have shown that muscle fatigue occurred and increased in almost direct proportion to the rate of muscle glycogen depletion. Guyton suggested that muscle fatigue resulted from the inability of the contractile and metabolic processes of the muscle to continue supplying the same work output. Guyton also mentioned that the available ATP in the body can be completely depleted in an average of 10-15 seconds of maximal muscle exercise and must be replenished or fatigue occurs. Guyton recommended that muscular exercise and events which utilized the phosphagen energy system could expect reasonable replenishment within about three to five minutes.

Battinelli (1987) examined some of the possible causes of fatigue within a muscle and suggested that work-induced fatigue is multifaceted. Battinelli suggested that the fatigue rate was faster during power training exercise than during endurance training programs, and noted that anaerobic fatigue was related to metabolic end products in the fast twitch fibers. Battinelli was uncertain if isokinetic fatigue patterns were related to the muscle fiber type.

Spriet, Lindinger, McKelvie, Heigenhauser, and Jones (1989) investigated the relationships between muscle glycogenolysis, glycolysis, and H+ concentration in eight subjects performing three 30-second bouts of maximal isokinetic cycling of 100 rotations per minute. The exercise bouts were separated by four minutes of rest, and muscle biopsies were obtained before and after bout two and three. They concluded that total work in bout three was maintained by a greater reliance on slow twitch muscle fibers and oxidative metabolism.

Jansson, Dudley, Norman, and Tesch (1990) examined the possible relationship between the aerobic-oxidative potential of skeletal muscle and the metabolic and force recovery after intense exercise. Eleven subjects performed three bouts of 30 repetitions of unilateral knee extensions on an isokinetic device with 60 seconds of rest between bouts. Muscle biopsies were taken from the vastus lateralis prior to exercise, immediately after bout two and before bout three. The results suggested that "the recovery of force and the 'normalization' of metabolite content after short term, intense exercise are dependent on the aerobic-oxidative potential of skeletal muscle" (p. 147).

CHAPTER III

Methods and Procedures

For the purpose of this study, the following procedures were conducted for each subject.

Subjects

Subjects were 30 male students enrolled in physical education classes at Middle Tennessee State University.

Physical Information

Name, age, weight, and height of each subject was recorded. The height and weight were measured on a Health-O-Meter scale manufactured by Continental Scale Corporation of Chicago, Illinois.

Body Composition

The subjects were tested for body composition by underwater weighing using the Middle Tennessee State University Human Performance Laboratory Protocol. The subjects were measured for vital capacity using a Pneumoscan S301 Spirometer manufactured by KL Engineering Company in Sylmar, California. The water temperature was measured to determine its density by a YSI Tele-thermometer manufactured by Yellow Springs Instrument Co., Inc., of Yellow Springs, Ohio. The mode weight achieved for 10 trials on a digital strain gauge was used for calculation of percent body fat. The residual volume was estimated from a formula developed by Wilmore (1969). The Siri (1956) formula was used to determine percent body fat.

Strength Testing

The subjects were tested on the Cybex 340 Isokinetic Dynamometer to determine knee extension and flexion strength. Each subject was seated, and the proper anatomical adjustments were made. The seat back tilt was set at 85 degrees for all subjects, and the axis of the Cybex dynamometer was adjusted to the center of the knee joint. The Cybex adjustments were recorded to maintain the same positioning for all successive tests. The three-point lap/shoulder belt, thigh belt, and shin pad were securely fastened. The contralateral limb was positioned behind the contralateral limb stabilization bar. The subjects were instructed to hold the handgrips for added stabilization. The subjects were tested for knee extension and flexion at 60 degrees per second on one leg, repositioned and tested on the other leg. The dominant leg was used for all further testing.

Each subject performed four sets with five repetitions of knee extension and flexion exercise at an angular velocity of 60 degrees per second separated by a randomly selected rest interval of one, three, or five minutes. The subject returned to the Human Performance Lab on nonconsecutive days over a two-week period until all treatments had been administered. Each subject was positioned according to the adjustments recorded on the initial visit. Once positioned correctly, the dominant limb was weighed and corrected for gravity. Each subject performed four trial repetitions on the Cybex 340. Each subject then performed the first set of five repetitions. This was followed by the proper rest interval of one, three, or five minutes. The data were stored and the Cybex prepared for the next test. The trial repetitions were aborted for all successive sets (second set through the fourth set) with the help of the researcher by making short movements through the range of motion. At the end of the manually timed rest period, the subject was asked to repeat the five maximal voluntary extension and flexion contractions. This protocol was followed until completion of the fourth set of five repetitions. Each subject returned to the Human Performance Lab on the following nonconsecutive days for the same procedures with the other two rest intervals administered in random order.

Statistical Treatment

The data were analyzed using MANOVA and ANOVA statistical procedures. This was because LaTour and Miniard (1983) suggested that concern for Type I or Type II errors dictate the choice of statistical approach used. They suggested that the multivariate test was more appropriate if the concern were for Type I errors, while the univariate test was more appropriate if the concern were for Type II errors. Therefore, both the multivariate and univariate tests were examined. Multivariate tests (MANOVA) were computed on the within subject effect to determine differences. The Wilks' Lambda multivariate test was chosen to examine the data and indicated differences among group means. A large Wilks' Lamba value indicated that group means were not different while a small Lambda value indicated that group means were different. In addition, a series of three by four within subjects repeated measure ANOVAs were conducted to assess the effects of the rest interval (one, three, and five minutes) and sets (four at each interval) on each strength measurement (peak extension, peak flexion, average peak extension, and average peak flexion). The Greenhouse-Geiser Epsilon statistic was used to determine the homogeneity of variance. LaTour and Miniard indicated that the univariate tests tended to be more powerful than the multivariate approach if the homogeneity of variance assumptions were met.

To determine the location of specific differences among the treatments, individual pair-wise contrasts were made. The specific mean pair-wise comparisons for the rest interval were as follows: 1,-1,0, which compared the one-minute with the three-minute; 1,0,-1, which compared the one-minute with the five-minute; and 0,1,-1, which compared the three-minute with the five-minute rest interval. Pair-wise contrasts were also conducted for the sets and the rest interval by sets interaction. Pearson Product Coefficients were conducted to determine the relationship among fat-free body weight and strength measurements. The .05 level was used to determine significance.

CHAPTER IV

Results

The results were presented to examine the rest interval, sets, and rest interval by set interactions. Multivariate, univariate, and pair-wise contrasts were examined for each area. The characteristics of the subjects and the strength relationships to fat-free body weight were also examined.

Subjects

This study was approved by the Research Ethics Committee at Middle Tennessee State University (see Appendix A). Thirty subjects volunteered to participate and signed an informed consent prior to testing (see Appendix B). All 30 subjects completed all phases of testing. The physical characteristics of these subjects are presented in Table 1. The 30 male subjects had a mean of age 24.23 $\pm$ 4.80 years, a mean height 181.74 $\pm$ 7.44 centimeters, a mean weight 88.4 $\pm$ 16.05 kilograms, and a mean body fat 18.07 $\pm$ 7.66 percent.

Rest Intervals

This section examined the differences among the one-, three-, and five-minute rest intervals across sets. A MANOVA was conducted to assess differences in the rest interval, and the Wilks' Lambda values are presented in Table 2. The Wilks' Lambda values for these tests ranged from .46 to .54. The F values for the rest interval test

Table 1

Physical Characteristics of Subjects

Variable	N	Mean	SD
Age (yrs)	30	24.23	4.80
Height (cm)	30	181.74	7.44
Weight (kg)	30	88.40	16.05
Percent body fat	30	18.07	7.66

Table 2

MANOVA for Rest Intervals

Measurement	Wilks' Lambda Value	F	Num DF	Den DF	Significance
Peak Extension	.48	15.13	2	28	.01
Peak Flexion	.46	16.33	2	28	.01
Average Peak Extension	.49	14.36	2	28	.01
Average Peak Flexion	.54	12.08	2	28	.01

were peak extension, $F = 15.13$, $p < .01$; peak flexion, $F = 16.33$, $p < .01$; average peak extension, $F = 14.36$, $p < .01$; and average peak flexion, $F = 12.08$, $p < .01$. The results revealed significant differences among the one-, three-, and five-minute rest interval treatments.

The Greenhouse-Geiser Epsilon test for the rest interval indicated homogeneity with values that ranged from .92 to .99. The rest interval ANOVAs are presented in Table 3. The values for the strength measurements were peak extension, $F = 13.11$, $p < .01$; peak flexion, $F = 15.65$, $p < .01$; average peak extension, $F = 11.35$, $p < .01$; and average peak flexion, $F = 12.97$, $p < .01$. Pair-wise contrasts were conducted between the rest intervals to determine where significant differences occurred. The mean and standard deviations for the effects of the rest interval are presented in Table 4. The results of the rest interval contrasts for peak extension are presented in Table 5 and indicate significant differences, $F = 17.83$, $p < .01$, between the one-minute (187.64 ft•lbs) and three-minute (199.73 ft•lbs) rest intervals. Significant differences were also found, $F = 25.65$, $p < .01$, between the one-minute (187.64 ft•lbs) and the five-minute (199.70 ft•lbs) rest interval. No differences were found between the three-minute (199.73 ft•lbs) and the five-minute (199.70 ft•lbs) rest intervals.

