

## ABSTRACT

Haug, R. C. Development and validation of a maximal testing protocol for the NordicTrack cross-country ski simulator. MS in Adult Fitness/Cardiac Rehabilitation, December 1995, 30pp. (J. Porcari).

The purpose of this study was to develop a valid  $\text{VO}_2\text{max}$  testing protocol for the NordicTrack (NT) cross-country ski simulator. To be considered a valid protocol, the maximal values obtained from the cross-country skiing (XC) test had to be similar to those obtained from a maximal graded treadmill (TM) test. During pilot testing ( $n = 3$ ), cadence (strides/min), arm resistance, leg resistance, and grade were individually manipulated to study the effect on measured  $\text{VO}_2$ . It was found that the greatest benefit in terms of increasing  $\text{VO}_2$  during XC skiing can be realized by increasing the frequency of limb movement rather than arm and leg resistance. A protocol for the NT was developed from the findings of the pilot study and was compared to a TM  $\text{VO}_2$  max test utilizing the Bruce protocol. Thirteen male and 15 female volunteers (aged 22-49) served as subjects and completed both tests in random order. The maximal physiological responses from the XC and TM max tests were compared using paired t-tests. There were no significant ( $p > 0.05$ ) differences in maximal  $\text{VO}_2$  ( $42.5$  vs  $42.6$   $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ;  $3.27$  vs  $3.31$   $\text{l}\cdot\text{min}^{-1}$ ), HR ( $185$  vs  $185$  bpm), and RPE ( $19.0$  vs  $19.1$ ) for the XC and TM tests, respectively. There were significant ( $p < 0.05$ ) differences for VE ( $124.5$  versus  $118.6$   $\text{l}\cdot\text{min}^{-1}$ ) and RER ( $1.15$  vs  $1.21$ ) between the XC and TM tests, respectively. It was concluded that the testing protocol for the NT XC simulator is valid and can be expected to elicit similar maximal values when compared to TM testing.

DEVELOPMENT AND VALIDATION OF A MAXIMAL  
TESTING PROTOCOL FOR THE NORDICTRACK  
CROSS-COUNTRY SKI SIMULATOR

A MANUSCRIPT STYLE THESIS PRESENTED  
TO  
THE GRADUATE FACULTY  
UNIVERSITY OF WISCONSIN-LA CROSSE

IN PARTIAL FULFILLMENT  
OF THE REQUIREMENTS FOR THE  
MASTER OF SCIENCE DEGREE

BY  
RHEA HAUG  
DECEMBER 1995

COLLEGE OF HEALTH, PHYSICAL EDUCATION, AND RECREATION  
UNIVERSITY OF WISCONSIN-LA CROSSE

THESIS FINAL ORAL DEFENSE FORM

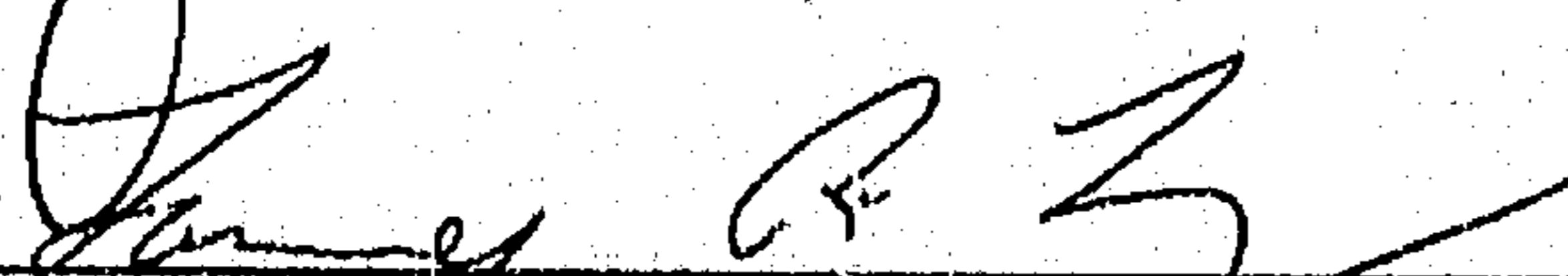
Candidate: Rhea Catherine Haug

We recommend acceptance of this thesis in partial fulfillment of this candidate's requirements for the degree:

Master of Science in Adult Fitness/Cardiac Rehabilitation

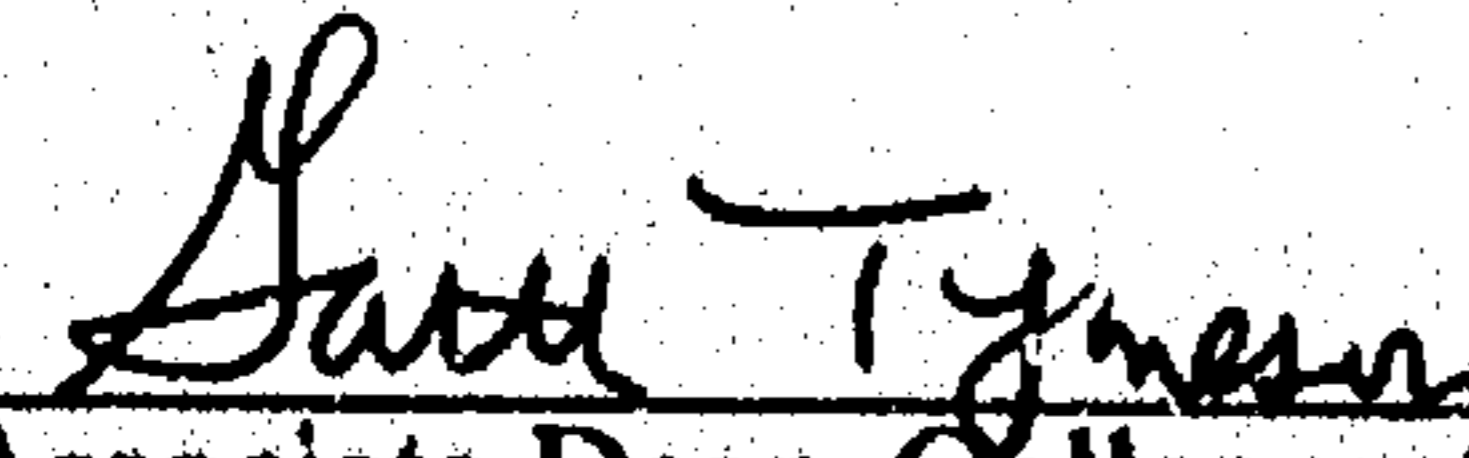
The candidate has successfully completed her thesis final oral defense.

