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THE EFFECTS OF WARM-UP ON ISOKINETIC MUSCLE TESTING

The Ohio State University

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The Effects of Warm-up on Isokinetic Muscle Testing

DISSERTATION

Presented in Partial Fulfillment of the Requirements for
the degree Doctor of Philosophy in the Graduate
School of The Ohio State University

By

Robert S. Axtell III, B.S., M.S.

* * * * *

The Ohio State University

1984

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DEDICATION

To my parents,
whose love and support
made this work possible.

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I would like to thank my advisor, Dr. Robert L. Bartels, for his guidance and support during my doctoral program. It was through his efforts that I was able to continue my graduate studies and experience the educational opportunities here at the University. I would also like to express my thanks to Dr. Elaine M. Filusch and Dr. Jean Snook for their guidance and advice as members of my reading committee.

The support, confidence and love of my parents, Mr. Robert S. and Elizabeth D. Axtell, and my two sisters, Susan and Sarah, have made this three-year experience a reality. For this I am sincerely grateful.

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Chapter I

INTRODUCTION

Isokinetic strength testing is relatively new to the area of muscle strength assessment. Perrine [33] discussed this as a movement at a mechanically fixed rate of speed whereby the resistance was inherently proportional to the muscle's dynamic tension developing capacity. He later patented the first isokinetic strength testing device in 1969. With the development of the isokinetic technique, it became possible to objectively study dynamic muscle characteristics of intact human skeletal muscle throughout a complete range of movement.

Since its development in 1969, the isokinetic dynamometer has been used in a number of different settings. Many physicians, orthopedic surgeons, physical therapists, and researchers have found isokinetic evaluations to be useful in assessing muscle strength after surgery, injury or specific training. Observation of a satisfactory agonist-antagonist, bilateral and force-velocity relationship are criteria used to assess muscular capability [23]. Those involved with treatment of neuromuscular disorders [2][12]

[40] rely on the dynamometer to provide objective strength measures which are essential for rehabilitation and evaluation of drug therapy. Therefore, it is important that the procedures used to measure isokinetic muscle strength provide reliable and valid data.

In the past decade much of the research in this area concentrated on the effects isometric, isotonic and isokinetic training have on muscular strength and power development. Recently, other investigators have used the muscle biopsy procedure [6] to relate fiber composition with force-velocity relationships under isokinetic loading. A review of the isokinetic literature demonstrates that the positioning technique used for strength evaluation of the knee is well described [20]. However, to date, there have been few research studies pertaining to isokinetic testing protocols. Mawdsley and Knapik [27] provided an early investigation into the effect one isokinetic testing variable has on torque production. They demonstrated in a study of only maximal contractions of the knee extensors that the first trial of a six-trial test was significantly different from other trials. Similarly, Croft [11] found that the first maximal contraction was not representative of the other maximal contractions. A number of studies reviewed have used only one repetition to evaluate peak torque [21] [26][27] ; however, as indicated, repetition

appears to be significantly different than other repetitions. These studies suggest that there is an appropriate number of repetitions that should be performed to assure the tester that he has seen a maximal contraction. Other variables such as type and length of the warm-up period, training and learning and overall fitness of the subject need to be studied in reference to their influence on maximal voluntary peak torque production.

STATEMENT OF THE PROBLEM

Many team physicians, orthopedic surgeons, neurologists, clinicians and other researchers agree that isokinetic strength testing is an objective method of quantifying dynamic muscle strength. This objective measure of muscle strength is often used to evaluate when an individual is strong enough to return to competition following an injury or surgery. The measurement used to describe isokinetic strength is called peak torque. This measurement criterion varies between repetitions [27] and suggests that the number of repetitions required to produce a peak torque is an important consideration when designing a testing protocol. It was found in a pilot study by Lanese et al. [24] that peak torque was always observed during the first three repetitions, which helped to further standardize the isokinetic testing procedure. Variation in the testing procedure

such as warm-up, orders of speeds tested, training and learning, and fitness level of the subject, has not been adequately addressed in the literature. The effect of such variations may lead to false peaks which in turn may result in erroneous conclusions about muscle function.

PURPOSE OF THE STUDY

Numerous researchers have suggested a need for universal standards for isokinetic muscle testing [15][16][26]. The number of repetitions, type and placement of the warm-up, speeds to test, sequence of testing speeds and the physical condition of the subject are all variables that can influence the subject's ability to execute a maximal isokinetic muscle contraction. If evidence is presented to show that these variables can affect peak torque production, then maybe professionals would be more willing to standardize their testing procedures. A standardized isokinetic muscle testing procedure will make it possible to compare the results of different studies. The purpose of this study was to examine the impact of warm-up procedures on maximal voluntary peak torque production in an untrained female population who were inexperienced isokinetic users.

STATEMENT OF EXPERIMENTAL HYPOTHESES

It has been reported [43] that "the subjects went through a standardized period of warm-up prior to the administration of the testing procedures". This study was designed to investigate the effects different warm-up procedures have on MVPT production. Specifically, the following hypotheses were tested.

1. There is no difference in torque production when subjects are exposed to different warm-up procedures.
2. There is no difference in the way the warm-up procedures affected torque production in the extension and flexion mode.
3. There is no difference in the absolute torque measurements made at 30 and 60 degrees per second.

DELIMITATIONS OF THE STUDY

1. The population for this study consisted of female volunteers from the graduate program in physical education from The Ohio State University.
2. Muscular strength was measured isokinetically using a CYBEX II isokinetic dynamometer (CYBEX Division Lumex, Inc., Ronkonkoma, NY.).
3. Subjects were untrained and inexperienced isokinetic users.

4. The effect of gravitational and other acceleration errors were such as to cause false early peaks in the muscle moment curves which can result in erroneous conclusions about muscle function.

LIMITATIONS OF THE STUDY

1. Efforts by the subjects varied due to motivation, attentiveness or verbal encouragement.
2. Measurement of muscular strength was only performed on the muscles that extended and flexed the knee.
3. The CYBEX II isokinetic dynamometer used for strength did not have the necessary capability to correct for gravitational and acceleration errors (8,42).

DEFINITION OF TERMS

CYBEX II Isokinetic Dynamometer

Is a device which permits resistive exercise at a constant velocity and allows clinical muscle evaluation in a setting simulating functional activity.

Torque

A measure of force that rotates an object about an axis of rotation and is determined by taking the cross-product of the length of the lever arm, measured from the axis of rotation to the point of application of the force by the component of force that is perpendicular to the lever arm.

Peak Torque

The maximum amount of force a muscle can develop at different speeds of joint movement. This represents the maximum work rate or power the muscle can develop at specific speeds of shortening.

MVPT

Maximum Voluntary Peak Torque

NM/Kg

Torque expressed in newton meters per kilogram of body weight.

Warm-up

The use of preliminary exercise procedures prior to the actual event or test of graded intensity.

Chapter II

REVEIW OF LITERATURE

The use of isokinetic strength measurement has received considerable attention during the last few years. Physicians and physical therapists have used this strength measurement tool to document rehabilitation athletes as a preventive measure prior to the beginning of a season. Neurologists have used this mode of testing to collect quantitative information about the maximal tension generated by the muscle in patients with various neuromuscular diseases. For exercise scientists, isokinetic muscle testing has continued to be the method of choice used to evaluate muscle function and strength. Review of the literature indicated there was a lack of continuity in the procedures used in isokinetic testing. There was little agreement between studies as to the testing speeds used, the number of testing repetitions used, length and type of warm-up to use, and whether training/learning and fitness level affect MVPT production. For these reasons, it has been difficult to make meaningful comparisons. with previous research. This study was designed to determine the effect different

warm-up procedures have on the production of maximum voluntary peak torque (MVPT).

SELECTION OF TESTING SPEEDS

The manufacturer of the CYBEX II isokinetic dynamometer has suggested specific testing speeds to delineate muscle function [20]. The speeds often selected include a slow velocity setting to examine muscle strength and a fast velocity to determine power capabilities of the muscle. The literature contained numerous studies where two or more testing speeds were used [2][15][25] [32][37][44] [49] and suggestions have been made to enhance our ability to select appropriate testing velocities. Perrine and Edgerton [34] demonstrated that at a zero speed, individual discomfort existed. In a study of isometric and isokinetic torque, Scudder [37] reported subjects could not tolerate the discomfort of effort below 3 RPM (18 Degrees/Second). This suggested that the discomfort was due to the duration of effort along with the high tension developed within the knee joint during these slow testing speeds. Furthermore, Perrine and Edgerton [34] reported that at 48 degrees per second subjects did not complain nor apparently did they feel any discomfort while performing a maximal effort. Yet no torque values at this "comfortable" test speed were higher than those at 96 degrees per second. This finding

demonstrated that little additional information was gained from the slow testing speed at the expense of possible discomfort to the subject.

A second consideration when selecting testing speeds is the ability to observe muscle force-velocity relationships, an objective strength measurement useful in evaluating muscle function. Thorstensson et al.[44] reported a force-velocity relationship in human knee extensors when he measured force with an isokinetic dynamometer. They observed in twenty-five active male subjects (17-37 years), a peak torque decline with increasing speed of muscle shortening from 238.3 NM (0 Deg/Sec) to 129.4 NM (180 Deg/Sec). This decline corresponded to a 45% reduction in force production. Perrine and Edgerton [34] showed in concentric muscle contractions that the in-vivo muscle force-velocity curve plateaus markedly at low velocities. The difference in these two curves in the high-tension area may reflect the action of some neural regulatory mechanism. Knowledge of this force-velocity model may well provide the clinician with valuable information that allows for a safe isokinetic testing or rehabilitation program.

