The Determination' of a Strength Gain of the Quadriceps and Hamstrings from Recreational Cross-Country Skiing

Cheryl A. Hofman
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THE DETERMINATION OF A STRENGTH GAIN OF THE QUADRICEPS AND HAMSTRINGS FROM RECREATIONAL CROSS-COUNTRY SKIING.

by

Cheryl A. Hofman

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THE DETERMINATION OF A STRENGTH GAIN OF THE QUADRICEPS AND HAMSTRINGS FROM RECREATIONAL CROSS-COUNTRY SKIING

Cheryl A. Hofman, M.A.

Western Michigan University, 1983

The purpose of this study was to determine a strength gain of the quadriceps and hamstrings due to recreational cross-country skiing. Eleven subjects, four male and seven female, from two selected, beginning cross-country ski classes at Western Michigan University participated. For both the pretest and posttest, each subject performed five maximal, reciprocal contractions of the dominant and nondominant knee flexors and extensors. The data were collected on a Cybex II Dual Channel Dynamometer and Instrumentation System, #7104. Two Analyses of Variance, randomized block, factorial designs were used to analyze the dependent variable, torque, as it related to the independent variables of dominant and nondominant leg, pretest and posttest in the quadriceps and in the hamstrings. After skiing approximately 40 minutes per day, two days per week, for six weeks, the only significant result was that the participants experienced a significant increase in the strength of the dominant and nondominant hamstrings.
ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my thesis advisor, Dr. Mary Dawson. Her wealth of knowledge and unlimited guidance were invaluable during this study. Recognition of the other members of my advisory committee, Dr. Harold Ray and Dr. Roger Zabik, is also in order. I thank you, gentlemen.

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Lastly, I would like to thank the students for volunteering to participate in this study and for their dedication to its completion.

Cheryl A. Hofman
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# TABLE OF CONTENTS

ACKNOWLEDGEMENTS.............................................. ii
LIST OF TABLES............................................... v
LIST OF FIGURES.............................................. vi

Chapter

I. INTRODUCTION............................................ 1
   Statement of the Problem................................. 2
   Purpose of the Study....................................... 2
   Significance of the Study.................................. 2
   Delimitations of the Study................................. 3
   Limitations of the Study..................................
   Hypotheses................................................. 4
   Definition of Terms....................................... 5

II. REVIEW OF RELATED LITERATURE............................. 6
   Principles of Strength Development........................ 6
   Isotonic Resistance Training................................ 7
   Isokinetic Resistance Training............................... 11
   Cross-Country Skiing Related to Long Distance Running..... 15
   Training for Cross-Country Skiing........................... 19
   The Cybex II................................................ 21
   Summary of the Related Literature........................ 24

III. EXPERIMENTAL PROCEDURES................................ 27
   Subjects.................................................... 27
   Instrumentation............................................ 28

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<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procedures</td>
<td>28</td>
</tr>
<tr>
<td>Analysis of Data</td>
<td>29</td>
</tr>
<tr>
<td>IV. ANALYSIS AND INTERPRETATION OF DATA</td>
<td>31</td>
</tr>
<tr>
<td>Analysis of Torque Scores for the Quadriceps</td>
<td>31</td>
</tr>
<tr>
<td>Analysis of Torque Scores for the Hamstrings</td>
<td>34</td>
</tr>
<tr>
<td>Discussion</td>
<td>36</td>
</tr>
<tr>
<td>V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS</td>
<td>42</td>
</tr>
<tr>
<td>Summary</td>
<td>42</td>
</tr>
<tr>
<td>Conclusions</td>
<td>44</td>
</tr>
<tr>
<td>Recommendations</td>
<td>44</td>
</tr>
<tr>
<td>APPENDICES</td>
<td>46</td>
</tr>
<tr>
<td>Appendix A</td>
<td>47</td>
</tr>
<tr>
<td>Appendix B</td>
<td>48</td>
</tr>
<tr>
<td>Appendix C</td>
<td>49</td>
</tr>
<tr>
<td>BIBLIOGRAPHY</td>
<td>50</td>
</tr>
</tbody>
</table>
LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mean Peak Torque Values for the Quadriceps</td>
<td>32</td>
</tr>
<tr>
<td>2. ANOVA for the Quadriceps</td>
<td>33</td>
</tr>
<tr>
<td>3. Mean Peak Torque Values for the Hamstrings</td>
<td>34</td>
</tr>
<tr>
<td>4. ANOVA for the Hamstrings</td>
<td>35</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Posttest Peak Torque Curves for the Dominant and Non-dominant Hamstrings</td>
<td>39</td>
</tr>
<tr>
<td>2. Pretest and Posttest Peak Torque Curves for the Dominant Hamstrings</td>
<td>40</td>
</tr>
</tbody>
</table>
CHAPTER I
INTRODUCTION

Year-round fitness has become an obsession with people in the United States. Summertime conditioning is no problem due to the wide variety of recreational activities enjoyed in the warm weather. However, when the snow flies, covering the softball diamonds, beaches, outdoor tennis courts and roads, what then? In years past, the population moved inside, seeking membership in racquet clubs, health spas, and YMCA's. The benefits of winter outdoor activities were largely ignored. Today, the trend is shifting. The out-of-doors is the place to be.

Cross-country skiing has gained in popularity through the last few decades. During the 1940's and 1950's, most cross-country skiing was done by racers. Even in the 1960's, the sport was little appreciated. The late 1970's produced a surge of interest in this sport. With this growing interest, the question of, "How good is this for me?", arises. Until now, most studies have dealt with training programs for elite skiers or the biomechanical analysis of skiing form. Niinimaa (1978) studied performance and efficiency of intercollegiate cross-country skiers. He also studied the determinants of performance in Nordic skiing (1979). Lowdon (1979) discussed specificity of training for cross-country ski racing. The recreational cross-country skier was left to fend for himself.
Statement of the Problem

The problem of this study was to determine the effect of recreational cross-country skiing on the strength of the quadricep and hamstring muscles. The following subproblems were concurrently examined:

1. Determination of initial torque differences between the dominant and nondominant quadriceps and hamstrings;
2. Assessment of a torque gain in the dominant quadriceps and hamstrings with knee flexion and extension; and
3. Detection of a torque gain in the nondominant quadriceps and hamstrings with knee flexion and extension.

Purpose of the Study

Cross-country skiing is considered a form of exercise as well as a recreational sport. The purpose of this study was to investigate physiological changes brought about by participation in this activity. Specifically, the torque produced around the knee joint before and after participation in this sport was studied. Use of these results would enable a teacher/coach to justify inclusion of this activity in an education program; or, they could aid in the development of a winter training program.