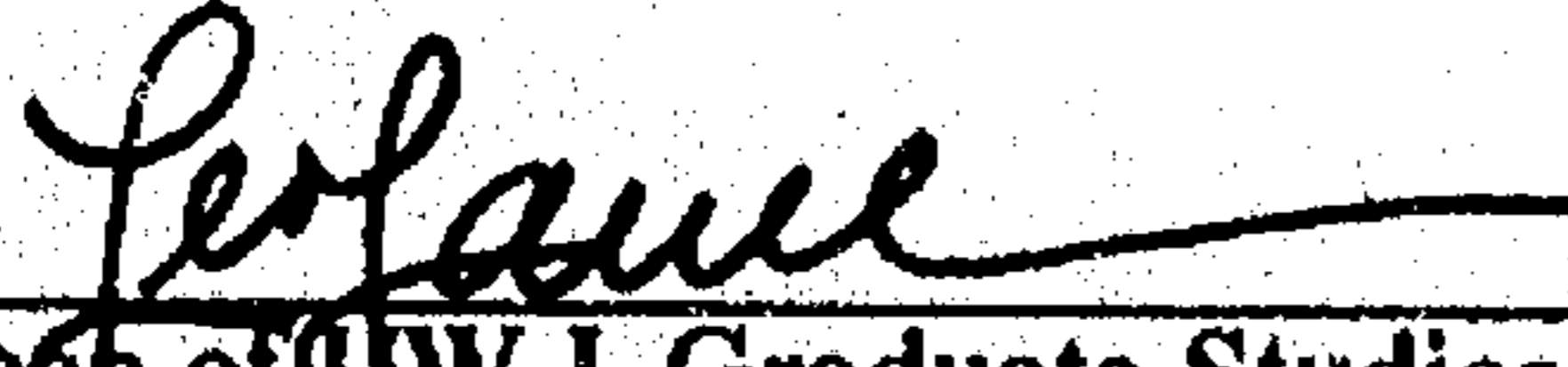
  
\_\_\_\_\_  
Thesis Committee Chairperson Signature Date 7-18-95

  
\_\_\_\_\_  
Thesis Committee Member Signature Date 7/18/95

Glenn Brica  
\_\_\_\_\_  
Thesis Committee Member Signature Date 7-18-95

This thesis is approved by the College of Health, Physical Education, and Recreation.

  
\_\_\_\_\_  
Associate Dean, College of Health,  
Physical Education, and Recreation Date 7-31-95

  
\_\_\_\_\_  
Dean of UW-L Graduate Studies Date 24 August 1995

## ACKNOWLEDGMENTS

I dedicate this thesis to my parents for their strength and support throughout this year. Your belief in me has kept me going through the difficult times. I love you! I would like to thank Dr. John Porcari for his dedication and interest in this project, as well as my previous one! Your insight and knowledge extends well beyond the classroom. I also thank Dr. Larry Terry and Dr. Glenn Brice, for without your guidance and support this project would not have been possible. Finally, a special thanks to the many wonderful friends I have made this past year. I could not have done it without you! Best of luck in the future!

## TABLE OF CONTENTS

	PAGE
ACKNOWLEDGMENTS .....	iii
LIST OF TABLES .....	v
LIST OF APPENDICES .....	vi
INTRODUCTION .....	1
METHODS .....	3
Pilot Study .....	3
Testing Protocol .....	5
RESULTS .....	8
DISCUSSION .....	11
REFERENCES .....	15
APPENDICES .....	17

## LIST OF TABLES

TABLE	PAGE
1. Cross-country test protocol .....	5
2. Descriptive characteristics of the subject population .....	8
3. Maximal physiological responses obtained during the treadmill and cross-country skiing tests .....	9
4. Regional RPE values for each stage of the XC test .....	10
5. Average $VO_2$ values for each stage of the XC test .....	11

LIST OF APPENDICES

APPENDIX	PAGE
A. INFORMED CONSENT .....	17
B. REVIEW OF LITERATURE .....	20

## INTRODUCTION

Although walking and jogging are the most commonly utilized modes of aerobic activity, fitness experts have been searching for alternative forms of exercise which emphasize total body fitness rather than only lower body fitness. One type of machine designed to give a total body workout which has become increasingly popular in recent years is the cross-country ski simulator. Originally designed to allow cross-country skiers the opportunity to train when weather conditions were unfavorable, it is now a popular form of aerobic activity for all types and levels of fitness enthusiasts.

One of the many added benefits of cross-country skiing is that it can be a beneficial form of exercise for individuals who cannot tolerate the stress of running. These include the elderly, the obese, and those having overuse injuries. The movement pattern of cross-country skiing employs smooth kicking and gliding motions with the legs and pulling motions with the arms. This seems to be less stressful on muscles and joints than either running or jogging. Furthermore, cross-country skiing, both in actual and simulated forms, has been shown to have positive physiological effects in both the young and old. Simard and Roy (15) found cross-country skiing to have a favorable impact on maximal oxygen consumption ( $VO_2max$ ), vital capacity, and flexibility in the aging population. In another study, recreational cross-country skiers were shown to have a relatively

high  $\text{VO}_2\text{max}$  ( $56.6 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) and a low percent body fat (10.1%) as compared to the general population (9).

The main limiting factor for most types of exercise lasting longer than 3 minutes in duration is the ability of the cardiorespiratory system to deliver oxygen to the working muscles (5). The best means of assessing this system is to measure  $\text{VO}_2\text{max}$  during exercise. Because muscles need oxygen to perform work for an extended period of time, large muscle groups must be engaged in order to load the respiratory and circulatory systems to a maximum. For this reason treadmill and bicycle exercises have been the two most used laboratory tests for determining  $\text{VO}_2\text{max}$ . Because treadmill work utilizes a larger muscle mass it typically results in higher maximal values than either cycle or arm ergometry (1).

Theoretically then, cross-country skiing, either in the actual or simulated form, should result in even higher  $\text{VO}_2\text{max}$  values than treadmill work due to the utilization of both the arms and legs. However, most studies have shown equal or lower values for simulated cross-country tests compared to treadmill testing (2, Hinze, unpublished observations, 10). It is possible that these conflicting results could be due to differences in the subject population or the testing protocol. Subjects familiar with skiing as a mode of exercise tend to have similar treadmill and skiing  $\text{VO}_2\text{max}$  values (2, 10, 13), whereas those unfamiliar with skiing as a mode of exercise tend to have lower skiing than treadmill  $\text{VO}_2\text{max}$  values (Hinze, unpublished observations).

Due to the increasing popularity of simulated cross-country ski machines, their use for exercise testing in laboratory settings is becoming more frequent. To

date there is not a well-established protocol to test individuals on this piece of equipment. The purpose of this study was to develop a  $\text{VO}_2\text{max}$  testing protocol for cross-country skiing using the NordicTrack 900. It is believed that the  $\text{VO}_2$  response to a properly developed protocol should compare favorably to the results obtained during a treadmill  $\text{VO}_2\text{max}$  test.