The literature regarding the influence of testing speed order appeared to be limited. In a study of the comparison of quadriceps and hamstring torque values during isokinetic exercise, Wyatt and Edwards [49] used two testing sequences

to diminish the variability that may have been caused by learning or fatigue. Half of the subjects were tested in a "slow first" sequence of 60, 180 and 300 degrees per second and the remaining subjects were tested in "fast first" sequence using the reverse order. Whether there was a difference in peak torque production between sequences was not reported. Scudder [37] randomized the order of testing speeds to minimize the effect of strengthening and learning but did not evaluate possible differences. The awareness of these two studies to testing speed sequence suggested the variable had an effect on peak torque production.

NUMBER OF REPETITIONS TO PRODUCE MVPT

When conducting isokinetic muscle testing, clinicians, neurologists, physicians and physical therapists used MVPT as the measurement criterion. Numerous investigators [21][27][43][49] have had their subjects perform a varying number of repetitions to observe a MVPT. Schneck and Forward [36] observed that the strength of maximal isometric contractions increased over six trials during the same testing period. This suggested that the often used two or three repetitions may not be sufficient to elicit a MVPT isometrically. In two isokinetic studies [15][43], the use of two and three repetitions to observe MVPT was used however, neither investigation supported the selection of the number

of repetitions used to observe a peak torque. In reference to the work done by Schneck and Forward [36], two or three testing repetitions may not be sufficient to observe a MVPT. In another isokinetic study [27], it was reported that a significant difference ($P < 0.05$) in MVPT was observed in the knee extensors at 30 degrees per second between trial 1 and trial 3. This supports the earlier work by Schneck and Forward. Similarly, Wyatt and Edwards [49] observed that MVPT usually occurred during the second and third extension. These inconsistencies indicated that there was a need to investigate how many contractions were necessary to produce a MVPT and if that number was different for each speed tested.

THE EFFECT OF WARM-UP PROCEDURES ON MVPT

Many investigators [1] [3][13] [30][41] have indicated that a warm-up has a beneficial effect on performance. One of the important values of the warm-up was in its use as a preventive measure in reducing the risk of injury. Start and Hines [41] showed that an "adequate" warm-up prevented strains, muscle tears and muscle soreness. The purpose of the warm-up was to raise general body and deep muscle temperatures and to stretch the ligaments and other collagenous tissues which promoted greater flexibility (20). By raising the temperature of the muscle, metabolic processes in

the cell were able to proceed at a higher rate. For every degree of temperature increase, the rate of metabolic reactions increased by about 13% - which may significantly affect muscle testing. Furthermore, nerve impulses travelled faster at higher temperatures. Therefore, in order to be able to move faster, body temperature should remain elevated. Asmussen and Boje [1] reported that a given amount of work can be performed better i.e. in a shorter time when the body is warmed up by a preliminary work period. Hogberg and Ljunggren [19] also observed that a greater muscular tension could be developed when "warmed up" than when not and that the harder the preliminary work the better was the performance in work of short duration (12-15 seconds).

In reference to the duration of the warm-up period Hogberg and Ljunggren [19] reported that results after a 15-minute warm-up were better than those after a 5-minute one. However, no significant improvement in performance was observed when the warm-up period was extended from fifteen to thirty minutes. Hogberg and Ljunggren (19) in 1947, also found no deterioration in performance associated with fatigue due to a strenuous warm-up. Hogberg [19] recommended a warm-up procedure of 15-30 minutes in duration at a relatively high rate of energy expenditure and a rest period between the warm-up and the start of the

activity lasting no more than a few minutes. It appeared that after a 45-minute rest that the beneficial effect of the warm-up was lost and muscle temperature returned to pre-warm-up levels [19].

The effect a warm-up procedure had on MVPT production during a CYBEX II isokinetic muscle test has received little attention in the literature. Thorstensson [44] had their subjects go through a period of "standardized warm-up". However, the specifics of the warm-up were not given. Before testing, Gleim et al. [15] had their subjects perform a "few" submaximal efforts in an attempt to familiarize them with the apparatus. In this case Gleim offered some explanation of the warm-up but the use of a "few submaximal efforts" left some questions concerning the content of the warm-up. Johnson and Siegel [21] gave specific directions for their warm-up but gave no basis for its selection. Two studies [26][27] have specified the type of warm-up used and have found that it can effect torque production. Mawdsley and Knapik [27], who used no warm-up, observed that submaximal or maximal warm-up sessions were not needed to assure stability of values if inexperienced subjects were tested for the second time. On the other hand, using experienced subjects, Mawdsley and Croft [26] found that six maximal isokinetic trials at 30 Deg/Sec did not differ significantly in either the presence or absence

of three submaximal contractions. It appeared that the time spent warming up prior to an isokinetic muscle test was not of long enough duration to observe a significant increase in muscle temperature [19] and therefore, have an effect on torque production.

TRAINING EFFECTS ON MVPT

Most researchers agreed that increases in strength were due to physiological or anatomical factors. However, little consideration was given to the possibility that learning played an important role relative to changes in strength [39]. Learning has been shown to affect strength testing results following practice. Whitley and Elliot [46] suggested that time was sufficient for physiological changes to take place in the muscle to produce increased strength. Whitley and Elliot BIBREF REFID=Whitley. also stated that increased strength was partially accounted for by learning associated with an improved neural function in the coordination and integration centers of the central nervous system. Smith [39], in his study of strength increments following massed and distributed practice relative to motor learning, found results similar to Whitley and Elliot. These results suggested that on a retest, the force measured may be greater because the subject has "learned the test".

Frequent strength testing sessions have been shown to have a training effect. Hettinger [18] has reported that strength training bouts given at a rate of once per week or less resulted in significant gains in strength while one training bout every fourteen days produced no change in muscle strength. Johnson and Siegel [21] found that the reliability of isokinetic movement of the knee extensors was more affected by testing over days than over trials. However, it was not clear whether the results reflected a training or a learning effect. In 1981, Mawdsley and Knappik [27] reaffirmed the work of Hettinger by showing that a series of maximal voluntary knee trials performed every fourteen days did not change muscle strength significantly over a six week period. These findings suggested that if testing was performed every fourteen days that any changes in strength could be attributed to strength gain and not learning.

EFFECT OF AGE AND FITNESS ON MVPT

Maximum muscle strength of men and women is reached between the ages of twenty and thirty [18], a time when muscle cross-sectional area is greatest. After this time period there is a progressive decline in strength for most muscle groups [18]. At sixty-five years, a man's muscle strength was approximately 80% of his maximum at age

thirty [18]. Many studies [25,] [28] have used subjects whose ages have ranged from 17 to 50 years. Using such a wide range of ages in the sample has made it difficult to generalize these results to the public. Inclusion of older subjects may have reduced strength values which may lead to erroneous conclusions about a given population.

The physical condition of the subjects tested has often been quite different. The subjects have ranged from the sedentary individual with no prior experience with the isokinetic apparatus [27], to subjects who were habitually active [43] and to those who were untrained but familiar with the isokinetic testing device [28]. Mawdsley and Knappik [27] pointed out that if inexperienced subjects were used they should be tested more than once. This suggested that the experience of the subject with the testing apparatus affected torque production.

In summary it is evident that little is known about the effect warm-up procedures have on isokinetic muscle testing. It has been shown that maximal performance of short duration can be improved with a 15-minute submaximal bicycle ride used as a warm-up. It has also been shown that submaximal repetitions performed on the CYBEX II [21] were necessary to obtain stable measures. The warm-up procedure has become an important part of isokinetic muscle testing procedures but there is no experimental evidence as to the

effect different warm-up procedures have on torque production. Because investigators have used different warm-ups before measuring isokinetic muscle strength, an investigation into the effect warm-up has on isokinetic muscle strength appeared to be justified.

Chapter III

RESEARCH DESIGN AND PROCEDURES

It is the purpose of this investigation to study the effect different warm-up procedures have on the muscle's ability to produce a maximal voluntary peak torque during a CYBEX II isokinetic muscle evaluation of the extensors and flexors of the knee.

RESEARCH DESIGN

This research project was designed to determine the effects of various warm-up procedures on isokinetic muscle strength during a CYBEX II isokinetic muscle test. To achieve experimental control, a rotation or counterbalanced design was used. In the counterbalanced design, each group of subjects was exposed to each treatment at different times during the experiment.

SELECTION OF SUBJECTS

The subjects in this investigation consisted of fifteen female volunteers from the graduate program in physical education who represented a normal population. They were

all familiar with the isokinetic principles but were inexperienced users of the equipment. Prior to the first test session, each subject signed an informed consent (See appendix A). Table 1, presents the physical description of the subjects. The physiological variables evaluated in this investigation are presented in Table 2 and the torque measurements for knee extension and knee flexion can be seen in appendices B and C.

Table 1

Physical Variables of the Subjects

MEASURE	UNIT	MEAN	S.D.
AGE (AGE)	YR	27.10	4.27
HEIGHT (HT)	CM.	165.80	5.00
WEIGHT (BODYWT)	KG.	59.50	8.45

Table 2

Physiological Strength Variables

MEASURE	UNIT
MAXIMUM EXTENSION TORQUE (KE*MAX)	N.M.
MAXIMUM EXTENSION TORQUE/BODYWT (KE*KG)	N.M./KG
MAXIMUM FLEXION TORQUE (KE*MAX)	N.M.
MAXIMUM FLEXION TORQUE/BODYWT (KE*KG)	N.M./KG

*DENOTES VARIOUS SPEEDS OF EXERCISE

EVALUATING MUSCULAR STRENGTH

In 1967 Perrine introduced the first isokinetic testing device which made it possible to objectively measure and study the dynamic characteristics of the muscle. It allowed for a maximal voluntary contraction of the muscle group being tested by controlling the speed of movement. The CYBEX II measures the torque production (muscle strength) of a muscle group which crosses a particular joint in the body.

