Effects of circuit weight training on strength maximal oxygen uptake anaerobic threshold and work output during simulated cross-country ski movements

James A. Narum

The University of Montana

Follow this and additional works at: https://scholarworks.umt.edu/etd

Let us know how access to this document benefits you.

Recommended Citation

https://scholarworks.umt.edu/etd/7205

This Thesis is brought to you for free and open access by the Graduate School at ScholarWorks at University of Montana. It has been accepted for inclusion in Graduate Student Theses, Dissertations, & Professional Papers by an authorized administrator of ScholarWorks at University of Montana. For more information, please contact scholarworks@mso.umt.edu.
COPYRIGHT ACT OF 1976

This is an unpublished manuscript in which copyright subsists. Any further reprinting of its contents must be approved by the author.

Mansfield Library
University of Montana
Date: 1982
THE EFFECTS OF CIRCUIT WEIGHT TRAINING ON STRENGTH, MAXIMAL OXYGEN UPTAKE, ANAEROBIC THRESHOLD, AND WORK OUTPUT DURING SIMULATED CROSS-COUNTRY SKI MOVEMENTS

By

James A. Narum

B.A., Concordia College, Moorhead, Minnesota, 1980

Presented in partial fulfillment of the requirements for the degree of

Master of Science

UNIVERSITY OF MONTANA

1982

Approved by:

Chairman, Board of Examiners

Dean, Graduate School

Date
Narum, James A., Master of Science, August 1982, Physical Education

The Effects of Circuit Weight Training on Strength, Maximal Oxygen Uptake, Anaerobic Threshold, and Work Output During Simulated Cross-Country Ski Movements

Director: Dr. Brian J. Sharkey

The effects of upper body strength and endurance circuit weight training (CWT) on strength, maximal oxygen uptake ($\dot{VO}_2$ max), anaerobic threshold (AT), and work output (WO) during simulated cross-country ski movements were investigated. Twenty male college students were randomly assigned to either the strength or endurance CWT regimen. Three circuits of five upper body exercises (bench press, lat pull, tricep extension, bicep curl, and arm pulls) were completed by all subjects three times per week for seven weeks. The strength CWT group ($n = 11$) performed four to eight RM (repetition maximum) with each exercise, whereas the endurance CWT group ($n = 9$) performed 15-25 RM for the bench press, lat pull, tricep extension, and bicep curl, and 50-100 repetitions for the arm pulls. Following the training program, the pre and post training measurements were compared within each group and between groups.

The results showed that subjects in the strength CWT group increased strength significantly in the bench press, lat pull, tricep extension, bicep curl, and total strength (sum of strength scores), by $17\%$, $19\%$, $18\%$, $20\%$, and $18.5\%$, respectively, and WO by $54\%$. The subjects in the endurance CWT group significantly increased strength in each of the four strength measures and total strength by $7\%$, $19\%$, $15\%$, $9\%$, and $11\%$, respectively, and WO by $74\%$. Maximal oxygen uptake was not significantly increased in either group after training. The difficulties encountered while determining the AT with the gas exchange method necessitated that the AT results be excluded from statistical interpretation. There were no significant differences in strength, $\dot{VO}_2$ max, or WO between the two training groups after training.

It was concluded that both upper body strength and endurance CWT increased strength and WO in untrained college subjects after seven weeks of training, but did not increase $\dot{VO}_2$ max. These results suggested that either strength or endurance CWT could be highly beneficial for ski training in untrained, beginning, cross-country skiers.
ACKNOWLEDGEMENTS

The author wishes to express a special word of thanks to Dr. Richard Washburn and Mr. Michael Smith for their many hours spent testing in the lab, editing, and for their encouragement throughout the course of this project. I would also like to thank Dr. Brian Sharkey and Dr. Kathleen Miller for their assistance with this project, and their contributions to my professional development during the past year.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>ii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>iii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>viii</td>
</tr>
</tbody>
</table>

## Chapter

1. INTRODUCTION

   - Statement of the Problem ........................................... 3
   - Assumptions .................................................................. 4
   - Definitions ............................................................ 4

2. REVIEW OF LITERATURE

   - Strength Training Effects on Strength, \( \dot{V}O_2 \) max, and Anaerobic Threshold ........................................... 7
     - Strength .................................................................. 7
     - Maximal Oxygen Uptake ........................................... 9
     - Anaerobic Threshold .............................................. 9
   - Endurance Training Effects on Strength, \( \dot{V}O_2 \) max, and Anaerobic Threshold ........................................... 10
     - Strength .................................................................. 10
     - Maximal Oxygen Uptake ........................................... 11
     - Anaerobic Threshold .............................................. 12
   - Strength and Endurance Training Effects on Work Output ........... 13
   - Summary .................................................................... 16
<table>
<thead>
<tr>
<th>Chapter</th>
<th>METHODS AND PROCEDURES</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.</td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>Subjects</td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>Research Design</td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>Pre Training</td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Strength Measurement</td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Work Output Measurement</td>
<td></td>
<td>21</td>
</tr>
<tr>
<td>Maximal Oxygen Uptake and Anaerobic Threshold Measurements</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Training Procedure</td>
<td></td>
<td>26</td>
</tr>
<tr>
<td>Group A (strength)</td>
<td></td>
<td>27</td>
</tr>
<tr>
<td>Group B (endurance)</td>
<td></td>
<td>27</td>
</tr>
<tr>
<td>Post Testing</td>
<td></td>
<td>28</td>
</tr>
<tr>
<td>Statistical Treatments</td>
<td></td>
<td>28</td>
</tr>
<tr>
<td>4.</td>
<td>RESULTS</td>
<td>30</td>
</tr>
<tr>
<td>Strength</td>
<td></td>
<td>31</td>
</tr>
<tr>
<td>Maximal Oxygen Uptake</td>
<td></td>
<td>35</td>
</tr>
<tr>
<td>Anaerobic Threshold</td>
<td></td>
<td>36</td>
</tr>
<tr>
<td>Work Output</td>
<td></td>
<td>39</td>
</tr>
<tr>
<td>Changes in Work Output Within and Between Groups</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>Correlations Between Work Output and Strength and VO(_2) max</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>Body Weight</td>
<td></td>
<td>45</td>
</tr>
<tr>
<td>5.</td>
<td>DISCUSSION</td>
<td>46</td>
</tr>
<tr>
<td>Strength</td>
<td></td>
<td>46</td>
</tr>
<tr>
<td>Maximal Oxygen Uptake</td>
<td></td>
<td>49</td>
</tr>
<tr>
<td>Chapter</td>
<td>Page</td>
<td></td>
</tr>
<tr>
<td>------------------------------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>Anaerobic Threshold</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td>Work Output</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>6. SUMMARY</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>Conclusions</td>
<td>63</td>
<td></td>
</tr>
<tr>
<td>Recommendations</td>
<td>64</td>
<td></td>
</tr>
</tbody>
</table>

REFERENCES ............................................. 66

APPENDICES

A. INFORMED CONSENT FORM AND MEDICAL HISTORY QUESTIONNAIRE .................. 70
B. THE ROLLERBOARD ................. 73
C. THE NORDIC-TRAK ERGOMETER ....... 75
D. TRAINING EXERCISES AND EQUIPMENT .......... 76
E. INDIVIDUAL DATA FOR GROUP A ....... 79
F. INDIVIDUAL DATA FOR GROUP B ........ 80
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Physical Characteristics of Subjects</td>
<td>19</td>
</tr>
<tr>
<td>2. Effects of Strength Circuit Weight Training Within Group A</td>
<td>32</td>
</tr>
<tr>
<td>3. Effects of Endurance Circuit Weight Training Within Group B</td>
<td>33</td>
</tr>
<tr>
<td>4. Differences in Pre and Post Training Means and t values for Strength, $\dot{V}O_2$ max, and Work Output</td>
<td>34</td>
</tr>
<tr>
<td>5. Pre Training Correlations Between Work Output and Strength and $\dot{V}O_2$ max</td>
<td>41</td>
</tr>
<tr>
<td>6. Post Training Correlations Between Work Output and Strength and $\dot{V}O_2$ max</td>
<td>42</td>
</tr>
<tr>
<td>7. Means and t Values for Pre and Post Training Body Weight Within and Between Group A and Group B</td>
<td>45</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>1.</td>
<td>Determination of the Aerobic and Anaerobic Thresholds by the Gas Exchange Method</td>
</tr>
<tr>
<td>2.</td>
<td>The Rollerboard</td>
</tr>
<tr>
<td>3.</td>
<td>The Nordic-Trak Arm Ergometer</td>
</tr>
<tr>
<td>4.</td>
<td>Post Training Anaerobic Threshold Determination for Subject K.C.</td>
</tr>
<tr>
<td>5.</td>
<td>Post Training Anaerobic Threshold Determination for Subject B.W.</td>
</tr>
<tr>
<td>6.</td>
<td>Relationship Between Pre Training Work Output and Lat Pull Strength Scores</td>
</tr>
<tr>
<td>7.</td>
<td>Pre and Post Training Strength Means and Standard Deviations</td>
</tr>
<tr>
<td>8.</td>
<td>Pre and Post Training ( \dot{V}O_2 ) max Means and Standard Deviations</td>
</tr>
<tr>
<td>9.</td>
<td>Pre and Post Training Work Output Means and Standard Deviations</td>
</tr>
</tbody>
</table>
Chapter 1

INTRODUCTION

The diagonal stride, double poling, and skating techniques used in cross-country skiing require contributions from both the upper and lower body musculature, which makes cross-country skiing one of the most physically demanding sports. The changes in technique during the last few years have placed a greater emphasis on the use of the upper body. The upper body musculature of many beginning cross-country skiers is often insufficiently conditioned for prolonged work. Therefore, the development of a training program that could increase upper body work output would be especially beneficial for these skiers.

Many studies have investigated the effects of strength and endurance training on lower body work capacity, (endurance time to exhaustion, fatigable work, or absolute endurance), but few studies have investigated the effects of strength or endurance training on upper body work output. Several researchers have shown both lower and upper body strength and endurance training to increase work output (WO). Hickson et al. (17) found a 47% increase in bicycle endurance time to exhaustion following a high-resistance, low-repetition lower body weight training program, while Wilmore et al. (41) reported a 5.2% increase in treadmill endurance time to exhaustion following 10 weeks of endurance circuit weight training (CWT). Anderson and Kearney (2) found increased absolute endurance following nine weeks of high-resistance/low-repetition, moderate-resistance/
medium-repetition, and low-resistance/low-repetition upper body weight training.

Other researchers, however, have found no change in WO following upper body strength or endurance training. Clarke and Stull (7) reported no difference in fatigable work after a seven week arm endurance training program, while Stull and Clarke (36) found no change in fatigable work after six weeks of arm strength training. Based on these studies, the effect of strength and endurance training on upper body WO is unclear.

Investigators who have reported increases in WO following strength or endurance training are not certain of the factors responsible for these changes, but suggested they may be the result of changes in strength, maximal oxygen uptake ($\dot{VO}_2$ max), and/or anaerobic threshold (AT). However, the relationship between WO and strength, $\dot{VO}_2$ max, and AT are presently unclear.

Some studies that reported increases in WO also found increases in strength (2,10,14,15,17,41). But other studies that found increases in strength, did not find increases in WO (7,36).

Hickson, et al. (16) and Magel et al. (23) reported that increases in WO were closely paralleled by increases in $\dot{VO}_2$ max following endurance leg and arm training, respectively. However, Hickson et al. (17) found increases in WO without increases in $\dot{VO}_2$ max following lower body high-resistance weight training.

The AT is defined as "that workload intensity where the rate of lactic acid production exceeds its rate of removal."(21) This level has been found to vary among different athletes and may become a critical factor in determining an athlete's capacity for prolonged work. Astrand and Rodahl (3) observed that endurance athletes could continue to improve
their performances without increasing their $\dot{V}O_2$ max, which could have been due to an increased anaerobic threshold. Presently, however, little is known regarding the effect of various strength or endurance training programs on the AT, or the relationship between WO and the AT.

The effects of upper body strength and endurance CWT on strength, $\dot{V}O_2$ max, AT, and WO during simulated upper body cross-country ski movements are unknown. This lack of conclusive information suggested a need for further investigation.

Statement of the Problem

The purpose of this investigation was to determine the effects of upper body strength and endurance circuit weight training on strength, $\dot{V}O_2$ max, the anaerobic threshold, and work output, during simulated cross-country skiing movements in 18 to 30 year old college men. The secondary purpose of this investigation was to compare the two training methods to find the most effective method for increasing work output. To investigate these problems, the following null hypotheses were constructed:

1. There will be no significant differences in strength, $\dot{V}O_2$ max, AT, or WO, within the strength training group or the endurance training group following training.