## METHODS

### Pilot Study

Subjects. Three male volunteers (aged 24, 27, and 39 years) served as subjects. None were avid cross-country skiers although all three were familiar with using the NordicTrack.

Procedure. Workload can be increased on the NordicTrack by altering the arm resistance, leg resistance, speed, and elevation. The influence of these conditions on  $\text{VO}_2$  were tested using the NordicTrack 900. In each of the tests, one variable was altered while the other three remained constant. The tests for each of the variables consisted of four stages, each 5 minutes in duration. Upon completion of the fifth minute of each stage, the workload was increased until the test was terminated.

When arm resistance was used as the independent variable, resistance for the four stages was set at 4 lb, 6 lb, 8 lb, and 10 lb. The elevation was maintained at 5%, the leg resistance at 16 lb and the speed at a rate of 96 strides per minute. For each increase in workload in the first three stages, an average increase of 21.0% (5.7 ml  $\text{O}_2$ ), 2.4% (0.8 ml  $\text{O}_2$ ) and 4.2% (1.4 ml  $\text{O}_2$ ), respectively, was observed in  $\text{VO}_2$ .

When leg resistance was used as the independent variable, resistance for the four stages was set at 16, 20, 24, and 28 lb. The elevation was maintained at 5%, the arm resistance at 4 lb, and the speed at 96 strides per minute. For each increase in workload during the first three stages, an average increase of 12.5% (3.1 ml O<sub>2</sub>), 8.2% (2.3 ml O<sub>2</sub>), and 13.2% (4.0 ml O<sub>2</sub>), respectively, in VO<sub>2</sub> was observed.

When elevation was used as the independent variable, arm resistance was set at 4 lb, leg resistance at 16 lb, and speed at 80 strides per minute for the first two stages. During this time elevation was set at 5 and 10%. The average increase in VO<sub>2</sub> between these stages was 9.1% (1.9 ml O<sub>2</sub>). During the next two stages, arm and leg resistance remained the same, however, the speed was set at 96 strides per minute. Elevation was again set at 5 and 10% for the two stages. The average increase in VO<sub>2</sub> between these stages was 7.6% (2.1 ml O<sub>2</sub>). All three subjects agreed that an elevation of 5% was the most comfortable.

The last variable to be tested was speed. The stride rates, as set by a metronome, were 96, 120, 138, and 160 strides per minute. The increase in speed between each of the first three stages resulted in an average increase of 26.4% (7.0 ml O<sub>2</sub>), 29.6% (9.9 ml O<sub>2</sub>), and 24.4% (10.6 ml O<sub>2</sub>), respectively, in VO<sub>2</sub>.

The results of the pilot study agree with the findings of Goss, Robertson, and Spina (6) that the greatest benefit in terms of increasing VO<sub>2</sub> during simulated cross-country skiing can be realized by increasing the frequency of limb movement rather than arm and leg resistance. In addition it appears that a 10% elevation yields only a slight increase in VO<sub>2</sub> and tends to be more uncomfortable than the 5% elevation.

Based on the results of the pilot study the following protocol was developed for the cross-country ski simulator (see Table 1).

Table 1. Cross-country test protocol

Stage	Minutes	Grade	Strides/minute	Resistance	
				Arm (lb)	Legs (lb)
I	0-2	5%	88	2	8
II	2-4	5%	88	4	12
III	4-6	5%	96	4	16
IV	6-8	5%	112	4	16
V	8-10	5%	120	4	20
VI	10-12	5%	120	6	24
VII	12-14	5%	136	6	24
VIII	14-16	5%	152	6	24
IX	16-18	5%	168	6	24

Note: Women began at stage I and men at stage II

#### Testing Protocol

Subjects. Thirteen male volunteers between the ages of 24 and 43 and 15 female volunteers between the ages of 22 and 49 served as subjects. All subjects were apparently healthy with no known cardiovascular or metabolic disease.

Testing Schedule. The present study was approved by the Institutional Review Board at the University of Wisconsin-La Crosse. All subjects completed a health history questionnaire and an informed consent document (see Appendix A) prior to testing. Subjects then completed two to five practice sessions on the NordicTrack. This was followed by a maximal treadmill (TM) test and a maximal cross-country (XC) test. Subjects were randomly assigned the order for the XC and TM tests. All subjects performed the maximal exercise tests within 1 week of each other and with at least 3 days rest between the tests.

Practice Session. Subjects unfamiliar with the NordicTrack completed two to five practice sessions, with the actual number depending on the proficiency of the subject. During the final practice session subjects practiced on the treadmill and the NordicTrack while wearing the mouthpiece and headgear used to measure oxygen consumption. This was done to help reduce anxiety and to allow the subject to become familiar with the testing procedure. In accordance with the American College of Sports Medicine (ACSM) guidelines for exercise testing (1) subjects were told that no food, caffeine, or alcohol were to be consumed for at least 3 hours prior to testing. The subjects were also be asked not to perform heavy exercise for 3 days prior to each maximal exercise test.

Testing Sessions. Prior to each test the subject's height and weight were taken and entered into the Q-Plex (Q-Plex 1, Quinton Instrument Company, Seattle, WA). The Q-Plex, an automated metabolic cart, was used to assess the subjects' expired air for the determination of absolute and relative  $\text{VO}_2$ , ventilation (VE), and respiratory exchange ratios (RER). The gas analyzers were calibrated prior to

and respiratory exchange ratios (RER). The gas analyzers were calibrated prior to each test using gases of known percentage that were previously determined by the micro-Scholander method. The calibration of the flow meter was done using a 2.850 liter syringe pump at various flow rates. Heart rates were determined using a heart rate (HR) monitor (Polar-CIC INC, Port Washington, NY) and rating of perceived exertion (RPE) was determined using the Borg 15 point scale (4).

TM test. The test was performed on a Quinton model 24-72 treadmill utilizing the Bruce protocol, and was preceded by a 5-minute self-selected warm-up. Physiological responses were recorded at the end of each minute during the test and the subject's RPE was recorded at the end of each 3-minute stage and at maximal exertion.

XC test. The test was performed on the NordicTrack 900 and was also preceded by a 5-minute self-selected warm-up. The XC testing protocol from Table 1 was followed and physiological responses were recorded at the end of each minute and at maximal exertion. RPE was recorded for the arms alone, the legs alone, and the overall perception of effort at the end of each 2 minute stage and again at maximal exertion.

A test was determined to be a true  $\text{VO}_2\text{max}$  test if two of the following three criteria were met: 1) a plateau or decrease in oxygen consumption with an increase in workload, 2) a heart rate no less than 10 beats below age-predicted maximal heart rate, and 3) a RER value greater than 1.0.