PROCEDURE

The maximum voluntary peak torque (MVPT) of the right and left knee extensors and flexors were measured using a CYBEX II isokinetic dynamometer, dual-channel strip chart recorder, a double-width testing table and stabilizing accessories. The dynamometer and dual-channel recorder were calibrated daily according to the methods described by Beam [4] and can be found in appendix D. Strength, as measured in foot-pounds of torque, was recorded on the dual-channel recorder using the 180 foot-pound scale. The position angle scale was set to the 150 degree setting. The position stylus was placed one major division from the baseline with the knee in a fully flexed position. The first upward deflection of the pen represented extension at the knee joint. The torque channel damping was set at two for all speeds tested. The paper speed of the chart recorder was set at 5 mm/second for all tests.

Each subject performed five different warm-up treatments prior to the administration of the isokinetic muscle test. Warm-up number one was the control treatment and consisted of no warm-up. In warm-up number two the subjects performed static stretches of three muscle groups prior to the isokinetic muscle test. Stretch number one was used to stretch the hamstring muscle group. The subject sat on the floor with one leg straight and one leg flexed at the knee

with the bottom of the foot placed upon the medial aspect of the opposite knee. The subjects were instructed to lean forward towards the straightened leg as far as it was comfortably possible and they held this position for six seconds and then relaxed for six seconds. This sequence was performed six times with each leg. All six stretches for a particular leg were performed before changing and warming up the other leg

Stretch two was used to prepare the muscles of the lower leg for exercise. The subjects were instructed to place both hands on a wall with their arms extended as would be done at the beginning of a push-up performed on the floor and both feet were placed 3-5 feet from the base of the wall. The subject simulated a push-up motion in this upright position while keeping the heel of her foot in contact with the ground. A static stretch held for a six-second count followed by a six-second rest period was repeated six times.

The third warm-up used was performed on the CYBEX II isokinetic dynamometer. The subjects performed ten submaximal repetitions at each of three speeds (90, 150 and 240 degrees/second). The subject was instructed to exert submaximally (50 % of maximum) as was determined from their predicted maximum torque value described by Beam (5). The test administrator monitored each contraction and gave

immediate feedback if the effort was too strong or too weak. Each set of ten submaximal repetitions was separated by a one minute rest interval.

A five-minute submaximal bicycle ride was the fourth mode of warm-up used. A Fitron isokinetic cycle-ergometer was used for this treatment. The seat height was adjusted so as to allow approximately 15 degrees of knee flexion when the pedal was nearest the floor. All subjects pedalled at a rate of 90 revolutions per minute. The subjects pedalled against a resistance that resulted in a heart rate response of 50% of maximum as was previously determined by Karvonen et al (22). A radial pulse was taken three minutes into the exercise bout to make certain the workload was not too difficult. The fifth warm-up used the same cycle-ergometer ;however, the length of the warm-up was increased to fifteen minutes. The tester monitored heart rates every three minutes to be certain the intensity was within submaximal levels.

Upon the conclusion of all warm-up treatments, a three minute rest was given prior to the beginning of the test. The rest gave the test administrator time to align the subject to the dynamometer prior to the start of the test.

The subject was seated in the chair in such a way that the knee moved through 110 degrees of motion after which a seat belt was fastened around the waist and a velcro strap

was secured over the anterior thigh. The axis of rotation of the dynamometer was aligned with the center of rotation for the knee. With the knee in a flexed position, the test administrator palpated for the lateral femoral condyle (axis of rotation of the knee). The height of the dynamometer was adjusted to meet this level in the knee. The length of the lever arm was adjusted so that the inferior portion of the ankle pad contacted the lower leg approximately one inch above the malleoli and was fastened with a velcro strap arrangement. The subjects were instructed to maintain an upright seated position and were told to grab the side hand grips or seat for stability. It was necessary for the test administrator to stand on the base of the dynamometer to prevent excessive machine movement.

Following the specified warm-up for the session the subjects performed three maximal voluntary contractions of the extensors and flexors of the knee at four different speeds of movement. The test speeds were 30, 60, 180 and 300 degrees per second and this sequence was completed by the right and left leg. The order of testing of the four speeds was randomized to minimize the effect of learning - subjects performed either a fast first or slow first sequence of testing speeds. To begin a given testing speed, each subject started with her leg in full flexion which was limited by the chair arrangement. The three rep-

etitions performed for each testing speed were maximal voluntary contractions and were done continuously. Each subject was encouraged to perform maximally on each repetition but was not given any feedback as to how she performed.

The peak torques were recorded for the extensors and flexors of the knee at all four speeds tested in newton-meters of torque. The peak torque for either mode (extension or flexion) did not always occur on the same repetition. Lanese et al. [24], found that peak torque was seen in the first three repetitions. Therefore, three repetitions were incorporated into the testing protocol.

Maximum torque per kilogram of bodyweight was expressed in newton-meters per kilogram of body weight
(KE*MX/BODYWT;KF*MX/BODYWT)

(*DENOTES DIFFERENT SPEEDS OF MOVEMENT) To convert foot pounds of torque to Newton-meters it was necessary to multiply the measurement in foot-pounds by 1.356.

STATISTICAL ANALYSIS

Standard descriptive statistics were used to describe the physical characteristics of the subjects. Statistical analysis for significant differences between means was performed using an analysis of variance with repeated measures procedure. The analysis looked for differences in extension and flexion torque, in torque in NM/Kg. and in the

torque at 30 and 60 degrees per second. A Student Neuman-Keul's after test was used to perform a pairwise analysis of the significant differences observed from the ANOVA. The .05 level of confidence was used to test for statistical significance between means.

Chapter IV

RESULTS

It was the purpose of this investigation to study the effect different warm-up procedures have on torque production during an isokinetic muscle test. Fifteen college females who were inexperienced with the use of the isokinetic equipment were studied on five different occasions. They performed five different warm-up procedures prior to testing the extensors and flexors of the knee. Peak torque measurements were taken at 30, 60, 180 and 300 degrees per second.

The results show that there is no significant difference between the type of warm-up used (main effect) and knee extension torque in all speeds tested. It was also noted that there are no significant interactions (leg*treatment*group, treatment*group) in the extension mode for all speeds tested. In the analysis of variance with repeated measures [14], a Huynh Feldt adjusted probability value was used to test for statistical differences in the knee extensors and these P values can be seen in Table 3. A model for the statistical computations can be seen in appendices B and C.

Table 3

Probability Values For Knee Extension

The effects of different warm-up procedures upon torque at selected rates of knee extension.

 SPEED HUYNH FELDT PROB.

KEAR & KEAL	Leg*Trt*Group	.4642
	Trt*Group	.5442
	Trt	.2283
KEBR & KEBL	Leg*Trt*Group	.6578
	Trt*Group	.3526
	Trt	.2701
KECR & KECL	Leg*Trt*Group	.7779
	Trt*Group	.8059
	Trt	.7213
KEDR & KEDL	Leg*Trt*Group	.5690
	Trt*Group	.5472
	Trt	.4423

Key:

KE	= Knee Extension
A	= 30 Degrees per second
B	= 60 Degrees per second
C	= 180 Degrees per second
D	= 300 Degrees per second
R	= Right Leg
L	= Left Leg
Leg	= Mean differences between right and left leg
Group	= Mean differences between the five orders in which the treatments were administered.
Treatment	= Mean differences in warm-up procedures
*	= Statistical significance, $P < .05$

A Significant difference ($P < .05$) was found between the type of warm-up used (main effect) and knee flexion torque

at 60 degrees per second. There were no significant interactions (Treatment *Group, Leg*Treatment*Group) at any of the speeds tested and the probability values can be seen in Table 4. An application of a Student Neuman-Keul's test for individual mean comparisons was performed on the means of the five flexion treatments at 60 degrees per second. Although the analysis of variance detected a difference, the further comparison of means was not able to specify in what way these means were different. The results of the after test of means can be found in Table 5.

A similar analysis of variance with repeated measures was performed on the variable KE*KG and KF*KG, which represented the peak torque independent of leg and normalized for body weight. The results of this analysis showed no significant differences ($P < .05$) between treatments in both flexion and extension mode at all speeds tested. The probability values for the mean comparisons can be seen in Table 6.

Although seven of eight analyses found the different treatments to be the same, observation of the standard deviations of the flexion and extension torque measurements indicated that the variance of the strength measures was consistently lower in two of the five groups tested. These standard deviations can be found in Table 7 and Table 8.

Table 4

Probability Values For Knee Flexion

The effects of different warm-up procedures upon torque at selected rates of knee flexion.

SPEEDHUYNH FELDT PROB.