Significance of the Study

The limited amount of scientific literature dealing with recreational cross-country skiing supports the need for research in
this area. As the population becomes more involved with this sport, there is a growing concern as to possible prerequisites for participation. Can the average person strap on a pair of skis and go gliding through the wilds with little or no prior conditioning? Is he strong enough, both muscullarly and cardiovascularly, to take on the hills and plains? Is there a need to participate in exercise emphasizing strength fitness or will skiing itself take care of this need? Is recreational cross-country skiing strenuous enough to warrant an exercise warm-up of stretching? The question to be answered is, does one need to be in shape to ski recreationally or can one recreationally ski into shape? It would be better to know the facts before one begins to ski.

Delimitations of the Study

The study was delimited to:

1. Volunteers from two intact cross-country ski classes taught by the same instructor at Western Michigan University, Kalamazoo, Michigan;
2. The dominant and nondominant legs of each individual;
3. The torque around the knee joint; and
4. The two muscle groups; the hamstrings and quadriceps.

Limitations of the Study

The conduct of the study was limited by:

1. The weather;
2. Teaching methods;
3. Outside activity of the individual students;
4. Effort of the students during the test;
5. Discontinued participation by some of the students, and
6. The accuracy of the torque recording instrumentation.

Hypotheses

The purpose of the study was to determine the effect of recreational cross-country skiing on the quadricep and hamstring muscles. The hypotheses were as follows:

1. The dominant leg quadriceps will initially produce greater torque than the nondominant leg.
2. The dominant leg quadriceps will produce greater torque than the nondominant leg quadriceps in the posttest.
3. There will be an increase in the torque of the dominant leg quadriceps.
4. There will be an increase in the torque of the nondominant leg quadriceps.
5. The dominant leg hamstring will initially produce greater torque than the nondominant leg hamstrings.
6. The dominant leg hamstring will produce a greater torque than the nondominant leg hamstrings in the posttest.
7. There will be an increase in the torque of the dominant leg hamstrings.
8. There will be an increase in the torque of the nondominant
Definition of Terms

An understanding of the following terms is necessary for a meaningful review of this study:

1. **Dominant.** Leg of preference when kicking a ball.
2. **Knee Extension.** The knee is in the anatomical position.
3. **Knee Flexion.** Going from the fully extended position through the arc of motion; bringing the heel towards the buttocks.
4. **Nondominant.** Of lesser preference in use.
5. **Strength.** The tension building capacity of a muscle (Perrine, 1968).
6. **Torque.** A measure of the effort of some force to rotate an object about some axis of rotation. Torque is equal to the length of the lever arm, measured from the axis of rotation to the point of application of the force, multiplied by the component of force that is perpendicular to the lever arm (Laird, 1979).
7. **Torque/Strength Relationship.** The force output of a muscle, as well as the torque it generates at a joint, is a function of the tension that the muscle can develop (Walmsley, 1976).
8. **Torque/Time Curve.** The graphic display of torque over a period of time indicating flexion and extension.
CHAPTER II

REVIEW OF RELATED LITERATURE

This chapter reviews past studies related to general principles of strength development, isotonic training programs, isokinetic training programs, cross-country skiing related to long distance running, training for cross-country skiing, and the Cybex II.

Principles of Strength Development

All normal daily activity requires a certain amount of body strength. Certain activities require more lower body strength than upper body strength and vice versa. With normal activity, the necessary strength is produced and maintained by going about one's business. When one endeavors to participate outside of the realm of normal daily activity, an added stress is applied to the muscular and cardiovascular systems. Muller (1959) points out that increased activity is a stimulus for an increase in strength. It is important to know the amount of activity and the time needed to produce a strength gain.

Strength has been defined as the absolute maximum amount of force that one can generate in an isolated movement of a single muscle or group of muscles (Pollack, 1978; Sharkey, 1979). To promote strength, the muscles must be subjected to some form of overload; namely, the amount of activity must be increased beyond that to which the muscles are normally accustomed (Stull, 1981).
Exercise physiologists (Matthews & Fox, 1978; Sharkey, 1979) call this the overload principle. Simply stated, it means that the strength of a muscle will increase only when the muscle performs for a given period of time at its maximal strength and capacity. Sharkey (1979) defines overload as "sufficient tension, somewhere above two-thirds of the maximal force, applied to the contractile system" (p. 83). The results of continued maximal performance are adaptations in the musculature. Specific adaptations to a strength stimulus are increased actin and myosin and thicker connective tissue (Faulkner, 1968). Brouha (1974) also notes that repeated muscular work produces an increase in the size of skeletal muscle fibers. Fibers that are small from lack of use are present in every muscle and they develop to full size when regular exercise puts a greater demand upon the muscle. The increase in size is also accompanied by the development of more capillaries in the trained muscle (p. 276).

Isotonic Resistance Training

The methods of strength training discussed in this paper are those of isotonic resistance training and isokinetic resistance training. Isotonic resistance training utilizes the principle of dynamic contraction; that is to say, movement of a joint through a range of motion. The external resistance with isotonic training remains constant but the muscular tension varies through the range of motion of the joint (Mathews & Fox, 1978). There are definite disadvantages to this system:
The resistance in isotonic exercise is always constant, i.e. a fixed weight throughout the full range of motion, even though the strength of the muscle will vary considerably throughout this range due to the modifying effects of the lever system. Thus, a muscle or group of muscles contract at differing percentages of maximum through the range of motion, and the resistance will have its greatest effect on the muscle or muscle group at the extremes in the range of motion. In effect, the tension demand placed on the muscle during an isotonic contraction is maximal only during a small portion of its range (Pipes & Wilmore, 1975; 1976, p. 42).

The advantages of this type of training are its cost effectiveness, its availability, and the results it produces.

The initial advocates of an isotonic training program were DeLorme and Watkins who, in 1948, introduced a Progressive Resistance Program (PRE) based on repetition maximum (RM) (Barney, 1961). Their program utilized a ten RM, or the maximal resistance that was completed for ten repetitions before fatiguing. The training was performed in sets of ten on the ten RM load as follows:

First set - ten repetitions at one-half ten RM load.
Second set - ten repetitions at three-fourths ten RM load.
Third set - ten repetitions at full ten RM load.
(DeLorme, 1948, p. 264)

Capen (1956) designed a study to determine the most effective method of resistance training. Instead of using repetition maximum, he referred to execution maximum (EM). In a study of 159 male freshmen, he found that all methods were variations of a few basic programs. These ranged from the type using extremely heavy resistance performed with one execution, to the type using moderately heavy resistance allowing up to fifteen executions. Capen concluded
that the program with the heaviest resistance that permitted five
executions was superior for strength development.

In a study of 80 male subjects, Barney (1961) compared three
progressive resistance programs. Those using the DeLorme-Watkins
Method (N = 47) were considered the criterion or control group. The
Traditional Hypertrophy Program performed three sets of ten RM load
(N = 18), while the Traditional Strength Program group (N = 15)
performed the first set at a ten RM load, the second set with 5 - 10
pounds added to the ten RM weight, doing as many repetitions as
possible, and the third set with 5 - 10 pounds added per set of ten
RM until a one RM was reached. Barney concluded that all three
methods produced a significant strength gain, but one was not
superior over the other two.

