THE EFFECT OF VARIOUS LEG POSITIONS AT THE CATCH ON THE FORCE OF THE ROWING STROKE

A Thesis

Presented to

the Faculty of Graduate Studies

Lakehead University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

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ABSTRACT

Title of Thesis: The Effect of Various Leg Positions at the Catch on the Force of the Rowing Stroke

Boris Klavora: Master of Science, 1978

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The purpose of this thesis was to test in isolation various leg and body movements in the rowing action and to relate them to forces created on the oar handle. The subjects were four senior oarsmen. The independent variables were the four knee angles at the catch with hip flexion maximized at each. The dependent variable was the maximal force exerted on each trial. An intra-subject ABAB experimental design was used. Four random sequences of the three experimental conditions were determined and each subject was tested on all four testing orders. An analysis of variance revealed no significant difference in force magnitudes between the four treatments ($\underline{p}>.05$). The interaction between days and subjects was significant ($\underline{p}<.05$). Subjects' performances varied considerably from day to day, and also from trial to trial. All subjects displayed difficulty in stabilizing their performances under all treatment conditions.

ACKNOWLEDGEMENTS

The author wishes to extend a deep debt of gratitude to Dr. Brent Rushall for his invaluable assistance, direction, and support throughout all stages of this thesis.

Appreciation is extended to Mr. Clarida, Mr. Laser, Mr. J. Duncanson, and all other persons at the Lakehead University Engineering Departement for their cooperation and suggestions.

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The author acknowledges the cooperation and interest displayed by members of the Thunder Bay Rowing Club who served as subjects.

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Chapter 1

INTRODUCTION

Statement of the Problem

The purpose of this study was to test in isolation various leg and body movements in the rowing action and to relate them to forces created on the oar handle.

Significance of the Study

Back and particularly leg actions have been researched in jumping, running, and bicycling movements. However, results may not be relevant for back and leg actions in a sitting position which is peculiar to the sport of rowing. Should the actions be different from the ones that are known, this study would contribute to and expand the knowledge of leg and body actions.

At present, there is a controversy as to what is the most effective form of action at the beginning of the force phase of the rowing stroke, the catch. Two distinctly different body positions have been demonstrated by winning international crews in recent years. Without being objectively assessed, the two forms have been accepted by rowing coaches throughout the world. An attempt to discover the advantages and disadvantages of each style would make a contribution to the practical field of coaching rowing.

There is a reason of social importance for objectively assessing both techniques. In 1975 Canadian elite coaches chose the East German technique to be presented through the Canadian Association of Amateur Oarsmen Coaching Certification Program (Klavora, 1976). This program has the potential to be of great impact on all members of the rapidly growing rowing fraternity in Canada. The verification of whether or not this technique is mechanically the most effective would indicate an important finding for the sport. This study may inspire coaches and other rowing enthusiasts to follow a more scientific approach in determining the solutions to questions about rowing.

As a former Olympic oarsman and a coach, the investigator himself has a personal interest in clarifying some of the problems that are associated with rowing.

Coaching methods in the sport of rowing in Canada, as well as in many other countries, are still based on conventionalism and imprecise observations. None of the popular rowing techniques have been scientifically assessed. Research from other sports that has been done on body and leg actions may not be relevant for rowing. Therefore, it was the object of this study to 1) objectively assess the body and the leg actions in rowing, and 2) to propose, if possible, which of the distinctly different rowing techniques is the more effective.

Delimitations

1) The subjects of this study were three of the Thunder Bay Rowing Club's senior oarsmen and one former international oarsman. The effect of various knee angles at the catch on S's force output will be measured.

2) The independent variable was the subject's knee angle at the catch.

3) The dependent variable was the maximal exerted force.

4) The forces were measured by means of a tension load cell and recorded by an electric graph recorder.

<u>Limitations</u>

1) The testing was done in a controlled laboratory situation.

2) It was assumed that subjects' actions simulated the real action in rowing.

3) It was assumed that subjects exerted maximal force on each trial.

<u>Definitions</u>

<u>Force</u> is the capacity to do work or cause physical change.

<u>Knee Angle</u> is considered as the line extending from the greater trochanter of the femur to the lateral epicondyle of the femur, and another line from the lateral malleolus through the head of the fibula.

<u>Catch</u> is the transition from the resting-phase to the propulsive phase of the stroke. Oarsmen reach fully forward and insert blades into the water. The movements at the knee and hip joints change from flexion to extension.

<u>Drive</u> is the propulsive phase of the stroke. It starts when the blades are fully covered in the water and ends when they leave the water.

Chapter 2

REVIEW OF LITERATURE

A survey of available literature revealed a deficiency with regard to scientific research on the sport of rowing. Researchers were concerned primarily with the mechanics of equipment (Celentano, Cortili, Di Pampero, & Cerretelli, 1974; Gerdes, 1972; Herberger, Beyer, Harre, Krueger, Querg, & Sieler, 1970; Williams, J. G. P. & Scott, 1967), with the assessment of elite oarsmen (Hagerman, Addington, & Gaensler, 1972; Morgan, 1975; di Pampero, Cortili, Celentano, & Cerretelli, 1971; and Williams, L. R. T., 1977), with forces exerted on the oar throughout the stroke, and with the speed and the acceleration of the boat (Edwards, 1963, Herberger et al., 1970; and Ishiko, 1971). The rowing technique was also elaborated (Adam, Lenk, Nowacki, Rulfs, & Schroeder, 1977; Adam, 1962, Bourne, 1925; Edwards, 1963; Herberger et al., 1970; Klavora, 1977, 1976; and Wilson, 1959), however, all attempts have been of a descriptive nature about the muscles involved in rowing and/or the body action of winning crews.

It is a generally accepted principle in the sport of rowing that the powerful leg muscles are the most effective force-producers for propelling the boat. However, successful international crews have demonstrated the existence of a great variety of leg and body movements Karl Adam developed a technique whereby the stroke length at the catch was achieved by using longer slides. Extremely flexed knee and hip joints, allowing very little forward body swing, allowed the use of as much leg range as was physically possible. The possible mechanical disadvantage of the unfavorable initial knee angle was thought to be overcompensated for by increasing the distance of the leg work (Adam, 1962; and Adam et al., 1977).

The most recent East German Coaches recommended shorter slides that decreased the range of leg movement in the stroke. Stroke length is achieved by swinging more the upper trunk and the shoulders forward at the beginning and backward at the end of the stroke (Klavora, 1977)

It has not been verified yet which of the two techniques is mechanically more effective. Moreover, there is a complete gap in the research with regard to the characteristics of the leg and body actions in rowing.

A number of studies have been conducted to determine the amount of force which can be exerted by muscles when body parts are in different positions. Experiments on leg strength associated with varying knee angles have produced seemingly contradictory results. An early study by Carpenter (1938) proved knee angles between 115° and 124° to be the most effective for knee extension. Strength decreased rapidly at angles above 140° and below 105°. This is essentially in agreement with Everts and Hathaway (1938), who reported the highest readings at a knee angle of approximately 130°. A leg dynamometer was used for testing subjects in semi-erect positions.

Campney and Wehr (1965) found no significant strength difference resulting from knee angle changes from 80° to 130° in 10° increments. The extension strength at greater angles decreased rapidly. Subjects sat on the table with freely-hanging lower legs. They leaned backward with arms extended to the rear and hands grasping the sides of the table. A cable-tensiometer was used in testing.

Hugh-Jones (1947) examined the effect of limb position in seated subjects on their ability to utilize the maximum contractile force of limb muscles. Sitting with the trunk vertical and with their feet in the same horizontal plane as the hips, subjects were able to exert more force as the knee angle increased up to 160°. The activity in leg extension stopped just before the limb became straight.

An inverted leg press was another position used in leg strength testing. In this test, the subject lies on the back with legs raised above the hips. Force is exerted upward in a direction perpendicular to the trunk. Looking for the maximal force only, Berger (1966) and Lindeburg (1964) tested leg strength at angles greater than 100°. The findings of both studies showed a knee angle at around 140° to be the most effective for leg extension. Lindeburg used a strain gauge dynamometer to measure strength.

There is still considerable lack of agreement regarding the influence of the knee angle upon strength scores obtained through testing. Much of the difference in results between these studies is probably due to the variations in testing positions, whereby other muscles may affect the knee extensors' strength. For example, a difference of 24% in knee extension strength was found for subjects in two different sitting positions (Clarke, Elkins, Martin, & Wakim, 1950). The method of knee angle measurement (Linford & Rarick, 1968) as well as testing equipment used (Clarke, Bailey, & Shay, 1952; and Everts, & Hathaway, 1938) may also have contributed to contradictory results.

All studies and results support the assertion that muscular efficiency varies throughout the range of movement of the knee joint. Small knee angle changes do not affect significantly the leg extension strength in the middle range of motion (Campney & Wehr, 1965; Carpenter, 1938; Lindeburg, 1964; and Linford & Rarick, 1968), however, strength decreases as the knee angle approaches its upper and lower limits (Campney & Wehr, 1965; Carpenter, 1938; Clarke et al., 1950; and Williams, M. & Stutzman, 1959).

Research is scanty on trunk and hip extension strength and various hip angles. Clarke and Bailey (1950) tested hip extension strength in subjects in a supine position. Their ability to exert strength was the greatest when the hip was fully flexed. In the same study strength was analyzed for 13 other joint movements. Strength varied throughout the range of motion for all joints. This may be attributed to changes in muscle length and geometrical arrangements of bones (levers, angles of pull, etc.; Astrand & Rodhal, 1977; and Clarke & Bailey 1950).

Past research on leg and body strength throughout the range of motion may not be relevant to the action in rowing because the testing position differed greatly from those that occur in rowing.

Leg and body positions in rowing are quite peculiar. Oarsmen are seated on movable seats that facilitate knee flexion and extension. Their feet are secured to adjustable footstretchers that are angled around 45^{o} and placed deep in the shell. The oarsmen's heels are from 14 to 18 cm below the seat. A long stroke, which is one of the important features of rowing, requires maximal hip flexion at the catch. Knee flexion at the stroke's beginning varies from 40^{o} to 70^{o} between different oarsmen.

The normal range of motion at the ankle joint is about 60^{o} of voluntary movement, which includes around 20° of dorsal flexion, and 40° flexion (Barham & Wooten, 1973). Leighton (1959) found special flexibility performance ability in college men involved in specialized competitive sports. Baseball players, and swimmers, for example, had greater than average ankle flexion-extension (around 70°). No data on oarsmen's flexibility are available; however, greater than normal dorsal flexion may be expected in well-trained individuals. Nevertheless, the compressed body position at the catch may require the heels to be lifted from the footstretcher (Figure 1). This is particularly true for techniques that advocate a small knee angle at the catch. This heel raising may affect an oarsman's action. Therefore it further increases the specificity of body position in rowing.

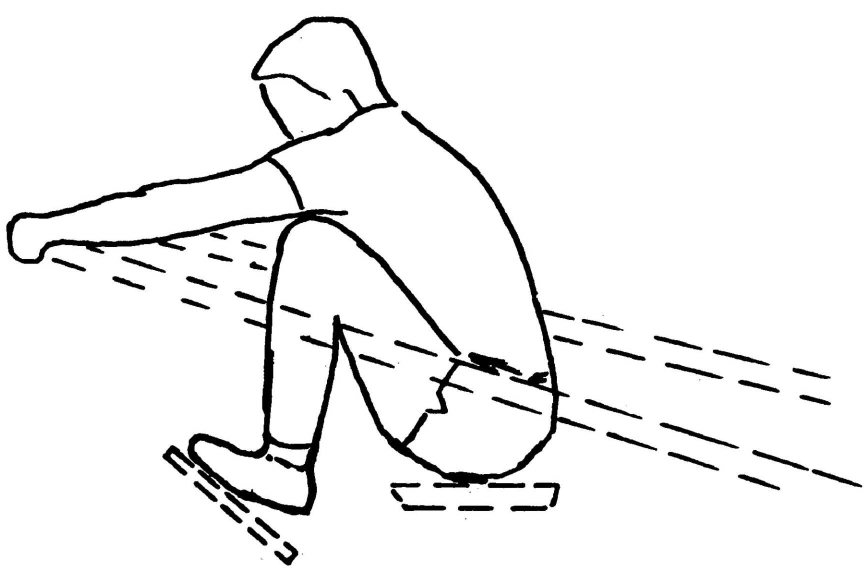


Figure 1. The Oarsman at Full Reach Lifts Heels From the Footstretcher.