KFAR & KFAL	Leg*Trt*Group	.5938
	Trt*Group	.9815
	Trt	.4561
KFBR & KFBL	Leg*Trt*Group	.1231
	Trt*Group	.8365
	Trt	.0270***
KFCR & KFCL	Leg*Trt*Group	.1831
	Trt*Group	.4452
	Trt	.2236
KFDR & KFDL	Leg*Trt*Group	.8095
	Trt*Group	.2077
	Trt	.0684

Key:

KE	= Knee flexion
A	= 30 Degrees per second
B	= 60 Degrees per second
C	= 180 Degrees per second
D	= 300 Degrees per second
R	= Right Leg
L	= Left Leg
Leg	= Mean differences between right and left leg
Group	= Mean differences between the five orders in which the treatments were administered.
Treatment	= Mean differences in warm-up procedures
***	= Statistical significance, $P < .05$

Table 5

Student Neuman-Keul's After Test

WARM-UP TREATMENT						
	3	2	1	4	5	
MEANS	63.46	63.53	64.76	66.03	66.03	
		$\bar{X} - \bar{X}$	$\bar{X} - \bar{X}$	$\bar{X} - \bar{X}$	$\bar{X} - \bar{X}$	
		2 3	1 3	4 3	5 3	
		0.06	1.30	2.56	2.56	
			$\bar{X} - \bar{X}$	$\bar{X} - \bar{X}$	$\bar{X} - \bar{X}$	
			1 2	4 2	5 2	
			1.24	2.50	2.50	
				$\bar{X} - \bar{X}$	$\bar{X} - \bar{X}$	
				4 1	5 1	
				1.26	1.26	
					$\bar{X} - \bar{X}$	
					5 4	
					0.00	

$$\frac{\bar{X} - \bar{X}}{1 \quad 2}$$

----- = CALCULATED F SCORE
(MSE/N)

MEAN SQUARE ERROR = 14.73
N = 30

MSE/N = 00.70

2.56/.70 = 3.65

REQUIRED F SCORE = 4.04

KEY:

MEAN 1 = NO WARM-UP

MEAN 2 = STRETCHING WARM-UP

MEAN 3 = CYBEX II WARM-UP

MEAN 4 = 5-MINUTE SUBMAXIMAL WARM-UP

MEAN 5 = 15-MINUTE SUBMAXIMAL WARM-UP

*NO DIFFERENCE WAS FOUND AFTER DOING A PAIRWISE COMPARISON OF THE MEANS.

Table 6

Probability Values For Torque/Body Weight

The effects of different warm-up procedures have upon torque per kilogram at selected rates of knee extension and knee flexion.

VARIABLE	EFFECTS	HUYNH FELDT PROB.
KEA/KG	TRT*GROUP TRT	.4293 .4093
KEB/KG	TRT*GROUP TRT	.4195 .3532
KEC/KG	TRT*GROUP TRT	.9601 .8063
KED/KG	TRT*GROUP TRT	.8131 .2447
KFA/KG	TRT*GROUP TRT	.9975 .3309
KFB/KG	TRT*GROUP TRT	.7719 .1144
KFC/KG	TRT*GROUP TRT	.7015 .3561
KFD/KG	TRT*GROUP TRT	.6218 .1852

Key:

KE = Knee Extension
 KF = Knee Flexion
 KG = Body weight in Kilograms
 A = 30 Degrees per second
 B = 60 Degrees per second
 C = 180 Degrees per second
 D = 300 Degrees per second
 Group = Mean differences between the five orders in which the treatments were administered.
 Treatment = Mean differences in warm-up procedures
 * = Statistical significance, $P < .05$

Table 7

Range of Knee Flexion Standard Deviations

The range of knee flexion standard deviations for all treatments.

GROUP					
	1	2	3	4	5

MOTION/ SPEED					
KFAR & KFAL	30.56-55.94	21.12-40.78	6.44-20.63	22.98-45.05	2.79-14.95
KFBR & KFBL	27.18-51.47	31.33-40.31	1.83-18.57	28.73-39.54	4.84-12.84
KFCR & KFCL	20.15-46.90	18.03-33.08	2.10-13.85	14.73-29.49	2.10-12.21
KFDR & KFDL	14.47-33.69	19.64-27.18	4.84-21.51	4.21-25.34	2.79-11.06

Key:

KF	= Knee Flexion
A	= 30 Degrees per second
B	= 60 Degrees per second
C	= 180 Degrees per second
D	= 300 Degrees per second
R	= Right Leg
L	= Left Leg
*	= Statistical significance, $P < .05$

Table 8

Range of Knee Extension Standard Deviations

The range of knee extension standard deviations for all treatments.

	GROUP				
	1	2	3	4	5
MOTION/ SPEED					
KEAR & KEAL	42.14-63.01	24.88-54.94	5.12-14.92	27.01-56.27	2.34-21.96
KEBR & KEBL	37.41-48.53	19.75-46.70	6.40-19.21	19.60-47.46	10.52-33.31
KECR & KECL	20.39-28.57	17.72-32.02	4.13-11.81	1.35-21.30	3.57-20.86
KEDR & KEDL	13.16-21.04	15.63-22.03	0.77-10.59	3.57-11.68	4.88- 9.38

Key:

KE = Knee Extension
 A = 30 Degrees per second
 B = 60 Degrees per second
 C = 180 Degrees per second
 D = 300 Degrees per second
 R = Right Leg
 L = Left Leg
 * = Statistical significance, $P < .05$

No significant difference was found in the mean torque

values of 30 degrees and 60 degrees per second during knee flexion ($P=.2251$). However, there was a significant difference in knee extension at these two test speeds ($P=.0022$).

Chapter V

DISCUSSION

The purpose of this investigation was to determine the effects different warm-up procedures have on force production during an isokinetic muscle test. The statistical analysis required the data to be divided into a knee extension and knee flexion data set. These two data sets were further analyzed at each of the four speeds tested. For these reasons, the discussion was centered on these areas: (1) flexion torque, (2) extension torque, (3) variance of torque scores and (4) comparison of 30 degrees per second and 60 degrees per second as they related to the isokinetic testing procedure.

Knee flexion at 60 degrees per second resulted in the only analysis that showed a significant difference in force production as a result of the different warm-up procedures. From Table 5 it can be seen that the two submaximal bicycle warm-ups produced higher torque recordings. This finding was in agreement with several investigators who found that a warm-up improved performance time [1] and a greater ability to exert muscular tension [19]. Hogberg, however,

found muscle tension to be greater in the 15-minute warm-up versus the 5-minute warm-up. In Hogberg's study the subjects used were well trained males and the ride did not cause fatigue. The population used in the present study was untrained and female and even though the ride was performed at 50% of their age predicted maximum heart rate [22] it may have been strenuous enough to have caused fatigue.

Winter [48] in his study of errors in the use of isokinetic dynamometers showed the error in mechanical work to vary from 23-43% in extension (against gravity) and 55-510% in flexion (with gravity). It was also shown that the effect of gravitational errors caused false early peaks in the torque curve which resulted in erroneous conclusions about muscle function. Winter [48] also stated that errors in flexion were higher for two reasons: (1) The flexor muscles were weaker than the quadriceps extensor group and thus a large torque moment was easier to achieve in extension than flexion. (For both patterns the size of the error decreases as the force exerted increases.) (2) In flexion the subject achieved the movement with little effort because he was aided by gravity and therefore, consciously or unconsciously failed to produce the desired contraction level. It may be due to these gravitational errors that caused statistical differences in the flexion mode.

No difference between treatments in knee extension was in direct disagreement with the findings of Asmussen and Boje [1] and Hogberg and Ljunggren [19]. As stated earlier, both of these studies showed improved performance times as well as an increased ability to produce muscle tension when a warm-up period preceeded the activity. As Wyatt [49] and the present study has shown, the quadriceps (knee extensors) produced a greater torque than the hamstrings (knee flexors) at each of the four test speeds. This greater torque output in knee extension reduced the possible contamination of torque scores which would have been due to gravity [48] and therefore, differences in strength measures would have been attributed to the warm-up. As a result, the warm-up was not responsible for a significant change in force production in the extensors of the knee.

After observing the mean torque of the treatments in both knee extension and knee flexion, a trend towards the 15-minute bicycle ride as being the warm-up that produced the highest torque measures was observed. These means averaged over groups can be viewed in Table 9 and Table 10. Such a trend was in agreement with Asmussen and Boje [1] and suggested the increase in torque was due to an increase in muscle temperature. The higher the muscle temperature (due to the previous warm-up regimen) the better the performance. As shown in Table 10 and Table 9 the 15-minute

bicycle warm-up produced the highest torque value 50% of the time. In right knee flexion at 300 degrees per second (KEDR) the 15-minute bicycle warm-up types ranged from 1.40 to 10.41% higher than the torque resulting from the other four warm-ups conditions Table 11. It may have been possible, with a larger sample size, to have seen significant differences at other test speeds as these percent differences suggest. It is possible that the reliability of our test instrument was low enough so that significant differences were not detected. The reliability of the CYBEX II has been stated to be .91 [28].

An important consideration when conducting isokinetic muscle testing is how reliable the baseline score is for the variable being measured [21]. Johnson and Siegel [21] found that when isokinetic force of the knee extensors was measured, a protocol which provided three submaximal trials followed by three maximal warm-up trials was essential before stable and reliable measures were seen. (Reliability coefficient .98 as ten trials for three days). Previous researchers [36] have suggested that changes in strength occurred with test repetitions over short and long term periods of time. The results of the present study have demonstrated that the variability of the test measurement when averaged over treatments was greatly reduced in two of the five groups.

Table 9

Mean Flexion Torques

Mean knee flexion torque following each of the warm-up procedures at each of the selected speeds.