In 1961, Capen used 14 college women from the physical education
majors at the University of Tennessee. He trained them with heavy
weights three times per week for ten weeks. Before and after the
training period, the women were tested for strength, power, muscular
endurance, and anthropometric measures. The results of his study
showed significant increases at the .01 level for strength, power,
and endurance.

Berger (1962) conducted two studies to determine the optimum
number of repetitions with which to train. In the one study, he used
199 male college students and divided them into nine groups. These
groups trained for twelve weeks using different repetitions per set
for progressive resistance exercises. From this study the optimum
number of repetitions was between three and nine.

In another study, Berger (1962) used nine groups (N = 20 per group) of freshmen and sophomore male students and trained them for twelve weeks. Training took place three times weekly with the variations in the programs involving one, two, and three sets, and two, six, and ten repetitions per set. The results showed that three sets and six repetitions per set were best for improving strength.

Withers (1970) studied the effect of varied weight-training loads on strength. He used fifty-five male college freshmen who were randomly assigned to one of three groups. The variations in the program were three sets of seven RM, four sets of five RM, and five sets of three RM. All subjects performed two workouts per week for nine weeks. He concluded that no one group attained improvements that were significantly different from those of the other groups.

In 1965, Berger designed a study to determine the percentages of maximum strength (one RM) used in training which were as effective for increasing strength as training with one RM. Seventy-five male subjects were divided into seven groups that trained as follows:

Three groups - twice weekly with 66, 80, or 90% of the one RM plus one weekly effort with the one RM.
Fourth group - three times weekly with one RM.
Fifth group - 66% of one RM three times weekly.
Sixth group - one RM determined each time for once weekly.
Seventh group - control (p. 141).

At the end of a six-week training period all groups, except group five and group seven, showed a significant strength increase.

Training schedules were investigated by Peterson (1975) in a study of cadet corp males. Although DeLorme and Watkins (1948)
initially advocated four consecutive days of training, Peterson advised three alternate days per week for an eight week period. He found an increase of fifty-eight percent in overall strength for each subject in less than six weeks of training.

The President's Council on Physical Fitness and Sports (1974) summarized Berger's research on strength training as follows:

"Training sessions should not be less than two weekly and may be as high as five weekly once the condition of the exercised muscle improves. The loads to be lifted need not be maximum every training session, but in at least one session per week the person should employ loads which elicit maximum muscle exertion. At least three bouts should be employed at each training session. (P. 8)"

Faulkner (1968) states that free weights, lifted one through six times with maximum effort, are the most effective method of producing skeletal muscle hypertrophy and increasing strength. A combination of these theories can be advocated, as seen from the completed research.

Isokinetic Resistance Training

Muscles somehow adaptively improve in response to regular, mechanically demanding usage. All regimens of muscle training are designed to stimulate as effectively as possible, through the principle of overload, this process of adaptation. Perrine (1968) points out that, in recent years, it has been realized that this adaptation process follows the principle of specificity.

Isokinetic exercise, an isotonic form of exercise in which the rate of movement is controlled, may provide a training that is
comparable or even better than isotonic exercise alone (Clarke, 1973). In isokinetic loading, the desired exercise speed always occurs immediately. Resistance then develops as a function of the amount of tension the muscle can develop at that speed and not the reverse; e.g. resistance first, speed secondarily, as it is in isotonic exercise.

An isokinetic exercise is a dynamic resistive exercise that incorporates a full range of movement, with the muscle exerting maximal force at all points in the range of motion. With isokinetic exercise the speed of motion is a controlled variable not present in isotonic exercise (Laird, 1979).

In the following, Hislop (1967) explains how isokinetic exercise devices work:

The load acting in isokinetic exercise cannot be traced to a familiar agent such as gravity or friction, but it is the result of the mechanical process of energy absorption which an isokinetic device performs in order to keep the exercise speed constant. Because the energy is not dissipated anywhere in the process, it completely converts to a resisting force which is always proportional to the input (muscular force). In effect, the resistance can accommodate all factors causing force variations through a range of motion. At the extremes of the range of motion where the muscle has its, least mechanical advantage, the resistance offered is least. As the motion approaches the point in the range where the mechanical advantage is greatest, the resistance increases proportionally. With resistance accommodating the varying force at the skeletal lever (external force) the muscle is able to maintain a state of maximum contraction through its full shortening range. This permits a maximum demand to be placed on the work capacity of a muscle (pp. 116 - 117).

Pipes and Wilmore (1976) designed a study to compare the effects of isotonic and isokinetic resistance training. Thirty-six men,
ages 28 - 38, were divided into four groups and trained 40 minutes per day, three days per week, for eight weeks. The isotonic group worked at seventy-five percent of one RM, performing three sets of eight repetitions. The isokinetic low speed and isokinetic high speed groups worked at 24 degrees per second and 136 degrees per second, respectively. The former performed three sets of eight repetitions while the latter did three sets of fifteen repetitions. The control group did not work.

Four methods were used to assess muscle strength. Static strength was measured with a cable tensiometer. Three different methods were used to determine dynamic strength measures. The first method was a one RM on an isotonic weight machine. Dynamic strength was also assessed isokinetically using a Cybex or the isokinetic program device at 24 and 136 degrees per second. In all exercise movements tested, with the exception of the leg press, the isokinetic high speed group increased relative strength significantly more than the isotonic or isokinetic slow speed group.

Thistle, et al., (1967) did a comparison of Progressive Resistance Exercise (PRE), isometric exercise, and isokinetic exercise. Sixty normal subjects were divided into four equal groups; e.g. three exercise and one control. The exercise groups worked four days per week for eight weeks. On the fifth day of weeks one, two, seven, and eight the subjects were tested for left quadricep strength. The results showed that the isokinetically trained group scored better on total work (up 35% as compared to 28% for PRE) and peak force (up
The previously mentioned study was duplicated by Smith and Melton (1981). Twelve adolescent males, sixteen to eighteen years of age, were trained three days per week for six weeks. Four groups, variable resistance, isokinetic low speed, isokinetic high speed, and control, were devised. The variable resistance group performed three sets of ten repetitions at 80% maximum; isokinetic low speed worked at 5, 10, and 15 rpm until 50% fatigue; and isokinetic high-speed worked at 30, 40, and 50 rpm until 50% fatigue. The results of this study differed from the one conducted by Pipes and Wilmore (1976) in that the isokinetic high speed group made gains only at high speeds. The most significant gain by the isokinetic high-speed was in tests of motor performance.