2. There will be no significant differences in strength, $\dot{V}O_2$ max, AT, or WO, between groups after training.

The first alternative hypothesis is that strength training will significantly increase strength. The remainder of the alternative hypotheses are nondirectional.
Assumptions

1. Subjects recorded all extra activities as requested.
2. Subjects gave maximum effort during all training and testing sessions.
3. Subjects did not participate in other activities that involved high-resistance upper body movements during the training program on a regular basis.

Definitions

To facilitate understanding of the remainder of this paper, terms that may be confusing or unfamiliar are defined.

Work Output (WO): Absolute endurance, short term endurance time to exhaustion, or fatigable work. Calculated by the formula: \( WO = (\text{Body Weight}) \times (\text{Vertical Rise}) \times (\text{Number of Repetitions}). \)

One Repetition Maximum (1 RM): The maximum weight that can be lifted in one all out effort.

Maximal Oxygen Uptake (\( \dot{VO}_2 \) max): The highest oxygen uptake the individual can attain during physical work (3).

Anaerobic Threshold (AT): The second nonlinear increase--breakaway point--in ventilation (\( \dot{V}_E \)) that also corresponds to a peak or initial decline in the fraction of expired carbon dioxide gas (\( F_{E}CO_2 \)) and a 4 mM/l lactate concentration in the blood. Figure 1 illustrates these criteria.
Figure 1

Determination of the Aerobic and Anaerobic Thresholds by the Gas Exchange Method (● = $\dot{V}_E/\dot{V}O_2$ max; ▲ = $F_{ECO_2}/\dot{V}O_2$ max; AerT = Aerobic Threshold; AT = Anaerobic Threshold)

Chapter 2

REVIEW OF LITERATURE

The nature of the training stimulus usually determines the type of physiological adaptation that will occur in skeletal muscle. Holloszy and Booth (18) reported that two quite distinct adaptive responses can be induced in skeletal muscle by regularly preformed, strenuous exercise. DeLorme (11) made a clear distinction between the relationship of resistance to number of repetitions, stating that high-resistance, low repetition exercises produced strength gains, whereas low-resistance, high-repetition exercises produced endurance gains, and claimed that each type of exercise was mutually exclusive and incapable of producing both results. The findings of Stull and Clarke (36) that fatigable work did not change following high-resistance, low-repetition training, and Nagle and Irwin (25), who found no increases in \( \dot{V}O_2 \text{ max} \) following training, support the claims made by DeLorme. However, since several other investigators (2,13,17,32) found that \( W_0 \) was increased after high-resistance, low-repetition training, and others (2,7,10,15) found that strength was increased after low-resistance, high-repetition training, the DeLorme axiom appears questionable.

There currently exists a great deal of confusion regarding the definitions of what constitutes strength and endurance training, since many studies have labeled a variety of resistances and repetitions as either being strength or endurance training. For the purposes of this
investigation, the definitions of strength and endurance weight training outlined by Sharkey (33) were utilized. He defined strength training as consisting of six to eight repetitions, three days each week, and endurance training as consisting of greater than ten repetitions, three days each week.

Several investigators have reported that WO was increased after strength training (2,13,17,32), while others reported similar results after endurance training (2,12,15,16,23,41). The factors responsible for these changes are unclear, but may be related to parallel increases in strength, VO\(_2\) max, or the AT. In order to better understand the adaptations of strength, VO\(_2\) max, and the AT that typically accompany strength and endurance training, the training protocols and results from a variety of strength and endurance training investigations will be examined. To facilitate continuity and understanding, this review will be divided into the following categories:

- Strength training effects on strength, VO\(_2\) max, and anaerobic threshold
- Endurance training effects on strength, VO\(_2\) max, and anaerobic threshold
- Strength and endurance training effects on work output

Summary

**Strength Training Effects on Strength, VO\(_2\) max, and Anaerobic Threshold**

**Strength**

There is little doubt that weight training is one of the most effective methods for increasing muscular strength. Numerous
investigators have found significant strength increases following a variety of high-resistance, low-repetition weight training programs. Hickson et al. (17) examined the effects of leg training for 10 weeks with a regimen consisting of three to five sets of five repetitions, three days a week, while Thorstensson et al. (37) investigated the effects of a similar leg training program consisting of three sets of six repetitions for eight weeks on strength. Both Hickson et al. and Thorstensson et al. found significant increases in leg strength of 43% and 67%, respectively. MacDougall et al. (22) reported that after five months of arm training, comprised of three to five sets of eight to ten repetitions, arm strength increased 28%. In a six week study by Stull and Clarke (36), consisting of three sets of 10 repetitions of variable resistance, an increase in arm strength was also found.

The optimum number of repetitions that will cause the greatest strength gains seems unclear. Berger (3) compared the strength gains that resulted after performing one set of 2, 4, 6, 8, 10, and 12 repetitions, three days a week for 12 weeks. He concluded that training with less than two repetitions and more than 10 repetitions did not increase strength as rapidly as training with 4, 6, and 8 repetitions. The changes that resulted from upper body weight training with three sets of six to eight RM, two sets of 30-40 RM, and one set of 100-150 RM, were examined by Anderson and Kearney (2). After nine weeks of training three days a week, it was determined that the six to eight RM group increased strength substantially more than either of the other groups. Astrand and Rodahl (3) and Sharkey (33) suggest that three sets of six repetitions may be the optimal weight training protocol for increasing strength. However, this still remains questionable, since O'Shea (27) found equal strength
gains when comparing protocols consisting of three sets of 2-3, 5-6, and 9-10 repetitions. There are a variety of sets and repetition combinations that will increase strength, but an optimal combination appears to be three sets of six RM, three days a week (3,8,33).

**Maximal Oxygen Uptake**

Strength training generally has not been considered a form of exercise that could improve $\dot{V}O_2$ max. Nagle and Irwin (25) reported no change in $\dot{V}O_2$ max following eight weeks of isotonic weight lifting that consisted of two sets of five repetitions, three days a week. This may have been partially due to the frequent and long rest periods that normally accompany typical strength training programs (13). However, even when exercises were organized in a circuit to reduce the amount of rest between exercises, Allen et al. (1) did not find increases in $\dot{V}O_2$ max after a 12 week strength CWT program that consisted of three circuits of eight repetitions, three days each week. Therefore, it seems that strength weight training, even if performed in a circuit, cannot increase cardiovascular function.

**Anaerobic Threshold**

Skinner and McLellan (34) reported there was little information in the literature regarding the influence of various types of exercise on the AT. In addition, the amount and intensity of training necessary to produce changes in the AT is unknown, which makes it difficult to predict what the effect of a high-resistance, low-repetition weight training program would be on the AT.
Endurance Training Effects on Strength, \( \dot{V}O_2 \) max, and Anaerobic Threshold

Strength

Åstrand and Rodahl (3) and Holloszy and Booth (18) both suggested that a light-resistance, high-repetition endurance exercise, such as running, swimming, and cycling, could increase \( \dot{V}O_2 \) max, and the capacity to perform prolonged work without accompanying increases in muscular strength. Jensen and Schultz (19) came to similar conclusions, and state that a weight training program consisting of 20-30 repetitions would increase endurance, but have little effect on strength.

Other investigators, however, have found upper body strength to increase after endurance weight training (2,7,15,41), while DeLateur et al. (10) found increases in lower body strength following similar training procedures. Subjects in the study by Anderson and Kearney (2) were required to perform either two sets of 30-40 RM, or one set of 100-150 RM, three days a week for nine weeks. As a result of training, strength increased by 8.2%, and 4.9% in the 30-40 RM and 100-150 RM groups, respectively. Clarke and Stull (7) also found significant increases in strength after performing one maximum bout of elbow extension exercise, three days a week for seven weeks. Hansen (15) studied the effects of performing one set of 100 repetitions of elbow flexion three days a week at 60% 1 RM for six weeks, and reported a 13.2% increase in dynamic strength. A similar 7.56% strength increase was experienced by subjects in a study conducted by Wilmore et al. (41). Subjects in this study were required to perform three sets of exercises at 40-55% 1 RM for 30 seconds, three days a week for 10 weeks.

DeLateur et al. (10) examined the effects of leg training to
exhaustion with either 55 or 25 pound weights for a total of 15 workout sessions. They found that both groups of subjects increased strength and concluded that their choice of weights (number of pounds) was not of prime importance in strength increases, as long as subjects continued the repetitions to the point of fatigue.

**Maximal Oxygen Uptake**

Ten weeks of an endurance arm cranking training program has been shown to increase \( \dot{V}O_2 \) max (35). However, the effectiveness of CWT on changing \( \dot{V}O_2 \) max is less understood, since previous CWT studies have reported mixed results.

Wilmore et al. (41) conducted a 10 week CWT program involving 16 males. These subjects performed as many repetitions as possible in 30 seconds for three sets at 40–55% 1 RM, and then rested 15 seconds between exercises. After training, Wilmore and his colleagues observed no change in \( \dot{V}O_2 \) max.

Other endurance CWT studies, however, have reported \( \dot{V}O_2 \) max increases after training. Gettman et al. investigated the effectiveness of CWT programs on \( \dot{V}O_2 \) max in three separate studies (12,13,14). The first investigation (12) consisted to 10 weeks of upper and lower body exercises that required subjects to perform two circuits of 15 repetitions at 50% 1 RM, three days a week. The second investigation (13) involved eight weeks of upper and lower body isokinetic training exercises that required subjects to perform two circuits of 10 repetitions at 50% 1 RM during the first four weeks, and two circuits of 15 repetitions at 90% 1 RM during the last four weeks. The third investigation (14) consisted of training the upper and lower body with two circuits of 12 repetitions,
three days a week for 20 weeks. Following training, Gettman et al. found increases in $\dot{V}O_2$ max of 4.7%, 3%, and 7% for each of the three investigations, respectively.

Wilmore et al. (39) measured the effect of 10 weeks of upper and lower body CWT on $\dot{V}O_2$ max. Subjects were required to perform as many repetitions as possible in 30 seconds for three circuits at 40% 1 RM, three days a week. Wilmore and his colleagues noted a 5.9% increase in $\dot{V}O_2$ max after training, and concluded that CWT was an excellent general conditioning activity with a significant aerobic component.

**Anaerobic Threshold**

The effect of endurance training on the AT, as defined by Skinner and McLellan (34), is largely unknown. LaFontaine et al. (20) attempted to answer this question by investigating the effects of 10 weeks of running on the AT. Subjects trained either at low, medium, or high intensity (percentage of $\dot{V}O_2$ max) and at either low (15 miles/week) or high (30 miles/week) quantity, five days each week. The investigators observed that low intensity exercise did not increase the AT, but that medium intensity/high quantity and high intensity/low quantity exercise led to AT increases. LaFontaine et al. concluded there might have been an intensity threshold that was exceeded at higher intensity training.

Astrand and Rodahl (3) noted that endurance athletes could continue to improve their performance without a corresponding increase in $\dot{V}O_2$ max, which could be due to an increased AT. Therefore, even if an endurance CWT program could not increase $\dot{V}O_2$ max, if the AT could be increased by such a training program, it might lead to improvements in work capacity.
**Strength and Endurance Training Effects on Work Output**

The studies that have investigated the effects of strength and endurance training on WO have produced conflicting results. Stull and Clarke (36) found no change in WO after strength training, while others (17,32) found significant increases in WO after similar training. On the other hand, even though endurance training studies have generally reported increases in WO after training (2,13,15,16,23,41), WO has also been found not to change after endurance training (7).

Stull and Clarke (36) examined the effects of strength training on strength and fatigable work in 20 male university students. These students, who completed a six week training program that consisted of three sets of 10 repetitions with varied resistance, did not experience any change in fatigable work, but significantly increased strength.

Other investigators, however, have reported increases in WO following strength training. Anderson and Kearney (2) examined the effects on strength training with three sets of six to eight RM on strength and absolute endurance. Subjects were tested on the bench press for strength using the 1 RM method, and for absolute endurance with a 60 pound weight. After nine weeks of training, subjects increased strength by 20.22%, and absolute endurance by 28%.