Statistical analysis. Standard descriptive statistics were used to characterize the subject population. Paired t-tests were used to compare the maximal values obtained from the XC and TM test. The level of significance was set at  $p < 0.05$ .

## RESULTS

Thirteen male and 15 female subjects completed both the XC and the TM tests. The descriptive characteristics of the subjects are presented in Table 2.

Table 2. Descriptive characteristics of the subject population

	Age (yrs)	Height (cm)	Weight (kg)
	X ± SD (range)	X ± SD (range)	X ± SD (range)
Overall	34.0 ± 6.9 (22 - 49)	173.4 ± 9.3 (157.5 - 190.5)	77.0 ± 16.2 (52.7 - 132.3)
Males	33.5 ± 6.2 (24 - 43)	178.6 ± 6.3 (167.6 - 190.5)	87.9 ± 15.8 (65.5 - 132.3)
Females	34.5 ± 7.6 (22 - 49)	168.8 ± 9.4 (157.5 - 182.9)	67.6 ± 9.3 (52.7 - 81.4)

Note: all values represent mean ± standard deviation

There were no significant ( $p > 0.05$ ) differences in  $VO_{2max}$  (relative and absolute), maximal HR, and maximal RPE values between the XC and TM tests (see Table 3). However, maximal VE was significantly ( $p < 0.05$ ) higher for the XC test, while RER was significantly higher for the TM test. The average time to exhaustion during the TM test was 13:16 minutes while the average time to exhaustion during the XC test was 12:53 minutes.

The regional RPE values for each stage of the XC test are presented in Table 4. It was found that there were no significant ( $p > 0.05$ ) differences between the

Table 3. Maximal physiological responses obtained during the treadmill and cross-country skiing tests

	Treadmill	NordicTrack	t (p)
Body weight (kg)			
Overall	77.0 ± 16.2	76.4 ± 16.1	1.04 (0.34)
Males	87.9 ± 15.8	87.3 ± 15.4	1.62 (0.26)
Females	67.6 ± 9.3	67.0 ± 9.6	1.79 (0.09)
VE (l·min <sup>-1</sup> )			
Overall	118.6 ± 26.89	124.5 ± 29.23	-2.98 (0.01)*
Males	139.4 ± 20.86	147.6 ± 20.20	-3.24 (0.01)*
Females	100.5 ± 16.44	104.5 ± 21.29	-1.33 (0.21)
VO <sub>2</sub> (l·min <sup>-1</sup> )			
Overall	3.31 ± 0.82	3.27 ± 0.78	0.66 (0.51)
Males	3.91 ± 0.58	3.88 ± 0.56	0.22 (0.83)
Females	2.80 ± 0.64	2.74 ± 0.48	0.72 (0.48)
VO <sub>2</sub> (ml·kg <sup>-1</sup> ·min <sup>-1</sup> )			
Overall	42.6 ± 5.7	42.5 ± 6.0	0.17 (0.86)
Males	45.1 ± 6.0	45.2 ± 6.4	-0.07 (0.95)
Females	40.5 ± 4.6	40.3 ± 4.6	0.43 (0.67)
RER			
Overall	1.21 ± 0.06	1.15 ± 0.06	4.60 (0.00)*
Males	1.21 ± 0.08	1.15 ± 0.05	2.69 (0.02)*
Females	1.22 ± 0.05	1.15 ± 0.05	3.70 (0.00)*
HR (bpm)			
Overall	185 ± 11.3	185 ± 11.2	0.28 (0.78)
Males	187 ± 10.2	187 ± 9.5	0.65 (0.53)
Females	184 ± 12.3	184 ± 12.6	0.21 (0.83)
RPE			
Overall	19.1 ± 0.9	19.0 ± 1.0	0.21 (0.83)
Males	19.5 ± 0.5	19.5 ± 0.7	0.56 (0.58)
Females	18.7 ± 1.0	18.7 ± 1.1	0.00 (1.00)

\* Significant difference between means ( $p < 0.05$ )

Note: all values represent mean ± standard deviation

Table 4. Regional RPE values for each stage of the XC test

Stage		Overall	Arms	Legs
I	Females	8.1 ± 1.4	8.0 ± 1.7	8.1 ± 1.9
II	Overall	9.4 ± 1.8	9.1 ± 1.9	9.4 ± 1.9
	Males	8.8 ± 1.6	8.4 ± 1.4	8.7 ± 1.7
	Females	9.9 ± 1.8	9.7 ± 2.1	9.9 ± 2.1
III	Overall	10.9 ± 1.7	10.6 ± 1.8	11.0 ± 2.0
	Males	10.4 ± 1.4	9.9 ± 1.4	10.4 ± 1.8
	Females	11.4 ± 1.9	11.1 ± 2.0	11.5 ± 2.1
IV	Overall	12.9 ± 2.4	12.4 ± 2.2	12.9 ± 2.3
	Males	12.6 ± 2.4	12.2 ± 1.8	12.7 ± 2.1
	Females	13.1 ± 2.4	12.6 ± 2.5	13.1 ± 2.6
V	Overall	14.0 ± 2.0	13.6 ± 2.0	14.1 ± 1.8
	Males	13.6 ± 1.6	13.5 ± 1.3	14.0 ± 1.7
	Females	14.3 ± 2.3	13.8 ± 2.6	14.3 ± 2.0
VI	Overall	15.9 ± 2.1	15.6 ± 2.0	16.0 ± 2.0
	Males	15.8 ± 2.2	15.6 ± 2.1	15.9 ± 2.0
	Females	16.1 ± 2.1	15.7 ± 2.0	16.2 ± 2.1
VII	Overall	17.6 ± 2.0	17.2 ± 1.9	17.6 ± 1.9
	Males	17.6 ± 2.3	17.2 ± 2.1	17.6 ± 2.2
	Females	17.5 ± 1.7	17.3 ± 1.8	17.6 ± 1.7
VIII	Overall	17.9 ± 1.7	17.6 ± 1.8	18.1 ± 1.6
	Males	17.2 ± 1.7	16.8 ± 1.9	17.3 ± 1.5
	Females	18.7 ± 1.4	18.3 ± 1.5	18.8 ± 1.5
IX	Males	18.7 ± 1.5	18.5 ± 2.0	18.7 ± 1.5

\* Significant difference between means ( $p < 0.05$ )