The acceleration of a rowing shell fluctuates throughout the stroke (Figure 2). It is the greatest soon after the release (the beginning of recovery or the resting phase of the stroke), reaches the lowest point at the catch, and then abruptly increases. This is the beginning of the propulsive phase. It is at this point that the force exerted on the oar reaches the maximal values of 80 to 100 kg (Ishiko, 1971).

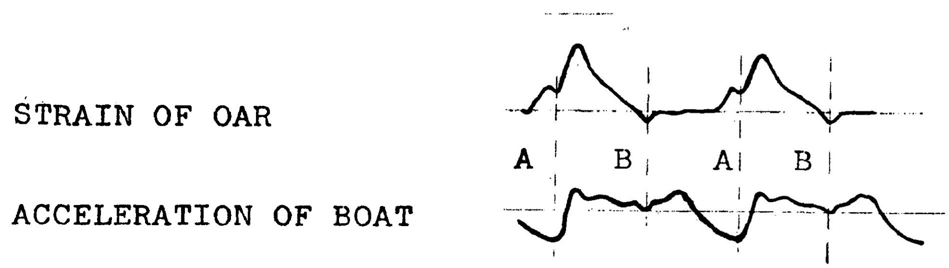
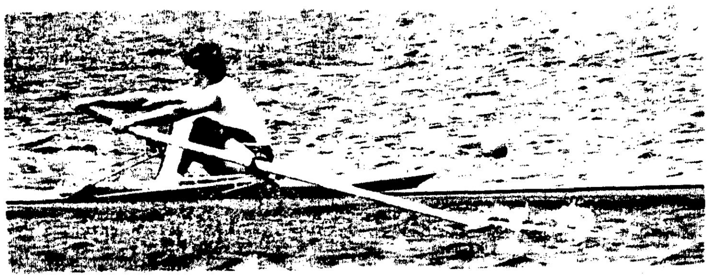


Figure 2. Forces Exerted on the Oar and Acceleration of the Boat (Ishiko, 1971; A = the catch; B = the release).

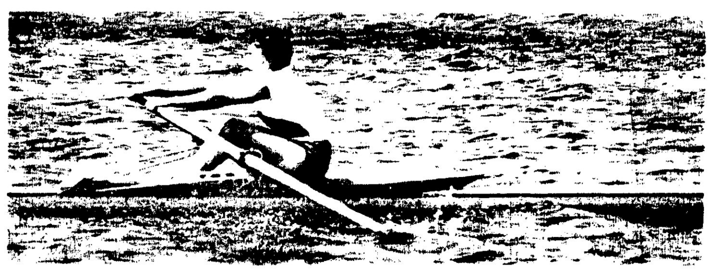
The scope of this thesis was to measure the effect of various knee angles at the catch on oarsmen's force output during the first part of the stroke, that is, from the catch to the point when the arms are engaged (Figure 3).

a. Full reach

b. Drive



c. Drive



d. Drive; arms are engaged

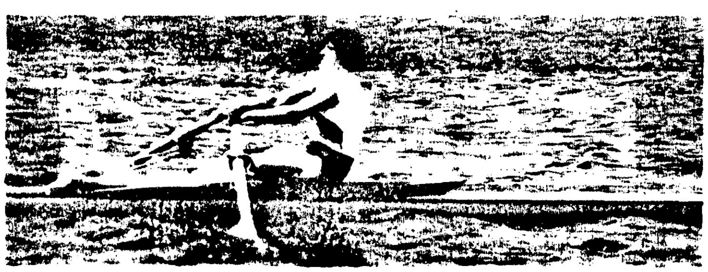


Figure 3. Stages of a Sculling Stroke; Arms Are Extended at the Elbows During the Beginning of Drive.

Chapter 3

METHODS AND PROCEDURES

Subjects

The subjects of the study (S1, S2 and S3) were three of the Thunder Bay Rowing Club's national level oarsmen. In the 1977 rowing season, they rowed in various events and won the coxed four at the Royal Canadian Henley held at St. Catharines. At the time of testing, they were fully employed and in heavy training. The fourth subject (S4) was a former international level oarsman, who had maintained a relatively high level of physical fitness.

Testing Location and Time

The testing took place from May 27 to June 7, 1978, in the gymnastic equipment storage room of the C. J. Sanders Fieldhouse at Lakehead University, Thunder Bay. The testing sessions were arranged at each subject's convenience. An attempt was made to test each subject at the same time each day.

Experimental Equipment

A firmly-secured "pool rowing trainer" ("Fredericton Clinic", 1977) was used for testing. Its design is similar to that of racing shells (footstretcher angle, slope of slides, seat, etc.). Therefore, a subject's testing position was similar to that attained in rowing. A tension standard-shaped load cell was made of 1' x 1/8' mild steel. The half-bridge (two micro-strain gauges[1]) was tested and balanced by the Lakehead University engineering laboratory. The forces exerted on

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[1] EA-06-250BG-120, micro-measurements, Romulus, Michigan

the load cell extended the steel plate. This deformation was measured by the change in electrical resistance of both strain gauges. The strain gauge output was displayed on a Vishay-Ellis 20-A Digital Strain Indicator in micro inches/inch (in./in.) of strain gauge, gauge length (hereafter referred to as "load cell unit"). Forces were recorded on a Beckman RS Dynograph as a force-time curve. All recordings were taken at a paper speed of 5 mm/second. A schematic outline of test design and testing equipment is displayed in Figure 4.

Experimental Design

An intra-subject ABAB experimental design (A refers to baseline, and B to the experimental condition, Kazdin, 1973) was used in this study. This research uses an alternate presentation of the baseline and the experimental condition within a subject. A preferred knee angle (P) was considered as the baseline condition. The experimental conditions were P decreased by 10° ($P-10^{\circ}$), P increased by 10° ($P+10^{\circ}$), and P increased by 20° ($P+20^{\circ}$).

Each day, testing started with the preferred angle (baseline condition). After the performance at another angle was measured, (experimental condition), the subject was re-tested at the preferred knee angle.

Each subject repeated trials at each knee angle until the performance stabilized, that is, when the exerted force of at least five consecutive trials fell within a 5 kg range, or when a stable performance force pattern was apparent. However, if the performance did not stabilize a maximum of 20 trials was allowed to prevent fatigue.

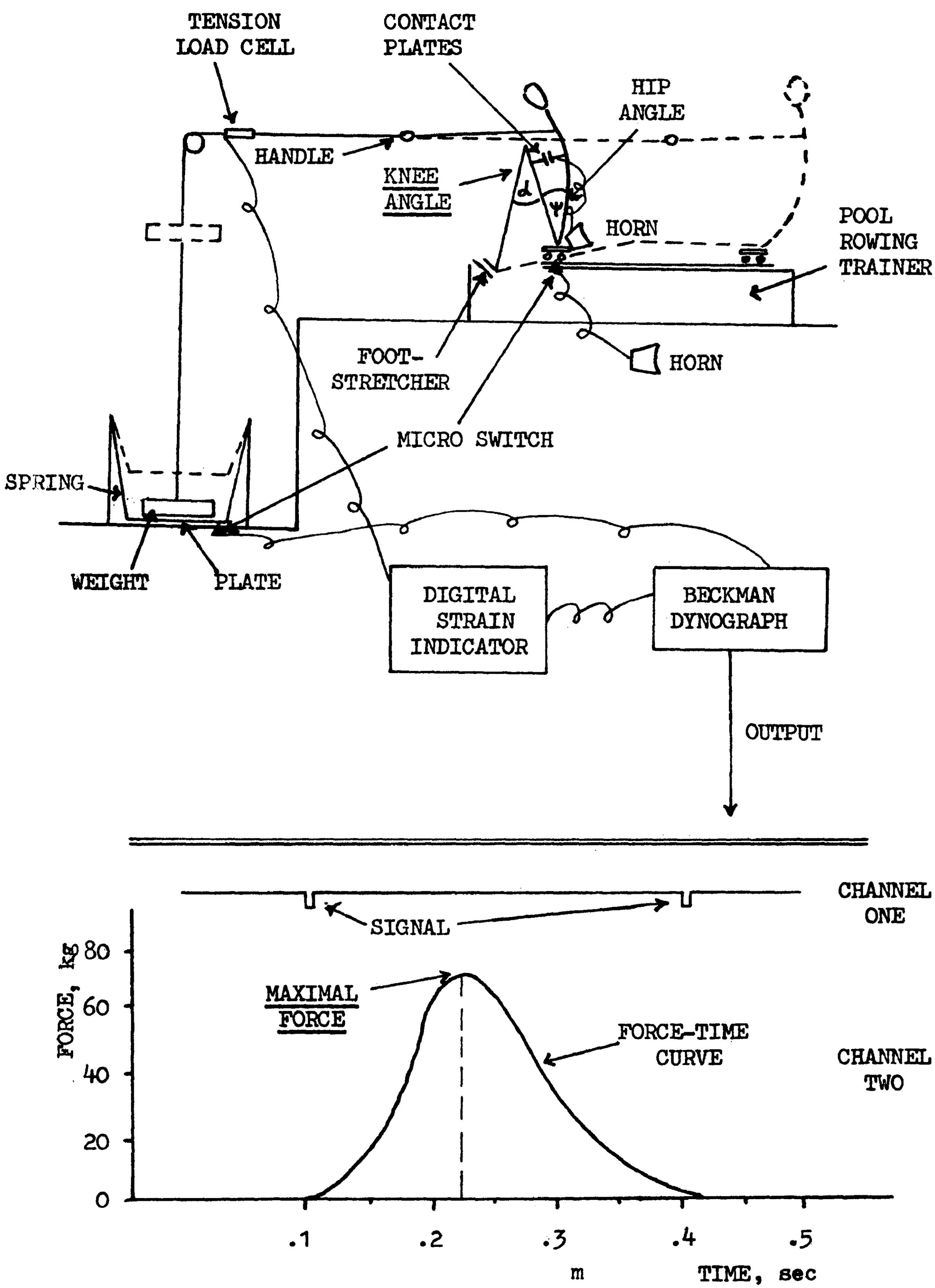

Figure 4 Test Design and Testing Equipment

Pilot Study

A pilot study was carried out at the beginning of May. The experimenter himself and all the subjects took part to familiarize themselves with the testing equipment and procedure, and to determine the weight to be attached to the cable as the stroke resistance. The subjects were to choose a weight that would create resistance similar to that experienced on the oar handle in rowing. A weight of 35 kg was acceptable to everyone.

The preliminary testing revealed several deficiencies in the experimental design and equipment. Maximally flexed knees and knee angles of 40°, 50°, 60°, and 70° had been proposed as the testing positions. However, S1 and S3 were unable to flex their knees to 40° (see Table 1). Furthermore, all subjects felt uncomfortable at the knee angle of 70°. The testing positions were therefore changed to be appropriate for each subject.

Initially, the subjects were asked to exert a maximum force on each trial. Doing this, they were unable to stabilize their performance. The subjects were then instructed to pull maximally but in a controlled manner, attempting to simulate the rowing action and effort of short sprints of up to 20 strokes. These instructions slightly reduced the previously demonstrated performance variability.

The force that an oarsman can exert on the oarhandle at the catch of a stroke increases gradually from zero at the beginning of the blade's entry into the water, to its peak when the blade is completely buried. In the pilot test, a force greater than 35 kg was required

Table 1

The Knee Angles and the Position of Equipment Under Various Treatment Conditions

Subject	Treatment	Knee Angles	Adjustments in Forward Reach
1	P - 10°	45°	0 cm
	P	54	-5.0
	P + 10°	65	-10.0
	P + 20°	d	-
2	P - 10°	35	0
	P	45	0
	P + 10°	55	-5.0
	P + 20°	65	-7.5
3	P - 10°	43	0
	P	54	-2.5
	P + 10°	65	-7.5
	P + 20°	d	-
4	P - 10°	36	0
	P	44	0
	P + 10°	55	-5.0
	P + 20°	65	-7.5

d = Subject did not experience this treatment to initiate the vertical movement of the weight. The subjects considered that this testing action was too jerky and quite different from that in rowing. To smooth the initiating action, a plate was secured 15 cm above the floor to six utility extension springs[1] that were attached to a frame. The weight forced the plate to the floor; however, a force of approximately 2 kg only was necessary to initiate its movements. The spring-assisted testing action was much smoother and, according to the subjects, it simulated quite well the action in rowing immediately after the catch, that is, the beginning of the propulsive phase.