Hickson et al. (17) studied the effects of a strength training program on lower body endurance time to exhaustion in nine males. After finishing a 10 week training program that included high-resistance/low-repetition squats, knee flexions and extensions, leg presses, and calf raises, subjects experienced increases of 47% and 12% on endurance time to exhaustion measures obtained during the bicycle and treadmill tests,
respectively. The investigators concluded that high-resistance/low-repetition weight training was capable of dramatically increasing short term endurance without accompanying increases in \( \dot{V}O_2 \) max when the trained muscles were used similarly during testing.

Most of the studies that have examined the effects of endurance training on \( WO \) have reported increases in \( WO \) following training. Clarke and Stull (7) however, did not find increases in fatigable work among 24 male subjects who underwent a seven week program that involved performing one maximum bout of elbow extension at 40 repetitions per minute to exhaustion while using a light resistance. However, the investigators did report increases in strength.

Anderson and Kearney (2) investigated the effects of two endurance weight training regimens that consisted of 30-40 RM and 100-150 RM, on absolute endurance in 28 male subjects. After nine weeks of training, absolute endurance increased by 41% and 39% in the 30-40 RM and 100-150 RM groups, respectively.

Hickson et al. (16) measured endurance time to exhaustion after 10 weeks of lower body endurance training. The training program consisted of performing six high intensity, five minute, bicycle intervals three days per week, and high intensity running for 40 minutes the remaining three days each week. Hickson and his colleagues tested subjects for \( \dot{V}O_2 \) max and endurance time to exhaustion after training and found a 44% increase in \( \dot{V}O_2 \) max that closely paralleled the significant increase in endurance time to exhaustion.

Subjects in a study conducted by Magel et al. (23) improved maximum work time to exhaustion by 38% after 10 weeks of arm interval training. The training program entailed five to six four minute work
bouts with five minute rest periods between intervals, 20 minutes a day, three days a week. These results led Magel and his associates to conclude that arm interval training was effective in increasing work time to exhaustion.

Several CWT programs have also reported increased W0 following endurance training (12,13,41). Gettman et al. explored the effects of CWT on endurance time to exhaustion, \( \dot{V}O_2 \) max, and strength in two separate investigations. In the first study (12), subjects performed both upper and lower body exercises involving two sets of 15 repetitions at 50% 1 RM, three days a week for 20 weeks. In the second study (13), subjects were required to perform eight weeks of upper and lower body exercises that consisted of two circuits of 10-15 repetitions for 30 second work bouts. During the first four weeks of training, subjects performed 10 repetitions at 50% 1 RM, whereas during the last four weeks, subjects performed 15 repetitions at 90% 1 RM. The first investigation yielded increases of 7.5%, 4.7%, and 17.6% for endurance time to exhaustion, \( \dot{V}O_2 \) max, and strength, respectively, while the second investigation yielded similar increases—3.5%, 3%, and 12.3%—for the same corresponding measures.

Wilmore et al. (41) conducted a 10 week CWT program with 16 males. Subjects performed three circuits involving a variety of upper and lower body exercises at 40-50% 1 RM for 30 seconds, with 15 seconds rest between exercises. After recording significant strength improvements, a 5.2% increase in endurance time to exhaustion, and no increase in \( \dot{V}O_2 \) max, Wilmore and his associates concluded that the noted increase in endurance time to exhaustion could have been due to an increased anaerobic capacity, and recommended this possibility be further explored.
There appears to be little doubt that one of the most effective ways to increase muscular strength is through weight training. The greatest strength gains seem to be achieved by performing three sets of high-resistance exercise for six repetitions, three days a week, although other regimens that involve similar resistances and less than 10 repetitions were also found to significantly increase strength. Extreme endurance activities, like running, were found to be largely ineffective for increasing strength. The effectiveness of endurance weight training programs involving 10 or more repetitions on increasing muscular strength remains questionable, since some investigators reported strength increases after training (2,7,10,15,41), while others suggested that endurance weight training did little to increase muscular strength (19).

It has been well documented that interval and long duration activities increase $\dot{V}O_2$ max, but the effectiveness of endurance weight training for changing $\dot{V}O_2$ max remains questionable. No change in $\dot{V}O_2$ max was reported in one endurance CWT program (41), while small, but significant, increases in $\dot{V}O_2$ max were reported in other endurance CWT programs (12,13,14,39). Strength training, on the other hand, does not seem capable of improving $\dot{V}O_2$ max, even if performed in a circuit regimen. However, Byrd and Barton (6) suggested that some of the nonsignificant findings might be due to the use of inappropriate and nonspecific tests to evaluate $\dot{V}O_2$ max. In order to get a true indication of whether or not weight training can result in significant increases in aerobic capacity, $\dot{V}O_2$ max must be evaluated with the specific muscles trained.
Although the effects of various training programs on the AT are largely unknown, it appears that a certain intensity level must be exceeded in order to increase the AT. Whether or not strength or endurance weight training can exceed this intensity to change the AT is presently unknown. By employing two weight training regimens of different resistances and repetitions, this question may be better understood.

The effect of strength and endurance training on WO remains unclear. Several investigators (7,36) reported no change in WO following strength and endurance training, while others found both strength and endurance training to effectively increase WO (2,12,15,16,16,23,32,41). From these studies reporting increases in WO, the factors responsible for these increases were unknown, but may have been due to parallel increases in strength, $\dot{V}O_2$ max, or the AT. It is unclear whether strength or endurance weight training would be more effective for increasing WO. Only one previous study (2) has compared the effects of the two regimens on absolute endurance and found no significant differences after strength or endurance weight training. Further investigation is needed to determine if either training regimen is more effective in increasing WO. This study focused on the effects of upper body strength and endurance CWT on strength, $\dot{V}O_2$ max, AT, and WO.
Chapter 3

METHODS AND PROCEDURES

Subjects

Twenty-two male volunteers from Health and Physical Education classes at the University of Montana during Winter Quarter 1982 were recruited to participate in the study. The subjects met the following criteria:

1. Male, 18 to 30 years old.
3. No upper body weight training within the previous month.
4. Not presently engaged in cross-country skiing, swimming, or any other activity that involves resisted upper body movements on a regular basis.

The 22 volunteer subjects were randomly assigned to one of two groups: Group A (strength training, N = 11), or Group B (endurance training, N = 11). Physical characteristics of the 20 subjects who completed this study are presented in Table 1.

Research Design

A pre-test, post-test design was used in order to determine the effects of two separate training methods on various parameters before and after training. A control group was not needed because this study intended to investigate the differences within and between the two
Table 1

Physical Characteristics of the Subjects

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R.R.</td>
<td>25</td>
<td>172.09</td>
<td>76.36</td>
</tr>
<tr>
<td>B.P.</td>
<td>28</td>
<td>187.96</td>
<td>97.27</td>
</tr>
<tr>
<td>K.C.</td>
<td>27</td>
<td>170.82</td>
<td>71.82</td>
</tr>
<tr>
<td>S.S.</td>
<td>18</td>
<td>182.25</td>
<td>66.59</td>
</tr>
<tr>
<td>B.B.</td>
<td>19</td>
<td>168.91</td>
<td>57.27</td>
</tr>
<tr>
<td>B.S.</td>
<td>19</td>
<td>179.71</td>
<td>71.59</td>
</tr>
<tr>
<td>R.M.</td>
<td>19</td>
<td>180.98</td>
<td>73.64</td>
</tr>
<tr>
<td>M.L.</td>
<td>18</td>
<td>177.17</td>
<td>71.36</td>
</tr>
<tr>
<td>M.S.</td>
<td>20</td>
<td>183.52</td>
<td>79.55</td>
</tr>
<tr>
<td>D.K.</td>
<td>21</td>
<td>186.06</td>
<td>72.73</td>
</tr>
<tr>
<td>M.C.</td>
<td>22</td>
<td>173.99</td>
<td>71.82</td>
</tr>
<tr>
<td>P.W.</td>
<td>26</td>
<td>185.42</td>
<td>79.55</td>
</tr>
<tr>
<td>B.W.</td>
<td>19</td>
<td>174.63</td>
<td>67.73</td>
</tr>
<tr>
<td>S.M.</td>
<td>28</td>
<td>178.44</td>
<td>80.00</td>
</tr>
<tr>
<td>J.P.</td>
<td>23</td>
<td>167.01</td>
<td>60.00</td>
</tr>
<tr>
<td>W.H.</td>
<td>21</td>
<td>166.37</td>
<td>57.27</td>
</tr>
<tr>
<td>B.K.</td>
<td>19</td>
<td>174.63</td>
<td>75.45</td>
</tr>
<tr>
<td>J.F.</td>
<td>24</td>
<td>173.36</td>
<td>71.59</td>
</tr>
<tr>
<td>P.J.</td>
<td>19</td>
<td>175.26</td>
<td>65.45</td>
</tr>
<tr>
<td>D.V.</td>
<td>23</td>
<td>187.96</td>
<td>86.36</td>
</tr>
<tr>
<td>Means</td>
<td>21.9</td>
<td>177.33</td>
<td>72.67</td>
</tr>
</tbody>
</table>
training groups, and not the difference between training and not training.

**Pre Training**

Pre testing was conducted in the Weight Room and Human Performance Laboratory at the University of Montana, from January 11 to January 15, 1982. Subjects scheduled two appointments during that time, in which they were tested for strength, WO, $\dot{V}O_2$ max, and AT. Subjects were instructed not to eat or drink any fluids, other than water, for a minimum of two hours before reporting for testing, and not to exercise the upper body on the day of the tests.

**Strength Measurement**

Subjects signed an Informed Consent Form and completed a brief Medical History (Appendix A) before being tested for maximum upper body strength. The 1 RM method described by Berger (4) was used with the following protocol:

1. Subjects were given approximately one to two minutes to perform general stretching and warm up exercises.

2. Subjects were given five to six warm up trials prior to attempting to lift as much weight as possible in one repetition. During the warm up, subjects performed each exercise with a moderate resistance consisting of 80-100 pounds for the bench press, and 30-50 pounds for the lat pull, tricep extension, and bicep curl. Subjects were instructed in the proper technique for each exercise during that time.

3. Subjects attempted to lift as much weight as possible in one repetition for the bench press, lat pull, tricep extension,
and bicep curl. If the subject was successful in a particular lift, either five or ten pounds was added (depending on the ease of the previous lift) on repeated trials until the subject could not lift the weight one time through the full range of motion. The weight that was last successfully lifted was recorded as the 1 RM.

**Work Output Measurement**

After subjects were tested for strength during the first appointment, they were tested for upper body WO on a rollerboard (Illustrated in Figure 2, Construction details in Appendix B). The rollerboard was found to have face validity and be a reliable (r = .91) laboratory testing instrument for determining work output (26). Work Output was calculated using the formula: $WO = (\text{Body Weight}) \times (\text{Vertical Rise}) \times (\text{Number of Repetitions})$. The following protocol was used:

1. Prior to each test, a thin layer of parafin wax was rubbed on the ramp and smoothed with a wax scraper.
2. Subjects were weighed and measured for height (wearing shoes) on a Medic-Detecto scale.
3. Subjects were instructed in the proper rollerboard technique. They were told to lay in a prone position on the rolling board and adjust their position on the board so their arms were fully extended and the back wheels of the rolling board rested against the bottom ridge of the ramp. Subjects were instructed to pull and extend their arms straight down and back, while allowing only a slight elbow bend when rolling up the ramp. Subjects were also instructed to allow themselves to roll down the ramp without lowering themselves
Figure 2

The Rollerboard
eccentrically.
4. Subjects were given one minute to perform general stretching and warm up exercises prior to testing.
5. Subjects were given three to four warm up trials on the rollerboard prior to testing. The investigator made any corrections in technique during that time to insure standardization.
6. With a Franz Metronome set at 72 beats per minute (bpm), subjects performed as many repetitions as possible by rolling up the incline ramp above a mark that was a vertical rise of 27 in. (0.686 m), or 87.5 in. (2.22m) from the bottom ridge of the ramp. Subjects rolled up the ramp every two beats, and rolled down the ramp every two beats.
7. The test was terminated when subjects could no longer keep pace with the metronome, or could no longer roll above the 27 in. vertical tape mark.
8. While the investigator helped subjects keep pace with the metronome and insured each repetition was completed above the tape mark, an assistant recorded the number of repetitions completed.