Note: all values represent mean ± standard deviation

Table 5. Average  $\text{VO}_2$  values for each stage of the XC test

Stage	<u>Overall</u>		<u>Males</u>		<u>Females</u>	
	$\text{VO}_2$ ( $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ )	METS	$\text{VO}_2$ ( $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ )	METS	$\text{VO}_2$ ( $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ )	METS
I					21.9 ± 3.4	6.3 ± 1.0
II	24.1 ± 3.3	6.9 ± 0.9	23.0 ± 2.6	6.6 ± 0.7	25.1 ± 3.6	7.2 ± 1.0
III	27.0 ± 3.3	7.7 ± 0.9	26.5 ± 3.4	7.6 ± 1.0	27.7 ± 3.3	7.9 ± 0.9
IV	31.3 ± 3.4	8.9 ± 1.0	31.4 ± 3.6	9.0 ± 1.0	31.2 ± 3.3	8.9 ± 0.9
V	35.6 ± 4.1	10.1 ± 1.2	36.3 ± 4.4	10.3 ± 1.3	35.0 ± 3.9	10.0 ± 1.1
VI	38.0 ± 3.9	10.9 ± 1.1	39.3 ± 3.9	11.2 ± 1.1	36.6 ± 3.4	10.5 ± 1.0
VII			43.0 ± 6.3	12.3 ± 1.8		
VIII			45.1 ± 4.5	12.9 ± 1.3		

Note: all values represent mean ± standard deviation

three regional RPE values (overall, arms alone, and legs alone) recorded for each stage of the XC test. Thus, the arm work was not a limiting factor for the XC test.

### DISCUSSION

The purpose of this study was to develop a valid  $\text{VO}_2\text{max}$  testing protocol for the NordicTrack 900 cross-country ski simulator. Because a TM test is considered to produce the highest  $\text{VO}_2\text{max}$  values, the maximal values obtained from the XC skiing test had to be similar to those obtained from a maximal graded TM test in order for it to be considered a valid protocol. It was found that there were no significant differences between the XC test and the TM test in  $\text{VO}_2\text{max}$  (absolute and relative), maximal HR, and maximal RPE values.

The findings of the present study agree with those of Porcari, Austen, Floyd, and Boyle (10) and Bart, Dorsen, and Leon (2) in finding no difference in  $\dot{V}O_2$  between a maximal simulated cross-country skiing test and a treadmill test. The present findings do, however, differ from those of Hinze (unpublished observations), who found the maximal values from a simulated cross-country ski test to be lower than those from a maximal treadmill test ( $52.3 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$  versus  $56.6 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ , respectively). The differences in results may be due to the testing protocol utilized.

Because there is no established protocol for determining  $\dot{V}O_{2\text{max}}$  during simulated cross-country skiing, the testing methods utilized in the present study differed from those of previous researchers (2, Hinze, unpublished observations, 10). The major differences among these studies and the current study was the protocol. The study by Porcari et al. (10) and the study by Bart et al. (2) utilized constant arm resistance settings of 4 lb and 1 kg, respectively, throughout the duration of the test. Leg resistance was based on an absolute value which increased during the test. Porcari et al. used a continuous protocol with 2 minute stages while Bart et al. used a discontinuous protocol with 3 minute stages. In contrast, Hinze (unpublished observations) used an arm resistance which increased from 2 to 3 kg after stage four and a leg resistance which was determined by multiplying the subjects' weight by a specific constant for each stage. The test was a continuous protocol consisting of 3 minute stages. Because the resistance settings utilized by Hinze may have greatly varied the ratio of arm work to total work for each subject, arm work may have been a limiting factor. Regional RPE's for this study were not presented.

Previous research has suggested that the subject population may also influence  $\text{VO}_2\text{max}$  values. Seals and Mullin (14) found that individuals who were upper body trained tended to have similar  $\text{VO}_2\text{max}$  values on a combined arm/leg test and a treadmill test, whereas individuals not upper body trained elicited lower maximal values on the combined arm/leg test. This suggests that those individuals not accustomed to cross-country skiing may have been limited by upper body fatigue during the simulated cross-country ski test. Similarly, studies which used trained cross-country skiers as subjects found no significant difference in maximal values between the ski simulator test and the treadmill test (2, 10). In contrast, Hinze's study (unpublished observations) did not use trained cross-country skiers and found maximal ski simulator values to be significantly lower than the maximal treadmill values. The present study, however, did not use trained cross-country skiers nor upper body trained athletes, yet maximal values between the XC test and the TM test were similar. This suggests that it is not necessary for an individual to be upper body trained to achieve a valid  $\text{VO}_2\text{max}$  test on an exercise requiring arm and leg work.

Several studies have also suggested that the  $\text{VO}_2\text{max}$  in combined arm and leg work is dependent on the proportion of arm and leg contributions to the total power output in eliciting  $\text{VO}_2\text{max}$  (3, 8). It is generally felt that when arm work contributes 10 to 30% of the total power output  $\text{VO}_2\text{max}$  values will be similar to those obtained during leg work alone. However, if arm work contributes less than 10 or greater than 30% of the total power output  $\text{VO}_2\text{max}$  values tend to be lower (3, 8). The present study generally maintained arm work at 25% of the total power output, hence these results agree with those found in previous studies.

Significant differences were found between the testing protocols for maximal VE and maximal RER. Maximal VE was approximately  $6.0 \text{ l}\cdot\text{min}^{-1}$  higher for the XC test than for the TM test with results being similar for both males and females. The higher values obtained during the XC test are likely due to the addition of arm work, as arm work tends to elicit higher ventilation than does leg work (1). Maximal RER was significantly lower for the XC test than for the TM test (1.15 versus 1.21), with results being similar for both males and females. The differences in values are possibly due to the fact that the XC test relied mainly on increases in speed to raise  $\text{VO}_2$ , whereas the TM test relied on increases in both speed and elevation. Previous studies have found that protocols utilizing higher elevations have yielded greater RER values than those using lower or no elevation at all (2, 7, 11, 12, 16). Protocols utilizing increases in both speed and elevation tend to cause localized muscular fatigue resulting in more lactic acid build-up, hence eliciting a higher RER value.

In conclusion, the protocol developed in this study may be used as a viable alternative to a maximal treadmill test. However, it is recommended that leg resistance be raised no higher than 16 lb for women and 20 lb for men, as body weight and lower body strength significantly influence the amount of leg resistance that can be moved at higher speeds. At higher leg resistances several subjects had difficulty maintaining the specified speed. Further investigation revealed that if leg resistance was decreased these higher speeds could be maintained. Further research should be conducted using these recommendations to determine if this would elicit greater  $\text{VO}_{2\text{max}}$  values than those found in this study.