Lesmes, et al, (1978) investigated the effects of short duration, high intensity training on an isokinetic dynamometer. The subjects trained four days per week for seven weeks at 180 degrees per second. Knee flexors and extensors of five male volunteers were tested. Measurements of peak torque were obtained at velocities from 0 degrees to 300 degrees per second through 90 degrees of motion. One leg trained with six-second bouts while the other leg trained with thirty-second bouts. The results showed that (1) isokinetic training programs of six and thirty second durations can significantly increase peak torque and (2) velocity may be an important consideration in improving peak torque.

The advantage shown by the isokinetic groups in the performance
tests may have been due to the improvement of strength over a wider range of motion. In addition, the maximal torque development can occur at variable speeds. While the relative limb speed rarely exceeds 60 degrees per second with conventional isotonic procedures, most functional movements in athletics require limb speeds in excess of 90 degrees per second, with some exceeding 200 degrees per second. Isokinetic equipment allows strength training speeds to vary from 0 degrees per second to 300 degrees per second. Moffroid (1969) concluded that comparative findings of the usefulness of isokinetic exercise with normal subjects suggest:

1. Isokinetic exercise is an effective means of increasing muscular torque throughout an arc of motion.

2. Isokinetic exercise increases the work a muscle can do more rapidly than does isometric exercise or isotonic exercise using pulleys.

3. Muscular response to different loading systems tend to be specific; that is, a muscle which is overloaded in a partial range of motion will increase significantly more in this range than in other, less exercised joint positions (p. 745).

Cross-Country Skiing Related to Long Distance Running

As previously stated, strength-building exercise involves maximum load for a short period of time, with regular repetitions and load increments. Cross-country skiing subtly taxes the arms, legs, and shoulders giving one portion a rest while straining another (Baldwin, 1977). When looking at the cross-country skier, Lund (1972) theorized that one should study the long distance runner instead of the muscle builder. The long distance runner is
characterized more by his cardiovascular fitness than by his muscular strength. Plowman (1974), while studying female athletes, found runners and sprinters to average a $V_O_2\ max$ of 60 ml/kg. minute. The physiological characteristics of champion male athletes were discussed by Daniels (1974). He stated that middle distance runners and other endurance athletes all record $V_O_2\ max$ values above 70 ml/kg. minute. When studying cardiovascular responses to submaximal and maximal effort while cycling and running, Faulkner (1971) recorded $V_O_2\ max$ values of 4.91 l/minute, 4.57 l/minute, 4.28 l/minute and 4.17 l/minute for well trained distance runners and former sprinters who train regularly. In another study, ten nationally ranked marathon runners were treadmill tested to determine $V_O_2\ max$ (Costill, 1970). Mean $V_O_2\ max$ was 70.3 ml/kg. minute. The mean $V_O_2\ max$ for 11 highly trained distance runners studied by Costill (1970) for metabolic responses was 73.2 ml/kg. minute.

The cross-country skiers have been characterized as individuals possessing cardiovascular fitness. As an athletic performance, cross-country ski racing is similar to marathon running except that the pace varies considerably. Both events are high oxidative endurance events. Lowdon (1979) listed studies that have shown cross-country skiers to have the highest endurance fitness measures of all athletic groups. The values given in this study were from cross-country skiers, marathon runners, and physical education students. Cross-country skiers were listed as having maximum oxygen uptake of 84.3 ml/kg. minute, 88.3 ml/kg. minute, and 94.0 ml/kg.
minute while marathon runners were listed as having 78 ml/kg. minute and 69.7 ml/kg. minute. Astrand (1977) stated that elite cross-country skiers can work at 85% of their maximal aerobic power for at least one hour, oxygen uptake being 4.5 l/minute\(^{-1}\) or even higher. Marathon runners had energy expenditures requiring from 68% to 100% of their maximal oxygen uptake.

Christensen and Hogberg (1950) determined maximum values for oxygen uptake during skiing using the Douglas-Haldane method. The participants in this study were well trained students from the university and some of the best male and female Swedish skiers. Some of the values obtained from the skiers, once they reached a steady state, were 5.2 l/minute, 5.0 l/minute, and 5.1 l/minute, which were closer to the maximum values recorded during running.

The maximal oxygen uptake of men and women athletes from the Swedish National Team were recorded by Saltin and Astrand in 1967. Ninety-five males and thirty-five females, representing nineteen sports for men and nine sports for women, had their oxygen uptake determined during maximal treadmill running or while bicycling on an ergometer. The mean maximal oxygen uptake for the fifteen males with the highest values was 5.75 l/minute with an upper extreme of 6.17 l/minute. As a team, the five cross-country skiers achieved the highest value of 5.6 l/minute; the highest individual value from a world champion in cross-country skiing was 5.7 l/minute. The average maximum oxygen uptake for runners competing in the 3000 meter run was 5.6 l/minute; for those in the 800 - 1500 meter run 5.4 l/minute; and
for those in the 400 meter run, 4.9 l/minute. The maximum oxygen uptake for women cross-country skiers and runners was 3.8 l/minute and 3.1 l/minute respectively.

A study to determine cardiac output of athletes was devised by Ekblom (1968). The athletes were twenty-two to thirty-four year old males, all of whom were experts in endurance sports such as running, bicycling, orienteering, and cross-country skiing. The significance of this study is not in the study itself but in the anthropological measurements taken prior to the testing. The cross-country skier had a maximum oxygen uptake of 5.63 l/minute compared to 5.76 l/minute for a long-distance runner and 5.12 l/minute for a person participating in orienteering.

Seven members of the U.S. Nordic Ski Team were studied during maximal treadmill exercise by Hanson (1973). Four of the seven had been competitors in international class skiing for several years, while three were relatively recent additions to the team. The mean of both individual and group maximal exercise responses compared very closely with the highest values available in the literature at that time. The three highest values were 6.22 l/minute, 5.84 l/minute, and 5.41 l/minute.

Niinimaa (1978) used ten male intercollegiate cross-country skiers to identify factors influencing competitive performance and to estimate the efficiency of energy expenditure in skiing. The variables determined were maximum oxygen intake on the treadmill and maximum oxygen intake during 80% - 90% maximum skiing. The results
showed that the skiers averaged 89.2% of their maximum oxygen intake on the treadmill while skiing at 80% - 90% of maximum workload.

A study using fifty-four members of the U.S. Ski Team was constructed by Haynes (1980) to study characteristics of elite male and female ski-racers. Cross-country skiing, alpine skiing, and Nordic combined events were involved. When maximum oxygen uptake was determined, it was found that cross-country skiers had higher maximum oxygen uptake, adjusted for weight or lean body weight, than alpine skiers of the same sex.

It can be seen from the aforementioned studies that cardiovascular endurance is an important component for competitive cross-country skiers.