The results of the contrasts for peak flexion are presented in Table 6 and reveal significant differences, $F = 31.68$, $p < .01$, between the one-minute (110.52 ft•lbs) and three-minute (118.31 ft•lbs) rest interval. Significant differences were also found, $F = 15.55$,

Table 3

ANOVA for Rest Intervals

Variable	DF	Type III SS	Mean Square	F	Significance
Peak Extension	2	11656.44	5828.22	13.11	.01
Error	58	25790.73	444.67		
Peak Flexion	2	3950.72	1975.39	15.65	.01
Error	58	7319.62	126.20		
Average Peak Extension	2	11638.94	5819.47	11.35	.01
Error	58	29741.39	512.78		
Average Peak Flexion	2	3304.51	1652.25	12.97	.01
Error	58	7386.49	127.35		

Table 4

Means and Standard Deviations for the Main Effects of Rest Intervals

Variable	One Minute	Three Minute	Five Minute
Peak Extension			
Mean (ft•lbs)	187.64	199.73	199.70
SD (ft•lbs)	33.21	36.86	35.72
Peak Flexion			
Mean (ft•lbs)	110.52	118.31	116.38
SD (ft•lbs)	19.04	20.74	19.09
Average Peak Extension			
Mean (ft•lbs)	176.57	188.79	188.45
SD (ft•lbs)	31.82	36.58	34.80
Average Peak Flexion			
Mean (ft•lbs)	101.67	108.71	107.22
SD (ft•lbs)	16.85	18.57	18.40

Table 5

Pair-wise Contrasts of Peak Extension for Rest Intervals

Contrast	DF	Type III SS	Mean Square	F	Significance
1 min. vs. 3 min.	1	70083.33	70083.33	17.83	.01
Error	29	113978.67	3930.30		
1 min. vs. 5 min.	1	69793.63	69793.63	25.65	.01
Error	29	78919.37	2721.36		
3 min. vs. 5 min.	1	.30	.30	0.00	.99
Error	29	116590.70	4020.37		

Table 6

Pair-Wise Contrasts of Peak Flexion for Rest Intervals

Contrast	DF	Type III SS	Mean Square	F	Significance
1 min. vs. 3 min.	1	29140.83	29140.83	31.68	.01
Error	29	26672.17	919.73		
1 min. vs. 5 min.	1	16473.63	16473.63	15.55	.01
Error	29	30723.37	1059.43		
3 min. vs. 5 min.	1	1794.13	1794.13	1.71	.20
Error	29	30439.87	1049.65		

$p < .01$, between the one-minute (110.52 ft•lbs) and the five-minute (116.38 ft•lbs) treatments. No differences were found between the three-minute (118.31 ft•lbs) and the five-minute (116.38 ft•lbs) treatments.

The results of the contrasts for average peak extension are presented in Table 7 and revealed significant differences, $F = 16.48$, $p < .01$, between the one-minute (176.57 ft•lbs) and the three-minute (188.79 ft•lbs) treatments. Significant differences were also found, $F = 22.77$, $p < .01$, between the one-minute (176.57 ft•lbs) and the five-minute (188.45 ft•lbs) treatments. No differences were found between the three-minute (188.79 ft•lbs) and the five-minute (188.45 ft•lbs) treatments.

Table 7

Pair-wise Contrasts of Average Peak Extension for Rest Intervals

Contrast	DF	Type III SS	Mean Square	F	Significance
1 min. vs. 3 min.	1	71736.30	71736.30	16.48	.01
Error	29	126240.70	4353.13		
1 min. vs. 5 min.	1	67877.63	67877.63	22.77	.01
Error	29	86439.37	2980.67		
3 min. vs. 5 min.	1	53.53	53.53	.01	.92
Error	29	144216.67	4972.99		

The results of the contrasts for average peak flexion are presented in Table 8 and revealed significant differences, $F = 23.52$, $p < .01$, between the one-minute (101.67 ft•lbs) and the three-minute (108.71 ft•lbs) treatments. Significant differences were also found, $F = 13.54$, $p < .01$, between the one-minute (101.67 ft•lbs) and the five-minute (107.22 ft•lbs) treatments. No differences were found between the three-minute (108.71 ft•lbs) and the five-minute (107.22 ft•lbs).

Table 8

Pair-Wise Contrasts of Average Peak Flexion for Rest Intervals

Contrast	DF	Type III SS	Mean Square	F	Significance
1 min. vs. 3 min.	1	23800.83	23800.83	23.52	.01
Error	29	29340.17	1011.73		
1 min. vs. 5 min.	1	14785.20	14785.20	13.54	.01
Error	29	31664.80	1091.89		
3 min. vs. 5 min.	1	1068.03	1068.03	1.12	.30
Error	29	27632.97	952.86		

Sets

This section examined the effects of sets. The Wilks' Lambda multivariate test revealed differences within the four sets at each strength measurement, presented in Table 9. The Wilks' Lambda values ranged from .13 to .51. The F values indicated significant differences were present among the sets for peak extension, $F = 8.78$, $p < .01$; peak flexion, $F = 62.03$, $p < .01$; average peak extension, $F = 8.94$, $p < .01$; and average peak flexion, $F = 49.39$, $p < .01$. This indicated there were differences among sets.

The Greenhouse-Geiser values ranged from .67 to .81 for the sets and indicated homogeneity. The ANOVA values for sets are presented in Table 10 and were significant for peak extension, $F = 4.32$, $p < .01$; peak flexion, $F = 78.70$, $p < .01$; average peak extension, $F = 4.40$, $p < .01$; and average peak flexion, $F = 57.27$, $p < .01$. Contrasts

Table 9

MANOVA for Sets

Variable	Value	F	Num DF	Den DF	Significance
Peak Extension	.51	8.78	3	27	.01
Peak Flexion	.13	62.03	3	27	.01
Average Peak Extension	.50	8.94	3	27	.01
Average Peak Flexion	.15	49.39	3	27	.01

Table 10

ANOVA for Sets

Variable	DF	Type III SS	Mean Square	F	Significance
Peak Extension	3	1193.00	397.67	4.32	.01
Error	87	8010.17	92.07		
Peak Flexion	3	6246.84	2082.28	78.70	.01
Error	87	2301.99	26.46		
Average Peak Extension	3	923.61	307.87	4.40	.01
Error	87	6086.06	69.95		
Average Peak Flexion	3	4913.76	1637.92	57.27	.01
Error	87	2488.15	28.60		

were conducted between the sets to determine differences. The mean and standard deviations for sets across the rest interval are presented in Table 11. The results of these contrasts for the peak extension strength measurements are presented in Table 12 and showed significant differences for the second vs. third set ($p < .01$), and for the second vs. fourth set ($p < .02$). This seemed to be caused by a higher peak torque in set two, whereas the torques for sets three and four were affected by the fatigue at the one-minute rest interval.

Table 11

Means and Standard Deviations for the Main Effects of Sets

Variable	Set 1	Set 2	Set 3	Set 4
Peak Extension				
Mean (ft•lbs)	196.06	198.34	193.31	195.05
SD (ft•lbs)	35.40	34.95	36.31	37.35
Peak Flexion				
Mean (ft•lbs)	111.22	113.11	122.09	113.85
SD (ft•lbs)	19.26	19.84	21.21	20.42
Average Peak Extension				
Mean (ft•lbs)	185.20	186.51	182.10	184.58
SD (ft•lbs)	35.17	34.11	35.24	36.13
Average Peak Flexion				
Mean (ft•lbs)	103.44	103.86	112.26	103.90
SD (ft•lbs)	18.28	18.43	19.75	18.41

Table 12

Pair-Wise Contrasts of Peak Extension for Sets

Sets	DF	Type III SS	Mean Square	F	Significance
1 vs. 2	1	1414.53	1414.53	2.77	.10
Error	29	14793.47	510.12		
1 vs. 3	1	2033.63	2033.63	3.45	.07
Error	29	17093.37	589.43		
1 vs. 4	1	276.03	276.03	.26	.62
Error	29	31074.97	1071.55		
2 vs. 3	1	6840.30	6840.30	27.80	.01
Error	29	7136.70	246.09		
2 vs. 4	1	2940.30	2940.30	5.62	.02
Error	29	15176.70	523.33		
3 vs. 4	1	811.20	811.20	2.17	.15
Error	29	10846.80	374.03		

The contrasts for peak flexion are presented in Table 13 and showed significant differences for the first vs. second set ($p < .01$), the first vs. third set ($p < .01$), the first vs. fourth set ($p < .01$), the second vs. third set ($p < .01$), and the third vs. fourth set ($p < .01$). This was partially caused by the torque of set three which had the highest values.

The contrasts for average peak extension are presented in Table 14 and show significant differences for the first vs. third set ($p < .03$), the second vs. third set ($p < .01$), and the third vs. fourth set ($p < .02$). This was caused by the low torque values for set three.

Table 13

Pair-Wise Contrasts of Peak Flexion for Sets

Sets	DF	Type III SS	Mean Square	F	Significance
1 vs. 2	1	963.33	963.33	15.29	.01
Error	29	1826.67	62.99		
1 vs. 3	1	31882.80	31882.80	174.74	.01
Error	29	5291.20	182.46		
1 vs. 4	1	1856.53	1856.53	8.94	.01
Error	29	6021.47	207.64		
2 vs. 3	1	21762.13	21762.13	158.97	.01
Error	29	3969.87	136.89		
2 vs. 4	1	145.20	145.20	.84	.37
Error	29	5020.80	173.13		
3 vs. 4	1	18352.13	18352.13	96.87	.01
Error	29	5493.87	189.44		

The contrasts for average peak flexion are presented in Table 15 and showed significant differences were present for the first vs. third set ($p < .01$), the second vs. third set ($p < .01$), and the third vs. fourth set ($p < .01$). This was caused by the high torque values in set three.