A micro switch was placed on the floor under the spring-supported plate. It was connected to a 9 V battery and to the second chart recorder channel. When the plate contacted the micro switch, it produced a signal on this channel which indicated for each trial that the appropriate weight position had been attained.

To eliminate a disturbing side-to-side movement of the weight, four aluminum rails were secured along the weight's vertical path, allowing only 1 cm of lateral movement. They were occasionally sprayed with silicon to decrease friction.

The experimental knee angles were determined and measured during the second pre-testing session. Each subject warmed-up and stretched for 10 minutes, and then completed 20 trials on the testing equipment. The seat was positioned at the front stops, the knee and hip joints were maximally flexed and the arms extended horizontally. The proper

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[1] PAPCO 632, 11" x ½"

footstretcher position was set and recorded. The subject was then asked to put himself into a comfortable catching position, that is, to flex his knees to the angle that he usually experienced at the catch when rowing. Without pulling the weight, the subject went through four entire stroke movements, brought his trunk and arms to the "normal" catching position, and stopped the seat. The experimenter marked the seat position with chalk. The average of four trials was considered as the subject's preferred catching position, and the corresponding knee angle as the preferred angle. This knee angle was considered as the baseline condition in this study.

The subject was then positioned to the preferred catching position. The four anatomic landmarks that determine the knee angle were palpated and marked with a marker pen. The position of the knee joint axes was also determined and marked. Two straight lines were marked on subject's leg: one running from the lateral malleolus to the head of the fibula, and another from the greater trochanter of the femur to the lateral condyle of the femur. A goniometer[1] was secured to the subject's leg, the seat moved to the front stops (maximal knee angle or P-10^{o} experimental condition) and to the preferred catching position (preferred knee angle), and the knee angles at both positions were measured and recorded. The subject then extended his knees to 55^{o} (P+10^{o} experimental condition for S2 and S4) and 65^{o} (P+20^{o} experimental condition for S2 and S4; but P+10^{o} experimental condition for S1 and S3). The experimenter marked both seat positions. The subject was then asked

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1 International Standard Goniometer Rajowalt Company Atwood, Indiana

to extend and flex his knees several times. The same measures were repeated two more times. The average of three trials was considered to be the true value for the maximal and preferred knee angles (see Table 1) and the seat positions for knee angles of 55° and 65°. Appropriate wooden front stops were then made and labelled for each seat position. During the testing sessions the front stops were secured onto the slide with a rubber band.

Finally, the cable length at each knee angle had to be determined. With the appropriate front stop secured onto the slide, the subject positioned himself into the catching position, held the handle with his hands, the weight resting on the floor. The experimenter adjusted and recorded the chain length as the subject requested. This was necessary because it was found that the length of stroke, i.e., how far a subject could reach forward, varied with each angle (see Table 1).

Each subject was allowed enough trials to familiarize himself with the testing action. Familiarity was determined by the subject: that is, when he was satisfied and ready for testing. The testing times and days were then arranged at each subject's convenience. However, they were asked to schedule their testing sessions at the same time each day whenever possible. The subjects were also instructed to avoid strenuous physical activity, to eat properly, and to rest adequately prior to each testing session.

The load-cell was calibrated. The reliability within the working range was 89 to 93%. The consistency of the Dynograph was also checked and was satisfactory (see Appendix B).

Testing Sessions

The purpose of these sessions was to test the effect of different knee angles on the subjects' force output. The testing order was predetermined by random selection (see Appendix D). The author himself did all testing. Only the subject and the tester were present in the testing room. The room temperature remained 20° C throughout all testing sessions.

One hour prior to testing, the experimenter switched on the Digital Strain Indicator, checked the function of all instruments (Dynograph, load cell, horns), and adjusted the experimental equipment (footstretcher, cable length, front stop) to the subject's preferred catching position. Then he adjusted the Digital Strain Indicator zero setting and internal calibration and set to zero the graph recorder. The zero setting for the load cell and graph recorder was rechecked prior to each set of trials. The Digital Strain Indicator internal calibration was checked only occasionally during each testing session.

The subject, dressed in gym clothing (runners, shorts, and shirt) came 15 minutes prior to testing time and warmed-up. Then he removed his shirt and was seated on the testing machine, the two contact plates being secured to his thigh and chest. He was asked to make 20 warm-up trials to coordinate his body movements.

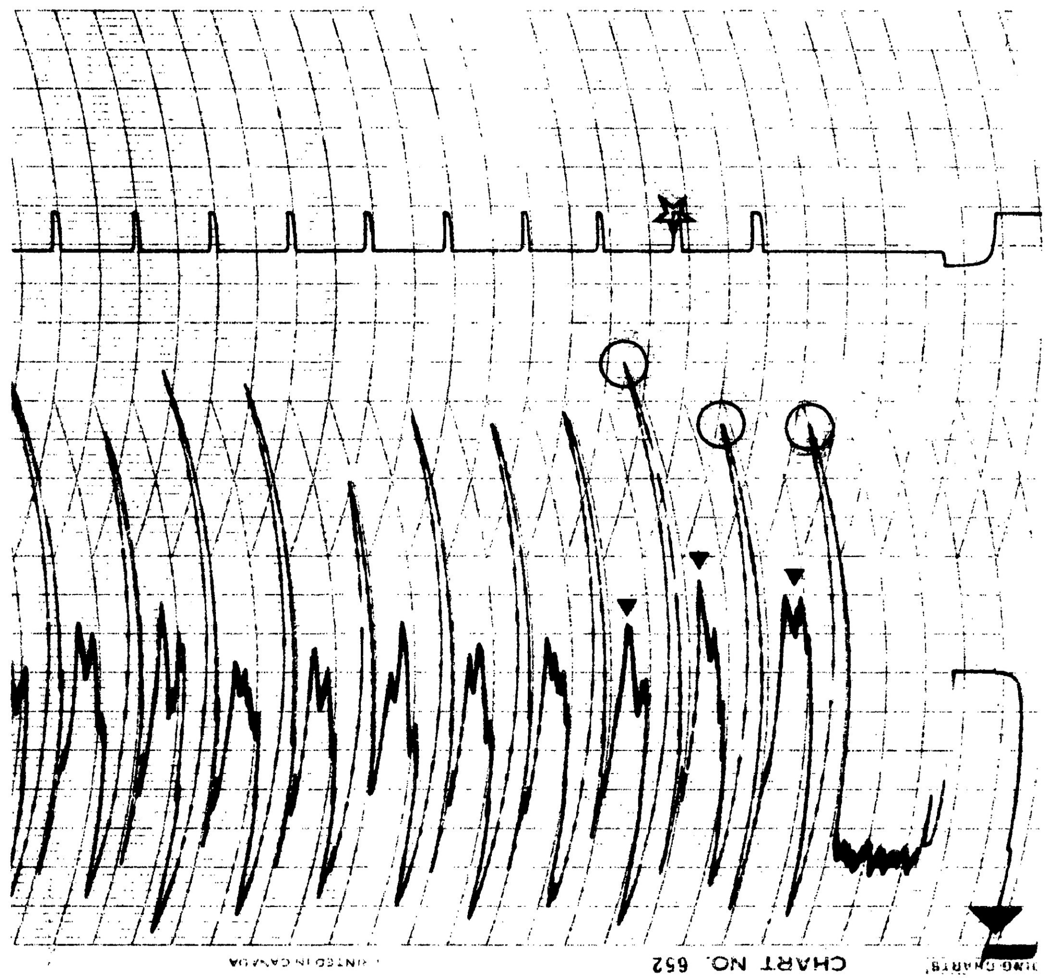
The signal on the graph recorder's second channel, produced by the micro-switch under the springed plate, indicated the weight contact with the floor. Forward movement of the seat (knee angle) and trunk (hip angle) were indicated by means of two bicycle horns that produced different sounds. A movable micro-switch was secured to the slide and a special lever on the seat. Lever pressure on the micro-switch engaged the horn, indicating an adequate forward movement of the seat. The trunk movement was controlled by means of contact plates. A contact of the two plates sounded the horn and thus signified an appropriate forward trunk movement. Simultaneous sounds of the two horns indicated the proper body and leg position for each catch. These sounds were the signal for the subject to pull the handle as hard and fast as possible. The arms remained extended at the shoulders in a horizontal position with the elbows straight throughout this action.

The tester attempted to standardize the motivational circumstances. Prior to the first series of trials, he asked the subject to concentrate and relax. He also encouraged the subject to perform as in rowing during a 20 stroke power drill at a moderate stroke rate, that is, to make in each series five preparatory trials, and then to start pulling each trial maximally but in a controlled manner. Similar instructions were also given occasionally between sets. The subject was not told the results of his efforts until all testing was completed.

Exerted forces were measured by the load cell and recorded on a Dynograph as a force-time curve. An example of the output recording is shown in Figure 5.

Data Analysis

Data were graphed for each subject, day, treatment, and trial. The maximal force exerted on each trial was determined from the force-time curve recordings in the following manner: The vertical distances from the zero-line to each force-time curve's peak were determined (in millimeters dynograph deflections) by counting the horizontal lines on the



= maximal forces
= recovery recoil
= Dynograph zero setting
= the signal on the second channel produced by the weight contact with the micro-switch on the floor

Figure 5 The Force-Time Curve Showing Exerted Forces

graph paper. The closest line was considered as the score. These scores were recorded and converted into kilograms (kg) by using the conversion table listed in Appendix C.

Data were analyzed using an analysis of variance (ANOVA). The treatment conditions in the ANOVA were limited to preferred angle 1, preferred angle + 10°, preferred angle 2, and preferred angle - 10°. The ordering of the occurrence of + 10° and - 10° conditions was randomized in the original design. The ANOVA was concerned with the effects of angles, order, subject, and days within subjects. Statistical significance was set at alpha = .05.

Chapter 4

RESULTS

The results are graphically presented in Figures 6 - 9. Each dot represents one trial. The representative averages for each series (the broken lines) were obtained by averaging the representative trials. The requirement for these representative trials was that they all fall within the range of 4 to 5 kg. Three methods were used in choosing the representative trials:

1. Five or more consecutive trials had to fall within the required range;

2. 80% of trials in a series of seven or more trials had to agree with the requirement;

3. In the sets with an unstable performance, pairs of trials were consecutively removed from one series (one trial from the lower and one from the upper force limit within the series) until the remaining trials accorded with the requirement.