Maximum Oxygen Uptake and Anaerobic Threshold Measurements

Subjects reported to the Human Performance Laboratory for the second appointment at which time \( \dot{V}O_2 \) max, and AT were determined using a Nordic-Trak Arm Ergometer that simulated upper body diagonal stride poling movements (Illustrated in Figure 3, Construction details in Appendix C). \( \dot{V}O_2 \) max, \( \dot{V}_E \), and \( F_ECO_2 \) were measured by a Beckman Metabolic Measurement
Figure 3

The Nordic-Trak Arm Ergometer
Cart. This instrument has been found to be a valid (40) and reliable (31) measuring device. \( \dot{V}O_2 \text{ max} \) was determined to be the point where oxygen uptake leveled off or decreased with an increased workload, or when subjects could no longer continue. The primary determinant of the AT was the second nonlinear "breakaway" increase in \( \dot{V}_E \) when \( \dot{V}_E \) was plotted against the percentage of \( \dot{V}O_2 \text{ max} \). The percentage of \( \dot{V}O_2 \text{ max} \) and percentage of \( F_ECO_2 \) were plotted against each other as a secondary criteria for calculating the AT, with the peak or initial decline being considered the AT. This method has been described in detail elsewhere (34). The following protocol was utilized during the test:

1. The Beckman Cart was calibrated before and after testing each subject.

2. The testing procedure was explained to subjects when they arrived at the laboratory.

3. Subjects were weighed on a Continental Scale. (The Continental Scale was used for this test instead of the Medic-Detecto scale because it was more accessible to the testing site)

4. Disposable electrodes were placed on the subject's chest in the standard V-5 configuration.

5. Subjects were instructed in the proper arm pulling technique and given a brief 15 second period of practice prior to testing.

6. Electrode leads were connected to the subject's chest electrodes, and the subject was fitted with a one-way breathing valve, mouthpiece, and noseplug.

7. Subjects began to exercise at a moderate tempo of 80-88 bpm
with no resistance, while the investigator matched the chosen tempo with a Franz metronome. Oxygen uptake, \( \dot{V}_E \) and \( F_{E}CO_2 \) were measured and recorded every 30 seconds by the Beckman Cart.

8. During the first five minutes of the test, the workload was increased each minute by turning the knob on the Nordic-Trak Ergometer one-half turn to the right. The speed remained the same during the first five minutes. After five minutes, subjects were given the choice of whether to increase the workload by increasing the resistance of the Nordic-Trak Ergometer, or the speed of the metronome.

9. When the investigator subjectively determined that subjects were fatigued and approaching their max, they were asked to pull as hard and fast as possible until they could no longer continue.

10. The test was terminated when subjects could no longer continue or when \( \dot{V}O_2 \) leveled off or decreased with an increased workload.

**Training Procedure**

All subjects trained three days each week for a period of seven weeks. Subjects were required to record attendance, number of repetitions and weight lifted for each exercise during each training session, as well as all physical activities performed outside the realm of the study. Subjects who missed more than a total of three workouts, and did not make them up within a week following the absence, were dropped from the study. At the beginning of the training program, the investigator
demonstrated proper technique for each exercise, and supervised workouts in order to assure standardization of training procedures and to answer questions from the subjects. After the first four weeks, the investigator did not supervise each training session, but, maintained close contact with subjects until the end of the study. Subjects performed the following CWT training regimens depending upon the group assigned to:

**Group A (strength)**

- Five to eight repetitions
- Three circuits, three days a week
- No rest between exercises, three minute rests between circuits
- The exercises were performed in this order: bench press, lat pull, tricep extension, bicep curl, and arm pulls.

**Group B (endurance)**

- 15-25 Repetitions (for the first four exercises)
- Three circuits, three days a week
- No rest between exercises, three minute rests between circuits
- The exercises were performed in this order: bench press, lat pull, tricep extension, bicep curl, and arm pulls.
- The following schedule of repetitions was followed for the
arm pulls:

<table>
<thead>
<tr>
<th></th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
<th>5th</th>
<th>6th</th>
<th>7th</th>
<th>Weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Circuit</td>
<td>60</td>
<td>80</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Second Circuit</td>
<td>60</td>
<td>75</td>
<td>90</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Third Circuit</td>
<td>50</td>
<td>70</td>
<td>85</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

When subjects in Groups A or B could perform more than eight or 25 repetitions, respectively, in any exercise (excluding arm pulls) the resistance was increased five pounds. Subjects in both groups were instructed to lift to the point of fatigue for each exercise instead of the traditional 30 second CWT work bouts. Although the bicep muscles are not actively involved to any great extent during upper body skiing movements, the bicep curl was included in this training program to balance the heavy work being done by the triceps. Appendix D illustrates the five exercises used during training.

**Post Testing**

Following seven weeks of training, subjects scheduled two testing sessions within a week following the last training session. Subjects were tested for strength, $\dot{V}O_2$ max, AT, and WO using the same testing protocols described in the pre testing session.

**Statistical Treatments**

A t-test for correlated groups was used to examine differences between pre and post test scores within each group, while a t-test for independent groups was used to examine pre and post test differences.
between the strength and endurance groups. The Pearson Product Moment Correlation Coefficient was used for all correlational analyses. The level of significance was set at the .05 level.
Chapter 4

RESULTS

The effects of seven weeks of upper body strength and endurance CWT on strength, \( \dot{VO}_2 \) max, and WO, within Groups A and B were determined using a t-test for correlated means. The within group strength changes for Group A were analyzed using a one-tailed test, whereas all other parameters within each group were analyzed using a two-tailed t-test. A two-tailed t-test for independent groups was used to compare the pre and post training means between groups for each of the same parameters. The significance level was set at .05 for all statistical treatments. The one-tailed t value needed for significant strength increases in Group A was 1.812 (10df). The t values needed for significance for all other parameters within Groups A and B were 2.228 (10 df), and 2.306 (8 df), respectively. The t value needed for significance between groups was 2.101 (18 df).

Twenty-two male subjects volunteered to participate in the seven week CWT program, but, final data was collected for only 20 subjects who fulfilled all attendance, training, and testing requirements. One subject withdrew from the University before the first training session, while the other subject sustained a shoulder injury, unrelated to the study, that prevented him from completing all the final tests. Both subjects had been assigned to Group B.

Tables 2 and 3 present the pre and post training means, standard
deviations, mean differences, percentage changes, and the t values for strength, \( \dot{VO}_2 \) max, and WO, for subjects in Group A (strength) and Group B (endurance), respectively. The differences between Groups A and B in pre and post training means and t values for strength, \( \dot{VO}_2 \) max, and WO measures are presented in Table 4. The individual data for all parameters measured are contained in Appendix E for Group A, and Appendix F for Group B.

**Strength**

All of the mean strength values for the bench press, lat pull, tricep extension, and bicep curl showed significant increases in both groups after training. In order to get an indication of overall strength improvement, total strength (mean of the sum of all four strength scores) was also calculated. Total strength was also found to be significantly increased in both groups after training. The mean strength percentage differences in each of the four exercises and total strength were 17%, 19%, 18%, 20%, and 18.5% for Group A, and 7%, 19%, 15%, 9%, and 11% for Group B, respectively.

The 11 subjects in Group A all increased total strength. The largest increase of 30% was experienced by subject P.W., and the smallest increase of 9.6% was experienced by subject D.K. Based on pre and post 1 RM strength scores, most subjects in Group A increased strength on each exercise, but, subjects D.K., W.H., and J.P. were exceptions. Subjects D.K. and W.H. failed to increase strength in the lat pull and bench press, respectively, while the 1 RM tricep extension test for subject J.P. indicated a decrease in tricep extension strength.

All nine of the subjects in Group B increased total strength.
Table 2

Effects of Strength Circuit Weight Training Within Group A (N = 11)

<table>
<thead>
<tr>
<th></th>
<th>Pre mean (SD)a</th>
<th>Post mean (SD)</th>
<th>Mean difference</th>
<th>Percent change</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bench Press (lbs)</strong></td>
<td>150.0 (32.94)</td>
<td>175.9 (36.32)</td>
<td>25.91</td>
<td>+ 17.0</td>
<td>- 7.16b</td>
</tr>
<tr>
<td><strong>Lat Pull (lbs)</strong></td>
<td>75.5 (9.07)</td>
<td>90.0 (12.45)</td>
<td>14.55</td>
<td>+ 19.0</td>
<td>- 7.90b</td>
</tr>
<tr>
<td><strong>Tricep Ext. (lbs)</strong></td>
<td>70.0 (14.32)</td>
<td>82.7 (15.06)</td>
<td>12.73</td>
<td>+ 18.0</td>
<td>- 3.55b</td>
</tr>
<tr>
<td><strong>Bicep Curl (lbs)</strong></td>
<td>75.5 (13.50)</td>
<td>90.9 (14.63)</td>
<td>15.46</td>
<td>+ 20.0</td>
<td>- 9.82b</td>
</tr>
<tr>
<td><strong>Total Strength</strong></td>
<td>370.91 (59.10)</td>
<td>439.55 (70.87)</td>
<td>68.64</td>
<td>+ 18.5</td>
<td>-11.04b</td>
</tr>
<tr>
<td><strong>VO(_2) max</strong></td>
<td>2.74 (.48)</td>
<td>2.93 (.48)</td>
<td>.19</td>
<td>+ 7.0</td>
<td>- 1.92</td>
</tr>
<tr>
<td><strong>VO(_2) max</strong></td>
<td>38.17 (3.56)</td>
<td>40.86 (5.75)</td>
<td>2.69</td>
<td>+ 7.0</td>
<td>- 1.58</td>
</tr>
<tr>
<td><strong>Work Output</strong></td>
<td>1572.64 (386.60)</td>
<td>2424.58 (438.87)</td>
<td>851.94</td>
<td>+ 54.0</td>
<td>- 9.75c</td>
</tr>
</tbody>
</table>

a Standard deviation

b \(t > 1.812\) significant at \(p = .05\)

c \(t > 2.228\) significant at \(p = .05\)

d Mean of the sum of bench press, lat pull, tricep extension, and bicep curl
<table>
<thead>
<tr>
<th></th>
<th>Pre mean (SD)a</th>
<th>Post mean (SD)a</th>
<th>Mean difference</th>
<th>Percent change</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bench Press (lbs)</td>
<td>171.10 (79.88)</td>
<td>183.89 (56.61)</td>
<td>12.79</td>
<td>+ 7.0</td>
<td>- 3.12b</td>
</tr>
<tr>
<td>Lat Pull (lbs)</td>
<td>77.22 (15.43)</td>
<td>91.67 (20.77)</td>
<td>14.45</td>
<td>+ 19.0</td>
<td>- 5.36b</td>
</tr>
<tr>
<td>Tricep Ext. (lbs)</td>
<td>71.11 (23.29)</td>
<td>81.66 (23.72)</td>
<td>10.55</td>
<td>+ 15.0</td>
<td>- 8.10b</td>
</tr>
<tr>
<td>Bicep Curl (lbs)</td>
<td>83.89 (24.85)</td>
<td>91.67 (24.87)</td>
<td>7.78</td>
<td>+ 9.0</td>
<td>- 4.60b</td>
</tr>
<tr>
<td>Total Strength c (lbs)</td>
<td>403.33 (124.50)</td>
<td>448.89 (122.90)</td>
<td>45.56</td>
<td>+ 11.0</td>
<td>- 15.50b</td>
</tr>
<tr>
<td>VO₂ max (l·min⁻¹)</td>
<td>2.65 (.54)</td>
<td>2.83 (.36)</td>
<td>.18</td>
<td>+ 7.0</td>
<td>- 1.82</td>
</tr>
<tr>
<td>VO₂ max (ml·kg⁻¹·min⁻¹)</td>
<td>35.10 (4.13)</td>
<td>37.83 (4.33)</td>
<td>2.73</td>
<td>+ 8.0</td>
<td>- 1.98</td>
</tr>
<tr>
<td>Work Output (kg·m⁻¹)</td>
<td>1673.24 (507.75)</td>
<td>2914.23 (904.32)</td>
<td>1240.99</td>
<td>+ 74.0</td>
<td>- 7.06b</td>
</tr>
</tbody>
</table>

aStandard deviation
b t > 2.306 significant at p = .05
cMean of the sum of bench press, lat pull, tricep ext., and bicep curl.
Table 4

Differences in Pre and Post Training Means and t Values for Strength, \( \dot{V}O_2 \) max, and Work Output