Rest Interval by Sets Interaction

This section examined the interactions of the rest interval by sets. Multivariate tests were used to examine differences in the rest interval by sets interaction. The MANOVA is presented in Table 16. The Wilks' Lambda values ranged from .34 to .62, and indicated significant interactions were present for peak extension, $F = 4.73$,

Table 14

Pair-Wise Contrasts of Average Peak Extension for Sets

Sets	DF	Type III SS	Mean Square	F	Significance
1 vs. 2	1	464.13	464.13	1.37	.25
Error	29	9827.87	338.89		
1 vs. 3	1	2594.70	2594.70	5.43	.03
Error	29	13856.30	477.80		
1 vs. 4	1	93.63	93.63	.12	.73
Error	29	23221.37	800.74		
2 vs. 3	1	5253.63	5253.63	26.28	.01
Error	29	5797.37	199.81		
2 vs. 4	1	974.70	974.70	2.38	.13
Error	29	11858.40	508.91		
3 vs. 4	1	1702.53	1702.53	5.83	.02
Error	29	8471.47	292.12		

$p <$ 01; peak flexion, $F = 7.61$, $p < .01$; average peak extension, $F = 6.35$, $p < .01$; and average peak flexion, $F = 2.46$, $p < .05$. This indicated there were significant differences among the effects of the rest interval and sets interaction.

The Greenhouse-Geiser test showed values which ranged from .63 to .70 for the rest interval by sets interaction and indicated homogeneity. The ANOVA values for the rest interval by sets interaction showed significant differences and are presented in Table 17. The F values were significant

Table 15

Pair-Wise Contrasts of Average Peak Flexion for Sets

Sets	DF	Type III SS	Mean Square	F	Significance
1 vs. 2	1	45.63	45.63	.64	.43
Error	29	2061.37	71.08		
1 vs. 3	1	20961.63	20961.63	138.55	.01
Error	29	4387.37	151.29		
1 vs. 4	1	56.03	56.03	.28	.60
Error	29	5716.97	197.14		
2 vs. 3	1	19051.20	19051.20	133.30	.01
Error	29	4144.80	142.92		
2 vs. 4	1	.53	.53	.00	.96
Error	29	6123.47	211.15		
3 vs. 4	1	18850.13	18850.13	73.63	.01
Error	29	7423.87	256.00		

Table 16

MANOVA for Rest Interval by Sets Interaction

Variable	Value	F	Num DF	Den DF	Significance
Peak Extension	.46	4.73	6	24	.01
Peak Flexion	.34	7.61	6	24	.01
Average Peak Extension	.39	6.35	6	24	.01
Average Peak Flexion	.62	2.46	6	24	.05

significant for peak extension, $F = 8.86$, $p < .01$; peak flexion, $F = 4.52$, $p < .01$; average peak extension, $F = 11.25$, $p < .01$; and average peak flexion, $F = 2.89$, $p < .01$.

Table 17

ANOVA for Rest Interval by Sets Interaction

Variable	DF	Type III SS	Mean Square	F	Significance
Peak Extension	6	3400.78	566.80	8.86	.01
Error	174	11136.05	64.00		
Peak Flexion	6	898.77	149.80	4.52	.01
Error	174	5766.89	33.14		
Average Peak Extension	6	3338.64	556.44	11.25	.01
Error	174	8609.69	49.48		
Average Peak Flexion	6	753.69	125.62	2.89	.01
Error	174	7566.64	43.49		

Because the rest interval by sets interactions were significant, the simple main effects of rest interval (contrast of one-minute, three-minute, and five-minute rest intervals) were examined at each set (first, second, third, and fourth). The means and standard deviations for peak extension by rest intervals and sets are presented in Table 18. The contrasts for peak extension are presented in Table 19. No differences were found between the rest intervals for set one.

Table 18

Means and Standard Deviations for Peak Extension by Rest Intervals and Sets

Peak Extension	Set 1	Set 2	Set 3	Set 4
One Minute				
Mean (ft•lbs)	194.87	190.17	182.87	182.67
SD (ft•lbs)	35.84	32.15	33.77	32.24
Three Minute				
Mean (ft•lbs)	197.60	203.23	197.57	200.50
SD (ft•lbs)	35.33	37.24	39.32	38.87
Five Minute				
Mean (ft•lbs)	195.70	201.63	199.50	201.97
SD (ft•lbs)	35.03	35.45	35.85	38.94

The contrasts for set two showed significant differences, $F = 14.71$, $p < .01$, between the one-minute and three-minute rest intervals. There were also significant differences, $F = 17.22$, $p < .01$, between the one-minute and five-minute rest intervals. No differences were found between the three-minute and five-minute rest intervals for set two.

The contrasts for set three showed significant differences, $F = 22.60$, $p < .01$, between the one-minute and three-minute rest intervals; and significant differences, $F = 33.93$, $p < .01$, between the one-minute and five-minute rest intervals. No differences were found between the three-minute and five-minute rest intervals for set three.

Table 19

Pair-Wise Contrasts of Peak Extension for Rest Intervals by Sets Interaction

Rest Interval (Set)	DF	Type III SS	Mean Square	F	Significance
1(1) vs. 3(1)	1	224.13	224.13	0.70	.41
Error	29	9219.87	317.93		
1(1) vs. 5(1)	1	20.83	20.83	0.07	.79
Error	29	8280.17	285.52		
3(1) vs. 5(1)	1	108.30	108.30	0.28	.60
Error	29	11048.70	380.99		
1(2) vs. 3(2)	1	5122.13	5122.13	14.71	.01
Error	29	10095.87	348.13		
1(2) vs. 5(2)	1	3944.53	3944.53	17.22	.01
Error	29	6643.47	229.09		
3(2) vs. 5(2)	1	76.80	76.80	0.27	.61
Error	29	8159.20	281.35		
1(3) vs. 3(3)	1	6482.70	6482.70	22.60	.01
Error	29	8318.30	286.84		
1(3) vs. 5(3)	1	8300.03	8300.03	33.93	.01
Error	29	7094.97	244.65		
3(3) vs. 5(3)	1	112.13	112.13	0.35	.56
Error	29	9337.87	322.00		
1(4) vs. 3(4)	1	9540.83	9540.83	26.06	.01
Error	29	10616.17	366.07		
1(4) vs. 5(4)	1	11174.70	11174.70	34.22	.01
Error	29	9470.30	326.56		
3(4) vs. 5(4)	1	64.53	64.53	0.15	.70
Error	29	12495.47	430.88		

Rest Interval 1 = one minute
3 = three minutes
5 = five minutes

The contrasts for set four showed significant differences, $F = 26.06$, $p < .01$, between the one-minute and three-minute rest intervals; and significant differences, $F = 34.22$, $p < .01$, between the one-minute and five-minute rest intervals. No differences were found between the three- and five-minute rest intervals for set four.

The means and standard deviations for peak flexion by rest intervals and sets are presented in Table 20. The contrasts for peak flexion are presented in Table 21. No differences were found among the one-, three-, and five-minute rest intervals for set one.

Table 20

Means and Standard Deviations for Peak Flexion by Rest Intervals and Sets

Peak Flexion	Set 1	Set 2	Set 3	Set 4
One Minute				
Mean (ft•lbs)	110.13	108.17	115.07	108.70
SD (ft•lbs)	19.37	19.21	19.80	20.55
Three Minute				
Mean (ft•lbs)	112.30	117.37	126.60	116.97
SD (ft•lbs)	19.46	20.99	23.14	21.24
Five Minute				
Mean (ft•lbs)	111.23	113.80	124.60	115.87
SD (ft•lbs)	18.95	19.33	20.71	19.46

Table 21

Pair-Wise Contrasts of Peak Flexion for Rest Intervals by Sets Interaction

Rest Interval (Set)	DF	Type III SS	Mean Square	F	Significance
1(1) vs. 3(1)	1	140.83	140.83	2.39	.13
Error	29	1708.17	58.90		
1(1) vs. 5(1)	1	36.30	36.30	0.38	.54
Error	29	2740.70	94.51		
3(1) vs. 5(1)	1	34.13	34.13	0.27	.61
Error	29	3709.87	127.93		
1(2) vs. 3(2)	1	2539.20	2539.20	28.31	.01
Error	29	2600.80	89.68		
1(2) vs. 5(2)	1	952.03	952.03	14.69	.01
Error	29	1878.97	64.79		
3(2) vs. 5(2)	1	381.63	381.63	3.14	.09
Error	29	3529.37	121.70		
1(3) vs. 3(3)	1	3990.53	3990.53	26.33	.01
Error	29	4395.47	151.57		
1(3) vs. 5(3)	1	2726.53	2726.53	19.95	.01
Error	29	3963.47	136.67		
3(3) vs. 5(3)	1	120.00	120.00	1.22	.28
Error	29	2852.00	98.34		
1(4) vs. 3(4)	1	2050.13	2050.13	14.45	.01
Error	29	4115.87	141.93		
1(4) vs. 5(4)	1	1540.83	1540.83	8.75	.01
Error	29	5108.17	176.14		
3(4) vs. 5(4)	1	36.30	36.30	0.40	.53
Error	29	2656.70	91.61		

Rest Interval 1 = one minute
3 = three minutes
5 = five minutes

The contrasts for set two showed significant differences, $F = 28.31$, $p < .01$, between the one-minute and three-minute rest intervals; and significant differences, $F = 14.69$, $p < .01$, between the one-minute and five-minute rest intervals. No differences were found between the three-minute and five-minute rest intervals for set two.

The contrasts for set three showed significant differences, $F = 26.33$, $p < .01$, between the one-minute and three-minute rest intervals; and significant differences, $F = 19.95$, $p < .01$, between the one-minute and five-minute rest intervals. No differences were found between the three-minute and five-minute rest intervals for set three.

The contrasts for set four revealed significant differences, $F = 14.45$, $p < .01$, between the one-minute and three-minute rest intervals; and significant differences, $F = 8.75$, $p < .01$, between the one-minute and five-minute rest intervals. No differences were found between the three-minute and five-minute rest intervals for set four.

The means and standard deviations for average peak extension by rest intervals and sets are presented in Table 22. The contrasts for average peak extension are presented in Table 23. No differences were found among the one-, three-, and five-minute rest intervals for set one.