The following trends are evident from graphs:

1. Performances within each set of trials varied a great deal. The difference between the maximal and minimal forces exerted within one set fluctuated between a low of 4.4 kg (Figure 7, Day 1, P + 20^{o}) and the high of 21.7 kg (Figure 6, Day 4, P_1). The required performance stability, that is, five consecutive trials within the range of 4 to 5 kg, was achieved in only 29 sets (28% of all sets performed): 14 times at the preferred knee angle and 15 times at other knee angles. However, the performances of only 10 sets (16%; all trials within 5 kg range) could be considered as stable (Figure 7, Day 1: P + 20^{o}; Day 2: P_1;

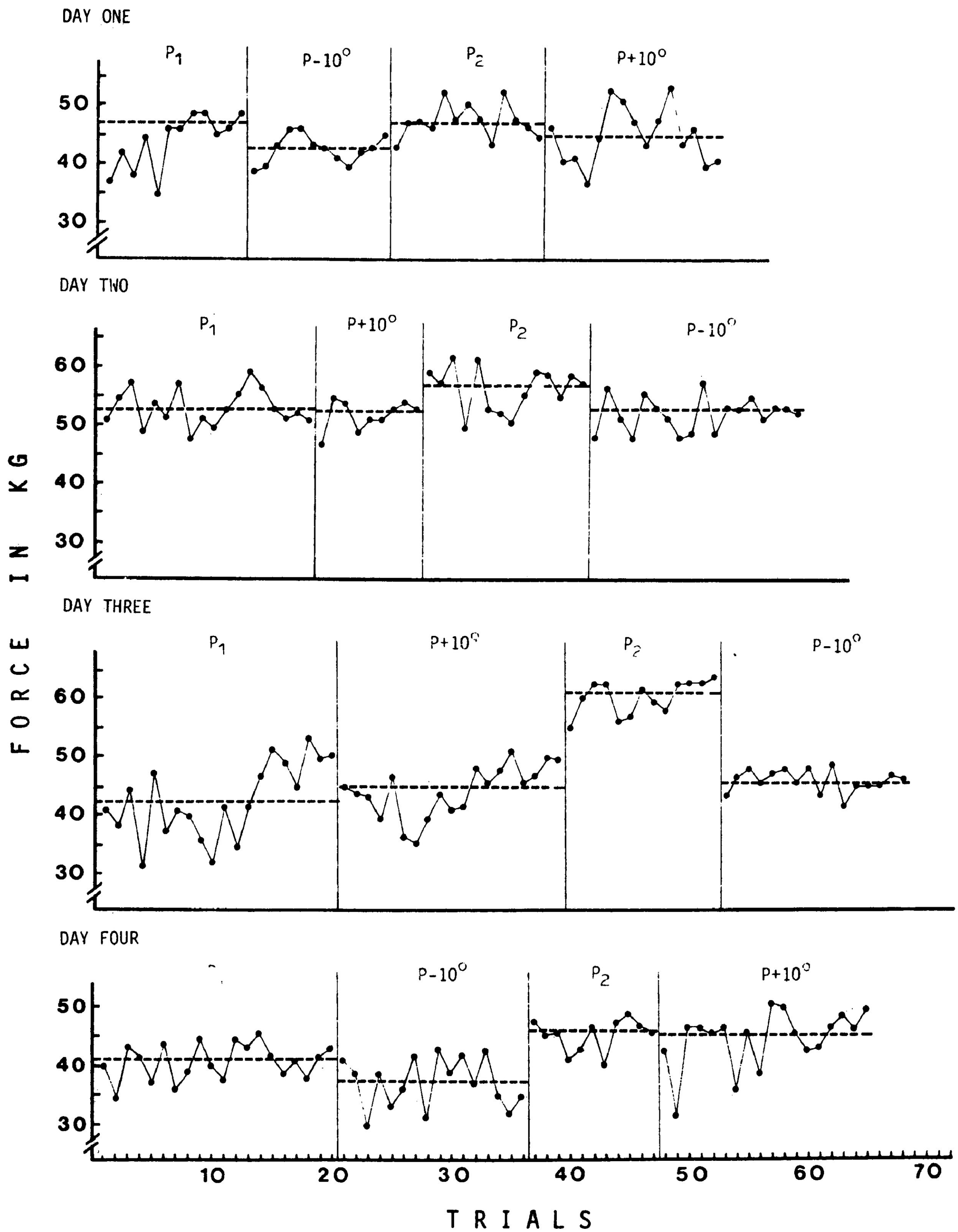


Figure 6. **Forces Exerted on Each Trial and the** Representative Average **Forces for Each of the Treatment Conditions for S1**

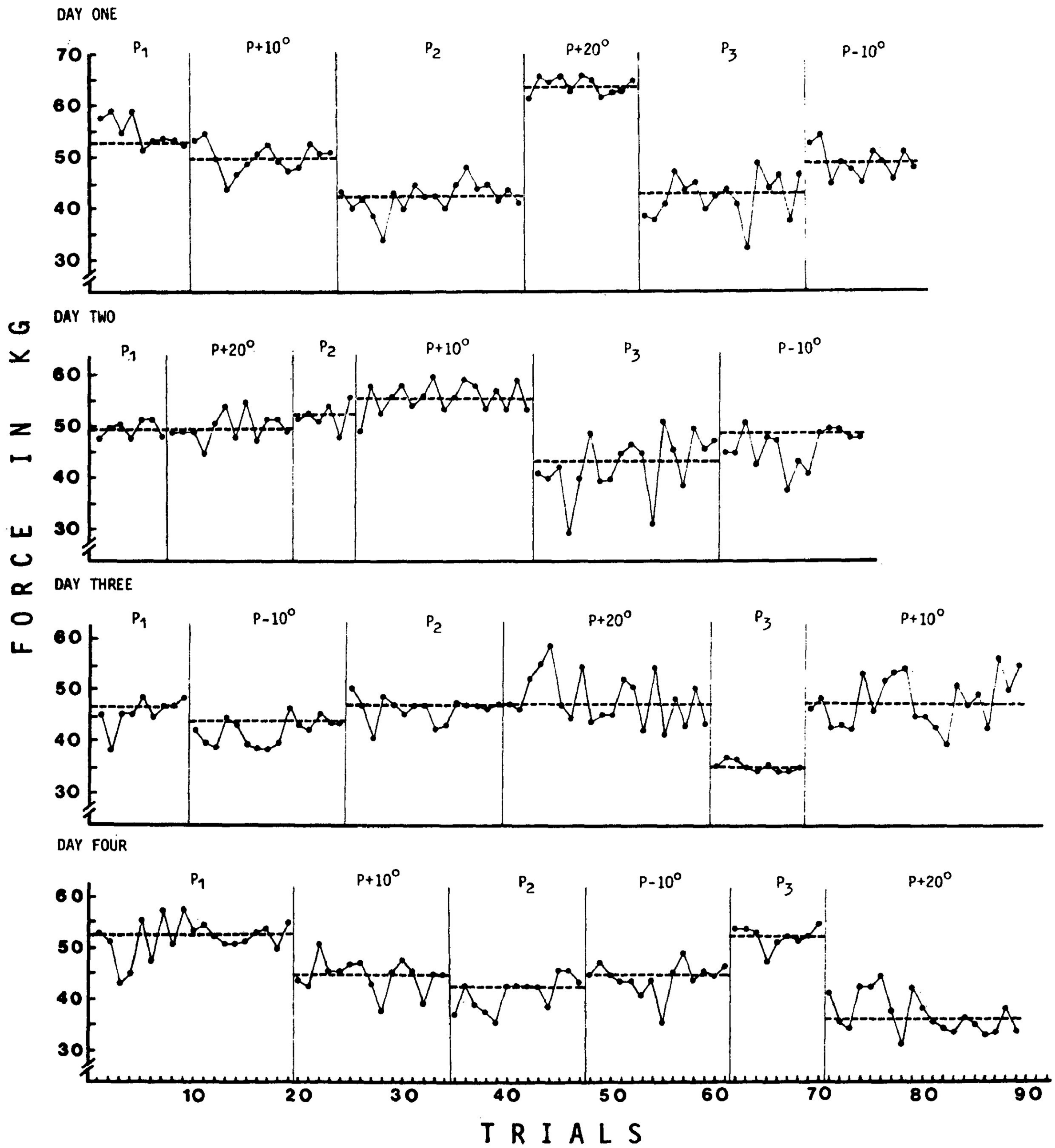


Figure 7. Forces Exerted on Each Trial and the Representative Average Forces for Each of the Treatment Conditions for S2

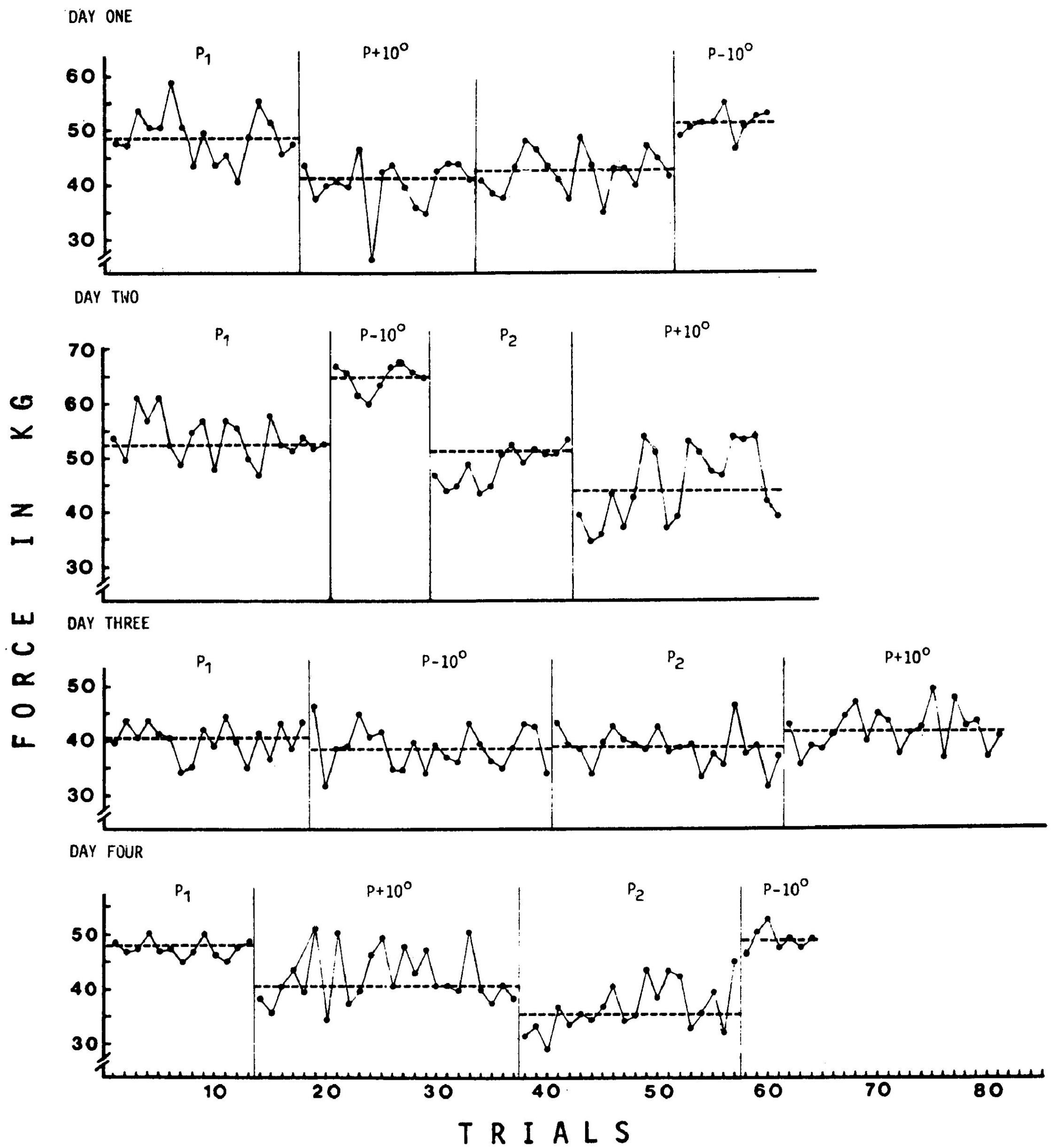


Figure 8. Forces Exerted on Each Trial and the Representative Average Forces for Each of the Treatment Conditions for S3