Training for Cross-Country Skiing

As previously stated, cross-country skiers and long-distance runners are both characterized by their high level of cardiovascular fitness. Christensen (1950), however, does not believe that cross-country skiers should prepare for skiing by merely running. He states,

The effort during cross-country skiing is spread to a large number of powerful muscles, not only the leg muscles. Almost every muscle in the body will be working and will be working under relatively favourable conditions, due to the alternation of work and relative rest during the glide (p. 301).

The cross-country skier, then, needs more all-round body strength than a long-distance runner.

When the cross-country skier works to train his muscles, he is
dealing with three kinds of physical strength (Caldwell, 1973). The first type is that gained by weight lifting. This is good for the muscles involved in lifting the weights, which are not always the same muscles needed in cross-country skiing (p. 88). The second type of strength is specificity strength. This is attained by doing exercises related to the skiing motions. The third type is overall, coordinated body strength, which is the integration of individual muscular efforts. Rees (1975) gives some guidelines for muscle training. It must accomplish two things; it should strengthen muscles and it should produce quick, supple muscles. He suggests preseason work consisting of walking, hiking, cycling, jogging, or easy ski striding (p. 158). For upper body work, Caldwell (1973) recommends hard work like shoveling, digging ditches by hand, and cutting wood with an axe or a cross-cut (p. 89). As previously recommended, the exercises used by the cross-country skier should simulate the movement patterns and use the same muscles as does his skiing technique. Consequently, the best way to condition oneself for recreational cross-country skiing is to ski cross-country (Baldwin, 1977; Caldwell, 1973; Lowdon, 1979). The endurance component, according to Jerome (1969), can also be dealt with in this manner. If one participates in cross-country skiing regularly at a rate that keeps one working aerobically (i.e. gives the heart and lungs a good workout) and if one keeps it up until muscular fatigue advises one to stop, it would seem obvious that one is going to benefit both in strength and endurance (p. 101).
The Cybex II

One device for measuring the strength of an isotonic contraction is the Cybex II isokinetic dynamometer. In an isokinetic contraction, maximum effort is exerted during a concentric muscle contraction in which the angular velocity of the limb segment is constant throughout the range of motion used. The Cybex II measures strength in units of torque, the product of force, monitored on a transducer oriented perpendicularly to the limb segment, and the distance between the cuff attachment on the limb and the knee joint center (Murray, 1980, p. 413).

Moffroid (1969) determined the reliability and validity of the Cybex II. Seven different loads were placed on the horizontal lever arm at a distance of two feet from the axis. Ten test-retest sessions using these seven loads at this one position produced a coefficient of reliability of .995 (p. 735).

The validity of the Cybex II to measure work was established by having various weights fall, acting at a 1.5 foot distance from the axis. The weights fell from the vertical position through a 180 degree arc (Moffroid, 1969). The rate of descent was governed by the isokinetic device. Work in this case, equalled force times vertical distance. Five measurements were made. The correlation between the mechanical computation and the measured value was .946 (p. 736). The isokinetic device was thus shown to: (a) transmit torque reliably through the range of motion at a given test speed;
and (b) measure torque validly.

Torque measurement accuracy pertains to accuracy of measurement in absolute terms of comparing Cybex II measurements to actual functional demands or for comparing measurements made on one system to those made on another (Lumex, 1981). Possible measurement error is greatest at the extremes (high and low end) of the scale, least or none at the midscale calibration point. When using a 360 foot-pound scale, the accuracy is ± 1.5 foot-pounds of torque (p. 81).

Torque measurement repeatability pertains to the consistency of measurement of a single system for comparing measurements from one time to measurements made at any other time (Lumex, 1981). The repeatability for the 360 foot-pound scale is ± 2.0 foot-pounds. For the 180 and the 30 foot-pound scales, repeatability is ± 1.0 foot-pounds of torque (Lumex, 1981, p. 82).

Strength testing on an isokinetic device is not a new concept. Moffroid (1969) tested sixty subjects, twelve men and forty-eight women, between the ages of eighteen and thirty-one years old. The dominant limb was determined by handedness. The pretest consisted of five reciprocal contractions of the quadriceps and hamstrings at 3.75 revolutions per minute. Once weekly for four weeks the subjects were again tested on the isokinetic device.

In another study (Moffroid, 1969) thirty subjects were tested on an isokinetic device at fast and slow velocities. Handedness again determined the dominant leg and five maximal reciprocal contractions of the quadriceps and hamstrings comprised the pretest
Johnson and Siegel (1978) conducted a study using forty females between the ages of seventeen and fifty to determine the reliability of an isokinetic movement of the knee extensors. The test was conducted at 180 degrees per second on a Cybex II. Three submaximal warm-up kicks were given and then the subjects were directed to exert maximal force of the knee extensors through the range of motion of 90 degrees to full extension. Six test trials on each of three consecutive days were administered. It was concluded that for this population, a protocol which provided for three submaximal warm-up trials followed by three maximal efforts was essential before stable measures were manifested.

In a study using thirty male and thirty female young adult volunteers, Goslin (1979) attempted to establish normative data for clinical use of isokinetic testing devices in knee cases. The subjects were tested in the seated and in the prone position for knee flexion and extension. All testing was done at 30 degrees per second. Each subject gave five extensions and five flexion trials through the full range of motion with a thirty second rest period. The highest maximum torque for knee extension during seated knee extension was defined as the dominant leg. Maximum torque scores of the dominant and nondominant leg showed differences between the two legs.

A comparison of quadriceps and hamstring torque values during isokinetic exercise was done by Wyatt (1981). A group of fifty participants, both male and female, between the ages of twenty-five
and thirty-four, were studied. Maximal peak torque of reciprocal knee flexion and extension were measured at velocities of 60, 180, and 300 degrees per second. These measurements were used to determine: (a) mean maximum torque; (b) the torque ratio between the hamstrings and quadriceps; (c) the torque difference between the different speeds; (d) torque difference between dominant and non-dominant knees; (e) torque ratio between dominant and nondominant knees; and (f) the absolute difference between the knees.

The results were as follows:

1. As the speed increased, torque output decreased.
2. The ratio between hamstrings and quadriceps moved closer to unity as the speed of exercise increased.
3. There was a difference between the dominant and nondominant knee in males, but not in females.
4. The quadriceps produced greater torque than the hamstrings at all three speeds.
5. The dominant knee produced significantly greater torque in males, but not in females.

Summary of the Related Literature

Strength was defined as the absolute amount of force that one can generate in an isolated movement of a single muscle or group of muscles. Increases in strength were brought about by overloading the muscle; e.g., increasing the amount of activity beyond that
which is normal. Two methods of strength training, isotonic and isokinetic, were discussed.