Table 22

Means and Standard Deviations for Average Peak Extension by Rest Intervals and Sets

Average Peak Flexion	Set 1	Set 2	Set 3	Set 4
One Minute				
Mean (ft•lbs)	183.90	178.23	172.37	171.77
SD (ft•lbs)	34.29	30.60	32.57	32.68
Three Minute				
Mean (ft•lbs)	186.57	191.23	187.40	189.87
SD (ft•lbs)	35.26	36.51	38.10	38.82
Five Minute				
Mean (ft•lbs)	185.13	190.07	186.53	192.10
SD (ft•lbs)	35.95	35.22	35.04	36.88

The contrasts for set two revealed significant differences, $F = 15.60$, $p < .01$, between the one-minute and three-minute rest intervals; and significant differences, $F = 22.53$, $p < .01$, between the one-minute and five-minute rest intervals. No differences were found between the three-minute and five-minute rest intervals.

The contrasts for set three revealed significant differences, $F = 20.79$, $p < .01$, between the one-minute and three-minute rest intervals; and significant differences, $F = 21.70$, $p < .01$, between the one-minute and five-minute rest intervals. No differences were found between the three-minute and five-minute rest intervals.

Table 23

Pair-Wise Contrasts of Average Peak Extension for Rest Intervals by Sets Interaction

Rest Interval (Set)	DF	Type III SS	Mean Square	F	Significance
1(1) vs. 3(1)	1	213.33	213.33	0.69	.41
Error	29	8930.67	307.95		
1(1) vs. 5(1)	1	45.63	45.63	0.19	.67
Error	29	7119.37	245.50		
3(1) vs. 5(1)	1	61.63	61.63	0.19	.67
Error	29	9395.37	323.98		
1(2) vs. 3(2)	1	5070.00	5070.00	15.60	.01
Error	29	9422.00	324.90		
1(2) vs. 5(2)	1	4200.83	4200.83	22.53	.01
Error	29	5408.17	186.49		
3(2) vs. 5(2)	1	40.83	40.83	0.12	.73
Error	29	9748.17	336.14		
1(3) vs. 3(3)	1	6780.03	6780.03	20.79	.01
Error	29	9456.97	326.10		
1(3) vs. 5(3)	1	6020.83	6020.83	21.70	.01
Error	29	8046.17	277.45		
3(3) vs. 5(3)	1	22.53	22.53	0.06	.81
Error	29	10523.47	362.88		
1(4) vs. 3(4)	1	9937.20	9937.20	23.22	.01
Error	29	12408.80	427.89		
1(4) vs. 5(4)	1	12403.33	12403.33	32.61	.01
Error	29	11028.67	380.30		
3(4) vs. 5(4)	1	136.53	136.53	0.29	.59
Error	29	13565.47	467.77		

Rest Interval 1 = one minute
3 = three minutes
5 = five minutes

The contrasts for set four revealed significant differences, $F = 23.22$, $p < .01$, between the one-minute and three-minute rest intervals; and significant differences, $F = 32.61$, $p < .01$, between the one-minute and five-minute rest intervals. No differences were found between the three-minute and five-minute rest intervals for set four.

The means and standard deviations for average peak flexion by rest intervals and sets are presented in Table 24. The contrasts for average peak flexion are presented in Table 25. No differences were found among the one-, three-, and five-minute rest intervals for set one.

The contrasts for set two revealed significant differences, $F = 17.26$, $p < .01$, between the one-minute and three-minute rest intervals; and significant differences, $F = 11.64$, $p < .01$, between the one-minute and five-minute rest intervals. No differences were found between the three-minute and five-minute rest intervals.

The contrasts for set three revealed significant differences, $F = 21.73$, $p < .01$, between the one-minute and three-minute rest intervals; and significant differences, $F = 13.07$, $p < .01$, between the one-minute and five-minute rest intervals. No differences were found between the three-minute and five-minute rest intervals.

Table 24

Means and Standard Deviations for Average Peak Flexion by Rest Intervals and Sets

Average Peak Flexion	Set 1	Set 2	Set 3	Set 4
<u>One Minute</u>				
Mean (ft·lbs)	102.30	99.33	105.97	99.07
<u>SD</u> (ft·lbs)	17.26	17.52	17.98	18.37
<u>Three Minute</u>				
Mean (ft·lbs)	104.93	107.77	116.10	106.03
<u>SD</u> (ft·lbs)	18.67	19.71	20.41	18.59
<u>Five Minute</u>				
Mean (ft·lbs)	103.10	104.47	114.70	106.60
<u>SD</u> (ft·lbs)	18.90	18.05	20.85	18.28

The contrasts for set four revealed significant differences, $F = 9.18$, $p < .01$, between the one-minute and three-minute rest intervals; and significant differences, $F = 9.59$, $p < .01$, between the one-minute and five-minute rest intervals. No differences were found between the three-minute and five-minute rest intervals for set four.

Table 25

Pair-Wise Contrasts of Average Peak Flexion for Rest Intervals by Sets Interaction

Rest Interval (Set)	DF	Type III SS	Mean Square	F	Significance
1(1) vs. 3(1)	1	208.03	208.03	1.68	.20
Error	29	3582.97	123.55		
1(1) vs. 5(1)	1	19.20	19.20	0.21	.65
Error	29	2628.80	90.64		
3(1) vs. 5(1)	1	100.83	100.83	0.69	.41
Error	29	4222.17	145.59		
1(2) vs. 3(2)	1	2133.63	2133.63	17.26	.01
Error	29	3585.37	123.63		
1(2) vs. 5(2)	1	790.53	790.53	11.64	.01
Error	29	1969.47	67.91		
3(2) vs. 5(2)	1	326.70	326.70	2.86	.10
Error	29	3312.30	114.22		
1(3) vs. 3(3)	1	3080.53	3080.53	21.73	.01
Error	29	4111.47	141.77		
1(3) vs. 5(3)	1	2288.13	2288.13	13.07	.01
Error	29	5075.87	175.03		
3(3) vs. 5(3)	1	58.80	58.80	0.39	.53
Error	29	4317.20	148.87		
1(4) vs. 3(4)	1	1456.03	1456.03	9.18	.01
Error	29	4598.97	158.59		
1(4) vs. 5(4)	1	1702.53	1702.53	9.59	.01
Error	29	5149.47	177.57		
3(4) vs. 5(4)	1	9.63	9.63	0.12	.73
Error	29	2305.37	79.50		

Rest Interval 1 = one minute
3 = three minutes
5 = five minutes

Strength and Fat-Free Body Weight Relationship

The Pearson Product Correlation Coefficients were examined for the relationship between fat-free body weight and the strength measurements. The correlations for peak extension are presented in Table 26; for peak flexion in Table 27; for average peak extension in Table 28; and for average peak flexion in Table 29. The strength measurements had a significant relationship with fat-free body weight on 47 of 48 strength measurements correlated.

Table 26

Pearson Correlation Coefficients Between Fat-Free Body Weight and Peak Extension Strength Measurements

Statistic	Set 1	Set 2	Set 3	Set 4
		One Minute		
r	.62	.64	.68	.60
r^2	.38	.41	.46	.35
p	.01	.01	.01	.01
		Three Minute		
r	.47	.63	.63	.67
r^2	.22	.40	.40	.46
p	.01	.01	.01	.01
		Five-Minute		
r	.68	.64	.70	.67
r^2	.46	.41	.49	.45
p	.01	.01	.01	.01

Table 27

Pearson Correlation Coefficients Between Fat-Free Body Weight and Peak Flexion Strength Measurements

Statistic	Set 1	Set 2	Set 3	Set 4
		One Minute		
r	.56	.53	.48	.44
r^2	.32	.28	.23	.19
p	.01	.01	.01	.02
		Three Minute		
r	.58	.53	.54	.45
r^2	.34	.28	.30	.21
p	.02	.01	.01	.01
		Five-Minute		
r	.41	.46	.58	.51
r^2	.17	.21	.34	.26
p	.01	.01	.01	.01

Table 28

Pearson Correlation Coefficients Between Fat-Free Body Weight and Average Peak Extension Strength Measurements

Statistic	Set 1	Set 2	Set 3	Set 4
		One Minute		
r	.60	.64	.62	.56
r^2	.37	.40	.38	.31
p	.01	.01	.01	.01
		Three Minute		
r	.47	.59	.62	.63
r^2	.22	.35	.39	.40
p	.01	.01	.01	.01
		Five-Minute		
r	.64	.60	.64	.67
r^2	.40	.35	.41	.45
p	.01	.01	.01	.01

Table 29

Pearson Correlation Coefficients Between Fat-Free Body Weight and Average Peak Flexion Strength Measurements

Statistic	Set 1	Set 2	Set 3	Set 4
		One Minute		
r	.51	.50	.41	.30
r^2	.26	.25	.17	.09
p	.01	.01	.02	.11
		Three Minute		
r	.50	.51	.53	.41
r^2	.25	.26	.28	.17
p	.01	.01	.01	.02
		Five-Minute		
r	.39	.39	.54	.47
r^2	.15	.16	.30	.22
p	.03	.03	.01	.01

CHAPTER V

Discussion, Summary, Conclusions, and Recommendations

In this chapter, the results of the study are examined and discussed. Also, a summary is given, and conclusions and recommendations are made.

Discussion

The results of the study revealed significant differences for the rest interval, sets, and the rest interval by sets interaction. Because of the complexity of statistical analyses, this chapter presents the results in a more readable manner. The peak extension and peak flexion values were examined for absolute maximum torque values or tension. Atha (1981) noted that tension, not fatigue, was the strengthening stimulus. These measurements, therefore, indicated the maximal tension produced in one set of five maximal voluntary, knee extension and flexion contractions, and thus indicated the overload stimulus to the muscle.

The average peak extension and average peak flexion strength measurements examined the overall effects on strength produced at each rest interval treatment. These measurements demonstrated the effect of fatigue across sets and the overall stimulus to the muscle, by an average of peak extension and peak flexion over five repetitions.