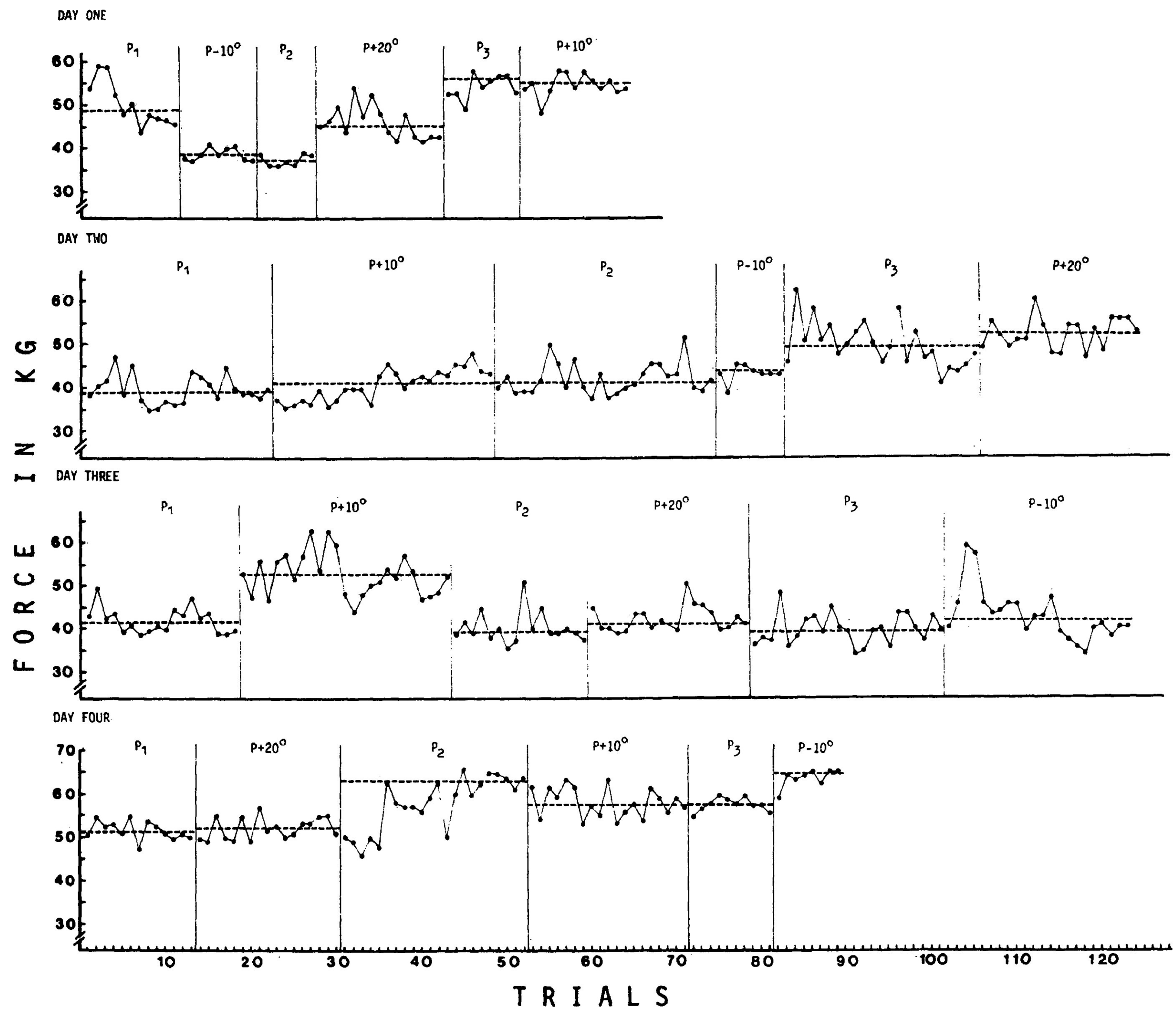


Figure 9. **Forces Exerted on Each Trial and the Representative Average Forces for Each of the Treatment Conditions for S4**

Day 3: P_3; Day 4: P_3; Figure 8, Day 4: P_1; Figure 9, Day 1: $P - 10^{\circ}$, P_2, and $P + 10^{\circ}$; Day 4: P_3 and $P - 10^{\circ}$). Generally speaking, the force magnitude of consecutive trials continuously fluctuated. The greatest difference between two consecutive trials was 17 kg (Figure 8, Day 4, $P + 10^{\circ}$).

2. Stable performances were infrequent. On six occasions all the average scores for each baseline condition in a session fell within the 5 kg range (Figure 6: Day 1, 2, and 4; Figure 8: Days 2 and 3; Figure 9: Day 3). However, the variability between the baseline averages was much greater in other testing sessions. For example, a difference of 15.7 kg between the average baseline scores for Session 8 was recorded in S1. The difference between the highest and the lowest representative average baseline scores within one subject ranged from a low of 8.9 kg (P_1) in S2 to a high of 24.5 kg (P_2) in S4 (see Table 2). Although the action under the baseline condition was replicated the most frequently, there was no evidence of an increase in performance stability. This suggests that it is characteristic that these subjects vary their performances considerably.

3. Within subjects' performance variability at other knee angles was also evidenced (see Table 2). At $P - 10^{\circ}$, the difference between the maximal and minimal representative average scores varied from 4.0 kg (S2) to 26.1 kg (S3). Corresponding values at $P + 10^{\circ}$ were 2.4 kg in S3 and 16.9 kg in S4. Thus, forces that subjects exerted at each knee angle varied greatly from one day to the other. Within-set performance variability appeared to be considerable at all knee angles.

4. The ranking of performances under the treatment conditions varied

Table 2

The Difference Between the Highest and Lowest Representative Average Scores (kg) Under One Treatment Condition

Subject	P_1	$P - 10^{\circ}$	P_2	$P + 10^{\circ}$	P_3	$P + 20^{\circ}$
1	10.0	14.0	14.7	6.3	d	d
2	8.9	4.0	9.7	11.9	16.4	11.0
3	11.6	26.1	15.4	2.4	d	d
4	12.3	24.2	24.5	16.9	19.0	15.3

d = Subject did not experience this treatment

from one testing session to the other in S2 and S4 (see Table 3). The former recorded best daily performances at three different knee angles, and the latter at four. The other two subjects performed in a somewhat more stable manner. S1 scored four times maximally under P_2 condition. Contrastingly, his performance under P_1 condition ranked much lower. S3 performed best three times under $P - 10^{\circ}$ experimental condition and on four occasions recorded second best averages under P_1 condition.

5. The force magnitude seemed to fluctuate a great deal from one day to the other. For example, all but one S1's representative average scores in Session 2 were above 50 kg (see Table 3). His performance declined markedly in the last session when three average scores dropped by 10 kg and one by 5 kg. This fluctuation was even higher in S4 with differences of up to 24 kg between the relevant average scores of Sessions 3 and 4.

6. Performance variability changed considerably from one day to the

Table 3

The Representative Average Forces Under the Treatment Conditions and Their Daily Ranking

Subject	Day	TREATMENT											
		P_1		P - 10°		P_2		P + 10°		P_3		P + 20°	
1	1	47.0	2*	42.7	4	47.2	1	44.8	3	d		d	
	2	49.9	4	51.0	3	55.2	1	50.7	2	d		d	
	3	42.1	4	45.7	2	60.6	1	44.4	3	d		d	
	4	40.9	3	37.0	4	45.6	1	45.1	2	d		d	
2	1	52.6	2	48.4	5	42.0	6	49.9	3	48.6	4	63.4	1
	2	49.4	4	48.6	5	52.1	2	55.5	1	42.9	3	49.4	4
	3	46.5	4	43.9	5	46.9	3	47.8	1	35.3	6	47.1	2
	4	52.4	1	44.6	3	42.1	5	44.5	4	52.1	2	36.1	6
3	1	48.5	2	50.9	1	42.1	3	40.8	4	d		d	
	2	52.1	2	64.4	1	50.8	3	43.7	4	d		d	
	3	40.5	2	38.1	4	38.2	3	41.6	1	d		d	
	4	48.1	2	49.0	1	35.4	4	40.4	3	d		d	
4	1	48.6	3	38.3	5	37.0	6	55.1	2	56.0	1	45.1	4
	2	38.9	6	43.8	3	40.9	4	40.7	5	48.8	2	51.9	1
	3	41.7	2	41.5	3	38.8	5	52.2	1	38.6	6	40.4	4
	4	51.3	6	64.3	1	62.6	2	57.5	4	57.6	3	52.0	5

* Numbers denote the daily ranking of performances

other. For example, all S1's representative averages for Day 2 were within a range of 5 kg but on Day 3 the range increased to 16.2 kg (see Table 3). Similarly, S3's averages for day 3 were also within a 5 kg range but on Day 2 the range was 20.7 kg.

7. The analysis of variance (see Table 4) revealed no significant differences between treatments nor any testing order effect. Warm-up, learning, and fatigue did not appear to have affected the subjects' performances. Futhermore, there was no significant difference in performance between subjects. The interaction between subjects and days was significant at .05 level of confidence. This indicated a subject's performance varied from day to day with little similarity between subjects.

Table 4

The Analysis of Variance of the Force Amplitudes Under Four Treatment Conditions

Source	SS	df	MS	F
Total	2885.43	63		
Treatments	31.43	3	10.48	0.362
Order	43.47	3	14.49	0.500
Days within Subjects	1589.65	15	105.98	3.654*
- Subjects	124.38	3	41.46	1.430
Residual	1220.88	42	29.01	

*Significant at the .05 level of confidence

Cell entries used in the ANOVA are listed in Appendix E.

8. The length of forward reach and various knee angles at the catch were related (see Table 1). The more flexible subjects, S2 and S4, had similar patterns. Their forward reach did not change at the

two most compressed knee angles but their ability to reach forward was decreased by 5 cm under the P + 10° condition, and by an additional 2.5 cm at P + 20° angle. The forward reach of the other two subjects was shortened by 2.5 cm at P + 20° angle. The forward reach of the other two subjects was shortened by 2.5 to 5 cm whenever the knee angle increased by 10°. This indicates that the stroke length forward is determined partly by the angle of the knee that is attained in the stroke.

Chapter 5

DISCUSSION

Variability and inconsistency were the two most distinctive characteristics of the subjects' performances. It is possible that the testing equipment and the nature of movements in testing could have caused these excessive fluctuations.

According to the subjects, the testing action immediately prior to the force phase (the spring-assisted lowering of the weight to floor) and the force phase itself simulated quite well the rowing action at similar stages. But they felt that the force phase in testing did require a little more speed. The arm action differed somewhat from that of sculling, because the arm abduction, that is peculiar to sculling, did not take place. However, the subjects, who soon familiarized themselves with the movements required for testing, felt comfortable and did not think that the difference in the arm action could have affected their performance. Their principal expressed concern was with the steady pull on the handle caused by the suspended weight during recovery. This was deemed to be rather uncomfortable and much different to that of rowing.

The uncontrolled rowing environment renders testing and research in this sport more difficult. Wind and water conditions, balance, speed of the rowing shell, and blade depth change continuously and rarely can be effectively controlled. All these factors may affect an oarsman's performance, that is, the magnitude of force that he can exert on the oar. Numerous uncontrollable conditions in a real rowing situation may justify and favour the equipment used in this study as a more objective testing environment. The subjects' positions on the testing equipment were similar to those used in a racing shell. The adequacy of their body movements in the testing situation was continuously controlled by the tester and, at the same time, evaluated by testing instruments (horns, dynograph signals). The work load remained constant for each trial. Furthermore, the testing environment was closely controlled to eliminate distractions as much as possible. One would expect the fluctuations in performance in such a controlled environment to be much smaller than those which would be displayed in the real rowing situation.

The subjects appeared to this investigator to have concentrated prior to each set, and to have exerted a maximum controlled effort on each trial. However, as Figures 6 to 9 demonstrate, none of them seemed to have succeeded in minimizing the variability in their performance. Most frequently, the magnitude of forces in successive trials changed in either direction. Although there were ten sets of trials with limited variances it seemed that large variances in performance were more characteristic of the subjects.

Ishiko (1971) and Schneider, Angst, and Brandt (1977) analyzed forces exerted on the oar in a rowing action. Both researchers referred to force-time patterns as being peculiar for each individual. According to Ishiko, "no particular national or international difference in the characteristics of the force-time curves can be observed." Schneider et al. stated, "that force curves may only be discussed intra-individually and that parameters for style exist but differ from oarsman to oarsman." The results of this study support these interpretations and further highlight that between days an individual's performance will vary.

The force-time curves in Ishiko's study demonstrated variability in force-time patterns within an individual. The muscular forces exerted on the oar were within a range of 80 to 100 kg. However, it is not clear as to whether this range referred to the variability of forces within one individual, or to the maximal forces of all the subjects involved in the study. His subjects were top international oarsmen and one might have expected the variability in their performances to have been smaller. On the other hand, some of Schneider et al.'s subjects were youth oarsmen, who possibly would not yet have perfected their rowing movements. Considerable variability in their performances would be expected. Neither Schneider nor Ishiko discussed the fluctuations in the performance of their subjects. This now appears to be an important variable which has attracted little attention in research on the sport of rowing itself.