<table>
<thead>
<tr>
<th></th>
<th>Group A Pre mean (SD)a</th>
<th>Group B Pre mean (SD)</th>
<th>Pre t</th>
<th>Group A Post mean (SD)</th>
<th>Group B Post mean (SD)</th>
<th>Post t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bench Press (lbs)</td>
<td>150.00 (32.94)</td>
<td>171.10 (79.88)</td>
<td>-.963</td>
<td>175.91 (36.32)</td>
<td>183.89 (56.61)</td>
<td>-.382</td>
</tr>
<tr>
<td>Lat Pull (lbs)</td>
<td>75.45 (9.07)</td>
<td>77.22 (15.43)</td>
<td>-.319</td>
<td>90.00 (12.45)</td>
<td>91.67 (20.77)</td>
<td>-.222</td>
</tr>
<tr>
<td>Tricep Ext. (lbs)</td>
<td>70.00 (14.32)</td>
<td>71.11 (23.29)</td>
<td>-.131</td>
<td>82.73 (15.06)</td>
<td>81.66 (23.72)</td>
<td>+.122</td>
</tr>
<tr>
<td>Bicep Curl (lbs)</td>
<td>75.45 (13.50)</td>
<td>83.89 (24.85)</td>
<td>-.968</td>
<td>90.91 (14.63)</td>
<td>91.67 (24.87)</td>
<td>-.085</td>
</tr>
<tr>
<td>Total Strengthb (lbs)</td>
<td>370.91 (59.07)</td>
<td>439.55 (70.87)</td>
<td>-1.420</td>
<td>403.33 (124.50)</td>
<td>448.89 (122.90)</td>
<td>-.213</td>
</tr>
<tr>
<td>( \dot{V}O_2 ) max (l·min(^{-1}))</td>
<td>2.74 (.48)</td>
<td>2.65 (.54)</td>
<td>-.002</td>
<td>2.93 (.48)</td>
<td>2.83 (.36)</td>
<td>+.530</td>
</tr>
<tr>
<td>( \dot{V}O_2 ) max (ml·kg(^{-1})·min(^{-1}))</td>
<td>38.17 (3.56)</td>
<td>35.10 (4.13)</td>
<td>+1.912</td>
<td>40.86 (5.75)</td>
<td>37.83 (4.33)</td>
<td>+1.305</td>
</tr>
<tr>
<td>Work Output (kg·m(^{-1}))</td>
<td>1572.64 (386.60)</td>
<td>1673.24 (507.75)</td>
<td>-.583</td>
<td>2424.58 (438.87)</td>
<td>2914.23 (904.32)</td>
<td>-1.586</td>
</tr>
</tbody>
</table>

\( ^a \)Standard deviation

\( ^b \)Mean of the sum of bench press, lat pull, tricep ext., and bicep curl.

\( t \geq 2.101 \) significant at \( p = .05 \) between groups A and B
Subject K.C. increased total strength by 19%, the most of any subject, whereas subject B.S. increased total strength by 8%, the smallest strength gain in Group B. Subjects R.R. and B.B. did not increase lat pull strength, while the 1 RM bench press test for subject B.P. indicated that bench press strength decreased 4.8% after training.

There was no significant difference between subjects in Groups A or B for either pre or post training total strength. Even though the 18.5% increase in total strength for Group A was larger than the 11% increase experienced by Group B, these differences were not statistically significant. The same pattern between groups was exhibited between pre and post scores in the bench press, lat pull, tricep extension, and bicep curl.

Maximal Oxygen Uptake

Group A experienced a .19 l·min⁻¹ (7%) and a 2.69 ml·kg⁻¹·min⁻¹ (7%) increase in $\dot{V}O_2$ max, while Group B experienced a .18 l·min⁻¹ (7%) and a 2.73 ml·kg⁻¹·min⁻¹ (8%) increase in $\dot{V}O_2$ max after training. None of these changes, however, were found to be statistically significant.

Six of the 11 subjects in Group A increased $\dot{V}O_2$ max slightly, while the other five subjects decreased $\dot{V}O_2$ max (ml·kg⁻¹·min⁻¹) slightly after training. Subject W.H. increased $\dot{V}O_2$ max by 34%, the most of any subject within Group A, whereas subjects D.K. and J.P. decreased $\dot{V}O_2$ max by 9.2% and 10.9%, respectively, the most of any subjects in Group A.

Maximal oxygen uptake (ml·kg⁻¹·min⁻¹) increased slightly in five subjects, decreased slightly in three subjects, and remained the same in one subject within Group B. The range of percentage change for $\dot{V}O_2$ max was from an increase of 22.7% for subject S.S., to a decrease of 9.4% in
subject B.P. Two other subjects, B.B. and M.S. also experienced large increases in $\dot{V}O_2$ max of 21.2% and 20.8% respectively.

There was no significant difference in $\dot{V}O_2$ max, when expressed in $l\cdot min^{-1}$ or $ml\cdot kg^{-1}\cdot min^{-1}$, between Groups A and B. Neither of the post test t values between groups of .530 ($l\cdot min^{-1}$) and 1.305 ($ml\cdot kg^{-1}\cdot min^{-1}$) were statistically significant.

**Anaerobic Threshold**

In this study, it was difficult to plot and detect the AT accurately and consistently. Two departures from linearity of $\dot{V}E$ were not evident when these data were analyzed. Only one point of non-linearity was evident and this was assumed to be the AT. In most instances, when $F_{ECO_2}$ was plotted against the percentage of $\dot{V}O_2$ max, the peak of $F_{ECO_2}$ correlated well with the one nonlinear $\dot{V}E$ increase. From this information, the AT was determined. Figure 4 illustrates the post test $\dot{V}E$ and $F_{ECO_2}$ curves used to calculate the AT for subject K.C. of Group B -- this was one of the plots where the AT was more easily determined.

The AT could not be determined for subjects M.C., B.W., and B.K. in Group A, and subjects R.R. and M.S. in Group B. In these subjects, the rise in $\dot{V}E$ relative to the percentage of $\dot{V}O_2$ max, was nonsystematic and did not produce even one clear ventilatory breakaway point, which made it impossible to determine the AT. The post test AT determination for subject B.W. from Group A illustrates this point in Figure 5.

The individual assumed AT values are presented in Appendix E for subjects in Group A and in Appendix F for subjects in Group B. However, due to the confusion surrounding the definition of the AT and the
Figure 4

Post Training Anaerobic Threshold Determination for Subject K.C. (● = $\dot{V}_E/\dot{V}O_2$ max; ▲ = $F_{CO_2}/\dot{V}O_2$ max)
Post Training Anaerobic Threshold Determination for Subject B.W. ($\bullet = \dot{V}_E/\dot{V}O_2 \text{ max}; \▲ = \dot{F}_{CO_2}/\dot{V}O_2 \text{ max}$)

Note: The AT could not be determined from this plot.
inability to detect even one nonlinear ventilatory breakaway point in a large number of subjects, the results were difficult to interpret. These difficulties necessitated that the AT results be excluded from statistical analyses and interpretation.

Work Output

Changes in Work Output Within and Between Groups

The changes in WO within both Group A and Group B were statistically significant. The mean WO change for Group A was 851.94 kg·m⁻¹ or 54%, while the mean change for Group B was 1240.99 kg·m⁻¹ or 74%.

All subjects in both groups experienced increases in WO after training. The percentage improvement for subjects in Group A ranged from the 108% increase in subject W.H. to the 26.6% increase in subject M.C. The percentage improvement for subjects in Group B ranged from the 112.6% increase in subject M.L. to the 31.1% increase in subject R.R. Two other subjects from Group B, K.C. and M.S., also experienced large WO increases of 107.9% and 105.8%, respectively. The 72.1% increase by subject B.P. from Group B was also very substantial, since his pre training level of 2803.41 kg·m⁻¹ was almost twice as large as the pre training levels of many other subjects in Group B.

Even though both Groups A and B significantly increased WO by 54% and 74%, respectively, the differences between groups were not statistically significant. The t value between groups was -1.583 before training, and -1.586 after training.

Correlations Between Work Output and Strength and VO₂ max

The Pearson Product Moment Correlation Coefficient was used to
analyze the relationship between WO, strength, and \( \dot{V}O_2 \) max. Because of the confusion surrounding the AT measurements, the relationship between WO and the AT was not determined. The statistical significance level was set at .05 for all correlational analyses. The two-tailed, Pearson \( r \) values needed for statistical significance within Group A and Group B were \( r = .602 \) (9 df), and \( r = .666 \) (7 df), respectively.

The correlations between the pre training WO and the pre training strength and \( \dot{V}O_2 \) max are presented in Table 5. Table 6 presents the correlations between the same variables after training.

The correlation of \( r = .64 \) between pre training WO and pre training bicep curl strength was statistically significant in Group A, whereas all other correlations between pre training WO and strength and \( \dot{V}O_2 \) max were positive, but, not significant. When all subjects in Group B were included in the correlational analyses between pre training levels of WO and strength and \( \dot{V}O_2 \) max, there appeared to be a significant relationship between WO and each of the strength measures, but, no significant relationship between WO and \( \dot{V}O_2 \) max. After graphing the correlations, however, it was clear that when subject B.P. was included in the correlations within Group B, all the correlations were extremely elevated. The scatterplot in Figure 6 substantiates this point by illustrating the relationships between pre training WO and lat pull strength for both groups. The correlation of \( r = .48 \) for Group A was accurately reflected in the plot, but, the correlation for Group B did not appear to be \( r = .84 \). All other pre and post training correlations between WO, strength, and \( \dot{V}O_2 \) max that included subject B.P. were similarly elevated. The pre and post training correlations, therefore, without subject B.P. were calculated and reported. When subject B.P. was not included in the
Table 5

Pre Training Correlations Between Work Output, Strength, and $\dot{V}O_2$ max

<table>
<thead>
<tr>
<th></th>
<th>Group A WO</th>
<th>Group B WO</th>
<th>Combined A + B WO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bench Press</td>
<td>.13</td>
<td>.86</td>
<td>.62</td>
</tr>
<tr>
<td></td>
<td>*(.51)</td>
<td>*(.54)</td>
<td>*(.49)</td>
</tr>
<tr>
<td>Lat Pull</td>
<td>.48</td>
<td>.84</td>
<td>.71</td>
</tr>
<tr>
<td></td>
<td>*(.64)</td>
<td>*(.67)</td>
<td>*(.41) b</td>
</tr>
<tr>
<td>Tricep Ext.</td>
<td>.30</td>
<td>.90</td>
<td>.67</td>
</tr>
<tr>
<td></td>
<td>*(.64)</td>
<td>*(.64)</td>
<td>*(.41)</td>
</tr>
<tr>
<td>Bicep Curl</td>
<td>.64</td>
<td>.89</td>
<td>.80</td>
</tr>
<tr>
<td></td>
<td>*(.64)</td>
<td>*(.64)</td>
<td>*(.63) b</td>
</tr>
<tr>
<td>Total Strength</td>
<td>.37</td>
<td>.78</td>
<td>.65</td>
</tr>
<tr>
<td></td>
<td>*(.50)</td>
<td>*(.50)</td>
<td>*(.35)</td>
</tr>
<tr>
<td>$\dot{V}O_2$ max</td>
<td>.50</td>
<td>.57</td>
<td>.58</td>
</tr>
<tr>
<td>(l.min$^{-1}$)</td>
<td>*(.02)</td>
<td>*(.36)</td>
<td></td>
</tr>
<tr>
<td>$\dot{V}O_2$ max</td>
<td>.11</td>
<td>.42</td>
<td>.20</td>
</tr>
<tr>
<td>(mL.kg$^{-1}$.min$^{-1}$)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Without subject B.P.

$^a r \geq .602$ significant at $p = .05$ for Group A

$^b r \geq .444$ significant at $p = .05$ for Combined Group

$^c r \geq .666$ significant at $p = .05$ for Group B
Table 6
Post Training Correlations Between Work Output, Strength, and $\dot{\text{VO}_2}$ max

<table>
<thead>
<tr>
<th></th>
<th>Group A WO</th>
<th>Group B WO</th>
<th>Combined A + B WO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bench Press</td>
<td>-.05</td>
<td>.84</td>
<td>.54 *(.24)</td>
</tr>
<tr>
<td></td>
<td>*(.60)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lat Pull</td>
<td>.48</td>
<td>.87</td>
<td>.73 *(.45)</td>
</tr>
<tr>
<td></td>
<td>*(.60)</td>
<td></td>
<td>*(.23)</td>
</tr>
<tr>
<td>Tricep Ext.</td>
<td>.25</td>
<td>.79</td>
<td>.63 *(.23)</td>
</tr>
<tr>
<td></td>
<td>*(.52)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicep Curl</td>
<td>.31</td>
<td>.79</td>
<td>.63 *(.23)</td>
</tr>
<tr>
<td></td>
<td>*(.34)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Strength</td>
<td>.18</td>
<td>.87</td>
<td>.66 *(.29)</td>
</tr>
<tr>
<td></td>
<td>*(.59)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\dot{\text{VO}_2}$ max (l·min$^{-1}$)</td>
<td>.41</td>
<td>.86</td>
<td>.50 *(.35)</td>
</tr>
<tr>
<td></td>
<td>*(.64)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\dot{\text{VO}_2}$ max (ml·kg$^{-1}$·min$^{-1}$)</td>
<td>-.23</td>
<td>.32</td>
<td>-.05</td>
</tr>
</tbody>
</table>

* Without subject B.P.

a $r \geq .444$ significant at $p = .05$ for Combined Group

$r \geq .602$ significant at $p = .05$ for Group A

$r \geq .666$ significant at $p = .05$ for Group B
Figure 6

Relationship Between Pre Training Work Output and Lat Pull Strength Scores (● = Group A; ▲ = Group B)
data analyses, all correlations between WO and strength for Group B were positive, but, not significant.