## REFERENCES

1. American College of Sports Medicine. *Guidelines for Exercise Testing and Prescription*, 4th Ed. Philadelphia: Lea and Febiger, 1991, pp. 45, 46, 144.
2. Bart, B. A., P. J. Dorsen, and A. S. Leon. Maximal oxygen uptake ( $VO_2$ max) by ski ergometry in men and women collegiate champion cross-country skiers. *Med. Sci. Sports Exerc.* 22:S65, 1990.
3. Bergh, U., I. L. Kanstrup, and B. Ekblom. Maximal oxygen uptake during exercise with various combinations of arm and leg work. *J. Appl. Physiol.* 41:191-196, 1976.
4. Borg, G. A. V. Psychological basis of perceived exertion. *Med. Sci. Sports Exerc.* 14:377-381, 1982.
5. Bowers, R. W. and E. L. Fox. *Sports Physiology*, 3rd Ed. Dubuque, IA: Wm. C. Brown, 1992, p. 49.
6. Goss, F. L., R. J. Robertson, and R. J. Spina. Aerobic metabolic requirements of simulated cross-country skiing. *Ergonomics* 32:1573-1579, 1989.
7. Lukaski, H. C., W. W. Bolonchuk, and L. M. Klevay. Comparison of metabolic responses and oxygen cost during maximal exercise using three treadmill protocols. *J. Sports Med.* 29:223-229, 1989.
8. Nagle, F. L., J. P., Richie, and M. D. Glese.  $VO_2$ max responses in separate and combined arm and leg air-braked ergometer exercise. *Med. Sci. Sports Exerc.* 16:563-566, 1984.
9. Ng, A. V., R. B. Demment, D. R. Bassett, et al. Characteristics and performance of male citizen cross-country ski racers. *Int. J. Sports Med.* 9:205-209, 1988.
10. Porcari, J. P., S. Austen, B. Floyd, and J. Boyle. Development of a  $VO_2$ max testing protocol for simulated cross-country skiing. *Med. Sci. Sports Exerc.* 27: S243, 1995.
11. Potiron-Josse, M. Comparison of 3 protocols of determination of direct  $VO_2$ max amongst 12 sportsmen. *J. Sports Med.* 23:429-435, 1983.

12. Pollock, M., R. Bohannon, K. Cooper, J. Ayres, S. Warda-White, and A. Linnerud. A comparative analysis of four protocols for maximal treadmill stress testing *Am. Heart J.* 92(1):39-46, 1976.
13. Ready, A. E., and H. R. Huber. Physiologic responses of nordic ski racers to three modes of sport specific exercise. *Can. J. Sport Sci.* 15(3):213-217, 1990.
14. Seals, D. R. and J. P. Mullin.  $VO_2$ max in variable type exercise among well-trained upper body athletes. *Res. Q. Exerc. Sport.* 53:58-63, 1982.
15. Simard, C. P. and J. R. Roy. Biological changes after one season of cross-country skiing adapted to old people. *Med. Sci. Sports Exerc.* 11:101, 1979.
16. Weltman, A., D. Snead, P. Stein, R. Schurrer, R. Rutt, and J. Weltman. Reliability and validity of a continuous incremental treadmill protocol for the determination of lactate threshold, fixed blood lactate concentrations, and  $VO_2$ max. *Int. J. Sports Med.* 11:26-32, 1990.

APPENDIX A  
INFORMED CONSENT

## INFORMED CONSENT FOR NORDICTRACK VO<sub>2</sub>MAX STUDY

Project Title: Development and validation of a maximal testing protocol for the NordicTrack cross-country ski simulator

Principle Investigators: Rhea Haug and John Porcari, Ph.D.

### Explanation of the Exercise Tests

As a subject for this study you will perform a maximal exercise test on a motorized treadmill and a NordicTrack ski simulator. For both tests the exercise intensity will begin at a level you can easily accomplish and will be advanced in stages depending on your fitness level. You will be fitted with a headgear device that will allow the collection and analysis of your expired air. Your heart rate will be monitored throughout the test and you will be asked questions pertaining to your subjective ratings of exertion. We may stop the test at any time due to signs of fatigue or physiological abnormalities. Also, you may stop the test at any time due to personal feelings of fatigue or discomfort.

### Risks and Discomforts

There exists the possibility of certain abnormal changes occurring during these tests. These changes include atypical heart rate responses, fainting, disorders in heart beat, and in rare instances, heart attack, stroke, or even death. Every effort will be made to minimize these risks by preliminary evaluation and by observations during the tests. Emergency equipment and trained personnel are available to deal with any unusual situations that may arise.

### Responsibilities of the Participant

Information you possess about your health status or previous experiences of unusual feelings with physical effort may effect the safety or value of your exercise tests. Your prompt reporting of feelings with effort during the exercise tests are also of great importance. It is your responsibility to disclose such information from your past or if it occurs during testing.

### Benefits to be Expected

The results obtained from these exercise tests will be discussed with you and may assist you in evaluating your aerobic capacity and in developing a training program.

### Inquires

Any questions about the procedures used in these exercise tests are encouraged. If you have any doubts or questions, please ask for further explanations.

**Freedom of Consent**

I have read the above document, and I have been fully advised of the nature of the procedure and the possible risks and complications involved in it, all of which risks and complications I hereby assume voluntarily. I understand that I may withdraw from this study at any time.

Participant Signature: \_\_\_\_\_ Date: \_\_\_\_\_

Investigators Signature: \_\_\_\_\_ Date: \_\_\_\_\_

APPENDIX B  
REVIEW OF LITERATURE

## REVIEW OF LITERATURE

Because cross-country skiing utilizes a larger muscle mass than treadmill running or cycling it should, in reality, yield the highest maximal oxygen consumption ( $VO_2\text{max}$ ) values. Because working muscle demands oxygen to metabolize energy, more working muscle mass should result in a higher demand for oxygen and thus a higher  $VO_2\text{max}$ . Research, however, has not found this hypothesis to be totally valid. When comparing combined arm and leg exercise to leg bicycling, some investigators have found a 5-10% higher  $VO_2\text{max}$  during combined arm and leg exercise (4, 14). Other studies, however, have reported  $VO_2\text{max}$  values to be the same (1, 13). The discrepancy in these results may be explained by the relative contribution of arm work to the total work performed. Unfortunately these studies do not use the same motion simulated during cross-country skiing, but rather the combination work was performed on machines, such as the Schwinn Airdyne or leg/arm ergometers. The few studies that have used simulated cross-country skiing to investigate the role of muscle mass on  $VO_2$  have conflicting results (2, Hinze, unpublished observations, 8, 9).

### The Role of Muscle Mass in Determining $VO_2$

Several studies have suggested that  $VO_2\text{max}$  in combined arm/leg cycling is dependent on the proportion of arm and leg contributions to the total power output in eliciting  $VO_2\text{max}$  (3, 6). To further confound the issue, investigators

have observed that the level of arm training of subjects will influence arm/leg proportions contributing to  $VO_2\text{max}$  (10, 11).