Isotonic training programs were based on dynamic contractions. A fixed resistance was applied through the range of motion. In isotonic exercise, the strength of the muscle will vary considerably throughout the range due to the modifying effects of the lever system. Thus, the resistance will have its greatest effect on the muscle at the extremes in the range of motion. Isotonic training programs varied in structure, but overload was the main principle used in their design. Optimal strength development resulted from a six repetition maximum (6RM) performed in three sets, based on a schedule of three alternate days per week for an eight week period. The resistance increased when the subject could easily perform more than six repetitions in the final set.

Isokinetic training was based on contractions in which the resistance was proportional to the dynamic force of the muscle. The control of the speed on the isokinetic machine limited acceleration of the limb in mid-range of the contraction. This limitation caused a proportional increase in resistance to the muscle, thereby maintaining the overload.

Isokinetic devices were used in the measurement of strength as well as in the development of strength. The principle of specificity was supported by the strength measurements reflecting the type of training used for strength development.

Long-distance runners and elite cross-country skiers had
comparable maximum oxygen-uptake capacities when studied in the laboratory. The values for both groups were in the range of 5.7 l/minute to 7.4 l/minute.

Training for cross-country skiing should incorporate total body fitness. General strengthening is good, but specificity strengthening (i.e., doing exercises that are related to the skiing motions) is more highly recommended. The endurance component is attained through walking, bicycling, and easy jogging. The general consensus on training for recreational cross-country skiing is to ski cross-country.

The Cybex II has been determined to be valid and reliable in its recording of torque measurements. The accuracy and repeatability of the measurements vary only slightly for each of the different scales. Norms for testing the knee joint have been developed by various researchers.
CHAPTER III

EXPERIMENTAL PROCEDURES

The purpose of this study was to determine the effect of recreational cross-country skiing on the strength of the quadricep and hamstring muscles.

The procedures used in the collection and analysis of data for this study are organized under the following headings: Subjects, Equipment, Procedures, and Analysis of Data.

Subjects

A cluster sample was used for this study. The subjects were male and female volunteers from two selected, beginning cross-country ski classes at Western Michigan University. Both classes were taught by the same instructor. The classes began January 5 and 6, 1982. At this time, the students who volunteered were asked to fill out a questionnaire/consent form. This can be seen in Appendix A.

Eleven subjects, four males and seven females, participated in this study. The mean age for the men was twenty with a range of 18 - 22. Mean weight was 143.75 pounds, with a range of 132 - 165 pounds. The mean height for the male subjects was 69.5 inches, with a range of 68 - 71 inches. Three of the four males were right-handed. One of the right-handed males was left-footed. All but one of the four had no previous experience in cross-country skiing and
none of the four ran or jogged regularly.

The seven women had a mean age of twenty, with a range of 19 - 22. Mean weight was 129.5 pounds with a range of 105 - 155 pounds. Mean height was 64.3 inches. The range was 62 - 67 inches. Of the seven women, six were right-handed and all were right-footed. Two women had previous experience with cross-country skiing and one of these ran three times per week and lifted weights regularly.

Instrumentation

A Fitron Cycle Ergometer was used in the warm-up preceding the data collection. Torque data were collected with a Cybex II Dual Channel Dynamometer and Instrumentation System, #7104. The analysis of the torque data was accomplished through the use of a Neumonics 1224 Electronic Digitizer with built-in program power.

Procedures

The collection of torque data took place at the Western Michigan University Sports Medicine Clinic, which is located in the University Health Center. The format for data collection was a pretest/posttest design. Data collection dates were January 5 and 6, and February 16, 17, and 18, 1982.

As a warm-up, each subject rode the Fitron Cycle Ergometer five minutes at 100 RPM, producing less than one kilopondmeters/minute. The subject was then placed on the Cybex II table where proper adjustments of the equipment were made to ensure accuracy of the
data. The Cybex II Speed Selector was set at 10 RPM. Chart speed was set at 25 mm/second. The subject was instructed to extend and flex the knee as fast and as hard as possible. One practice kick was given per leg. Five repetitions were completed with each leg with a twenty second rest interval between each kick. The process was repeated for the posttest. Between pretest and posttest the students were required to ski two hours per day, two days per week, for six weeks.

Analysis of Data

The peak torque produced on the Cybex II by each set of quadriceps and hamstrings was computed with a Neumonics 1224 Electronic Digitizer displacement option. Each peak torque was computed three times, the score being the average of the three obtained values. Values for hamstring peak torque and quadriceps peak torque of the dominant and nondominant leg were computed individually.

Two Analyses of Variance, randomized block, factorial design (Kirk, 1969, p. 238 - 241) were used to make the following comparisons:

1. Initial differences between dominant and nondominant quadriceps peak torque;
2. Differences between posttest results of dominant and nondominant quadriceps peak torque;
3. Differences between pretest and posttest peak torque for
the dominant quadriceps;

4. Differences between pretest and posttest peak torque for the nondominant quadriceps;

5. Initial differences between dominant and nondominant hamstrings peak torque;

6. Differences between posttest results of dominant and nondominant hamstring peak torque;

7. Differences between the pretest and posttest peak torque for the dominant hamstrings;

8. Differences between the pretest and posttest peak torque for the nondominant hamstrings.

An alpha level of .05 was used to determine significance.

The computer program used to compute the data was UCLA Biomedical Package, Program BMD08V. The program was available through the Western Michigan University Decsystem 10 Computer.
The purpose of this study was to determine the effect of recreational cross-country skiing on the strength of the quadricep and hamstring muscles. Male and female volunteers from two beginning cross-country ski classes at Western Michigan University served as subjects for this study. Collection of the dependent variable was done with a Cybex II. Two Analyses of Variance, randomized block, factorial design (Kirk, 1969, pp. 238 - 241) were performed on these data. The results and analyses are presented as follows: Analysis of Torque Scores for the Quadriceps; Analysis of Torque Scores for the Hamstrings; and Discussion.

Analysis of Torque Scores for the Quadriceps

Performance on the dependent variable, torque, was measured in foot-pounds of torque and recorded by a Cybex II Dual Channel Dynamometer and Instrumentation System, #7104. The scores obtained for each subject were from five maximal reciprocal contractions of the flexors and extensors of the dominant and nondominant knees in the pretest and posttest. The performance of the group on the dependent variable is shown in Table 1.
Table 1

Mean Peak Torque Values for the Quadriceps

<table>
<thead>
<tr>
<th>Leg</th>
<th>Pretest (ft-lbs)</th>
<th>Posttest (ft-lbs)</th>
<th>Pretest Standard Deviation (ft-lbs)</th>
<th>Posttest Standard Deviation (ft-lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominant</td>
<td>106.12722</td>
<td>102.67320</td>
<td>35.266938</td>
<td>29.626418</td>
</tr>
<tr>
<td>Nondominant</td>
<td>109.30832</td>
<td>101.34486</td>
<td>26.637785</td>
<td>22.747659</td>
</tr>
</tbody>
</table>