All correlations between post training WO, strength, and \( \dot{V}O_2 \) max in Group A were not significant. The correlations between WO and bench press, and \( \dot{V}O_2 \) max (ml·kg\(^{-1}\)·min\(^{-1}\)) were slightly negative, while the correlations between WO and the remainder of the strength and \( \dot{V}O_2 \) max variables were positive after training. There were positive relationships between all of the post training WO, strength, and \( \dot{V}O_2 \) max measures in Group B, but, none were significant.

In order to further investigate whether the nonsignificant correlations between WO and strength and \( \dot{V}O_2 \) max within each group were partially due to the small size of the groups, subjects from both groups were combined to form one larger group. The subjects in the combined group possessed similar characteristics since there were no significant differences in strength, \( \dot{V}O_2 \) max, or WO between groups before or after training. The pre training combined group correlations between WO and strength and \( \dot{V}O_2 \) max are presented in Table 5, and the correlations between the same variables after training are presented in Table 6. All correlations in the combined group were measured and recorded without subject B.P. The two-tailed Pearson r value needed for statistical significance at the .05 level for the combined group was \( r = .444 \) (18 df).

The correlations between the combined group pre training WO and lat pull strength of \( r = .49 \), and bicep curl strength of \( r = .63 \), were statistically significant. All other pre training correlations involving strength and \( \dot{V}O_2 \) max were positive, but, not significant. The only post training correlation that was statistically significant in the combined group was between WO and lat pull strength (\( r = .45 \)). All other
combined post training correlations between WO and strength and \( \dot{V}O_2 \) max, except between WO and \( \dot{V}O_2 \) max (ml·kg\(^{-1}\)·min\(^{-1}\)), were positive, but, not significant. There was a slightly negative correlation, \( r = -0.05 \), between WO and \( \dot{V}O_2 \) max (ml·kg\(^{-1}\)·min\(^{-1}\)) in the combined group after training.

**Body Weight**

Body weight was measured and recorded before and after training since it was needed for calculating WO. Table 7 outlines the means and \( t \) values for pre and post training body weight within and between groups.

**Table 7**

Means and \( t \) Values for Pre and Post training Body Weight Within and Between Group A and Group B

<table>
<thead>
<tr>
<th></th>
<th>GROUP A</th>
<th></th>
<th>GROUP B</th>
<th></th>
<th>BETWEEN GROUPS A + B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre mean (SD)</td>
<td>Post mean (SD)</td>
<td>Mean difference</td>
<td>( t )</td>
<td>Pre mean (SD)</td>
</tr>
<tr>
<td>Body Weight (kg)</td>
<td>71.63 (8.72)</td>
<td>72.40 (8.63)</td>
<td>.76</td>
<td>-2.27(^{b})</td>
<td>73.94 (10.78)</td>
</tr>
</tbody>
</table>

\(^{a}\) Standard Deviation  
\(^{b}\) \( t \geq 2.228 \) significant at \( p = .05 \) for Group A  
\( t \geq 2.306 \) significant at \( p = .05 \) for Group B  
\( t \geq 2.101 \) significant at \( p = .05 \) Between Groups A and B

The body weight within Group A changed significantly from 71.63 kg to 72.40 kg after training, while the body weight change within Group B of 73.94 kg to 74.92 kg was not statistically significant. There was no significant difference in body weight between the groups either before or after training.
Chapter 5

DISCUSSION

This study clarified the misconception that muscular adaptations resulting from strength and endurance training are mutually exclusive and incapable of producing similar adaptations since both strength and endurance CWT regimens produced comparable physiological adaptations in strength, \( \dot{V}O_2 \) max, and WO. These results have some important training implications for untrained beginning cross-country skiers.

This chapter discusses the results of this study and their relationship to other studies reported in the literature, as well as some explanations that may account for the physiological adaptations that occurred in strength, \( \dot{V}O_2 \) max, AT, and WO. The practical training implications suggested by these results for untrained beginning skiers are also discussed.

**Strength**

The total strength percentage increases within Group A and Group B compared favorably with strength increases reported by other investigators. The 18.5% increase in total strength by Group A after seven weeks of strength training, was similar to the 20% strength increase reported by Anderson and Kearney (2) after nine weeks of upper body high-resistance/low-repetition weight training, and the 28% strength increase reported by MacDougall et al. (23) after five months of similar training.
When the strength increases in these studies were expressed as percentage improvement per week, however, the 2.64% per week improvement experienced by subjects from Group A in this study was greater than the 2.22% per week and 1.40% per week improvements experienced by subjects in the papers by Anderson and Kearney, and MacDougall, respectively.

The 11.3% increase in total strength experienced by subjects in Group B was similar to the 8% increase in strength after nine weeks of endurance weight training found by Anderson and Kearney (2), and the 13.2% increase in strength found by Hansen (15), following six weeks of arm endurance weight training. When these strength increases were expressed as percent improvement per week, the 1.57% per week improvement experienced by subjects from Group B, was greater than the .88% per week improvement experienced by subjects in the study conducted by Anderson and Kearney, but, less than the 2.2% per week improvement experienced by subjects in Hansen's study. In any case, the results of this study indicated that strength could be increased substantially by endurance CWT.

The variations between weekly strength percentage improvements in these studies could have been due to the differences in individual pre training strength levels, differences in the effectiveness of the training protocols, and/or learning. Therefore, comparing weekly strength gains between studies must be done cautiously.

The nonsignificant differences in strength scores between Group A and Group B came as a surprise, since Berger (4) noted that training with more than 10 repetitions did not increase strength as rapidly as training with 4, 6, and 8 repetitions. Anderson and Kearney (2) also reported that three sets of six to eight repetitions increased strength more than two sets of 30-40 RM, or one set of 100-150 RM, which substantiated Berger's
findings. Sharkey (33) was also in agreement with these others by stating that weights less than 66% 1 RM do not provide as much stimulus for strength development as do weights exceeding 66% 1 RM. Since Group A trained at 80-90% 1 RM, and Group B trained at 40-60% 1 RM, it was surprising that the different training regimens failed to produce significantly different adaptations in muscular strength.

There are a number of possible explanations that may have accounted for the nonsignificant strength differences between Group A and Group B in this study. Sale and MacDougall (30) suggested that with beginners in strength training, a wide range in the number of repetitions and sets could produce similar strength improvements, at least for the first several weeks of training. The similarity of strength gains by the untrained, inexperienced, subjects in Groups A and B supported this possibility. Subject P.W. from Group A experienced a 30% increase in total strength, while subject K.C. from Group B experienced a 19% increase in total strength. The lowest strength gain of 9.6% by subject D.K. from Group A closely paralleled the lowest total strength gain of 8% by subject B.S. in Group B. As subjects become more experienced and trained, the number of repetitions and sets, as well as the duration of the training program, may become more important in determining the amount of strength improvement.

DeLateur et al. (10) reported that in producing strength gains, the choice of weights (number of pounds) was not of prime importance as long as the subjects continued to perform the repetitions to the point of fatigue. Subjects in Groups A and B did not follow the traditional CWT protocol that calls for each exercise to be performed for as many repetitions as possible in 30 seconds. The subjects in this study lifted to
the point of fatigue on each exercise before moving to the next exercise. This variation in training protocol could have been responsible for the similar strength gains experienced by subjects in both groups.

The nonsignificant differences in strength between groups may also have been due to the large variability of the data. Figure 7 illustrates the mean values—including plus or minus one standard deviation.

The possibility also exists that the endurance training protocol as defined, was in fact a strength training protocol, even though the training regimen consisting of 15–25 repetitions has commonly been termed endurance training. Holloszy and Booth (18) suggested that two distinctly different adaptive responses could be induced in skeletal muscle if the two training stimuli were different from one another. The possibility exists that even though different numbers of repetitions were performed with different resistances, the stimuli produced from both protocols were similar. If this were true, further clarification and re-definition of training protocols that constitute strength and endurance training need to be made.

Maximal Oxygen Uptake

The nonsignificant increases in \( \dot{V}O_2 \) max within Groups A and B corresponded to the findings of Allen et al. (1) and Wilmore (41), who both reported no change in \( \dot{V}O_2 \) max after 12 weeks of strength CWT, and 10 weeks of endurance CWT, respectively. The inability of strength CWT to increase \( \dot{V}O_2 \) max came as no surprise, since Nagle and Irwin (25) also failed to find increases in \( \dot{V}O_2 \) max after strength training. The inability of the endurance CWT regimen to produce significant changes in \( \dot{V}O_2 \) max, however, was surprising, since Gettman et al. (12,13,14) and
Figure 7

Pre and Post Training Strength Means and Standard Deviations
Figure 7 (continued)
Figure 7 (continued)
Wilmore et al. (39) discovered small, but, statistically significant increases in $\dot{V}O_2$ max after CWT.

The $\dot{V}O_2$ max results of this study were confusing since the non-significant 7% increases experienced by subjects in both Groups A and B closely resembled the significant 7% and 5.9% increases in $\dot{V}O_2$ max reported by Gettman et al. (14) and Wilmore et al. (39) after 20 and 10 weeks of endurance CWT, respectively. A possible explanation for the discrepancies in percentage increases and statistical significance may have been due to the large within group variability. The mean differences and standard deviations in the pre and post training $\dot{V}O_2$ max scores for both groups are illustrated in Figure 8.

Even though neither groups significantly increased $\dot{V}O_2$ max, several individual subjects from both groups increased $\dot{V}O_2$ max dramatically after training. The large 34% increase in $\dot{V}O_2$ max by subject W.H. from Group A, and the 22.7%, 21.2%, and 20.8% increases experienced by subjects S.S., B.B., and M.S., from Group B, far exceeded the modest 7% increases noted by Gettman et al. (14) after 20 weeks of endurance CWT. These large increases more closely approximated the 19% $\dot{V}O_2$ max increases that Stamford et al. (35) found following 10 weeks of an endurance arm cranking program.

Several reasons were considered as possible explanations for the large individual $\dot{V}O_2$ max increases. The large increases in all four subjects could have been due to their low initial $\dot{V}O_2$ max scores, since Sharkey (33) reported that less fit individuals have a greater potential to improve aerobic fitness than more highly trained individuals. Since subjects D.K. and J.P. from Group A and subject B.P. from Group B also had low initial $\dot{V}O_2$ max scores and decreased $\dot{V}O_2$ max by 9.2%, 10.9%, and
Figure 8

Pre and Post Training $\dot{V}O_2$ max Means and Standard Deviations
9.4%, respectively, this possibility was questionable. Another possible explanation for the large individual increases in VO$_2$ max could have been due to increased participation in upper body aerobic activities outside the realm of the study. An examination of their individual activity records, however, failed to substantiate this hypothesis. A third, and most likely explanation for these large reported individual VO$_2$ max increases in subjects W.H., S.S., B.B., and M.S., may be related to strength gains, which could have increased the active muscle mass in their arms or increased the utilization of additional body muscle groups during the VO$_2$ max test.

**Anaerobic Threshold**

The gas exchange method used in this study was ineffective for determining the AT during arm work. It was difficult to accurately plot and detect the AT because of the absence of two nonlinear increases in $\dot{V}_E$ and the nonsystematic increases in $\dot{V}_E$. These findings could have been due to a number of factors. The Nordic-Trak device was often unable to produce consistent increases in workload. As testing proceeded, the Nordic-Trak device heated up and reduced the set workload rather than maintaining it. Another explanation could have been due to the relationship between the arm rhythm and the respiratory rate. During the testing sessions, it became apparent that the breathing frequency was synchronized with the work rate of the arms, which varied according to the speed and resistance applied throughout the test. As a result, $\dot{V}_E$ and/or VO$_2$ did not consistently increase in a linear pattern, which made it difficult to pinpoint a ventilatory nonlinear breakaway point in all subjects.