		SPEED IN DEGREES PER SECOND			
		30	60	180	300
T R E A T M E N T	R1	125.63	119.62	87.76	68.39
	R2	123.30	119.99	81.37	62.14
	R3	120.61	118.28	87.51	66.91
	R4	123.42	122.32	87.39	65.82
	R5	126.60*	123.78*	87.88*	69.37*
	L1	124.16*	118.51	83.21	64.72
	L2	122.18	113.63	81.00	61.77
	L3	120.61	115.46	81.99	64.09
	L4	120.98	120.48*	84.68*	64.83
	L5	121.45	119.01	84.31	65.82*

Key:

R = Right Leg

L = Left Leg

1 = No Warm-up

2 = Stretching Warm-up

3 = CYBEX II Warm-up

4 = 5-Minute Bicycle Warm-up

5 = 15-Minute Bicycle Warm-up

*DENOTES HIGHEST MEAN

Table 10

Mean Knee Extension Torques

Mean knee extension torques following each of the warm-up procedures at each of the selected speeds.

SPEED IN DEGREES PER SECOND					

		30	60	180	300

T R E A T M E N T	R1	200.89*	186.31	120.72	81.26
	R2	197.33	187.04	122.32	80.89
	R3	196.97	183.01	121.09	82.74
	R4	142.28	138.85	90.48*	60.28
	R5	199.68	190.72*	119.74	84.20*
	L1	191.46*	179.69	119.26	80.64
	L2	187.29	178.58	120.11	81.26
	L3	185.70	178.46	119.01	80.27
	L4	187.47	179.92	122.18*	82.74
	L5	190.23	184.97*	121.45	83.58*

Key:

R = Right Leg

L = Left Leg

1 = No Warm-up

2 = Stretching Warm-up

3 = CYBEX II Warm-up

4 = 5-Minute Bicycle Warm-up

5 = 15-Minute Bicycle Warm-up

*DENOTES HIGHEST MEAN

Table 11

Range of Differences in Mean Torque

The range of differences in mean torque following specific warm-up procedures.

MOTION/SPEED	WARM-UP TREATMENT PRODUCING GREATEST TORQUE	RANGE OF % DIFFERENCES FROM THE REMAINING WARM-UP MEANS
KFAR	5	0.70- 4.73
KFAL	1	1.50- 2.85
KFBR	5	1.18- 4.45
KFBL	4	1.22- 5.69
KFCR	5	0.14- 7.40
KFCL	4	0.43- 4.34
KFDR	5	1.40-10.41
KFDL	5	1.50- 5.97
KEAR	1	0.60- 3.96
KEAL	1	0.64- 3.00
KEBR	5	1.28- 4.04
KEBL	5	2.31- 3.19
KECR	4	0.29- 2.39
KECL	4	0.60- 2.60
KEDR	5	1.74- 3.93
KEDL	4	1.01- 3.95

Key:

KF = Knee Flexion

KE = Knee Extension

A = 30 Degrees per second

B = 60 Degrees per second

C = 180 Degrees per second

D = 300 Degrees per second

1 = No Warm-up

2 = Stretching Warm-up

3 = CYBEX II Warm-up

4 = 5-Minute Bicycle Warm-up

5 = 15-Minute Bicycle Warm-up

*DENOTES HIGHEST MEAN

A large reduction in the standard deviations of the torque

measurements was observed in groups three and five. These data can be found in Table 7 and Table 8. This observation suggests that in order to obtain consistent results, some warm-up should be used. However, the magnitude of the variances in the other three groups make it difficult to see significant differences. With one analysis resulting in a significant difference and the magnitude of the variances of the other 3 groups being so great, one can conclude that a larger sample size is necessary.

When research has been performed using the CYBEX II isokinetic dynamometer, the choice of speeds used has often varied [16] [27] [31] [38]. In most cases a wide spectrum of speeds have been used ranging from 0 to 300 degrees per second. In the present study no difference in torque production between 30 and 60 degrees per second was an important finding in terms of recommending test speeds for isokinetic testing of the lower leg. It was determined by using a subjective rating scale that exercise at 30 degrees per second was painfully hard and that the same exercise at 60 degrees per second was moderately difficult. See Table 12 for the results of the rating scale. The results of the analysis of variance and the subjective rating scale have demonstrated that one can learn the same information from a test at 60 as compared to 30 degrees per second and at the same time cause less pain and/or discomfort to the subject.

Table 12

Difficulty Rating Scale

Subjective Rating Scale of comparative difficulty at each testing velocity.

SPEED				
SUBJECT	30 DEG/SEC	60 DEG/SEC	180 DEG/SEC	300 DEG/SEC

001	1.75	1.75	2.50	3.00
002	1.00	1.50	2.50	3.00
003	1.00	2.00	3.00	3.00
004	1.00	1.00	2.50	3.00
005	1.50	2.00	2.50	3.00
006	1.50	2.00	3.00	3.00
007	1.00	2.00	3.00	3.00
008	1.20	2.00	3.00	3.00
009	1.50	1.50	2.50	3.00
010	2.00	2.00	2.00	3.00
011	2.00	2.00	3.00	3.00
012	1.00	2.00	3.00	3.00
013	1.50	2.00	2.50	3.00
014	1.00	1.50	2.00	2.50
015	1.00	1.00	2.00	3.00
MEAN =	1.35	1.76	2.60	2.96
S.D. =	.37	.37	.40	.13

SCALE:

- 1 = PAINFULLY HARD
- 2 = MODERATELY HARD
- 3 = EASY

Chapter VI

SUMMARY AND CONCLUSIONS

The purpose of this investigation was to study the effect warm-up had on torque production during an isokineic muscle test. Fifteen college age healthy females volunteered as subjects and underwent the battery of five test sessions. Subjects reported to the laboratory on four different occasions and strength measures were obtained following the five different treatments (warm-ups). The treatments consisted of no warm-up, static stretching, submaximal repetitions on the CYBEX II, 5-minute submaximal bicycle and 15-minute submaximal bicycle ride which were followed by the isokinetic muscle test.

The results were intended to indicate which warm-up procedure, if any, allowed for the greatest force production. The results of this study along with previous studies concerning number of repetitions to see a peak torque, frequency of test sessions and experienced versus inexperienced subjects have made it possible for future investigators to document why they have selected specific procedures in the isokinetic testing process.

No significant differences existed between warm-up used and torque production in all speeds for knee extension. On the other hand, there was a significant difference between warm-up used and torque production at 60 degrees per second in knee flexion. No differences in torque production in knee flexion were seen at 30, 180 and 300 degrees per second. There were no significant differences between the torque produced at 30 and 60 degrees per second in knee flexion which suggests one of these two speeds could be eliminated from the testing protocol. There was however, a significant difference in knee extension. The tendency towards less variable scores in two of the testing groups a larger sample is necessary to see significant differences in torque following selected warm-up procedures.

CONCLUSIONS

Within the boundaries of this study, the following conclusions may be justified.

1. A warm-up of moderate intensity should be used to assure consistent isokinetic strength scores.
2. The warm-up used under these conditions did not cause significant differences in the results of an isokinetic muscle test.

3. The torque production was not significantly different at 30 and 60 degrees per second in knee flexion which gives the test administrator a choice as to which slow testing speed is to be used.

RECOMMENDATIONS

1. Perform a similar study involving other musculature that are often tested using the CYBEX II isokinetic dynamometer.
2. Perform a similar study where muscle temperature is monitored to assure the muscle reached temperature levels documented in past research and that resulted in improved performance.
3. Perform a similar study with a larger sample size and with gravity effects eliminated.

Appendix A

INFORMED CONSENT FOR ISOKINETIC MUSCLE TESTING

Subject _____

(Last Name) (First) (Middle Initial)

Age at last birthday _____

1. In order to determine an appropriate level of strengthening for my lower extremities, I, _____, hereby consent to voluntarily engage in an isokinetic strength evaluation under the direction of a trained technician.
2. The purpose of the test is to determine the strength of the muscles that cross the knee joint. The information obtained will be helpful in assessing the strength of the lower extremity.
3. You will perform several different warm-up procedures before performing the isokinetic strength evaluation. The work levels during the warm-up periods will be easily accomplished and the isokinetic test will be an all out effort for a relatively short time period. The test may be discontinued at any time because of fatigue or discomfort.

4. I understand that I have the right to ask that the test be stopped at any time if I feel that I cannot continue and that my desires will be respected.
5. I have been advised that if I desire a more detailed and complete explanation of any of the foregoing, such an explanation will be given me.
6. I do not request such explanation
_____.
7. The information which is obtained will be treated as privileged and confidential and will not be released or revealed to any person except my physician without my written consent. The information obtained, however, may be used for a statistical or scientific purpose with my right to privacy retained.
8. Further, I, the undersigned, release and discharge the co-sponsors of The Ohio State University, its officers, agents, faculty, physicians, technologists and any others connected therewith from all claims and damages whatsoever that the undersigned or his representative may have arising from or incident to this test.
9. I acknowledge that I have read this document in its entirety, that it has been read to me and that I fully understand it. Any questions which may occurred to me have been answered to my satisfaction.

DATE _____

(Signature of the Patient

(Adress)

(Signature of the Witness

Appendix B
CALIBRATION OF THE TORQUE-CHANNEL

The calibration procedure requires that the three torque scales be calibrated independently. The following table includes the levels to which the pen recorder should reach assuming that each of the torque scales are chosen during the calibration procedure.

Table 13
Evaluation of torque for each scale of calibration

SCALE	TORQUE	MINOR DIVISIONS *
30 ft.-lb.	20.86 ft.-lb.	20.9
180 ft.-lb.	90.19 ft.-lb.	15.1
300 ft.-lb.	131.06 ft.-lb.	10.9

* Each major division is divided into three minor divisions.