The aim of this study was to measure the effect of knee angle variations at the catch on the magnitude of exerted forces. Changing the knee angles did not affect the subjects' performances in any predictable manner. The scores that were achieved at an angle in one testing session could not be replicated in other sessions. The fluctuations in the magnitude of the exerted forces of those was high in all subjects. Thus, the knee angle at the catch may not affect an oarsman's performance as much as is commonly believed. The knee angle at the catch and forward reach were related, but the relationship differed with each subject. In light of the results of this study, this aspect of rowing technique should most probably be considered individually. That is, the knee angle which feels the most comfortable and its effect on forward reach should be considered for each athlete.

Since the original intent of this study was to decide which of the Adam and East German styles was better, the above finding does not shed any light on deciding a preference. Although the styles differ in both knee angles and body positions at the catch, these differences have no predictable outcome on the magnitude of the forces created. Therefore, one style cannot be recommended over another.

The synchronization of movements of members of rowing crews is considered to be an important aspect of coaching rowing. It is commonly proposed that all crew members move their legs, bodies and arms in unison. This importance could be overestimated. According to Ishiko (1971) a uniformity of blade and body movements does not ensure a uniformity of force-time patterns. Similarly, a uniformity of body-leg positions would not cause a maximization of the forces exerted. Coaches are thus faced with a difficulty. From a theoretical viewpoint what needs to be achieved is a synchronization of the peak forces and the entire force-time patterns. This implication serves as recognition for the need of sophisticated measurement devices to determine the force-time patterns of crew members. Thus, the common coaching effort involved in changing oarsmen's styles is most probably, in vain.

The crews that are to represent Canada at major international regattas are frequently determined by a single trial race. If the within subjects day-to- day fluctuations in the magnitude of exerted forces that were demonstrated in this study are considered, then the reliability of a single race for team selection ought to be questioned. The results of one day's testing may not represent the real abilities of all crews involved in the trial. Therefore, trials consisting of a number of performances on different days may prove to be a more reliable method for selecting the best national crews. Certainly, they would indicate performance consistencies.

Variability in force magnitudes was the most distinctive characteristic in the performance of all this study's subjects. It was interesting to note, that fluctuations at the preferred knee angle were just as great as at the other knee angles. The subjects replicated trials at this position the most frequently, and one would have expected the variability of the baseline condition to decrease somewhat because of a practice effect. However, this did not occur. It would appear that the force exerted on an oar will vary considerably from stroke to stroke even in elite athletes.

There are various factors in this study that could have caused extensive fluctuations in the performances demonstrated. Testing equipment might be one. The suspended weight caused the recovery phase to be uncomfortable and may have distracted the subjects in their preparation for each catch. Arm movements were different. On this equipment the arm pull was inhibited. Also the action during the force phase was considered to be somewhat faster than the action of the drive phase in rowing. The subjects would have preferred a greater resistance during the testing force phase, but this would have made the recovery too uncomfortable and difficult. This smaller resistance may have created a reduced resistance but it allowed faster movements. The results of this study may support this assertion. The highest registered forces reached values of around 65 kg, which are by 15 to 35 kg less than those recorded on the oars and reported by Ishiko. One was led to believe that it was the subjects' speed, rather than their strength, that affected the magnitudes of exerted forces in the testing situation. S4's results may give good reason for this assumption. Of all the subjects, he was physically the weakest, but his performance in testing Session 4 (Figure 9) was the highest recorded during the study. A rowing ergometer with precise speed and work-load control should be used in any possible future studies. The possibility of it better simulating the rowing environment may facilitate more stability in performance.

Performance in testing involved the simultaneous action of knee, hip, and trunk extensors. Clarke (1950) measured the isometric strength of knee and hip extensors through the whole range of joint movements. His subjects exerted with their knee extensors an average force of 110 pounds at knee angles from 40° to 60°. The power of the hip extensors was the greatest when the hip was fully flexed. The average pull of the subjects tested was 180 pounds. These results may not be relevant for the dynamic action in rowing and its peculiar body position at the catch. Nevertheless, in this study the action of the strong hip and trunk extensors may have obscured any differences in the treatments that were applied. A future study should include strength as a relevant associated measure. Information about knee, hip, and trunk extension strength at the catch position may further contribute to understanding of the rowing action.

Changes in the dependent variable should also be considered for future investigations. The effect of knee angles on force magnitude might be observed more easily at earlier stages of the drive, that is, before maximal force is achieved. Another possibility might be to determine the relation between the knee angle and the time that elapses from the beginning of pull to the moment of peak force.

The laboratory testing environment as well as the action in testing, will always differ from the real situation in rowing shell. These two factors may have contributed to the subjects' inability to stabilize their performances. In the intra-subject replication research design, the baseline must be stabilized prior to the commencement of testing. The effect of an experimental condition cannot be demonstrated unless the baseline scores are replicated. Preliminary baseline trials are necessary and must be repeated until the performance stability is achieved. In this circumstance a greater number of trials would have produced undue fatigue which would adversely affect performance. In the future a researcher may wish to experiment with the experimental design. For example, the number of test sessions and the number of sets at each knee angle could be increased and the number of trials within each series pre-set. The warm-up as well as the rest between sets could also be lengthened and standardized for all subjects.

The subjects in this investigation were usually tested following their day's work. Hence, fatigue may have contributed to the fluctuations in performance. A future study should consider, if possible, testing in the morning. It may be necessary to control other factors, such as sleep, motivation, and the resistance in the pull, if the true effects of the treatments are to be fully evaluated.

Finally, elite subjects in training, who have already perfected their rowing movements, should be used in a similar investigation. Less variability in their performances and more stable baselines would be expected.

The effect of various knee angles at the catch on the exerted force magnitudes in rowing may not be as great as it is generally believed. All the common assumptions concerning this aspect of the rowing technique might be too presumptuous. This study has failed to clarify the existing controversy of the preference between two styles of rowing. Future studies should include suggested modifications in the design and investigation of this topic. Perhaps they could contribute to a better understanding of the action in rowing.

Chapter 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

This thesis studied in isolation the relationship between various leg and body movements in the rowing action and forces created on the oar handle. The subjects were four national ranked oarsmen from the Thunder Bay Rowing Club.

Each subject had two preliminary testing sessions to become familiar with testing equipment, testing procedure, and the action in testing. A modified pool rowing trainer was used to simulate the action in rowing. The independent variables were four different knee angles at the catch with hip flexion maximized in each position. The dependent variable was the maximal force that the subject exerted on each trial.

An intra-subject ABAB experimental design was used in this study. Four random orders of the three experimental conditions were determined. Each subject was tested with all four testing orders. Since no obvious effect of the experimental conditions could be discerned, an analysis of variance was used to determine whether a significant difference in force magnitudes at different knee angles existed. The baseline conditions and only two experimental conditions for the four subjects were included in the analysis. No significant difference between treatments was evident nor was there a difference in performance between subjects. The interaction between subjects and days was significant. This indicated a subject's performance varied from day to day with little similarity between subjects.

Conclusions

It has been a popular belief, that the leg and body position at the catch may affect the ability of oarsmen to create forces on the oar handle. This study revealed that there was no significant difference in the magnitude of forces exerted between the four treatments. Excessive variability in force magnitudes was the most distinctive characteristic in the performance of all subjects. Average scores achieved under one experimental condition on one day could not be replicated on another day. Variability in successive trials was marked.

The lack of a difference in performance between the four treatment conditions may have been caused by the nonspecific experimental environment and the simulated action involved in the testing. In addition, the subjects may not have yet perfected their movements which may be necessary to achieve stable performances.

Recommendations

1. A rowing ergometer with precise speed and work-load control should be used in future research to better simulate the action in rowing.

2. A stable baseline must be achieved before the commencement of each testing condition.

3. Subjects' strength at various body positions that are peculiar to rowing should be measured.

4. The subjects in future studies should be elite oarsmen.

A replication of this thesis implementing these suggestions may clarify the effect that various knee angles at the catch have on the exerted forces in rowing.

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APPENDIX A

Sixteen Tables, One for Each Testing Day, Showing the Forces Exerted on Each Trial and the Representative Average Forces for Each Treatment Condition. Forces are Expressed in Kilograms

Subject 1, Day 1

TREATMENT			
P_1	$P - 10^\circ$	P_2	$P + 10^\circ$
37.3	38.9	42.8	46.1*
42.1	39.7	46.9*	40.5
38.1	43.6*	47.8*	41.3
44.4	46.1	46.1*	36.6
35.0	46.1	52.1	44.4*
46.1*	43.6*	47.8*	52.9
46.1*	42.8*	50.3	51.2
48.6*	41.3*	47.8*	47.8
48.6*	39.7	43.6	43.6*
45.2*	42.1*	52.1	47.8
46.1*	42.8*	47.8*	53.8
48.6*	45.2	46.1*	43.6*
47.0[1]▲	42.7[3]	44.4	46.1*
		47.2[3]	38.9
			40.5
			44.8[3]

* Representative trials

▲ Numbers denote the method that was used for choosing the representative trials (see page 23)

Subject 1, Day 2

TREATMENT			
P_1	$P - 10^{\circ}$	P_2	$P + 10^{\circ}$
49.5	45.2	56.6	46.1
52.9*	52.9	55.5*	54.6
55.5	52.1	59.9	48.6
46.9	46.9	47.8	51.2
52.1*	49.5*	59.9	53.8
49.5*	49.5*	51.2	51.2
55.5	51.2*	50.3	49.5
46.1	52.1*	48.6	46.1
49.5*	51.2*	53.8*	46.9
47.8	50.7[1]	57.7	55.5
51.2*		56.6*	46.9
53.8*		52.9*	51.2*
57.7		56.6*	52.9*
54.6		55.5*	49.2*
51.2*		55.2[3]	51.2*
49.5*			51.2*
50.3*			50.3*
49.5*			51.0[1]
51.0[3] ▲			

* Representative trials

▲ Numbers denote the method that was used for choosing the representative trials (see page 23)

Subject 1, Day 3

TREATMENT			
P_1	$P - 10^{\circ}$	P_2	$P + 10^{\circ}$
40.5*	44.4*	54.6	42.8
38.1	43.6*	59.9	46.1
44.4*	42.8*	62.1	47.8
31.2	38.9	62.1	45.2
46.9	46.1	55.5	46.9
37.3	35.8	56.6	47.8
40.5*	35.0	61.0*	45.2
39.7	38.9	58.8*	47.8
35.8	43.6*	57.7*	42.8
31.9	40.5	62.1*	48.6
41.3*	41.3	62.1*	41.3
34.2	47.8	62.1*	45.2*
41.3*	45.2*	63.2	45.2*
46.1	47.8	60.6[1]	45.2*
51.2	50.3		46.9*
48.6	45.2*		46.1*
44.4*	46.1*		45.7[1]
52.9	49.5		
49.5	49.5		
50.3	44.4[3]		
42.1[3]▲			

* Representative trials

▲ Numbers denote the method that was used for choosing the representative trials (see page 23)

Subject 1, Day 4

TREATMENT			
P_1	P - 10°	P_2	P + 10°
39.7*	40.5*	46.9*	42.1
34.2	38.1*	44.4*	31.2
42.8	29.6	45.2*	46.1*
41.3*	38.1*	40.5	46.1*
36.6	32.7	42.1	45.2*
43.6	35.8	46.1*	46.1*
35.8	41.3	39.7	35.8
38.9	30.4	46.9	45.2*
44.4	42.1	48.6	38.1
39.7*	38.1*	46.1	50.3
37.3	41.3	45.2*	49.5
44.4	36.6*	45.6[3]	45.2*
42.8	42.1		42.1*
43.6	34.2		42.8*
41.3*	31.2		46.1*
38.1	34.2		48.6
40.5*	37.0[3]		46.1*
37.3			49.5
41.3*			45.1[3]
42.5*			
40.9[3]▲			

* Representative trials

▲Numbers denote the method that was used for choosing the representative trials (see page 23)