The results of this study led to some confusion as to whether the
point obtained was the AT as described by Skinner and McLellan (34), MacDougall (21), and Rupp et al. (29), or the AT as described by Davis (9), Wasserman et al. (38), and Withers (42). Skinner and McLellan, MacDougall, and Rupp et al. all defined the AT as the second "breakaway" nonlinear increase in $\dot{V}_E$, and the peak or initial decline of $F_{E}CO_2$. However, Davis, Wasserman et al., and Withers all defined the AT as the first point of nonlinear increase in $\dot{V}_E$ that corresponded to the peak or slight decline in $F_{E}O_2$ without a peak or decrease in $F_{E}CO_2$. Since there was only one nonlinear increase in $\dot{V}_E$ that corresponded to the peak or slight decline in $F_{E}CO_2$, the results of this portion of the investigation were confusing, and therefore were not considered for further analysis and discussion.

**Work Output**

The 54% total increase in WO found in Group A after seven weeks of strength CWT compared favorably with the results reported by Hickson et al. (17), who found a 47% increase in bicycle endurance time to exhaustion after 10 weeks of lower body strength training, and Shaver (32) who also reported increased upper body endurance time to exhaustion after strength training. The 54% increase in WO in this study, however, was larger than the 28% increase in absolute endurance noted by Anderson and Kearney (2) after nine weeks of upper body strength training. The weekly percentage increase in WO of 7.71% per week found in this study was much larger than the weekly percentage increases of 4.7% per week reported by Hickson et al. and the 3.1% per week increases reported by Anderson and Kearney.

The reported 74% increase in WO in Group B after endurance CWT
far exceeded the increases in endurance time to exhaustion of 5.2% noted by Wilmore (41) after 10 weeks of endurance CWT, 7.5% obtained by Gettman (12) following 20 weeks of upper and lower body endurance CWT, and 38% found by Magel et al. (23) after 10 weeks of arm interval training. The 74% increase in WO was also much greater than the 41% and 39% increases in absolute endurance reported by Anderson and Kearney (2) after nine weeks of endurance weight training. When these WO increases were expressed as percentage improvement per week, the 10.57% per week increase in WO by Group B in this study far exceeded the weekly percentage increases in endurance time to exhaustion of .52% per week, .38% per week, and 3.8% per week reported by Wilmore, Gettman, and Magel, respectively, and the 4.5% per week and 4.3% per week increases in absolute endurance found by Anderson and Kearney.

The large weekly percentage improvements in WO by both groups in this study can be partially accounted for by the large individual improvements within each group. Subjects W.H., B.K., B.W., and D.V., from Group A increased WO by 108%, 97%, 90%, and 88%, respectively, after training, while subjects M.L., K.C., M.S., and B.P., from Group B increased WO by 113%, 108%, 106%, and 72%, respectively, after training. These large individual increases in WO for subjects in both groups could have been due to several factors, including low pre training WO levels, individual training responses, and/or learning.

The significant change in body weight of .76 kg within Group A and the nonsignificant .99 kg body weight change within Group B after training accounted for a small amount of the increases in WO found within each group. Since both of these changes were small, however, the practical significance for either of these changes in body weight was minimal.
The majority of the increase in WO within each group was therefore due primarily to the increased number of repetitions performed on the rollerboard.

The large increases in WO within both groups could have been partially due to the similarity between the training exercises and the rollerboard test. Pechar et al. (28) emphasized the importance of selecting an appropriate work test when assessing functional changes resulting from exercise training programs. In this study, the lat pull and arm pulls closely replicated the upper body movements used during the rollerboard test, while the bench press and tricep extension worked related upper body muscle groups. This hypothesis was supported by the small increases in WO found in studies by Wilmore (41) and Gettman (12), who utilized CWT protocols that trained both the upper and lower body, and then tested only lower body WO with a treadmill walk to exhaustion.

Both groups in this study increased WO significantly, but, the 74% increase in WO for Group B was not statistically greater than the 54% increase in WO for Group A. These findings agree with the results of a study by Anderson and Kearney (2), who showed no significant differences in absolute endurance scores between strength training with six to eight RM, and higher repetition training of 30-40 RM and 100-150 RM.

The nonsignificant differences in WO between groups in this study came as a surprise, however, since the percentage of WO increases within each group was considerably different. The nonsignificant difference in WO between groups was not due to changes in body weight since there were no significant differences found in body weight between groups either before training (t = -.529) or after training (t = -.564). The nonsignificant difference in WO between groups, however, could have been due to
the large post training standard deviations, as illustrated in Figure 9.

There appeared to be a trend for larger increases in WO after endurance training compared to strength training. The WO differences between groups might have become statistically significant if the training program would have been longer. This possibility should be explored in future research.

The positive correlations between WO and lat pull strength of $r = .48$ in Group A, $r = .60$ in Group B, and $r = .45$ in the combined group after training, indicated that strength was associated with WO. A statistically significant correlation between WO and lat pull strength was found only in the combined group, which was probably due to the difference in sample size. Even though there was a slightly negative correlation of $r = -.05$ between WO and bench press strength in Group A after training, the positive correlations between WO and bench press, tricep extension, bicep curl, and total strength within each group and the combined group, supported the existence of a relationship between WO and strength.

It was unknown, however, whether the increases in WO were caused by the increases in strength or by other factors. The strength-related factors responsible for the increases in WO could have been due to increased short-term energy stores (ATP, CP), and/or more efficient neuromuscular pathways and muscle motor unit recruitment. MacDougall et al. (22) found that resting levels of ATP, ADP, and CP were increased significantly after strength training, and concluded that by increasing these short-term energy stores, heavy work could be sustained longer.

The positive correlations between WO and $\dot{V}O_2$ max $(1 \cdot \text{min}^{-1})$ of $r = .41$ in Group A, $r = .64$ in Group B, and $r = .35$ in the combined group
Figure 9

Pre and Post Training Work Output
Means and Standard Deviations
after training, suggested that \( \dot{V}O_2 \) max was associated with WO. The negative correlations between WO and \( \dot{V}O_2 \) max (l·min\(^{-1}\)) of \( r = -0.23 \) in Group A, and \( r = -0.05 \) in the combined group after training, suggested that when \( \dot{V}O_2 \) max was adjusted for body weight, it was not associated with WO levels. The relationship between WO and \( \dot{V}O_2 \) max in this study was unclear. Future studies, however, should investigate the relationship between WO and \( \dot{V}O_2 \) max when the training program induces a change in WO and \( \dot{V}O_2 \) max.

The relationship between the AT and WO remains unknown. Before the relationship between the AT and WO can be investigated, however, the definition of the AT and procedures for its determination must first be standardized.

The results of this investigation have some important training implications for untrained, beginning, cross-country skiers. Although Bergh (5) suggests that weight training has very little value for ski training, this study found that upper body strength and endurance CWT increased both strength and WO after only seven weeks and therefore could be highly beneficial for ski training. Since many untrained beginning skiers lack sufficient upper body strength and work capacity, a strength or endurance CWT program may be the best training method to increase both strength and WO adequately. Since the physiological adaptations in both regimens have been shown to be very similar, skiers could choose the regimen of personal preference. The increases in strength and WO that would result from a CWT program could help skiers meet the high demands for upper body use that the sport of cross-country skiing presently requires.
Chapter 6

SUMMARY

This study investigated the effects of upper body strength and endurance circuit weight training on strength, maximal oxygen uptake, anaerobic threshold, and work output, during simulated cross-country ski movements in a sample of untrained college men.

Twenty-two subjects who met the criterion for participation in this study were randomly assigned into two training groups: Group A (strength) and Group B (endurance). The exercise program for both groups consisted of seven weeks of CWT three days per week. Subjects in Group A performed four to eight repetitions on the bench press, lat pull, tricep extension, bicep curl, and arm pulls, whereas subjects in Group B performed 15-25 repetitions on the same first four exercises, and from 50-100 repetitions on the arm pulls. Following the seven week training period, the pre and post training measurements were compared within each training group, and between training groups.

There was a significant increase in all strength scores within Group A and Group B. No significant differences were noted between any of the strength scores between training groups.

Maximal oxygen uptake increased slightly within both training groups, but, these changes were not significant. There was no significant difference in ⁰₂ max between training groups.

The AT was difficult to determine by the gas exchange method used in this study. The failure to meet all the defining criteria for
the AT and the inability to detect any nonlinear ventilatory breakaway point in a large number of subjects, necessitated that the results not be statistically analyzed or discussed.

Work output showed significant increases within Groups A and B after training, but, no significant differences in WO were noted between groups either before or after training. Correlations between pre and post training WO and each of the combined strength tests and total strength indicated that strength was associated with WO levels. There was a positive correlation between combined group pre and post training WO and combined group pre and post training \( \dot{V}O_2 \) (l·min\(^{-1}\)), and a slight negative correlation between combined group post training WO and combined group post training \( \dot{V}O_2 \text{ max} \) (ml·kg\(^{-1}\).min\(^{-1}\)). Therefore, the relationship between WO and \( \dot{V}O_2 \text{ max} \) was unclear.

The muscular adaptations resulting from strength and endurance CWT were not mutually exclusive and incapable of producing similar adaptations as suggested by DeLorme (11). The subjects who trained for strength gained as much endurance as those who trained for endurance. Those who trained for endurance gained as much strength as those who trained for strength. These results suggested that either strength or endurance CWT could be a valuable training method for beginning cross-country skiers.

**Conclusions**

The results of this investigation support the following conclusions:

1. Both upper body strength CWT comprised of four to eight repetitions, and endurance CWT comprised of more than 15
repetitions significantly increased strength and WO in un-
trained college subjects following seven weeks of upper body
training.
2. Both strength and endurance CWT were equally effective in
increasing strength and WO, since there were no differences
in strength or WO increases between the two groups using
different training regimens.
3. Seven weeks of upper body strength or endurance CWT did not
produce significant changes in $\dot{V}O_2$ max within or between the
two groups.

**Recommendations**

Based on the results of this study, the following recommendations
for future study are proposed:

1. Additional CWT studies with trained and untrained subjects
   consisting of a wider range of repetitions should be con-
ducted over a longer period of time.
2. Future studies should be conducted to compare the differences
   between a CWT protocol that requires subjects to perform as
   many repetitions as possible in 30 seconds, and a protocol
   that requires subjects to lift to the point of fatigue.
3. The AT and $\dot{V}O_2$ max should be measured in two separate tests
during arm work to eliminate some of the problems inherent
with determining the AT with the gas exchange method.
4. Future studies that attempt to determine the AT for upper
   body simulated cross-country ski movements should use another
type of arm ergometer that allows workloads to be accurately
calibrated.

5. Future research should investigate the relationships between changes in WO and changes in strength, \( \dot{V}O_2 \) max, and the AT, to discover the factors that account for changes in WO.

6. The effects of strength and endurance CWT on WO and actual skiing performance should be investigated.
References


APPENDIX A

Informed Consent Form and Medical History Questionnaire

TO SUBJECTS:

The purpose of this study is to determine the effects of strength and endurance training on upper body strength, work output, and aerobic fitness during simulated cross-country ski movements.

You will perform a maximal strength test, and two additional maximal tests—one to determine work output, and one to determine aerobic fitness, during which heart rate will be monitored by electrocardiograph (ECG), and expired air will be collected and analyzed. You will also participate in a seven week upper body strength or endurance training program three days each week.

You can expect some discomforts due to muscular fatigue during testing, and minor muscle soreness at the beginning of the training program. You will complete a brief medical history questionnaire designed to detect medical problems that might prevent your safe participation in this study. During the aerobic fitness test, if the ECG is or becomes abnormal, the test will be immediately terminated and you will be referred to medical care. Instruction and supervision will also be given during the maximum strength test, work output test, and training, to reduce any risk involved. You can expect to gain insight into your exercise capabilities and improve your muscular fitness by participating in this study.
In the event physical injury results from biomedical or behavioral research the human subject should individually seek appropriate medical treatment and shall be entitled to reimbursement or compensation consistent with the self insurance program for Comprehensive General Liability established by the Department of Administration under the authority of Title 82, Chapter 43, RCM 1947 or by the satisfaction of the claim or judgement by means provided by MCA Sec. 2-9-315. In the event of a claim for such physical injury further information may be obtained from the University Legal Counsel.