Rest Intervals. The rest interval section examined the values for each rest interval. The peak extension value for the one-minute rest interval had a mean of 187.64 ft·lbs, whereas the values for three-minute and five-minute rest intervals were 199.73 and 199.70 ft·lbs. The peak flexion values were 110.52 for the one-minute, 118.31 for the three-minute, and 116.38 ft·lbs for the five-minute rest intervals. The one-minute values are significantly lower than the three- and five-minute values. The average peak extension and average peak flexion values followed the same trend with the one-minute values lower than the three- or five-minute values. The statistical analysis found significant differences between the one- and three-minute and between the one- and five-minute rest intervals but not between the three- and five-minute intervals.

These data revealed that the length of the rest interval was important for recovery of muscle force. The one-minute rest interval did not allow complete recovery of muscular strength and resulted in fatigue.

The present study revealed that the muscle groups fatigued and showed a strength decrement index of 6.3 for peak extension and 1.65 for peak flexion, 6.6 for average peak extension and 3.1 for average peak flexion. Pastor (1959) reported values that revealed a strength decrement index of 2.5 and 3.3, 30 seconds after exercise for five and six repetitions, respectively.

Other researchers, Clarke et al. (1954, 1955) and Davis (1954), also reported decrements in strength shortly following exhaustive and intense exercise. Ariki et al. (1985a) reported that 90 seconds' rest was the optimal rest interval length between speeds of the velocity spectrum protocol when compared with rest intervals of 30 and 60 seconds. This finding suggested that strength measurements obtained at rest intervals of 30 and 60 seconds were not as great as the values obtained at the rest interval of 90 seconds. The strength values for the present study were not as great at the one-minute interval as they were at the three- and five-minute intervals and indicated that one minute was not sufficient time to allow recovery to initial strength measurements. This finding was in agreement with Kraemer et al. (1988), who noted that a reduction in the rest interval impaired maximal force production capabilities. Since tension was the stimulus for strength gain according to Atha (1981), the one-minute interval did not provide as great an overload on the muscle as the three- or five-minute rest interval. However, a one-minute rest interval between strength training sets was recommended by Corbin and Lindsey (1991).

A three-minute rest interval for isotonic weight training was recommended by Rasch (1982) and Morehouse and

Miller (1976), and for isokinetic training by Ariki et al. (1985). MacDougal et al. (1977) also used a three-minute rest interval in their research. The three-minute rest interval allowed sufficient recovery of muscle force and revealed an increase in torque over initial strength measurements. Peak flexion, average peak extension, and average peak flexion measurements were all higher at the second through the fourth set than at the first set measurement. Peak extension increased at the second set, fell .03 ft•lbs below the initial level at the third set, and then increased again at the fourth set. Stull and Clarke (1971) also reported an increase in isotonic strength, but they measured at approximately four minutes after exercise instead of the three minutes used in the present study. In contrast, Clarke et al. (1954) and Pastor (1959) reported a decrease in strength two and a half minutes after exercise.

Other researchers indicated that the rest interval should be longer than three minutes. The research of Pastor (1959), Clarke (1962), and Funderburk et al. (1974) indicated that a longer rest interval was needed to allow the muscle to recover. Lamb (1984) indicated that isotonic and isokinetic exercise required a longer rest period of five to ten minutes because both types of exercise caused a greater depletion of energy reserves and a greater production of lactic acid. The five-minute rest interval allowed strength to surpass initial values on all successive sets. The second through the fourth sets were higher than the first set for peak extension, peak flexion, average peak exension, and average peak flexion. In contrast, Clarke et al. (1954) reported decrements after five and a half minutes, and Pastor (1959) reported decrements after seven and a half minutes. Pastor's results revealed a strength decrement index that was 1.48 greater than that of the control group.

Therefore, the present study agreed with Guyton (1986), who suggested that three- to five-minute rest intervals were sufficient to allow reasonable replenishment from muscular exercise. Guyton suggested that the availability of adenosine triphosphate in the body was completely depleted after 10 to 15 seconds of intense exercise and had to be replenished by a rest interval or else fatigue occurred. The exercise for the present study took about 15 seconds to complete for each set.

Other researchers attempted to examine and explain the process of fatigue and recovery. McCafferty and Horvath (1977) indicated that short-term heavy exercise used high-energy phosphate stored in the muscle and non-oxidative glycolysis. They suggested that the energy stores were insufficient for repeated exercise bouts unless replenished by rest periods of sufficient duration; however, they did not define sufficient duration. According to Battinelli

(1987), fatigue was multifaceted and related to metabolic end products in fast twitch muscle fibers. Recent researchers, however, indicated that recovery from heavy exercise was related to the aerobic oxidative capacity of skeletal muscle. Spriet et al. (1989) suggested that oxidative metabolism was very important in supplying energy for short, high-intensity exercise, and Jansson et al. (1990) stated that the recovery of force and the return of metabolite contents after short-term, intense exercise were dependent on the aerobic-oxidative potential of skeletal muscle. These studies provided rationale for the reasons the one-minute rest was not sufficient. The present study did not attempt to explain the causes of fatigue and recovery, but did examine the rest interval and its effects on the force production capabilities.

Sets. The section on sets examined the effects of the four sets across the rest intervals. The differences between the sets were caused by the high mean values for peak extension and average peak extension in set two, and the low mean values for set three. Set four was also lower due to the fatigue and decrement which occurred for the fourth set value of the one-minute treatment. The mean values for peak flexion and average peak flexion increased in the second and third set and then returned to just above the second set value for set four. This caused differences between most of the sets for peak flexion and average peak flexion. The reasons for these responses were unclear. The third set values both revealed a surge in torque. The hamstring muscle required three sets to reach optimal performance.

The mean value for peak extension strength of set one was compared with normative isokinetic data. Set one was used because this value indicated the mean obtained from the first set of the three different rest intervals. Set two through four was affected by the rest interval treatments and the previous sets. Davies' (1987) normative data indicated that males had peak extension (quadriceps) torque values at an angular velocity of 60 degrees per second equal to their body weight. The 30 subjects in the present study had a mean weight of 194.48 pounds. The overall mean peak extension strength value for set one was 196.06 ft•lbs.

Davies also recommended a hamstring ratio (peak flexion) of 60-69 percent of the quadriceps (peak extension) strength at 60 degrees per second. The present study had a mean peak flexion for set one of 111.22 ft•lbs. This value divided by the mean value for peak extension of 196.06 ft•lbs yielded a .57 ratio. This ratio is .03 below the ratio recommended by Davies. The values for the other sets were set two .55, set three .63, and set four .58. The value for set three would fall under the norms recommended by Davies. However, these ratios must be cautiously examined because they were altered by the effects of the rest interval treatments and prior sets. The hamstrings/ quadriceps ratios for the mean values for the average peak flexion divided by the average peak extension torque showed ratios of .56 for set one, .56 for set two, .61 for set three, and .56 for set four.

The highest values for peak flexion and average peak flexion occurred at the third set while the lowest peak extension and average peak extension values occurred at the third set. This made the ratios for the third set the highest. These high third set values indicated that the hamstrings muscle required a longer period than the quadriceps to reach optimal performance.

Rest Interval by Sets Interaction. The rest interval by sets interaction section examined the relationship between the rest interval and sets and revealed significant interactions. This was partly caused by the decreasing torque values across the sets at the one-minute rest interval for peak extension and average peak extension, and the increase in torque values for all but one set for the three- and five-minute rest intervals. The torque values for peak flexion and average peak flexion were higher than initial set values for the three- and five-minute rest intervals. The one-minute rest interval revealed the second and fourth sets below initial torque levels. While the differences between the one-minute and three-minute rest interval, and the one-minute and five-minute rest interval caused the significant interaction, the relationship of the three- and five-minute interactions were also involved. The five-minute torque values for set one were lower than the three-minute torque values for peak extension, peak flexion, average peak extension, and average peak flexion. However, the five-minute torque values were higher than the three-minute torque values for the fourth set at peak extension, average peak extension, and average peak flexion. These torque values indicated that a cross-over occurred between the three-minute and five-minute rest intervals. The cross-over showed a variation in the response of the three- and five-minute rest intervals, although the actual reported values are not significantly different.

Strength and Fat-Free Body Weight Relationship. The strength measurements had a significant relationship with fat-free body weight on 47 of 48 strength measurements correlated. The average peak flexion torque at the fourth set for the one-minute interval did not show a significant relationship with fat-free body weight. A significant relationship was found for peak extension, peak flexion, and average peak extension at all sets (one through four), for each rest interval (one-, three-, and five-minute). A relationship was also found for average peak flexion at all sets and intervals except the fourth set at the one-minute rest interval, which also revealed the lowest torque values. This relationship on 47 of 48 strength measures was in agreement with Beam, Bartels, and Ward (1982) who found a significant relationship between knee extension and flexion torque and lean body weight, and also a significant relationship for other strength tests.

Strength and Rest Interval Trends. The trends for the peak extension by set and ret interval are presented in Figure 1. The one-minute rest interval treatment declined across sets from the first set of 194.87 ft•lbs to the fourth set of 182.67 ft•lbs. The one-minute rest interval treatment did not allow complete recovery of the muscle group, thus fatigue inhibited the strength on each successive set. The one-minute treatment resulted in a net change from the first set to the fourth set of a negative 12.2 ft•lbs or a strength decrement index (Clarke et al., 1955) of 6.3. The three-minute rest interval treatment increased from 197.60 ft•lbs for the first set to 200.50 ft•lbs for the fourth set. This revealed that three-minutes were sufficient to allow muscular recovery. The net change from the first to the fourth set of the three-minute treatment was an increase of 2.9 ft•lbs. The five-minute rest interval treatment revealed an increase from 195.70 ft•lbs on the first set to 201.97 ft•lbs on the fourth set. The net change from the first to the fourth set of the five-minute treatment was an increase of 6.27 ft•lbs.