Subject 2, Day 1

TREATMENT					
P_1	P + 10°	P_2	P + 20°	P_3	P - 10°
57.7	52.9	42.8*	61.0*	38.1	52.1
58.8	54.6	39.7	65.4	37.3	52.9
54.6	49.5*	41.3*	64.3*	40.5*	44.4
58.8	43.6	38.1	65.4*	46.9	48.6*
51.2*	46.1	33.5	62.1*	43.6*	46.9*
52.9*	48.6*	42.8*	65.4*	44.4	44.4
53.8*	50.3*	39.7	64.3*	39.7	50.3
52.9*	52.1*	44.4	61.0*	42.1*	48.6
52.1*	48.6*	42.1*	62.1*	43.6*	45.2
	46.9	42.1*	62.1*	40.5*	50.3*
	47.8*	39.7*	64.3*	31.9	47.8*
	52.1	44.4		48.6	
	50.3*	47.8		43.6*	
	50.3*	43.6*		46.1	
		44.4		37.3	
		41.3*		46.1	
		43.6*			
		40.5*			
52.6[1]▲	49.9[3]	42.0[3]	63.4[1]	42.3[3]	48.4[3]

* Representative trials

▲ Numbers denote the method that was used for choosing the representative trials (see page 23)

Subject 2, Day 2

TREATMENT					
P_1	$P + 20^\circ$	P_2	$P + 10^\circ$	P_3	$P - 10^\circ$
47.8*	48.6*	51.2*	48.6	40.5*	44.4
49.5*	48.6*	52.1*	57.7*	39.7	44.4
50.3*	48.6*	50.3*	52.1	42.1*	50.3
47.8*	44.4	53.8*	55.5*	29.0	42.1
51.2*	50.3*	47.8	57.7*	39.7	47.8
51.2*	53.8	55.5	53.8*	48.6	46.9
47.8*	47,8*	52.1[3]	57.7*	38.1	37.3
49.4[1]▲	54.6		59.9	39.7	42.8
	46.9		52.9*	44.4*	40.5
	51.2*		55.5*	46.1	48.6*
	51.2*		58.8	44.4*	49.5*
	48.6*		57.7*	30.5	49.5*
	49.4[3]		52.9*	50.3	47.8*
			56.6*	45.2	47.8*
			52.9*	38.1	48.6[1]
			58.8	49.5	
			52.9	45.2	
			55.5[3]	46.9	
				42.9[3]	

* Representative trials

▲ Numbers denote the method that was used for choosing the representative trials (see page 23)

Subject 2, Day 3

TREATMENT					
P_1	P - 10°	P_2	P + 20°	P_3	P + 10°
45.2	42.1	50.3	46.9*	35.8*	46.9*
38.1	39.7	46.9	46.1*	37.3*	48.6*
45.2*	38.9	40.5	52.1	36.6*	42.8
45.2*	44.4	48.6	52.9	35.0*	43.6
48.6*	42.8	46.9	56.6	34.2*	42.8
44.4*	38.9	45.2	46.9*	35.8*	53.8
46.9*	38.1	46.9	44.4	34.2*	46.1*
46.9*	38.1	46.9	54.6	34.2*	52.1
48.6*	39.7	42.1	43.6	35.0*	53.8
46.5[1]	46.1*	42.8	45.2	35.3[1]	54.6
	42.8*	47.8*	45.2		45.2*
	42.1*	46.9*	52.1		45.2
	45.2*	46.9*	50.3		42.8
	43.6*	46.1*	42.1		39.7
	43.6*	46.9*	54.6		51.2
	43.9[1]▲	46.9[1]	41.3		47.8*
			48.6*		49.5*
			42.8		42.8
			50.3		56.6
			43.6		50.3*
			47.1[3]		55.5
					41.8[3]

* Representative trials

▲ Numbers denote the method that was used for choosing the representative trials (see page 23)

Subject 2, Day 4

TREATMENT					
P_1	P + 10°	P_2	P - 10°	P_3	P + 20°
52.9	43.6	36.6	44.4*	53.8*	41.3
51.2	42.1*	33.5	46.9*	53.8*	35.8*
42.8	50.3	42.1	44.4*	52.9*	34.2*
52.1	45.2*	38.9	43.6*	46.9*	42.1
45.2	45.2*	37.3	43.6*	51.2*	42.1
55.5	46.2*	35.0	40.5	52.1*	44.4
47.8	46.9	42.1*	43.6	52.1*	37.3*
54.6	42.8*	42.1*	39.7	51.2*	31.2
57.7	37.3	42.1*	35.0	52.1*	42.1
50.3	45.2*	42.1*	46.1	54.6*	38.1*
58.8	47.8	38.1*	45.2	52.1^{2}	35.8*
57.7	45.2*	43.6*	45.2		34.2*
53.8*	38.9	43.6*	48.6		33.5
54.6*	44.4*	42.8*	43.6		36.6*
52.1*	44.4*	42.1^{2}	45.2		35.0*
50.3*	44.5^{3}		44.4		32.7
50.3*			46.1		33.5
51.2*			44.6^{1}		38.1*
52.9*					33.5
53.8*					36.1^{3}
49.5					
54.6					
$52.4^{1\blacktriangle}$					

* Representative trials

▲ Numbers denote the method that was used for choosing the representative trials (see page 23)

Subject 3. Day 1

TREATMENT			
P_1	P - 10°	P_2	P + 10°
47.8*	43.6	40.5*	48.6*
46.9*	37.3	38.1	50.3*
53.8	39.7*	37.3	51.2*
50.3*	40.5*	42.8*	51.2*
50.3*	39.7*	47.8	54.6
58.8	46.1	46.1	46.1
50.3	32.0	42.8*	50.3*
43.6	42.1*	40.5*	52.1*
48.6*	42.8	37.3	52.9*
43.6	38.9*	48.6	50.9[3]
45.2	35.8	43.6*	
40.5	34.2	34.2	
48.6*	42.1*	42.8*	
55.5	42.8	42.8*	
51.2	42.8*	39.7	
45.2	40.5*	46.9	
46.9*	40.8[3]	44.4	
48.5[3]▲		41.3*	
		42.1[3]	

* Representative trials

▲ Numbers denote the method that was used for choosing the representative trials (see page 23)

Subject 3, Day 2

TREATMENT			
P_1	$P - 10^\circ$	P_2	$P + 10^\circ$
53.8	66.5*	46.1	38.9
51.2	65.4*	43.6	34.2
49.5	61.0*	44.4	35.8
61.0	59.9*	48.6	42.8*
58.8	63.2*	42.8	36.6
56.6	66.5*	44.4	42.1*
61.0	67.6*	50.3*	53.8
52.1	65.4*	52.1*	56.6
48.6	64.3*	48.6*	36.6
54.6	64.4[2]	51.2*	38.9
56.6		50.3*	52.9
47.8		50.3*	50.3
56.6		52.9*	46.9
55.5		50.8[2]	46.1*
49.5			53.8
46.1			52.9
57.7			53.8
52.1*			41.3
51.2*			39.7
53.8*			43.7[3]
51.2*			
52.1*			
52.1[1▲]			

* Representative trials

▲ Numbers denote the method that was used for choosing the representative trials (see page 23)

Subject 3, Day 3

TREATMENT			
P_1	$P - 10^{\circ}$	P_2	$P + 10^{\circ}$
39.7*	46.1	42.8	42.8*
43.6	31.2	38.9*	35.0
40.5*	38.1*	38.1*	38.9
43.6	38.9*	33.5	38.1
41.3*	44.4	39.7*	41.3*
40.5*	40.5	42.1	44.4
34.2	41.3	39.7*	46.9
35.0	34.2	38.8*	39.7*
42.1*	34.2	38.1*	44.4
38.9*	39.7*	42.1	43.6
44.4	33.5	37.3*	37.3
39.7*	38.9*	38.1*	41.3*
35.0	36.6*	38.9*	42.1*
41.3*	35.8*	32.7	49.5
36.6	42.8	37.3*	36.6
42.8	38.9*	35.0	47.8
38.1	35.8	46.1	42.1*
43.6	34.2	37.3*	43.6
	38.1*	37.3*	36.6
	42.8	38.8*	32.0
	42.1	31.2	40.5*
	33.5	36.6*	
40.5[3▲]	38.1[3]	38.2[3]	41.4[3]

* Representative trials

▲ Numbers denote the method that was used for choosing the representative trials (see page 23)

Subject 3, Day 4

TREATMENT			
P_1	$P - 10^{\circ}$	P_2	$P + 10^{\circ}$
48.6*	38.1	31.2	46.1
46.9*	35.8	33.5	50.3*
47.8*	40.5*	29.0	52.9
50.3*	43.6	36.6*	47.8*
46.9*	39.7*	33.5	49.5*
47.8*	38.1	32.0	47.8*
45.2	51.2	34.2*	49.5*
46.9	34.2	36.6*	49.0[3]
50.3	50.3	40.5	
46.1	37.3	34.2*	
45.2	39.7*	35.0*	
47.8	46.1	43.6	
48.6	48.6	38.1	
48.1[1]▲	40.5*	43.6	
	47.8	42.1	
	42.8*	32.7	
	46.9	35.8*	
	40.5*	39.7	
	29.7	32.0	
	39.7*	45.2	
	50.3	35.4[3]	
	39.7*		
	37.3		
	40.5*		
	38.1		
	40.4[3]		

* Representative trials

▲ Numbers denote the method that was used for choosing the representative trials (see page 23)

Subject 4, Day 1

	TREATMENT				
P_1	P - 10°	P_2	P + 20°	P_3	P + 10°
53.8	50.3	45.2	45.2*	52.1	53.8
58.8	46.9	42.8	46.1*	52.1	54.6
58.8	47.8	38.1*	49.5	48.6	47.8
52.1	37.3*	35.8*	43.6*	57.7*	52.9*
47.8	36.6*	35.8*	53.8	53.8*	57.7*
50.3	38.1*	36.6*	46.9*	55.5*	57.7*
43.6	40.5*	35.8*	52.1	56.6*	53.8*
47.8	38.1*	38.9*	47.8	56.6*	57.7*
46.9	39.7*	38.1*	43.6*	52.1	55.5*
46.1	40.5		41.3		53.8*
45.2	37.3		47.8		55.5*
	36.6*		42.1		52.9*
			41.3		53.8
			42.1		
			42.1		
48.6[3] ▲	38.3[1]	37.0[1]	45.1[3]	56.0[1]	55.1[1]

* Representative trials

▲ Numbers denote the method that was used for choosing the representative trials (see page 23)

Subject 4, Day 2

TREATMENT					
P_1	$P + 10^\circ$	P_2	$P - 10^\circ$	P_3	$P + 20^\circ$
38.1*	36.6	39.7*	42.8	45.2	48.6
40.5*	35.0	42.1*	38.1	56.6	54.6
41.3*	35.8	38.1	45.2*	62.1	51.2*
46.9	36.6	38.9	45.2*	50.3*	48.6*
38.1*	35.8	38.9	42.8*	57.7	45.2
45.2	39.7*	41.3*	42.8*	52.9	50.3*
36.6	35.0	49.5	42.8*	50.3*	50.3*
34.2	36.6	45.2	43.8[1]	53.8	59.9
35.0	39.7*	39.7*		46.1	53.8*
36.6	39.7*	46.1		46.9*	46.9
35.8	39.7*	39.7*		49.5*	46.9
38.1*	35.8	38.9		52.1	53.8*
43.6	42.1*	42.8*		54.6	53.8*
42.1	45.2	37.3		49.5*	46.1
40.5*	42.8	38.1		45.2	52.9*
37.3*	39.7*	39.7*		49.5*	47.8
44.4	41.3*	40.5*		57.7	55.5
39.7*	42.1*	42.8*		45.2	55.5
38.1*	41.3*	45.2		52.1	55.5
38.1*	43.6	45.2		46.1	55.5
37.3*	42.1*	42.1*		47.8*	52.1*
39.7*	45.2	42.8*		40.5	51.9[3]
38.9[3]▲	44.4	51.2		43.6	
	47.8	39.7*		44.4	
	43.6	38.9*		42.8	
	42.8	41.3*		44.4	
	40.7[3]	40.9[3]		46.9*	
				48.8[3]	

* Representative trials

▲ Numbers denote the method that was used for choosing the representative trials (see page 23)