Bergh, Kanstrup, and Ekblom (3) conducted a study to determine if  $VO_2$  during maximal combined arm and leg exercise was influenced by the ratio of arm to total work intensity. These results were then compared to maximal uphill and bicycle values. Each of the ten male subjects performed submaximal and maximal work in the following types of exercise: 1) uphill running on a treadmill, 2) arm work (cranking), 3) bicycling in upright position (sitting), and 4) combined arm and leg exercise (cranking and leg bicycle work). The combined arm and leg work was performed four different ways, the arm work being 10, 20, 30, and 40%, respectively, of the total arm plus leg work. The  $VO_2\text{max}$  values for arm ergometry, leg ergometry, combined work of 10%, and combined work of 40% were significantly lower than treadmill running. The  $VO_2\text{max}$  values for combined work of 20% and combined work of 30% ( $4.34 \text{ l}\cdot\text{min}^{-1}$ , and  $4.27 \text{ l}\cdot\text{min}^{-1}$ , respectively) were lower, but not significantly different than treadmill running ( $4.44 \text{ l}\cdot\text{min}^{-1}$ ). Results of this study suggest that the ratio of arm work to total work may be an important factor influencing  $VO_2$ , and that the leg workload in combined exercises should be intense enough to tax aerobic power close to maximum.

The results of Nagle, Richie, and Giese (6) agree with the findings of Bergh et al. (3) that the relative contributions of the arms and legs in performing maximal exercise affects  $VO_2\text{max}$  values. Nagle et al. had non-arm trained males perform maximal arm work (push-pull) alone, leg work alone, and combined arm/leg work

on an air-braked ergometer. The combination tests consisted of three different trials with the arms contributing 10, 20, and 30%, respectively, of the total combined workload. No significant differences in  $\text{VO}_2\text{max}$  were found for the 10% combined ( $4.086 \cdot \text{l} \cdot \text{min}^{-1}$ ) and 20% combined ( $3.775 \cdot \text{l} \cdot \text{min}^{-1}$ ) workloads, but the values for the 10% combined workload were significantly higher than the values for the arm work alone ( $2.522 \cdot \text{l} \cdot \text{min}^{-1}$ ), leg work alone ( $3.580 \cdot \text{l} \cdot \text{min}^{-1}$ ), and the 30% combined ( $3.402 \cdot \text{l} \cdot \text{min}^{-1}$ ) workload. This study agrees with the finding of Bergh et al. (3) that the 20% combination workload was not significantly different from leg work alone, however, there is disagreement on the 10% combined and 30% combined values.

One of the factors that may influence the extent to which arm/leg proportions contribute to  $\text{VO}_2\text{max}$  is the level of arm training of subjects. Seals and Mullin (10) maximally tested well-trained upper body athletes and untrained individuals in four different types of exercise: 1) arm cranking, 2) legs only cycling, 3) graded treadmill running, and 4) combined arm cranking and leg cycling. The untrained individuals attained their highest  $\text{VO}_2\text{max}$  on the treadmill, whereas the well-trained upper body athletes attained equivalent values in treadmill and combined arm/leg exercise. It appears from this study that treadmill running appears to be the most appropriate mode of exercise for eliciting  $\text{VO}_2\text{max}$  values in individuals not trained for upper body activities.

#### Simulated Cross-Country Skiing

Simulated cross-country skiing employs the arms and legs in motions similar to those used in cross-country skiing. The arm and leg muscles act to

propel the body forward as if actually on skis. The intensity of the workout can be controlled through manipulation of arm resistance, leg resistance, grade, and speed. To date, literature concerning simulated cross-country skiing, and more specifically the NordicTrack, is limited. Most studies however, have shown equal or lower values for simulated cross-country skiing tests compared to treadmill tests (2, Hinze, unpublished observations, 8, 9).

Bart, Dorsen, and Leon (2) tested male and female collegiate cross-country skiers to determine the effects of simulated cross-country skiing on  $VO_{2max}$ . Each subject performed two maximal exercise tests, one on a treadmill and one on a NordicTrack ski simulator. A modified Bruce protocol was used consisting of a 3 minute recovery period after the third stage and each stage thereafter. The NordicTrack protocol consisted of 3-minute exercise stages with increasing speed, leg resistance, and elevation, interspersed by 3-minute rest periods. The arm resistance was maintained at 1 kg throughout the test. No significant differences in  $VO_{2max}$  were found between the two tests for either the men or the women. The maximal values for the men on the treadmill and the NordicTrack were  $60.6 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$  and  $56.8 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ , respectively.  $VO_{2max}$  values for the women on the two tests were even closer, eliciting an average value of  $57.4 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$  on the treadmill and  $57.1 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$  on the NordicTrack.

Another study comparing  $VO_{2max}$  values elicited during simulated cross-country skiing and treadmill running was done by Porcari, Austen, Floyd, and Boyle (8). Fourteen male cross-country skiers, ranging in age from 22 to 41, each completed a maximal exercise test on a treadmill and a NordicTrack ski simulator.

A modified Balke protocol (self-selected running speed with an increase in grade of 2.5% every 2 minutes) was utilized. The NordicTrack protocol consisted of 2-minute stages with either the speed or leg resistance being altered. Arm resistance remained at 4 lb and the grade at 10% throughout the test. The  $VO_2\max$  values attained during the NordicTrack test ( $56.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) were not significantly different from those of the treadmill test ( $57.7 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ).

A study by Ready and Huber (9) used cross-country ski racers to compare ski-walking, ski-walking with arm resistance provided by a pulley system, and a skimill test. The skimill test involved the use of a treadmill with a modified belt covered with carpet. Classic racing skis and nylon tipped poles were used by the subjects to perform the test. Although the average time to exhaustion was significantly less for the skimill test than for the other tests, there was no difference in the response to maximal exercise.

While each of the previous studies found no significant difference in  $VO_2\max$  values between treadmill testing and simulated cross-country ski testing, one study has found conflicting results. Hinze (unpublished observations) tested fourteen healthy male volunteers between the ages of 21 and 34 on both a NordicTrack ski simulator and a treadmill. The treadmill test consisted of seven, 3-minute stages with the grade being held constant at 5%. Arm resistance remained at 2 kg for stages I-IV and then increased to 3 kg for the remaining three stages. The speed increased during each stage in uneven increments from 96 strides per minute in the first stage to 184 strides per minute in the last stage. The leg resistance was determined by the subjects' body weight. The subjects' body

weight, in kg, was multiplied by .10, .12, .12, .14, .14, .16, and .16, respectively, for the seven stages. The mean relative oxygen consumption for treadmill running ( $56.5 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) was statistically higher than the value obtained during maximal simulated cross-country skiing ( $52.3 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ).