Before the calibration procedure can be performed, the recorder must be "zeroed". This process assures that the torque-channel baseline remains constant when using any of the three ft.-lb scales. The "zeroing" procedure is as follows:

1. Turn on the power to the RECORDER and SPEED SELECTOR.
2. Set the DAMPING of the RECORDER to 2.
3. Remove all attachments from the input shaft of the dynamometer, and turn the face of the dynamometer away from the benches.
4. Set the SPEED SELECTOR to 30 degrees per second (5 RPM).
5. Set the FT.-LB. SCALE to 180.0
 - a. Set the CHART SPEED to 5 mm./second to advance the paper.
 - b. Adjust the stylus on the torque channel using the "ZERO ADJUST" knob so tht it is on the baseline.
 - c. Set the FT.-LB. SCALE to 30 FT.-LB.
 - d. Stop the paper drive. (At this point if the stylus (At this point if the stylus does not deflect go on to Preparation of the Dynamometer. If the stylus does deflect proceed with step 6.
6. Identify the potentiometer marked "ZERO NULL" on the upper right hand side of the RECORDER housing.
 - a. Set the CHART SPEED TO 5 mm./second.
 - b. Adjust the position of the stylus to the baseline by turning the "ZERO NULL" potentiometer. (Turning the potentiometer clockwise raises the stylus, turning the potentiometer counterclockwise lowers the stylus.)
 - c. Stop the paper drive.

- d. Repeat beginning at step 5.

Preparation of the Dynamometer

1. Attach the "LONG INPUT ADAPTER" to the dynamometer and insert the CALIBRATION arm. The length of this assembly should be 2.75 ft. (Measured from the center of the input shaft of the dynamometer to the center of the "T" portion of the calibration bar.)
2. Place the appropriate amount of weight onto the calibration arm to calibrate each torque scale as mentioned in the above table.

Calibration of the Dynamometer/Recorder

1. Set the SPEED SELECTOR to 30 degrees/second (5 /RPM).
2. Set the baseline of the torque channel using the "ZERO ADJUST" knob.
3. Set the CHART SPEED to 5 mm./second to advance the paper.
4. Bring the weighted calibration arm up to speed and allow it to drop passing the horizontal position, catching it just before it contacts the floor.
5. Stop the paper drive.
6. Observe the graph on the RECORDER. (At this point if the torque recorded on the RECORDER is equal to the calculated torque go on to the next torque scale. Once all three scales have been independently calibrated, go on to further calibration or OPERATION. If

however, the achieved torque and calculated torque are not equal, proceed with the next step 7.

7. Identify the potentiometers marked "30", "180" and "360" on the upper right hand side of the RECORDER housing.
 - a. If the recorded torque is greater than the calculated torque, turn the potentiometer counter-clockwise. If the recorded torque is less than the calculated torque, turn the potentiometer clockwise.
 - b. Repeat beginning with step 2.

Appendix C

KNEE EXTENSION - ANALYSIS OF VARIANCE PROGRAM

DATA KNEE;