Subject 4, Day 3

TREATMENT					
P_1	P + 10°	P_2	P + 20°	P_3	P - 10°
42.8*	46.9	38.1*	44.4	35.8	39.7
49.5	55.5	41.3*	39.7*	37.3*	45.2
38.1	46.1	38.1*	39.7*	36.6	58.8
42.1*	56.6	44.4	38.1*	47.8	56.6
46.1	55.5	37.3*	41.3*	35.0	45.2
43.6*	56.6	39.7*	38.9*	37.3*	42.8*
38.9	52.9*	35.0	42.8*	41.3	43.6*
40.5*	56.6	36.6	42.8*	42.1	45.2
39.7*	52.9*	43.6	39.7*	44.4	38.9
40.5*	62.1	50.3	41.3*	39.7*	42.1*
39.7*	58.8	36.6	46.9	39.7*	42.1*
44.4	52.1*	39.7*	41.3	33.5	44.4
42.1*	47.8	44.4	38.9	34.2	38.1
42.8*	55.5	38.1*	49.5	38.9*	44.4
41.3	47.8	38.1*	44.4	39.7*	36.6
46.9	43.6	39.7*	45.2	35.0	35.0
42.1*	47.8	38.1*	44.4	43.6	33.5
43.6*	49.5*	36.6	42.8	43.6	39.7*
38.1	50.3*	38.8[3]	38.9	39.7*	40.5*
47.8	53.8*		39.7	36.6*	37.3
38.9	51.2*		42.1	42.1	39.7*
38.1	39.5		40.5	38.9*	39.7
38.9	56.6		40.4[1]	38.6[3]	41.5[3]
41.7[3]▲	52.9*				
	46.1				
	46.9				
	47.8				
	53.8*				
	52.2[3]				

* Representative trials

▲ Numbers denote the method that was used for choosing the representative trials (see page 23)

Subject 4, Day 4

TREATMENT					
P_1	P + 20°	P_2	P + 10°	P_3	P - 10°
50.3*	49.5	49.5	61.0	54.6*	58.8
54.6	48.6	48.6	53.8	54.6*	64.3*
52.1*	54.6	45.2	61.0	56.6*	63.2*
52.9*	49.5	49.5	58.8*	57.7*	64.3*
54.6	48.6	46.9	63.2	59.9*	65.4*
46.9	54.6	62.1	61.0	58.8*	62.1*
53.8*	48.6	57.7	52.9	59.9*	65.4*
51.2*	56.6	56.6	56.6*	57.7*	65.4*
50.3*	51.2*	56.6	54.6	57.7*	64.3^{1}
49.5*	52.1*	55.5	63.2	57.7*	
50.3*	49.5*	58.8	52.9	55.5*	
49.5	50.3*	62.1	53.8	57.6^{1}	
$51.3^{3\blacktriangle}$	52.9*	49.5	57.7*		
	52.9*	59.9*	53.8		
	54.6*	65.4*	61.0		
	54.6*	59.9*	58.8*		
	50.3*	62.1*	55.5*		
	52.0^{1}	64.3*	58.8*		
		64.3*	56.6*		
		63.2*	57.5^{3}		
		61.0*			
		63.2*			
		62.6^{1}			

* Representative trials

▲ Numbers denote the method that was used for choosing the representative trials (see page 23)

APPENDIX B

Calibration of Experimental Instruments

Known weights were suspended on the cable to calibrate the dynamometer. The handle was secured to a special frame at the pulley's height. Thus, pull on the dynamometer was exerted in a horizontal direction. The reliability within the working range was 89 to 93% (see table on the following page). Occasionally, the load cell was recalibrated during the testing.

The consistency of the Dynograph was checked by comparing several calibration recordings with the corresponding dynamometer units that were displayed on the Digital Strain Indicator. (See the following table).

Calibration of the Beckman RS Dynograph

Calibration Number	Load Cell Units (in./in.)	Dynograph Deflection (mm)
2	99	51.1
3	97	49.5
1	110	58.5
3	110	56.0
1	141	70.0
3	140	70.5
2	150	78.0
3	150	75.0

APPENDIX B (cont.)

Three Calibrations of the Load Cell Expressed in the Load Cell Units (μ inches/inch) and Dynograph Deflections

Force[a] (kg)	Load Cell Units in Calibration			Average Load Cell Units	Reliability of the Load Cell[d]	Average Dynograph Deflection
	1	2	3			
23.7*	63	56	64	61	88	31*
26.3	70	63	71	68	89	34
28.8	76	70	79	75	89	37
31.4	84	67	86	81	90	40
33.7	90	83	93	88	89	44
35.0*	90	87	97	91	90	46*
37.7	96	93	104	97	89	49
40.1	103	99	110	104	90	52
42.7	110	106	116	110	91	55
45.2*	117	112	122	117	92	59*
47.8	123	118	128	123	92	62
50.4	130	124	134	129	93	65
52.9	136	130	140	135	93	68
55.5*	141	134	145	140	92	71*
58.0	146	138	150	145	92	74
60.3	152	145	157	150	92	76
62.8	158	150	163	156	91	78
65.4*	164	155	167	162	92	80*

[a]All but two weight increments were 2.56 kg

[b]Weight increment of 1.3 kg

[c]Weight increment of 2.36 kg

[d]Reliability of the load cell was computed by the formula:

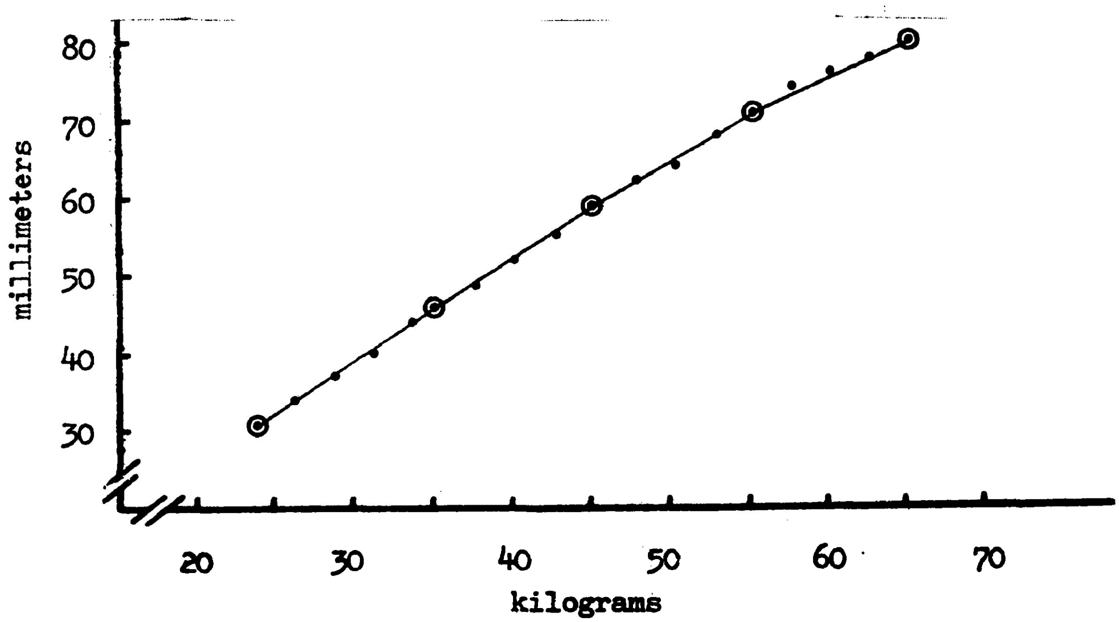
$$\frac{\text{the smallest number of load cell units at one weight}}{\text{the largest number of load cell units at the same weight}} \times 100 = \%\ \text{agreement}$$

* Upper and lower limits of the four sections in the load cell's working range (data from Appendix B)

APPENDIX C

Conversion Table

At calibration loads below 35 kg, a weight increase of 2.56 kg resulted in an average increase of seven load cell units. The corresponding average dynograph deflection increased by 3 mm. At calibration loads above 55 kg, the same weight increment caused a change of only five to six load cell units and dynograph deflections of merely 2 mm (see table in Appendix B). This load cell's uneven sensitivity produced a curvelinear relationship between the forces (suspended weights) and the corresponding dynograph deflections. To minimize the error caused by this relationship, it was necessary to divide the load cell's total working range into four sections. Within these sections the relationship between the two scales was considered to be linear (see the following figure).



O = Upper and lower limits of the four sections in the load cell's working range

The Curvelinear Relationship Between the Dynograph Deflections (mm) and the Corresponding Forces (kg). Straight Lines Represent the Computed Linear Relationship Between the Two Scales Within the Four Sections

The average forces that correspond to the dynograph deflections within each section were computed by the formula:

$$\frac{\text{weight at section's upper limit} - \text{weight at section's lower limit}}{\text{dynograph deflection at section's upper limit} - \text{dynograph deflection at section's lower limit}} = \text{average force per one millimeter (kg/mm)}$$

A conversion table was then tabulated for converting the dynograph deflections into kilograms (see the following table).

The Force Conversion Table to Convert Dynograph Deflections to Kilograms

FORCE		FORCE		FORCE	
mm	kg	mm	kg	mm	kg
31*	23.7*	48	36.6	65	50.3
32	24.6	49	37.3	66	51.2
33	25.2	50	38.1	67	52.1
34	26.0	51	38.9	68	52.9
35	26.7	52	39.7	69	53.8
36	27.5	53	40.5	70	54.6
37	28.2	54	41.3	71*	55.5*
38	29.0	55	42.1	72	56.6
39	29.7	56	42.8	73	57.7
40	30.5	57	43.6	74	58.8
41	31.2	58	44.4	75	59.9
42	32.0	59*	45.2*	76	61.0
43	32.7	60	46.1	77	62.1
44	33.5	61	46.9	78	63.2
45	34.2	62	47.8	79	64.3
46*	35.0*	63	48.6	80*	65.4*
47	35.8	64	49.5	81	66.5
				82	67.6

*Upper and lower limits of the four sections in the load cell's working range (data from Appendix B)

APPENDIX D

Testing Order

Four permutations (one for each testing session) of the numbers 1, 2, and 3 were randomly selected to determine the testing order for the three experimental conditions. For the first session, the subjects were randomly asigned to one of the testing orders. For the following sessions, they were rotated according to the one-step cyclic permutations. That is, the subject tested at the first testing order moved to the extreme bottom (fourth testing order), simultaneously moving all other subjects one position higher. Thus, each subject was tested with all four testing orders. See the following table.

Assignment of the Subjects to the Four Testing Orders

Order						Day			
						1	2	3	4
P_1	$P + 10^o$	P_2	$P - 10^o$	P_3	$P + 20^o$	S1	S4	S3	S2
P_1	$P - 10^o$	P_2	$P + 20^o$	P_3	$P + 10^o$	S4	S3	S2	S1
P_1	$P + 20^o$	P_2	$P + 10^o$	P_3	$P - 10^o$	S3	S2	S1	S4
P_1	$P + 10^o$	P_2	$P + 20^o$	P_3	$P - 10^o$	S2	S1	S4	S3

APPENDIX E

Cell Entries Used in the Analysis of Variance

		TREATMENT			
		P_1	$P - 10^{\circ}$	P_2	$P + 10^{\circ}$
Subject 1	Day 1	47.0[1*]	42.7[4]	47.2[3]	44.8[2]
	2	51.0[1]	51.0[4]	55.2[3]	50.7[2]
	3	42.1[1]	45.7[2]	60.6[3]	44.4[4]
	4	40.9[1]	37.0[2]	45.6[3]	45.1[4]
2	1	52.6[1]	48.4[2]	42.0[3]	40.9[4]
	2	49.4[1]	48.6[2]	52.1[3]	55.5[4]
	3	46.5[1]	43.9[4]	46.9[3]	47.8[2]
	4	52.4[1]	44.6[2]	42.1[3]	44.5[4]
3	1	48.5[1]	50.9[2]	42.1[3]	40.8[4]
	2	52.1[1]	64.4[2]	50.8[3]	43.7[4]
	3	40.5[1]	38.1[4]	38.2[3]	41.4[2]
	4	48.1[1]	49.0[4]	35.4[3]	40.4[2]
4	1	48.6[1]	38.3[2]	37.0[3]	55.1[4]
	2	38.9[1]	43.8[4]	40.9[3]	40.7[2]
	3	41.7[1]	41.5[2]	38.8[3]	52.2[4]
	4	51.3[1]	64.3[2]	62.6[3]	57.5[4]

*Numbers denote the order of presentation of the experimental conditions

P_1, P_2 = preferred knee angle

$P - 10^{\circ}$ = preferred knee angle decreased by 10°

$P + 10^{\circ}$ = preferred knee angle increased by 10°