An Analysis of Variance, randomized block, factorial design (Kirk, 1969, pp.238 - 241) was used to analyze the data. The analysis of variance for the quadriceps is shown in Table 2. The investigation compared the mean peak torque scores of the pretest for the independent variables of dominant and nondominant quadriceps. The mean peak torque scores for the posttest were compared in the same manner. Mean scores of pretest and posttest torque were compared for each independent variable; dominant and nondominant quadriceps.
Table 2
ANOVA for the Quadriceps

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>Degrees of Freedom</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
<td>30144.80</td>
<td>10</td>
<td>3014.48</td>
<td>27.08*</td>
</tr>
<tr>
<td>Treatments</td>
<td>423.85</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Legs</td>
<td>9.44</td>
<td>1</td>
<td>9.44</td>
<td>.09</td>
</tr>
<tr>
<td>Pre/Post</td>
<td>385.49</td>
<td>1</td>
<td>358.49</td>
<td>3.22</td>
</tr>
<tr>
<td>Interaction</td>
<td>55.49</td>
<td>1</td>
<td>55.49</td>
<td>.50</td>
</tr>
<tr>
<td>Residual</td>
<td>3340.29</td>
<td>30</td>
<td>111.34</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>33908.94</td>
<td>43</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*P < .05

The difference among the mean peak torque scores of the independent variables, pretest/posttest, was not significant. Cross-country skiing did not produce a significant change in torque produced by the quadriceps. The obtained F of 3.22 was not significant, $F(1, 30) = 4.17, p < .05$.

There was no significant increase in torque between the dominant quadriceps and the nondominant quadriceps. The obtained F, .09, as seen in Table 1, was not significant, $F(1, 30) = 4.17, p < .05$.

Cross-country skiing did not produce a significant effect between the dominant and nondominant legs.

The interaction effect, between pretest/posttest and legs was not significant. The obtained F, .50, was not significant, $F(1, 30)$...
A significant difference was found between the subjects. This result was expected due to the individual differences of the subjects. The obtained $F$, 27.08, was significant, $F(10, 30) = 2.16, \ p < .05$.

Analysis of Torque Scores for the Hamstrings

The dependent variable, torque, was measured in foot-pounds of torque. The measurement of the five maximal reciprocal contractions by the dominant and nondominant knee flexors and extensors were recorded by a Cybex II Dual Channel Dynamometer and Instrumentation System, #7104. Hamstring performance on the dependent variable is shown in Table 3.

Table 3
Mean Peak Torque for the Hamstrings

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominant</td>
<td>63.90046</td>
<td>73.94320</td>
<td>20.600872</td>
<td>23.021103</td>
</tr>
<tr>
<td>Nondominant</td>
<td>64.77003</td>
<td>71.55567</td>
<td>18.984369</td>
<td>18.919749</td>
</tr>
</tbody>
</table>

An Analysis of Variance, randomized block, factorial design (Kirk, 1969, pp. 238 - 241) was performed on these scores. The mean peak torque scores of the pretest for the independent variables of dominant hamstrings and nondominant hamstrings were compared. The mean peak torque scores of the posttest were compared in the same
manner. A comparison of the mean peak torque scores for pretest and posttest of the independent variable, dominant and nondominant hamstrings, was also made. Results of the analysis of variance can be seen in Table 4.

Table 4
ANOVA for the Hamstrings

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>Degrees of Freedom</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
<td>15438.24</td>
<td>10</td>
<td>1543.82</td>
<td>25.98*</td>
</tr>
<tr>
<td>Treatments</td>
<td>814.29</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Legs</td>
<td>6.34</td>
<td>1</td>
<td>6.34</td>
<td>.15</td>
</tr>
<tr>
<td>Pre/Post</td>
<td>778.78</td>
<td>1</td>
<td>778.78</td>
<td>18.12*</td>
</tr>
<tr>
<td>Interaction</td>
<td>29.17</td>
<td>1</td>
<td>29.17</td>
<td>.68</td>
</tr>
<tr>
<td>Residual</td>
<td>1289.07</td>
<td>30</td>
<td>42.99</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>17541.60</td>
<td>43</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p < .05

There was no significant difference between the mean peak torque scores of the dominant hamstrings and the nondominant hamstrings. Cross-country skiing did not produce a significant change in the torque between the dominant hamstrings and the nondominant hamstrings. The obtained F, .15, was not significant, F (1, 30) = 4.17, p < .05.

There is a significant difference between pretest and posttest
torque. Table 4 shows an obtained F of 18.12, which is significant, $F(1,30) = 4.17$, $p < .05$. Cross-country skiing did produce a significant change in the torque produced by the hamstrings. Table 3 shows an increase of 10.04274 foot-pounds in mean peak torque. Hence, a significant F, 18.12.

There was no interaction between pretest/posttest and legs. Hence, the obtained F, 0.68, was not significant, $F(1,30) = 4.17$, $p < .05$. No interaction existed.

The significant F, 25.93, for subjects was expected. This is due to individual differences from subject to subject.

Discussion

The results of this study showed no significant changes in the torque of the quadriceps muscles. Table 1 shows a decrease in mean peak torque from pretest to posttest scores. This did not produce a significant F in the Analysis of Variance. A summary of the torque data collected for the dominant and nondominant quadriceps can be seen in Appendix B.

The lack of increased strength may be attributed to the movements utilized by cross-country skiers. After the kick down and back, Rees (1975) states that the return of the leg and ski to the glide position is relaxed and pendulum-like, requiring very little energy. He also thinks that no attempt should be made to kick the ski forward into the glide position. This theory overlooks the power mechanism of the leg. As previously stated, research has revealed a 2:1 strength
ratio between quadriceps and hamstrings (Moffroid, 1969). The main use of the quadriceps, in this case, is an eccentric contraction, as the gliding leg should be flexed at the knee as it supports the entire body weight, centered over the gliding ski (Brunner, 1969).

Caldwell (1975) is not of the same belief as Rees. He agrees with the kick of the leg down and back. However, he also thinks the opposite leg should simultaneously be driven ahead with great power. He states:

In each stride the rear leg begins to swing forward with a relatively slow, pendulum-like motion. This slow movement does not last very long though, and it accelerates. The leg swings down, accelerating all the time, and then drives forward. As the feet pass, one should continue to exert pressure on the forward swinging leg, from the foot and on up. One knee gets into the act, then the upper leg just above the knee; and then with some skiers, the hips contribute to the thrust (p. 125).

If this were the way beginning skiers were taught to ski, this author feels a strength gain of the quadriceps mechanism would be present. Unlike walking, where extension occurs before heel strike, in a nonweight-bearing situation, in cross-country skiing the leg is driven forward with the ski in contact with the ground. As the leg is driven forward, the action would be active extension of the knee against the resistance of the ground. Resistance to extension would result in an increase in quadriceps strength.