INPUT NAME \$ AGE HT BODYWT

```

KEAR1 KEAL1 KEBR1 KEBL1 KECR1 KECL1 KEDR1 KEDL1
KEAR2 KEAL2 KEBR2 KEBL2 KECR2 KECL2 KEDR2 KEDL2
KEAR3 KEAL3 KEBR3 KEBL3 KECR3 KECL3 KEDR3 KEDL3
KEAR4 KEAL4 KEBR4 KEBL4 KECR4 KECL4 KEDR4 KEDL4
KEAR5 KEAL5 KEBR5 KEBL5 KECR5 KECL5 KEDR5 KEDL5 GROUP;
```

```

IF KEAR1 >= KEAL1 THEN KEAMX1 = KEAR1; ELSE KEAMN1 = KEAR1;
IF KEAR2 >= KEAL2 THEN KEAMX2 = KEAR2; ELSE KEAMN2 = KEAR2;
IF KEAR3 >= KEAL3 THEN KEAMX3 = KEAR3; ELSE KEAMN3 = KEAR3;
IF KEAR4 >= KEAL4 THEN KEAMX4 = KEAR4; ELSE KEAMN4 = KEAR4;
IF KEAR5 >= KEAL5 THEN KEAMX5 = KEAR5; ELSE KEAMN5 = KEAR5;
IF KEAR1 < KEAL1 THEN KEAMX1 = KEAL1; ELSE KEAMN1 = KEAL1;
IF KEAR2 < KEAL2 THEN KEAMX2 = KEAL2; ELSE KEAMN2 = KEAL2;
IF KEAR3 < KEAL3 THEN KEAMX3 = KEAL3; ELSE KEAMN3 = KEAL3;
IF KEAR4 < KEAL4 THEN KEAMX4 = KEAL4; ELSE KEAMN4 = KEAL4;
IF KEAR5 < KEAL5 THEN KEAMX5 = KEAL5; ELSE KEAMN5 = KEAL5;
IF KEBR1 >= KEBL1 THEN KEBMX1 = KEBR1; ELSE KEBMN1 = KEBR1;
IF KEBR2 >= KEBL2 THEN KEBMX2 = KEBR2; ELSE KEBMN2 = KEBR2;
IF KEBR3 >= KEBL3 THEN KEBMX3 = KEBR3; ELSE KEBMN3 = KEBR3;
IF KEBR4 >= KEBL4 THEN KEBMX4 = KEBR4; ELSE KEBMN4 = KEBR4;
IF KEBR5 >= KEBL5 THEN KEBMX5 = KEBR5; ELSE KEBMN5 = KEBR5;
IF KEBR1 < KEBL1 THEN KEBMX1 = KEBL1; ELSE KEBMN1 = KEBL1;
IF KEBR2 < KEBL2 THEN KEBMX2 = KEBL2; ELSE KEBMN2 = KEBL2;
IF KEBR3 < KEBL3 THEN KEBMX3 = KEBL3; ELSE KEBMN3 = KEBL3;
IF KEBR4 < KEBL4 THEN KEBMX4 = KEBL4; ELSE KEBMN4 = KEBL4;
IF KEBR5 < KEBL5 THEN KEBMX5 = KEBL5; ELSE KEBMN5 = KEBL5;
IF KECR1 >= KECL1 THEN KECMX1 = KECR1; ELSE KECMN1 = KECR1;
IF KECR2 >= KECL2 THEN KECMX2 = KECR2; ELSE KECMN2 = KECR2;
IF KECR3 >= KECL3 THEN KECMX3 = KECR3; ELSE KECMN3 = KECR3;
IF KECR4 >= KECL4 THEN KECMX4 = KECR4; ELSE KECMN4 = KECR4;
IF KECR5 >= KECL5 THEN KECMX5 = KECR5; ELSE KECMN5 = KECR5;
IF KECR1 < KECL1 THEN KECMX1 = KECL1; ELSE KECMN1 = KECL1;
IF KECR2 < KECL2 THEN KECMX2 = KECL2; ELSE KECMN2 = KECL2;
IF KECR3 < KECL3 THEN KECMX3 = KECL3; ELSE KECMN3 = KECL3;
IF KECR4 < KECL4 THEN KECMX4 = KECL4; ELSE KECMN4 = KECL4;
IF KECR5 < KECL5 THEN KECMX5 = KECL5; ELSE KECMN5 = KECL5;
IF KEDR1 >= KEDL1 THEN KEDMX1 = KEDR1; ELSE KEDMN1 = KEDR1;
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IF KEDR2 >= KEDL2 THEN KEDMX2 = KEDR2; ELSE KEDMN2 = KEDR2;
IF KEDR3 >= KEDL3 THEN KEDMX3 = KEDR3; ELSE KEDMN3 = KEDR3;
IF KEDR4 >= KEDL4 THEN KEDMX4 = KEDR4; ELSE KEDMN4 = KEDR4;
IF KEDR5 >= KEDL5 THEN KEDMX5 = KEDR5; ELSE KEDMN5 = KEDR5;
IF KEDR1 < KEDL1 THEN KEDMX1 = KEDL1; ELSE KEDMN1 = KEDL1;
IF KEDR2 < KEDL2 THEN KEDMX2 = KEDL2; ELSE KEDMN2 = KEDL2;
IF KEDR3 < KEDL3 THEN KEDMX3 = KEDL3; ELSE KEDMN3 = KEDL3;
IF KEDR4 < KEDL4 THEN KEDMX4 = KEDL4; ELSE KEDMN4 = KEDL4;
IF KEDR5 < KEDL5 THEN KEDMX5 = KEDL5; ELSE KEDMN5 = KEDL5;
KEADF1 = ( (KEAMX1 - KEAMN1) / KEAMX1 ) * 100;
KEADF2 = ( (KEAMX2 - KEAMN2) / KEAMX2 ) * 100;
KEADF3 = ( (KEAMX3 - KEAMN3) / KEAMX3 ) * 100;
KEADF4 = ( (KEAMX4 - KEAMN4) / KEAMX4 ) * 100;
KEADF5 = ( (KEAMX5 - KEAMN5) / KEAMX5 ) * 100;
KEBDF1 = ( (KEBMX1 - KEBMN1) / KEBMX1 ) * 100;
KEBDF2 = ( (KEBMX2 - KEBMN2) / KEBMX2 ) * 100;
KEBDF3 = ( (KEBMX3 - KEBMN3) / KEBMX3 ) * 100;
KEBDF4 = ( (KEBMX4 - KEBMN4) / KEBMX4 ) * 100;
KEBDF5 = ( (KEBMX5 - KEBMN5) / KEBMX5 ) * 100;
KECDF1 = ( (KECMX1 - KECMN1) / KECMX1 ) * 100;
KECDF2 = ( (KECMX2 - KECMN2) / KECMX2 ) * 100;
KECDF3 = ( (KECMX3 - KECMN3) / KECMX3 ) * 100;
KECDF4 = ( (KECMX4 - KECMN4) / KECMX4 ) * 100;
KECDF5 = ( (KECMX5 - KECMN5) / KECMX5 ) * 100;
KEDDF1 = ( (KEDMX1 - KEDMN1) / KEDMX1 ) * 100;
KEDDF2 = ( (KEDMX2 - KEDMN2) / KEDMX2 ) * 100;
KEDDF3 = ( (KEDMX3 - KEDMN3) / KEDMX3 ) * 100;
KEDDF4 = ( (KEDMX4 - KEDMN4) / KEDMX4 ) * 100;
KEDDF5 = ( (KEDMX5 - KEDMN5) / KEDMX5 ) * 100;
KEALB1 = KEAMX1 / BODYWT;
KEALB2 = KEAMX2 / BODYWT;
KEALB3 = KEAMX3 / BODYWT;
KEALB4 = KEAMX4 / BODYWT;
KEALB5 = KEAMX5 / BODYWT;
KEBLB1 = KEBMX1 / BODYWT;
KEBLB2 = KEBMX2 / BODYWT;
KEBLB3 = KEBMX3 / BODYWT;
KEBLB4 = KEBMX4 / BODYWT;
KEBLB5 = KEBMX5 / BODYWT;
KECLB1 = KECMX1 / BODYWT;
KECLB2 = KECMX2 / BODYWT;
KECLB3 = KECMX3 / BODYWT;
KECLB4 = KECMX4 / BODYWT;
KECLB5 = KECMX5 / BODYWT;
KEDLB1 = KEDMX1 / BODYWT;
KEDLB2 = KEDMX2 / BODYWT;
KEDLB3 = KEDMX3 / BODYWT;
KEDLB4 = KEDMX4 / BODYWT;
KEDLB5 = KEDMX5 / BODYWT;

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CARDS;

001 26 65 120

100 82 87 72 62 54 46 42
 96 83 104 78 66 53 45 39
 101 82 96 78 67 54 48 40
 102 83 96 77 61 58 46 40
 117 96 107 96 63 54 46 41 5
 002 26 66 124
 80 98 84 91 60 64 42 42
 89 82 76 93 57 63 39 47
 95 91 89 85 68 58 48 43
 80 96 78 94 58 64 42 42
 78 90 76 93 53 69 42 45 4
 003 26 68 147.50
 137 127 131 130 85 96 64 63
 139 130 132 116 91 90 64 63
 155 130 141 127 93 96 65 66
 144 124 130 125 92 92 61 63
 136 131 132 129 84 91 65 62 2
 004 24 64.5 130
 115 101 102 96 59 63 39 41
 112 117 104 102 64 65 37 41
 123 105 107 96 63 60 41 41
 100 101 92 90 54 62 40 44
 111 106 103 97 64 60 41 42 3
 005 25 65 115.75
 102 94 89 87 57 56 42 36
 95 92 91 88 63 54 42 36
 88 87 84 87 57 51 38 35
 96 95 93 86 59 56 38 38
 100 91 99 90 60 54 42 39 2
 006 27 65 122
 85 92 89 102 57 62 37 38
 87 90 87 95 66 63 47 42
 82 83 79 86 59 61 48 42
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 90 90 93 90 63 66 37 46 2
 007 27 66.5 176.75
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 143 126 130 119 78 78 47 52
 130 123 119 119 67 72 41 46
 148 137 141 139 84 83 57 59
 161 141 146 126 84 83 58 54 4
 008 23 61.5 119
 105 89 93 78 54 51 36 36
 104 98 89 85 54 52 40 31
 110 90 98 75 57 46 42 28
 107 90 97 81 63 50 42 36
 108 91 99 80 60 46 43 37 3
 009 38 64 123.75
 105 111 95 100 64 62 42 41
 101 99 94 97 63 61 45 42
 105 108 96 102 61 62 42 42
 106 91 102 91 61 59 38 39

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010 101 106 88 105 58 61 41 41 3
    26 69 152
    166 152 148 139 90 85 57 55
    153 149 137 140 88 93 60 59
    160 144 135 134 89 95 57 63
    144 150 143 137 89 90 54 62
    145 144 139 141 86 90 60 58 1
011      25 64 109
    82 84 76 64 54 45 36 37
    82 90 83 77 53 48 36 37
    76 84 81 84 54 55 36 35
    80 80 81 75 56 55 40 37
    85 72 88 75 58 54 39 36 5
012      22 63 111.5
    129 139 110 122 72 72 51 48
    128 131 114 117 73 74 49 48
    129 136 113 124 69 71 49 47
    131 146 120 130 77 78 51 48
    118 132 112 112 73 72 52 48 4
013      35 65 150
    96 97 96 110 60 75 42 50
    96 90 98 94 64 63 41 48
    85 101 92 101 60 70 36 45
    93 83 96 91 60 69 37 47
    96 95 90 107 51 66 39 43 5
014 27 65 125
    91 80 88 85 57 53 32 30
    90 80 97 78 61 61 35 36
    85 71 75 84 54 54 37 36
    77 69 90 78 59 48 35 31
    88 72 87 72 59 54 35 36 1
015 30 68 142
    100 90 100 72 76 60 43 42
    95 71 90 78 57 62 33 42
    83 80 88 74 70 66 47 46
    89 70 85 84 64 68 41 48
    95 95 97 91 61 71 47 54 1

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PROC BMDP PROG=BMDP2V DATA=KNEE;
PARMCARDS;
PROB      TITLE IS '  WARM-UP EFFECTS ON TORQUE PRODUCTION'.
INPUT     UNIT=3
          CODE='KNEE'
DESIGN    DEP=KEAR1,KEAR2,KEAR3,KEAR4,KEAR5,KEBL1,KEBL2,
          KEBL3,KEBL4,KEBL5.
          LEVELS ARE 2,5.
          NAMES ARE SPEED,TRT.
END

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Appendix D

KNEE FLEXION - ANALYSIS OF VARIANCE - SPEED