The investigator will be glad to answer any questions you have concerning the study at any time. Confidentiality will be assured in data publication by referring to you by number only. You are free to discontinue participation at any time, although a commitment for your participation throughout the study is requested.

I have read, and understand the above statement, and hereby give my consent to participate.

Name ____________________________ Date _____ Investigator _____________

The following questionnaire is designed to detect any medical problems that might prevent safe participation in an upper body testing and training study. These questions were taken from the PRE/FIT questionnaire which was adapted from the Physical Activity Readiness Questionnaire developed by the British Columbia Ministry of Health by Dr. Brian J. Sharkey.

Yes No

_____ _____ Has your doctor ever said you have heart trouble?

_____ _____ Do you frequently have pains in your heart and chest?

_____ _____ Do you often feel faint or have spells of severe dizziness?
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

Has your doctor ever told you that you have a bone or joint problem that has been aggravated by exercise, or might be made worse with exercise?

Is there a good physical reason not mentioned here why you should not follow an activity program even if you wanted to?

If you answered YES to one or more questions, you should not participate in this study. If you answered NO to all questions, you may participate in this study.

Name _____________________________

Date _____________________________
The Rollerboard

RAMP

TOP VIEW

120"

1/2" high
1 1/16" wide

Tape Mark 87.5"

95" long

24"

4"

RAMP AND PLATFORM

SIDE VIEW

106"

37 3/8"

13.4 degrees

27"

24.5"

36"

31"

ROLLING BOARD

BOTTOM VIEW

3"

2"

9 1/2"

12"
Rollerboard Construction Specifications

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramp Pressboard, 3/4&quot; thick, (95&quot; x 113/4&quot;)</td>
<td>1</td>
</tr>
<tr>
<td>2&quot; x 4&quot; (24&quot;, 9&quot;, 9&quot;, 120&quot;, 120&quot;)</td>
<td>5</td>
</tr>
<tr>
<td>Rolling Board Plywood, 3/4&quot; thick, (12&quot; x 37 3/8&quot;)</td>
<td>1</td>
</tr>
<tr>
<td>Plastic Wheels (2&quot; in diameter)</td>
<td>4</td>
</tr>
<tr>
<td>Metal Wheel Brackets with screws (2&quot; x 2 5/8&quot;)</td>
<td>4</td>
</tr>
<tr>
<td>Carpet Remnant (12&quot; x 37&quot;)</td>
<td>1</td>
</tr>
<tr>
<td>Platform Any platform 24&quot; high that the ramp can be attached to. A 13.4 degree angle from the floor should exist when the ramp sits on the platform</td>
<td>1</td>
</tr>
<tr>
<td>Platform used in this study was constructed from 2&quot; x 4&quot;'s and 1/4&quot; plywood</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous Ski handles with straps (6 3/4&quot; long)</td>
<td>2</td>
</tr>
<tr>
<td>Nylon straps (6' long and 1/2&quot; wide)</td>
<td>2</td>
</tr>
<tr>
<td>Straps are attached to the 2&quot; x 4&quot; at the top of the ramp and to the ski handles. A distance of 37&quot; exists between these two points of attachment</td>
<td></td>
</tr>
</tbody>
</table>
Construction:

One Nordic-Trak Arm Ergometry Device
Two Leather Braking Straps: 1" x 5"
Two Pulleys: 1½" in Diameter
One Mounting Board: 12" x 18"
Two "U" Bolts to mount the board to volleyball standard

The unit is secured to the center of the board using the central bolt provided with the Nordic-Trak device. The board is then mounted on a volleyball standard with the aid of "U" bolts at a height of 6.5 feet off the ground. The length of the rope on the ergometer is 14 feet. The volleyball standard is positioned at the head of the treadmill. The top of the standard is secured to the wall using straps to provide additional support.
APPENDIX D

Training Exercises and Equipment

Bench Press

Lat Pull
## Arm Pulls

### Training Equipment

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Universal Gym</td>
<td></td>
</tr>
<tr>
<td>Lat Pull Poles</td>
<td>1-2</td>
</tr>
<tr>
<td>Hardwood Poles (1&quot; dia. x 24&quot; long)</td>
<td>2</td>
</tr>
<tr>
<td>Eye Screws (5/8&quot; dia. x 2&quot; long)</td>
<td>2</td>
</tr>
<tr>
<td>Nylon Straps (1&quot; wide x 18&quot; long)</td>
<td>2</td>
</tr>
<tr>
<td>Apollo Exercisers</td>
<td>2</td>
</tr>
</tbody>
</table>
APPENDIX E

Individual Data For Group A

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age (years)</th>
<th>Bench Press (lbs)</th>
<th>Lat Pull (lbs)</th>
<th>Tricep Ext. (lbs)</th>
<th>Bicep Curl (lbs)</th>
<th>Total Strength (lbs)</th>
<th>VO2 max (l·min⁻¹)</th>
<th>VO2 max (ml·kg⁻¹·min⁻¹)</th>
<th>AT (%)</th>
<th>WO (kg·m⁻¹)</th>
<th>Body Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D.K.</td>
<td>21</td>
<td>120</td>
<td>150</td>
<td>85</td>
<td>95</td>
<td>75</td>
<td>75</td>
<td>80</td>
<td>365</td>
<td>400</td>
<td>2.36</td>
</tr>
<tr>
<td>M.C.</td>
<td>22</td>
<td>230</td>
<td>260</td>
<td>85</td>
<td>100</td>
<td>90</td>
<td>105</td>
<td>90</td>
<td>110</td>
<td>490</td>
<td>575</td>
</tr>
<tr>
<td>P.W.</td>
<td>26</td>
<td>115</td>
<td>160</td>
<td>70</td>
<td>90</td>
<td>65</td>
<td>80</td>
<td>80</td>
<td>100</td>
<td>330</td>
<td>430</td>
</tr>
<tr>
<td>B.W.</td>
<td>19</td>
<td>130</td>
<td>155</td>
<td>65</td>
<td>75</td>
<td>60</td>
<td>65</td>
<td>55</td>
<td>70</td>
<td>310</td>
<td>365</td>
</tr>
<tr>
<td>S.H.</td>
<td>28</td>
<td>160</td>
<td>195</td>
<td>90</td>
<td>105</td>
<td>85</td>
<td>95</td>
<td>90</td>
<td>105</td>
<td>425</td>
<td>500</td>
</tr>
<tr>
<td>J.P.</td>
<td>23</td>
<td>150</td>
<td>190</td>
<td>70</td>
<td>75</td>
<td>90</td>
<td>80</td>
<td>60</td>
<td>75</td>
<td>370</td>
<td>420</td>
</tr>
<tr>
<td>W.H.</td>
<td>21</td>
<td>120</td>
<td>120</td>
<td>60</td>
<td>70</td>
<td>45</td>
<td>60</td>
<td>60</td>
<td>80</td>
<td>370</td>
<td>420</td>
</tr>
<tr>
<td>B.K.</td>
<td>19</td>
<td>145</td>
<td>170</td>
<td>80</td>
<td>90</td>
<td>55</td>
<td>75</td>
<td>70</td>
<td>80</td>
<td>350</td>
<td>415</td>
</tr>
<tr>
<td>J.F.</td>
<td>24</td>
<td>180</td>
<td>200</td>
<td>80</td>
<td>105</td>
<td>70</td>
<td>100</td>
<td>90</td>
<td>100</td>
<td>420</td>
<td>505</td>
</tr>
<tr>
<td>P.J.</td>
<td>19</td>
<td>130</td>
<td>155</td>
<td>70</td>
<td>85</td>
<td>65</td>
<td>75</td>
<td>70</td>
<td>90</td>
<td>335</td>
<td>405</td>
</tr>
<tr>
<td>D.V.</td>
<td>23</td>
<td>160</td>
<td>180</td>
<td>80</td>
<td>100</td>
<td>70</td>
<td>100</td>
<td>90</td>
<td>110</td>
<td>400</td>
<td>490</td>
</tr>
</tbody>
</table>

Mean | 22.3 | 150.0 | 175.9 | 75.5 | 90.0 | 70.0 | 82.7 | 75.5 | 90.9 | 370.9 | 439.6 | 2.74 | 2.93 | 38.2 | 40.9 | 51.7 | 49.4 | 1572.64 | 2424.58 | 71.63 | 72.40

Mean Difference | 25.91 | 14.55 | 12.73 | 15.46 | 68.64 | .19 | 2.69 | -2.33 | 851.94 | .77

*Unable to determine
## APPENDIX F

### Individual Data For Group B

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age (years)</th>
<th>Bench Press (lbs)</th>
<th>Lat Pull (lbs)</th>
<th>Tricep Ext. (lbs)</th>
<th>Bicep Curl (lbs)</th>
<th>Total Strength (lbs)</th>
<th>VO₂ max (l·min⁻¹)</th>
<th>VO₂ max (m·kg⁻¹·min⁻¹)</th>
<th>AT</th>
<th>WO</th>
<th>Body Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R.R.</td>
<td>25</td>
<td>165</td>
<td>185</td>
<td>80</td>
<td>95</td>
<td>75</td>
<td>85</td>
<td>100</td>
<td>100</td>
<td>2.30</td>
<td>2.67 *</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>29.7</td>
<td>34.9</td>
<td>57.0</td>
</tr>
<tr>
<td>B.P.</td>
<td>28</td>
<td>315</td>
<td>300</td>
<td>110</td>
<td>140</td>
<td>125</td>
<td>140</td>
<td>150</td>
<td>690</td>
<td>730</td>
<td>3.85 *</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.56</td>
<td>39.3</td>
<td>35.6</td>
</tr>
<tr>
<td>K.C.</td>
<td>27</td>
<td>120</td>
<td>135</td>
<td>70</td>
<td>90</td>
<td>55</td>
<td>70</td>
<td>70</td>
<td>80</td>
<td>315</td>
<td>375 *</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.98</td>
<td>42.1</td>
<td>41.8</td>
</tr>
<tr>
<td>S.S.</td>
<td>18</td>
<td>100</td>
<td>110</td>
<td>55</td>
<td>65</td>
<td>45</td>
<td>60</td>
<td>50</td>
<td>60</td>
<td>250</td>
<td>293 *</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.57</td>
<td>30.4</td>
<td>37.3</td>
</tr>
<tr>
<td>B.B</td>
<td>19</td>
<td>150</td>
<td>165</td>
<td>65</td>
<td>80</td>
<td>60</td>
<td>70</td>
<td>75</td>
<td>75</td>
<td>350</td>
<td>390 *</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.53</td>
<td>35.8</td>
<td>34.3</td>
</tr>
<tr>
<td>B.S.</td>
<td>19</td>
<td>150</td>
<td>160</td>
<td>80</td>
<td>90</td>
<td>65</td>
<td>70</td>
<td>80</td>
<td>85</td>
<td>375</td>
<td>405 *</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.56</td>
<td>35.6</td>
<td>35.3</td>
</tr>
<tr>
<td>R.M.</td>
<td>19</td>
<td>160</td>
<td>190</td>
<td>80</td>
<td>80</td>
<td>70</td>
<td>80</td>
<td>75</td>
<td>90</td>
<td>385</td>
<td>440</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.67</td>
<td>34.1</td>
<td>34.1</td>
</tr>
<tr>
<td>M.L.</td>
<td>18</td>
<td>220</td>
<td>240</td>
<td>85</td>
<td>100</td>
<td>85</td>
<td>90</td>
<td>85</td>
<td>95</td>
<td>475</td>
<td>525</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>37.1</td>
<td>44.8</td>
<td>59.0</td>
</tr>
<tr>
<td>M.S.</td>
<td>20</td>
<td>160</td>
<td>170</td>
<td>70</td>
<td>85</td>
<td>60</td>
<td>70</td>
<td>80</td>
<td>90</td>
<td>370</td>
<td>415 *</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.69</td>
<td>31.5</td>
<td>33.3</td>
</tr>
</tbody>
</table>

| Mean    | 21.4 | 171.1 | 183.9 | 77.2 | 91.7 | 71.1 | 81.7 | 83.9 | 91.7 | 403.3 | 448.9 | 2.65 | 2.83 | 35.1 | 37.8 | 59.4 | 52.7 | 1673.24 | 2914.23 | 73.94 | 74.92 |

| Mean Difference | 12.79 | 14.45 | 10.55 | 7.78 | 45.56 | .18 | 2.73 | 6.7 | 1240.99 | 1.01 |

*Unable to determine*