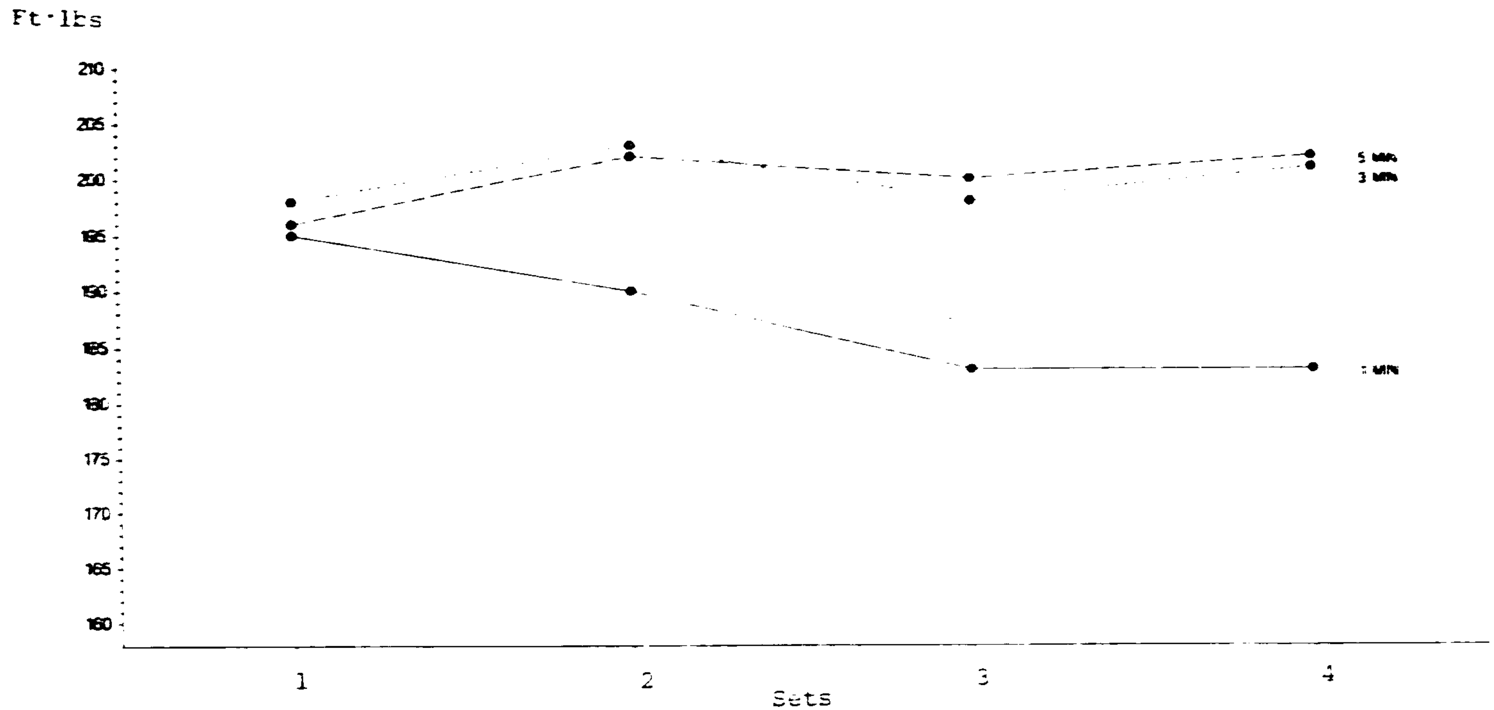

Figure 1. Peak Extension by Sets and Rest Intervals

This revealed peak extension measures for the fourth set of 182.67, 200.50, and 201.97 ft•lbs for the one-, three-, and five-minute treatments. The lowest value for the fourth set was revealed at the one-minute treatment with the highest values for the fourth set at the five-minute treatment.

Figure 2 shows the trends for peak flexion by set and rest interval. The one-minute treatment produced a decline from 110.52 ft•lbs for the first set to 108.70 ft•lbs for the fourth set. This was a net change of negative 1.82 ft•lbs or a strength decrement index of 1.65. The three-minute and five-minute treatments caused an increase from 112.30 and 111.23 ft•lbs for the first set to 116.97 and 115.87 ft•lbs for the fourth set. This was a net increase of 4.67 and 4.64 ft•lbs for the three- and five-minute treatments. The peak flexion values for the fourth set were 108.70, 116.97, and 115.87 ft•lbs, respectively, for the one-, three-, and five-minute treatments. This revealed that the lowest peak flexion value for the fourth set occurred at the one-minute interval, while the highest peak flexion values for the fourth set occurred at the three-minute interval treatment.

The trends for average peak extension by set and rest interval are presented in Figure 3. The one-minute interval treatment declined from 183.90 ft•lbs for the first set to 171.77 ft•lbs for the fourth set. This was a net change