The discrepancy in the results of these tests may be explained by the differences in subject populations and the testing protocols. The three studies which found no difference between simulated cross-country skiing and treadmill exercise all used experienced cross-country skiers, whereas the study by Hinze (unpublished observations) did not. As mentioned previously, individuals who are upper body trained tend to have similar  $\text{VO}_2\text{max}$  values on a combined arm/leg test and a treadmill test, whereas individuals not upper body trained elicit lower maximal values on the combined arm/leg test (10). It is possible that those individuals not accustomed to cross-country skiing may have been limited by upper body fatigue during the simulated cross-country ski test. Furthermore, testing protocols for both the ski simulator and treadmill exercises were different. Hinze's protocol utilized a higher initial arm load (2 kg) and increased the load during the test, while Bart et al. (2) and Porcari et al. (8) maintained a constant arm load of 1 kg and 4 lb, respectively. Bart et al. also utilized a discontinuous protocol as opposed to a continuous protocol. Hinze's protocol also increased leg resistance relative to the subjects body weight. This would result in variations from subject to subject in the arm to total work ratio, possibly going above the optimal 10 to 30% ratio (3, 6). Each of these factors may explain why Hinze found a lower  $\text{VO}_2\text{max}$  value for the simulated ski test as opposed to the treadmill test.

### Physiological Responses to Cross-Country Skiing

Cross-country skiing, both in actual and simulated forms, has been shown to have positive physiological effects in both the young and old. Ng et al. (7) tested 43 male recreational cross-country skiers with an average age of 31. Subjects performed a maximal treadmill test to determine  $VO_2\text{max}$  and percent body fat. Results of the study indicated that this group was a fit subgroup of the general population, with  $VO_2\text{max}$  averaging  $56.6 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$  and 10.1% body fat.

Cross-country skiing has also been shown to elicit favorable physiological responses in the aging population. Simard and Roy (12) investigated the biological changes in individuals ranging in age from 60 to 75 years after one season of cross-country skiing. Subjects skied 3 times per week, for 60 minutes each session, at a mean heart rate of 120 beats per minute. The training resulted in significant increases in  $VO_2\text{max}$ , trunk flexibility, and vital capacity.

Mostardi, Gandee, and Norris (5) conducted a 6-week training study to determine whether levels of conditioning associated with conventional leg work are comparable to those associated with both arm and leg work. The investigators trained six healthy men using both arms and legs while a similar group of five men trained using legs only. A Monarch bicycle was used for leg training, while an adaptable Fleisch ergostat was used for the arms. The subjects trained 3 times per week and covered an average distance of 3 miles per session. Both groups showed an increase of 12% in  $VO_2\text{max}$  after training. While there were no significant differences in the improvement of  $VO_2\text{max}$  between the two groups,

the arm and leg subjects were able to do more work at a lower heart rate during the training program. The authors concluded that combined arm and leg work places less physical stress on the heart and skeletal muscle than does leg work alone. This indicates that the feeling of stress may be related to metabolic rate per square area of working muscle rather than to total metabolism.

Stenberg, Astrand, Ekblom, Royce, and Saltin (13) have also demonstrated that exercise using combined arm and leg work was better tolerated and accepted by subjects because the overall stress and subjective physical effort was less. These studies suggest that an exercise which incorporates both arm and leg work may be beneficial and more tolerable to individuals. This type of exercise may be especially useful to the aging and cardiac populations. While these studies were not conducted using cross-country skiing as the mode of exercise, results of the studies may be applied to cross-country skiing since it requires both leg and arm work.

While it appears that cross-country skiing can elicit beneficial physiological effects, no form of combined arm and leg work has been able to produce a higher  $VO_2$ max value than a treadmill test. There also appears to be an optimal arm to total work ratio of 10 to 30%. The choice of subjects and the type of testing protocol for the combined work may influence  $VO_2$ max values.

## REFERENCES

1. Astrand, P. O. and B. Saltin. Maximal oxygen uptake and heart rate in various types of muscular activity. *J. Appl. Physiol.* 16:977-981, 1961.
2. Bart, B. A., P. J. Dorsen, and A. S. Leon. Maximal oxygen uptake ( $VO_2$ max) by ski ergometry in men and women collegiate champion cross-country skiers. *Med. Sci. Sports Exerc.* 22:S65, 1990.
3. Bergh, U., I. L. Kanstrup, and B. Ekblom. Maximal oxygen uptake during exercise with various combinations of arm and leg work. *J. Appl. Physiol.* 41:191-196, 1976.
4. Glezer, M. A., D. H. Horstman, and R. P. Mello. The effect on  $VO_2$ max of adding arm work to maximal leg work. *Med. Sci. Sports Exerc.* 6:104-107, 1974.
5. Mostardi, R. A., R. N. Gandee, and W. A. Norris. Exercise training using arms and legs versus legs alone. *Arch. Phys. Med. Rehabil.* 62:332-335, 1981.
6. Nagle, F. L., J. P., Richie, and M. D. Giese.  $VO_2$ max responses in separate and combined arm and leg air-braked ergometer exercise. *Med. Sci. Sports Exerc.* 16:563-566, 1941.
7. Ng, A. V., R. B. Demment, D. R. Bassett, et al. Characteristics and performance of male citizen cross-country ski racers. *Int. J. Sports Med.* 9:205-209, 1988.
8. Porcari, J. P., S. Austen, B. Floyd, and J. Boyle. Development of a  $VO_2$ max testing protocol for simulated cross-country skiing. *Med. Sci. Sports Exerc.* 27:S243, 1995.
9. Ready, A. E., and H. R. Huber. Physiologic responses of nordic ski racers to three modes of sport specific exercise. *Can. J. Sport Sci.* 15(3):213-217, 1990.
10. Seals, D. R. and J. P. Mullin.  $VO_2$ max in variable type exercise among well-trained upper body athletes. *Res. Q. Exerc. Sport.* 53:58-63, 1982.
11. Secher, N. H., N. Ruberg-Larsen, R. A. Binkhorst, and F. Bonde-Petersen. Maximal oxygen uptake during arm cranking and combined arm plus leg exercise. *J. Appl. Physiol.* 36:515-518, 1974.

12. Simard, C. P. and J. R. Roy. Biological changes after one season of cross-country skiing adapted to old people. *Med. Sci. Sports Exerc.* 11:101, 1979.
13. Stenberg, J., P. O. Astrand, B. Ekblom, J. Royce, and B. Saltin. Hemodynamic response to work with different muscle groups, sitting and supine. *J. Appl. Physiol.* 22:61-70, 1967.
14. Taylor H. L., E. Huskirk, and A. Henschel. Maximal oxygen intake as an objective measure of cardio-respiratory performance. *J. Appl. Physiol.* 8: 73-80, 1955.