The significance of this study lies in the torque data of the hamstring groups. As with the quadriceps, there was no significant difference between the dominant and nondominant hamstrings in the
pretest or posttest torque data. Table 3 shows a pretest difference of .86957 foot-pounds and a posttest difference of 2.38753 foot-pounds. Figure 1 illustrates the insignificant difference between the posttest torque values for the independent variables, dominant and nondominant hamstrings. These figures are representative of the mean. A summary of the torque data for the dominant and nondominant hamstrings can be seen in Appendix C.
A significant increase occurred within each hamstring. The dominant hamstrings showed an increase of 10.04274 foot-pounds and the nondominant hamstrings showed an increase of 6.78564 foot-pounds. Figure 2 illustrates the increase of mean peak torque for the dominant hamstrings. These figures are representative of the mean.
Figure 2. Pretest and Posttest Peak Torque Curves for the Dominant Hamstrings.

The increase in strength of the hamstrings is due to a number of factors. The first of these is the mechanics of the kick. The main power for the single stride is derived from the kick of the leg downward and back (Caldwell, 1975). The hip extensors - the gluteus maximus and hamstring muscles - provide much of the forward power thrust (Hixon, 1980). If the kick is powerful, the leg will straighten out behind. The leg whips back and, like a rubber band, immediately recoils slightly. The hamstrings are acting as a check-rein in this instance, as normal hip extension consists of only 15 degrees of motion.

A third factor deals with the overload principle of strength.
development. As the kick leg is powerfully extending back, the entire weight of the body is supported by the gliding leg (Nisson, 1974; Rees, 1975). Each time a kick is performed, the resistance is equivalent to the weight of the body. This action, repeated many times, will obviously fatigue the muscle and cause an increase in strength.
CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The problem of this study dealt with the effect of recreational cross-country skiing on the strength of the quadriceps and hamstring muscles. This chapter is divided into three sections; summary, conclusions, and recommendations.

Summary

The problem of this study was to determine the effect of recreational cross-country skiing on the strength of the quadriceps and hamstring muscles. Eleven volunteer subjects, four male and seven female, ranging in age from 18 - 22 years, participated in the study. All eleven subjects were enrolled in one of two selected, beginning cross-country ski classes at Western Michigan University in Kalamazoo, Michigan. A pretest-posttest design consisting of five maximal reciprocal contractions of the knee flexors and extensors of the dominant and nondominant legs was used. Torque data collection was done using a Cybex II Dual Channel Dynamometer Instrumentation System, #7104. The dependent variable, torque, was measured in foot-pounds of torque. The analysis of the torque data was accomplished through the use of a Neumonics 1224 Electronic Digitizer with built in program power. The program used was displacement. Two Analyses of Variance, randomized block, factorial design were used to make comparisons of dominant and nondominant quadriceps and
hamstrings in the pretest and posttest.

Results of the hypotheses were as follows:

1. The obtained $F$, .09, was not significant, $F (1,30) = 4.17$, $p = .05$, when comparing initial peak torque of the dominant and nondominant quadriceps.

2. The comparison of the posttest peak torque of the dominant and nondominant quadriceps produced an obtained $F$ of .09. This was not significant, $F (1,30) = 4.17$, $p = .05$.

3. The difference between the pretest and posttest peak torque of the dominant quadriceps, $F = 3.22$, was not significant, $F (1,30) = 4.17$, $p = .05$.

4. The peak torque difference between the pretest and posttest of the nondominant quadriceps produced an obtained $F$ of 3.22, which was not significant, $F (1,30) = 4.17$, $p = .05$.

5. The obtained $F$, .15, was not significant, $F (1,30) = 4.17$, $p = .05$, when comparing the initial peak torques of the dominant and nondominant hamstrings.

6. The posttest peak torque difference between the dominant and nondominant hamstrings, $F = .15$, was not significant, $F (1,30) = 4.17$, $p = .05$.

7. The peak torque difference between the pretest and posttest of the dominant hamstring, $F = 18.12$, was significant, $F (1,30) = 4.17$, $p = .05$.

8. The comparison of the pretest and posttest peak torque of the nondominant hamstrings, $F = 18.12$, was significant, $F (1,30) =
Conclusions

The results of the study show an increase in the peak torque of the dominant and nondominant hamstrings after six weeks of recreational cross-country skiing.

The conclusions, based on the findings of the study, are:

1. It appears that recreational cross-country skiing is not sufficient for the development of total leg strength.

2. The hamstrings benefit more than the quadriceps from recreational cross-country skiing.

Recommendations

The amount of research in the area of cross-country skiing has been extremely limited. The major portion of the research has been done on elite skiers and has dealt with cardiovascular fitness. As the number of recreational skiers grows, the need for pertinent research also grows.

A study using more than eleven subjects might provide more accurate data. A larger subject number with a more evenly distributed male:female ratio is recommended.

The time factor of the study should also be evaluated. Through studies of isotonic weight training, a training schedule of three times per week for eight weeks has been determined to produce the most significant results. The skiers in this study skied only
twice per week for six weeks. It is recommended that the number of
days skied be increased.
APPENDIX A

Questionnaire/Consent Form

I hereby agree to participate in the research study of Cheryl Hofman. I have been informed that this will entail a pretest and posttest situation which involves giving a maximal contraction of the leg muscles through the full range of motion on the Cybex II. I also understand that the results will be used in the writing of Cheryl Hofman's master's thesis without my identity being revealed.

Signed ________________

Population Information:

Sex: M F
Age:
Weight:
Height:
Handedness: Right Left
Do you run/jog regularly? Yes No If yes, how often?

Do you have any previous experience with cross-country skiing? Yes No If yes, how much?
APPENDIX B

Summary of Torque Data for Dominant and Nondominant Quadriceps

<table>
<thead>
<tr>
<th>Subject</th>
<th>Dominant Pretest (ft-lb)</th>
<th>Dominant Posttest (ft-lb)</th>
<th>Nondominant Pretest (ft-lb)</th>
<th>Nondominant Posttest (ft-lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>123.52778</td>
<td>119.32011</td>
<td>106.17400</td>
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<td>144.57856</td>
<td>174.36645</td>
<td>137.77167</td>
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<td>108.21289</td>
<td>109.86728</td>
</tr>
<tr>
<td>4</td>
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<td>153.08900</td>
<td>124.01911</td>
<td>129.32167</td>
</tr>
<tr>
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<td>125.37800</td>
<td>124.64845</td>
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### APPENDIX C

**Summary of Torque Data for Dominant and Nondominant Hamstrings**

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<tr>
<th>Subject</th>
<th>Dominant Pretest (ft-lb)</th>
<th>Dominant Posttest (ft-lb)</th>
<th>Nondominant Pretest (ft-lb)</th>
<th>Nondominant Posttest (ft-lb)</th>
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