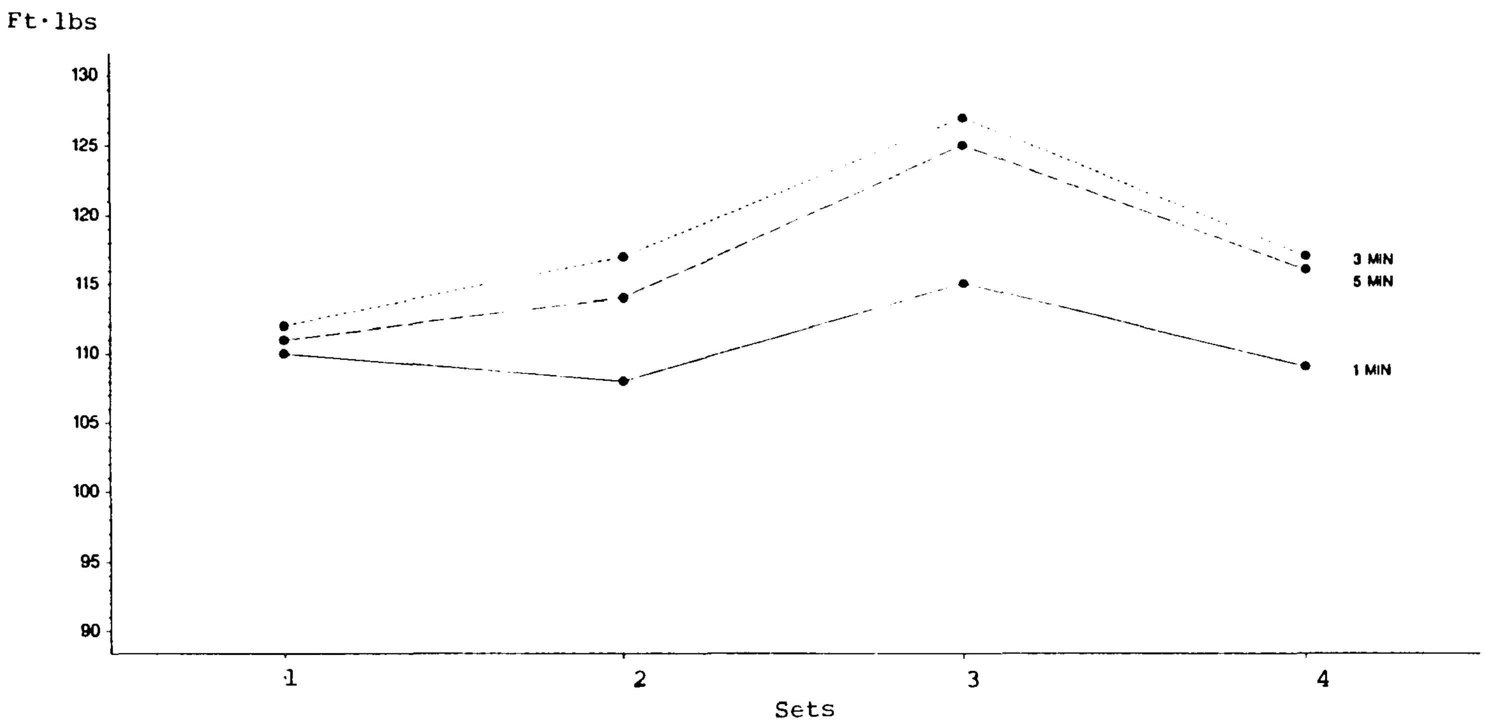

Figure 2. Peak Flexion by Sets and Rest Intervals

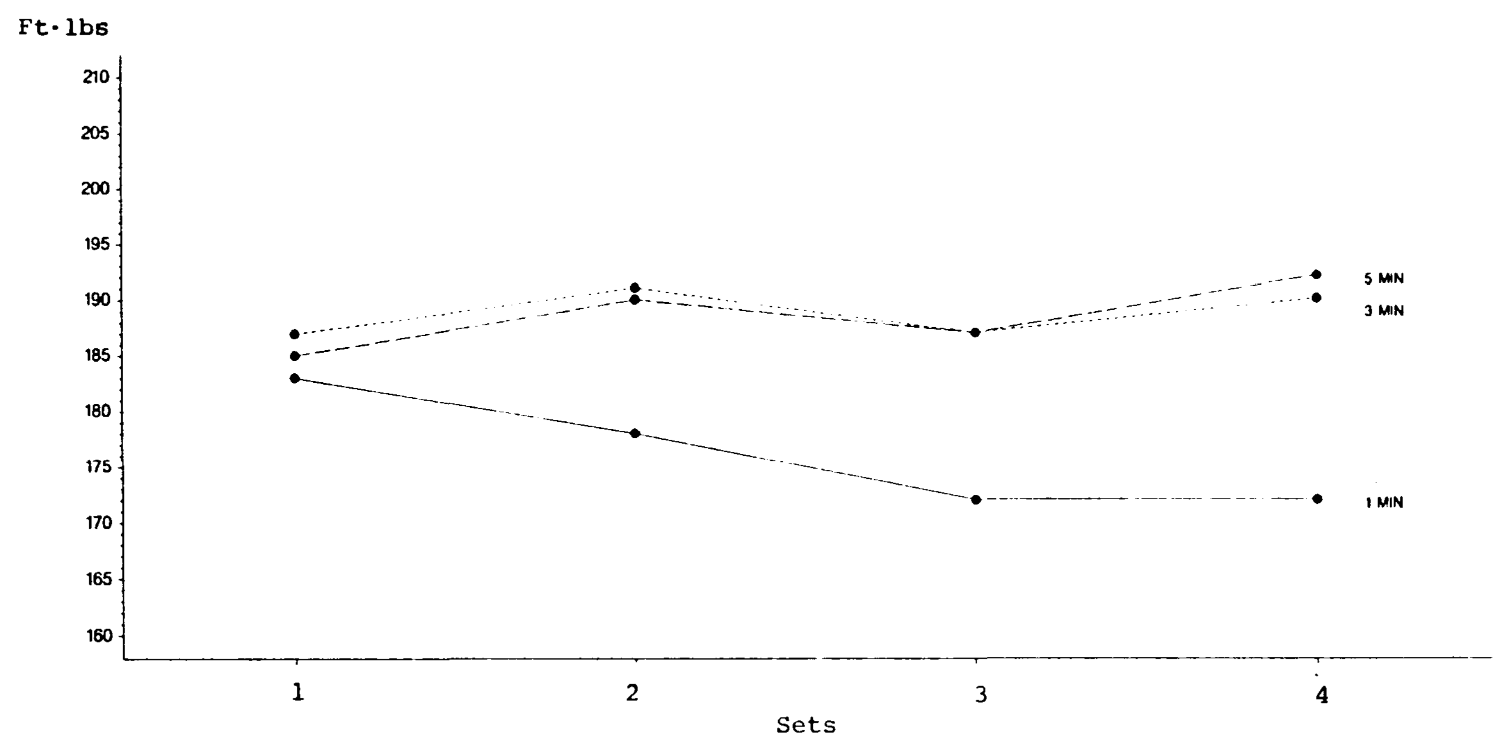

Figure 3. Average Peak Extension by Sets and Rest Intervals

of negative 12.13 ft•lbs or a strength decrement index of 6.6. The three- and five-minute rest interval treatments increased from 186.57 and 185.13 ft•lbs for the first set to 189.87 and 192.10 ft•lbs for the fourth set. These were net increases of 3.3 and 6.97 ft•lbs for the three- and five-minute treatments. The average peak extension values for the fourth set are 171.77, 189.87, and 192.10, respectively, for the one-, three-, and five-minute treatments. This data revealed that the lowest value for the fourth set occurred at the one-minute treatment, while the highest measure occurred at the five-minute treatment.

The trends for average peak flexion by set and rest interval are presented in Figure 4. The one-minute treatment declined from the first set, 102.30 to the fourth set, 99.07 ft•lbs. This was a net change of negative 3.23 ft•lbs or a strength decrement index of 3.1. The three- and five-minute treatments indicated an increase from the first set, 104.93 and 103.10 ft•lbs, to the fourth set, 106.03 and 106.60 ft•lbs. This revealed a net increase of 1.1 and 3.5 ft•lbs for the three- and five-minute treatments. The fourth set values for average peak flexion were 99.07, 106.03, and 106.60 for the one-, three-, and five-minute rest intervals. This indicated that the lowest measure for the fourth set occurred at the one-minute treatment while the highest fourth set measure occurred at the five-minute treatment.

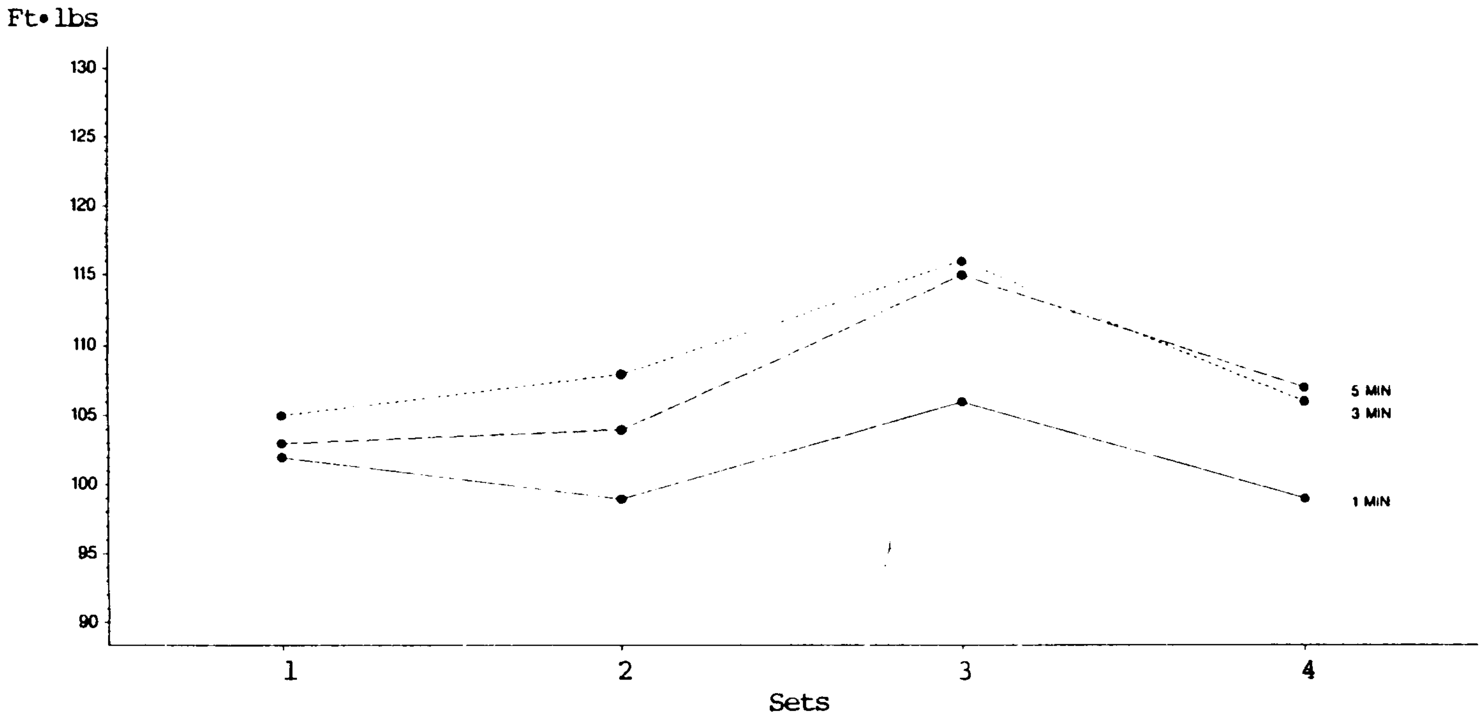

Figure 4. Average Peak Flexion by Sets and Rest Intervals

Summary

The study examined the effects of various rest intervals on isokinetic knee extension and flexion strength. The results revealed that the one-minute rest interval did not allow recovery of strength and fatigue resulted. The three-minute rest interval allowed recovery of strength between sets as did the five-minute rest interval. These results indicated that rest intervals of three minutes between sets are needed to allow recovery from maximal isokinetic knee extension and flexion exercise. Resting five minutes between sets was not significantly different from the three-minute rest interval.

The results of this study revealed that, if muscular tension overload is the goal of a training program, then proper rest intervals need to be utilized. Data provided by this study added to the existing research studies regarding the rest interval and the time needed for strength recovery. The information was also useful for teachers of physical education and for sports conditioning.

Conclusion

The study examines the effects of various rest intervals on knee extension and flexion strength. It is concluded that a three-minute rest interval allowed the muscle sufficient time for recovery after five isokinetic knee extension and flexion repetitions.

Recommendations

The following recommendations are made for future research.

1. There is a need for an isokinetic training study that would examine strength development using various rest intervals between sets but maintaining equal sets and repetitions.

2. There is a need for a study examining the amount and intensity of a warm-up period ideal for producing maximal isokinetic strength testing.

3. There is a need for an identical study using female subjects.

4. There is a need for a training study using free weights with various rest intervals but maintaining equal sets, repetitions and loads.

Appendices

Appendix A

Research Ethics Committee Approval Letter on-campus memo:

To: Timothy R. Johnson & Dr. Powell D. McClellan

From: Michael Principe, Chair
MTSU Research Ethics Committee

Subject: I.R.B. Review

Date: July 16, 1990

I have reviewed the materials for the proposed investigation "Isokinetic Knee Flexion and Extension Strength with Varied Interset Rest Intervals." I approve this study through the expedited review procedures authorized in 46.110 of 45 CRF Part 46.

I have kept a copy of your proposal and permission memorandum for our files. If this is a problem contact me.

Appendix B

Consent Form

STRENGTH RECOVERY EXPERIMENT (1990)

INFORMED CONSENT

The tests included in the experiment involve the determination of body composition by underwater weighing and the measurement of muscular strength. The underwater weighing involves being submerged briefly under water after exhalation of air. The strength test includes an initial testing to determine the dominate limb, and then involves performing four sets of five repetitions with the dominant limb. This testing is done on the Cybex 340, with varied recovery intervals on three different days.

Complications have been few during these types of tests. Occasionally mild lightheadedness may occur, but this is not usual and disappears quickly. Although safety is an advantage of isokinetic exercise, it is possible to experience some muscular soreness and/or strain.