DATA KNEE;

INPUT NAME \$ AGE HT BODYWT

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KFAR1 KFAL1 KFBR1 KFBL1 KFCR1 KFCL1 KFDR1 KFDL1
KFAR2 KFAL2 KFBR2 KFBL2 KFCR2 KFCL2 KFDR2 KFDL2
KFAR3 KFAL3 KFBR3 KFBL3 KFCR3 KFCL3 KFDR3 KFDL3
KFAR4 KFAL4 KFBR4 KFBL4 KFCR4 KFCL4 KFDR4 KFDL4
KFAR5 KFAL5 KFBR5 KFBL5 KFCR5 KFCL5 KFDR5 KFDL5 GROUP;
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IF KFAR1 >= KFAL1 THEN KFAMX1 = KFAR1; ELSE KFAMN1 = KFAR1;
IF KFAR2 >= KFAL2 THEN KFAMX2 = KFAR2; ELSE KFAMN2 = KFAR2;
IF KFAR3 >= KFAL3 THEN KFAMX3 = KFAR3; ELSE KFAMN3 = KFAR3;
IF KFAR4 >= KFAL4 THEN KFAMX4 = KFAR4; ELSE KFAMN4 = KFAR4;
IF KFAR5 >= KFAL5 THEN KFAMX5 = KFAR5; ELSE KFAMN5 = KFAR5;
IF KFAR1 < KFAL1 THEN KFAMX1 = KFAL1; ELSE KFAMN1 = KFAL1;
IF KFAR2 < KFAL2 THEN KFAMX2 = KFAL2; ELSE KFAMN2 = KFAL2;
IF KFAR3 < KFAL3 THEN KFAMX3 = KFAL3; ELSE KFAMN3 = KFAL3;
IF KFAR4 < KFAL4 THEN KFAMX4 = KFAL4; ELSE KFAMN4 = KFAL4;
IF KFAR5 < KFAL5 THEN KFAMX5 = KFAL5; ELSE KFAMN5 = KFAL5;
IF KFBR1 >= KFBL1 THEN KFBMX1 = KFBR1; ELSE KFBMN1 = KFBR1;
IF KFBR2 >= KFBL2 THEN KFBMX2 = KFBR2; ELSE KFBMN2 = KFBR2;
IF KFBR3 >= KFBL3 THEN KFBMX3 = KFBR3; ELSE KFBMN3 = KFBR3;
IF KFBR4 >= KFBL4 THEN KFBMX4 = KFBR4; ELSE KFBMN4 = KFBR4;
IF KFBR5 >= KFBL5 THEN KFBMX5 = KFBR5; ELSE KFBMN5 = KFBR5;
IF KFBR1 < KFBL1 THEN KFBMX1 = KFBL1; ELSE KFBMN1 = KFBL1;
IF KFBR2 < KFBL2 THEN KFBMX2 = KFBL2; ELSE KFBMN2 = KFBL2;
IF KFBR3 < KFBL3 THEN KFBMX3 = KFBL3; ELSE KFBMN3 = KFBL3;
IF KFBR4 < KFBL4 THEN KFBMX4 = KFBL4; ELSE KFBMN4 = KFBL4;
IF KFBR5 < KFBL5 THEN KFBMX5 = KFBL5; ELSE KFBMN5 = KFBL5;
IF KFCR1 >= KFCL1 THEN KFCMX1 = KFCR1; ELSE KFCMN1 = KFCR1;
IF KFCR2 >= KFCL2 THEN KFCMX2 = KFCR2; ELSE KFCMN2 = KFCR2;
IF KFCR3 >= KFCL3 THEN KFCMX3 = KFCR3; ELSE KFCMN3 = KFCR3;
IF KFCR4 >= KFCL4 THEN KFCMX4 = KFCR4; ELSE KFCMN4 = KFCR4;
IF KFCR5 >= KFCL5 THEN KFCMX5 = KFCR5; ELSE KFCMN5 = KFCR5;
IF KFCR1 < KFCL1 THEN KFCMX1 = KFCL1; ELSE KFCMN1 = KFCL1;
IF KFCR2 < KFCL2 THEN KFCMX2 = KFCL2; ELSE KFCMN2 = KFCL2;
IF KFCR3 < KFCL3 THEN KFCMX3 = KFCL3; ELSE KFCMN3 = KFCL3;
IF KFCR4 < KFCL4 THEN KFCMX4 = KFCL4; ELSE KFCMN4 = KFCL4;
IF KFCR5 < KFCL5 THEN KFCMX5 = KFCL5; ELSE KFCMN5 = KFCL5;
IF KFDR1 >= KFDL1 THEN KFDMX1 = KFDR1; ELSE KFDMN1 = KFDR1;
IF KFDR2 >= KFDL2 THEN KFDMX2 = KFDR2; ELSE KFDMN2 = KFDR2;
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IF KFDR3 >= KFDL3 THEN KFDMX3 = KFDR3; ELSE KFDMN3 = KFDR3;
IF KFDR4 >= KFDL4 THEN KFDMX4 = KFDR4; ELSE KFDMN4 = KFDR4;
IF KFDR5 >= KFDL5 THEN KFDMX5 = KFDR5; ELSE KFDMN5 = KFDR5;
IF KFDR1 < KFDL1 THEN KFDMX1 = KFDL1; ELSE KFDMN1 = KFDL1;
IF KFDR2 < KFDL2 THEN KFDMX2 = KFDL2; ELSE KFDMN2 = KFDL2;
IF KFDR3 < KFDL3 THEN KFDMX3 = KFDL3; ELSE KFDMN3 = KFDL3;
IF KFDR4 < KFDL4 THEN KFDMX4 = KFDL4; ELSE KFDMN4 = KFDL4;
IF KFDR5 < KFDL5 THEN KFDMX5 = KFDL5; ELSE KFDMN5 = KFDL5;
KFADF1 = ( (KFAMX1 - KFAMN1) / KFAMX1 ) * 100;
KFADF2 = ( (KFAMX2 - KFAMN2) / KFAMX2 ) * 100;
KFADF3 = ( (KFAMX3 - KFAMN3) / KFAMX3 ) * 100;
KFADF4 = ( (KFAMX4 - KFAMN4) / KFAMX4 ) * 100;
KFADF5 = ( (KFAMX5 - KFAMN5) / KFAMX5 ) * 100;
KFBDF1 = ( (KFBMX1 - KFBMN1) / KFBMX1 ) * 100;
KFBDF2 = ( (KFBMX2 - KFBMN2) / KFBMX2 ) * 100;
KFBDF3 = ( (KFBMX3 - KFBMN3) / KFBMX3 ) * 100;
KFBDF4 = ( (KFBMX4 - KFBMN4) / KFBMX4 ) * 100;
KFBDF5 = ( (KFBMX5 - KFBMN5) / KFBMX5 ) * 100;
KFCDf1 = ( (KFCMX1 - KFCMN1) / KFCMX1 ) * 100;
KFCDf2 = ( (KFCMX2 - KFCMN2) / KFCMX2 ) * 100;
KFCDf3 = ( (KFCMX3 - KFCMN3) / KFCMX3 ) * 100;
KFCDf4 = ( (KFCMX4 - KFCMN4) / KFCMX4 ) * 100;
KFCDf5 = ( (KFCMX5 - KFCMN5) / KFCMX5 ) * 100;
KFDDf1 = ( (KFDMX1 - KFDMN1) / KFDMX1 ) * 100;
KFDDf2 = ( (KFDMX2 - KFDMN2) / KFDMX2 ) * 100;
KFDDf3 = ( (KFDMX3 - KFDMN3) / KFDMX3 ) * 100;
KFDDf4 = ( (KFDMX4 - KFDMN4) / KFDMX4 ) * 100;
KFDDf5 = ( (KFDMX5 - KFDMN5) / KFDMX5 ) * 100;
KFALB1 = KFAMX1 / BODYWT;
KFALB2 = KFAMX2 / BODYWT;
KFALB3 = KFAMX3 / BODYWT;
KFALB4 = KFAMX4 / BODYWT;
KFALB5 = KFAMX5 / BODYWT;
KFB1B1 = KFBMX1 / BODYWT;
KFB1B2 = KFBMX2 / BODYWT;
KFB1B3 = KFBMX3 / BODYWT;
KFB1B4 = KFBMX4 / BODYWT;
KFB1B5 = KFBMX5 / BODYWT;
KFCLB1 = KFCMX1 / BODYWT;
KFCLB2 = KFCMX2 / BODYWT;
KFCLB3 = KFCMX3 / BODYWT;
KFCLB4 = KFCMX4 / BODYWT;
KFCLB5 = KFCMX5 / BODYWT;
KFDLB1 = KFDMX1 / BODYWT;
KFDLB2 = KFDMX2 / BODYWT;
KFDLB3 = KFDMX3 / BODYWT;
KFDLB4 = KFDMX4 / BODYWT;
KFDLB5 = KFDMX5 / BODYWT;
HT = HT * 2.54;
BODYWT = BODYWT / 2.2;
CARDS;

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001 26 65 120
 63 62 46 52 38 40 38 27
 55 58 57 54 41 39 28 31
 50 54 51 52 41 36 29 30
 53 58 49 54 33 38 30 29
 66 60 62 55 49 42 38 36 5
 002 26 66 124
 57 60 51 52 38 39 28 28
 59 57 55 51 36 41 27 30
 59 65 50 56 41 36 32 29
 60 64 60 64 46 40 28 29
 53 59 55 59 36 42 29 30 4
 003 26 68 147.50
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 96 93 96 89 69 66 57 57
 99 93 93 93 69 66 60 59
 107 96 93 90 72 69 55 52
 92 90 92 96 66 60 55 53 2
 004 24 64.5 130
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 72 72 72 65 53 48 39 39
 79 72 72 68 51 48 40 39
 76 78 67 69 48 49 41 40
 82 76 78 72 57 48 47 39 3
 005 25 65 115.75
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 64 54 63 57 42 37 30 30
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 006 27 65 122
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 65 66 62 65 41 43 30 35 2
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 84 90 89 87 58 56 36 38
 89 92 94 97 62 64 43 48
 102 94 95 93 68 66 48 46 4
 008 23 61.5 119
 65 58 62 60 46 45 36 35
 61 68 54 63 45 42 40 30
 65 67 62 64 48 44 41 29
 61 64 64 66 52 48 36 35
 60 65 61 65 48 47 43 38 3
 009 38 64 123.75
 69 69 68 66 50 45 31 29
 67 65 67 64 46 42 35 33
 62 64 60 67 44 39 34 31


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010  72 67 69 62 48 40 30 25
    67 69 60 64 42 39 25 28 3
    26 69 152
    93 99 87 94 65 64 56 48
    90 99 78 90 59 63 46 48
    91 91 85 85 64 70 47 54
    90 93 83 93 58 69 45 53
    93 86 92 87 64 69 51 53 1
011      25 64 109
    57 52 55 51 45 37 36 37
    51 47 53 41 39 33 35 31
    51 55 50 45 41 35 33 30
    57 56 57 51 43 36 36 30
    55 45 56 48 40 35 35 24 5
012      22 63 111.5
    74 76 69 72 47 48 36 33
    71 76 69 65 47 46 35 30
    68 69 67 68 47 45 36 32
    75 68 72 69 53 46 36 31
    76 77 69 72 50 47 36 35 4
013      35 65 150
    54 57 57 57 43 43 35 36
    66 52 62 52 39 42 35 36
    53 49 55 53 45 41 36 35
    48 44 59 45 37 39 32 36
    51 47 57 46 36 36 31 29 5
014      27 65 125
    53 49 49 50 35 33 23 22
    51 52 51 45 35 39 12 24
    48 47 56 44 38 36 24 24
    59 46 56 52 37 33 24 24
    57 50 57 42 36 36 29 28 1
015      30 68 142
    54 46 58 42 46 35 34 27
    56 42 54 41 8 24 24 1 2
    51 48 60 39 44 35 29 29
    50 42 52 48 42 38 32 30
    49 47 54 53 41 35 34 30 1

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```

PROC BMDP PROG=BMDP2V DATA=KNEE;
PARMCARDS;
PROB      TITLE IS '  WARM-UP EFFECTS ON TORQUE PRODUCTION'.
INPUT      UNIT=3.
           CODE='KNEE'.
DESIGN     DEP=KFAR1,KFAR2,KFAR3,KFAR4,KFAR5,KFAL1,KFAL2,
           KFAL3,KFAL4,KFAL5.
           GROUPING ARE GROUP.
           LEVELS ARE 2,5.
           NAMES ARE LEG,TRT.
END

```

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