In signing this consent form, you state that you have read and understand the description of the tests and their complications. You also give consent to allow the researchers to use the data obtained for any publications or presentations. Any questions which occurred to you have been answered to your satisfaction. Every effort will be exerted to insure your health and safety. You enter into the tests willingly and may withdraw at any time.

Signature of the Subject ______________________________

Signature of the Researcher ______________________________

Date Signed ______________________________

Witness ______________________________

Appendix C

Raw Data

Raw Data

Physical Characteristics

Subject Number	Age (Years)	Height (Inches)	Weight (Pounds)	Body Fat (Percent)
1	41	75.75	211.25	29
2	22	73.00	195.00	16
3	20	71.50	172.00	13
4	24	72.50	160.50	11
5	22	73.75	167.00	17
6	22	73.00	175.25	25
7	22	73.25	191.00	22
8	30	71.00	208.75	25
9	25	69.00	169.25	17
10	22	69.00	274.25	38
11	22	65.50	179.75	18
12	22	73.75	190.00	15
13	21	74.00	180.00	17
14	27	69.25	220.25	27
15	22	76.50	285.75	24
16	21	72.00	185.00	22
17	22	69.00	194.00	6
18	25	68.50	172.00	6
19	22	73.50	202.75	14
20	24	68.50	156.50	8
21	24	72.00	170.50	10
22	25	72.50	181.00	27
23	23	73.75	223.75	12
24	22	64.00	146.25	6
25	22	70.25	147.50	17
26	36	74.75	246.00	28
27	22	74.50	238.00	18
28	20	73.75	246.00	20
29	22	70.00	176.25	19
30	33	68.75	169.00	15

Peak Extension

	Rest Interval (Sets)											
	One-Minute				Three-Minute				Five-Minute			
Subj.	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
1	166	163	149	155	170	171	160	161	151	166	165	154
2	206	193	191	195	224	224	219	224	225	232	216	240
3	202	178	195	175	228	202	223	193	201	208	203	197
4	199	190	174	167	205	187	175	159	198	195	183	185
5	146	156	146	145	156	167	164	158	172	172	164	168
6	139	124	119	118	146	150	136	135	131	140	133	141
7	180	170	157	142	203	215	197	199	171	173	180	162
8	191	190	185	185	190	192	191	197	203	231	226	225
9	201	205	192	190	165	183	185	192	188	196	193	194
10	160	163	143	140	152	173	184	188	202	189	184	196
11	204	203	186	190	200	202	192	197	188	201	199	205
12	204	209	200	201	195	212	206	212	204	220	216	215
13	189	182	188	185	188	191	189	193	189	189	187	186
14	167	163	149	138	197	194	174	184	176	170	169	163
15	216	208	196	192	175	218	215	224	209	230	235	223
16	164	170	164	167	189	193	183	196	164	176	179	173
17	149	168	174	167	154	171	153	173	171	165	179	183
18	259	233	222	228	258	271	257	264	247	267	264	265
19	232	219	216	214	236	253	246	246	252	256	259	280
20	165	170	163	159	174	179	173	178	176	186	173	189
21	173	174	177	193	186	170	167	184	169	165	173	195
22	170	160	152	158	160	152	147	145	165	158	160	158
23	267	262	243	228	236	239	230	230	230	242	255	268
24	212	205	183	198	215	218	215	214	196	200	202	208
25	159	169	157	161	186	195	182	193	161	179	173	167
26	245	222	205	222	240	240	230	224	231	225	239	236
27	249	222	249	237	259	276	283	284	240	238	219	224
28	263	274	272	274	287	304	307	311	299	293	289	295
29	194	192	182	197	178	179	178	179	193	201	192	194
30	175	168	157	159	176	176	166	178	169	186	176	170

Peak Flexion

	Rest Interval (Sets)											
	One-Minute				Three-Minute				Five-Minute			
Subj.	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
1	114	108	113	106	118	122	126	133	112	109	118	127
2	117	113	118	109	114	122	136	121	118	124	129	124
3	130	121	133	114	119	126	125	131	121	132	138	126
4	114	118	128	112	106	108	128	124	118	120	130	119
5	113	120	125	124	111	119	118	127	123	122	122	115
6	77	70	76	81	83	87	101	88	96	92	97	88
7	115	108	114	110	119	134	143	112	108	104	114	118
8	106	119	117	129	105	113	120	112	122	131	138	124
9	107	109	107	94	109	113	126	117	119	117	132	130
10	102	101	108	87	93	103	122	122	110	109	124	114
11	117	114	127	114	122	124	132	116	100	100	111	111
12	95	98	106	94	112	118	124	114	90	95	116	108
13	113	113	128	111	114	120	130	113	114	118	127	114
14	87	92	94	90	94	102	101	90	92	93	103	92
15	113	112	115	103	120	121	138	115	108	114	139	112
16	82	82	95	97	89	92	99	99	84	89	101	88
17	108	106	104	111	115	110	121	109	105	111	117	106
18	101	100	105	97	106	115	115	100	108	109	120	115
19	138	141	126	138	153	153	175	161	147	153	167	146
20	101	104	112	106	102	107	115	108	112	106	109	88
21	79	74	90	88	86	76	82	73	67	69	79	79
22	106	106	110	98	94	95	104	97	100	104	115	103
23	138	129	137	124	136	141	146	136	130	133	145	142
24	112	104	103	99	109	110	119	109	107	113	121	110
25	95	92	113	118	116	124	137	122	106	112	123	118
26	118	106	115	98	116	122	132	119	123	126	140	132
27	142	131	146	146	138	144	153	142	118	131	151	148
28	167	167	185	181	175	187	204	183	173	169	185	167
29	103	99	102	92	101	112	115	117	106	103	112	101
30	94	88	100	90	94	101	111	99	100	106	115	111

Average Peak Extension

	Rest Interval (Sets)											
	One-Minute				Three-Minute				Five-Minute			
Subj.	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
1	157	152	144	146	161	162	153	151	141	155	158	149
2	200	191	181	188	216	214	210	211	213	218	207	221
3	195	171	184	172	219	198	210	187	194	198	181	188
4	183	175	170	163	185	173	169	152	191	187	189	191
5	144	149	138	133	153	156	159	155	166	163	153	157
6	126	115	112	108	133	135	127	123	123	124	115	130
7	168	158	149	131	195	204	193	191	158	160	158	153
8	173	171	168	167	167	172	165	175	190	205	199	210
9	189	182	187	183	155	165	170	180	175	183	183	183
10	151	145	124	116	145	158	167	171	177	180	180	193
11	196	191	185	183	185	190	186	184	185	196	191	193
12	196	198	192	195	187	201	199	205	190	211	201	209
13	178	171	175	182	186	183	185	185	182	189	180	182
14	155	149	136	133	180	180	162	168	165	158	149	152
15	201	197	188	185	165	205	207	211	203	216	216	220
16	160	161	156	158	178	187	178	186	157	158	161	163
17	141	158	160	158	141	150	144	146	153	143	158	170
18	249	221	210	213	243	256	251	254	238	256	254	252
19	211	211	208	196	228	235	238	241	245	247	251	258
20	158	158	149	146	168	172	161	164	168	173	169	175
21	163	168	173	181	173	160	159	180	160	158	160	191
22	160	153	146	150	142	140	138	138	149	151	150	153
23	253	243	228	216	221	223	220	224	220	234	241	256
24	200	191	175	188	205	211	203	209	190	190	190	196
25	153	163	155	153	181	188	170	186	160	173	168	165
26	231	208	186	204	228	230	213	221	215	218	219	230
27	238	208	224	220	250	260	265	267	220	216	203	204
28	249	256	260	251	276	288	291	296	283	276	268	280
29	181	183	173	188	170	175	171	170	184	199	184	188
30	158	150	135	146	161	166	158	168	159	167	160	151

Average Peak Flexion

	Rest Interval (Sets)											
	One-Minute				Three-Minute				Five-Minute			
Subj.	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
1	99	97	105	100	114	108	111	113	101	103	104	121
2	110	101	108	102	111	113	128	114	111	110	120	116
3	124	116	125	108	110	114	113	123	118	122	130	117
4	108	108	120	104	98	100	120	115	110	106	125	106
5	106	114	120	116	108	108	106	114	116	114	120	113
6	71	63	71	80	81	85	93	82	86	86	95	78
7	110	95	101	83	106	123	137	103	99	97	99	113
8	96	108	103	103	95	95	110	105	115	120	121	111
9	99	94	99	88	103	103	117	108	111	106	127	113
10	105	88	88	67	78	98	112	112	101	94	113	101
11	101	106	115	108	113	120	118	89	93	96	98	100
12	88	90	100	91	105	103	111	93	78	84	106	101
13	98	106	117	104	110	108	119	104	111	112	120	110
14	83	84	87	85	85	92	96	86	85	85	90	83
15	96	100	101	80	109	111	117	100	99	100	123	98
16	78	78	89	93	86	90	96	93	78	85	91	84
17	103	98	97	103	101	100	113	100	91	96	108	92
18	97	92	99	93	97	106	101	88	93	98	113	104
19	120	125	114	128	147	147	156	150	138	141	153	135
20	100	98	108	103	94	98	113	101	105	101	99	84
21	73	71	81	83	79	63	76	70	61	59	65	75
22	100	99	101	91	91	89	102	92	96	101	110	97
23	123	119	128	102	133	133	133	121	126	124	138	130
24	105	100	96	92	105	100	106	101	100	106	115	103
25	90	81	108	104	113	116	120	109	94	103	100	101
26	110	98	106	94	109	111	121	106	118	117	138	121
27	131	121	138	130	126	134	150	128	110	127	141	136
28	156	153	164	164	160	168	182	161	160	151	171	158
29	99	94	96	87	95	103	105	108	94	96	105	97
30	90	83	94	86	86	94	101	92	95	94	103	100

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