ABSTRACT

Austen, S. E. A VO_2max test protocol for simulated cross-country skiing. MS in Adult Fitness/Cardiac Rehabilitation, December, 1994, 25pp. (J. Porcari)

The purpose of this study was to develop a simulated cross-country skiing (XC) VO_2max test protocol for use with the NordiCare Strider (NS). The three variables that control workload on the NS (resistance, speed, and elevation) were assessed during a pilot study. A protocol for the NS was developed from the findings of the pilot study and was compared to a modified Balke treadmill (TM) VO_2max test (self-selected running speed with an increase in grade of 2.5% every 2 min). Volunteer male cross-country skiers ($N = 14$) served as subjects and completed the tests in random order. When the physiological responses from the XC and TM tests were compared there was no significant ($p > 0.05$) difference in VO_2 $L \cdot min^{-1}$ (4.17 versus 4.29), VO_2 $ml \cdot kg^{-1} \cdot min^{-1}$ (56.2 versus 57.7), RER (1.15 versus 1.13), HR (183 versus 184), and RPE (17.8 versus 17.9), respectively. It was concluded that the XC test was a valid VO_2max test for cross-country skiers.

A VO_2MAX TEST PROTOCOL FOR SIMULATED CROSS-COUNTRY SKIING

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

SCOTT E. AUSTEN

DECEMBER 1994

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

THESIS FINAL ORAL DEFENSE FORM

Candidate: Scott Edward Austen

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 his/her final oral examination.

John Porcari — 8/4/94
Thesis Committee Chairperson Signature — Date

William Floyd — 8/4/94
Thesis Committee Member Signature — Date

Jeff Boyle — 8/4/94
Thesis Committee Member Signature — Date

If Necessary

Thesis Committee Member Signature — Date

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

Gary Gilmore — 11-17-94
Associate Dean, College of Health, Physical Education, and Recreation — Date

[illegible signature] — 11/21/94
Dean of UW-L Graduate Studies — Date

ACKNOWLEDGMENTS

I dedicate this thesis to my family who instilled in me a drive to challenge myself and to continue to learn from life. I thank the members of the La Crosse Ski Club and the other skiers from the La Crosse area who made this study possible by volunteering as subjects. I would also like to thank Dr. John Porcari, Dr. William Floyd, and Mr. Jeff Boyle, my thesis committee members, who provided their diverse thoughts and incite to this project. Finally, a special thanks to Lisa, my fiancee, for the support and help she has provided throughout the past year.

TABLE OF CONTENTS

PAGE

LIST OF TABLES

TABLE PAGE

LIST OF APPENDICES

APPENDIX PAGE

INTRODUCTION

The principal limiting factor for most types of exercise lasting longer than 5 minutes is the ability of the cardiorespiratory system to deliver oxygen to the working muscle (9). The best means of assessing this system is to measure the maximal oxygen consumption (VO_2max) during exercise. The term VO_2max represents the maximal amount of oxygen the body can take in and utilize at maximal exertion, and can be expressed in absolute terms ($L\ O_2 \cdot min^{-1}$) or relative to body weight ($ml\ O_2 \cdot kg^{-1} \cdot min^{-1}$). These measurements are usually conducted in an exercise laboratory while the subject is exercising using standardized test protocols and connected to an automated metabolic cart (1). The most commonly used test mode is the treadmill, with the highest measured VO_2max values usually occurring during uphill treadmill running (12).

Exercising muscle needs oxygen to perform work for an extended period of time, thus, the larger the exercising muscle mass the higher the measured VO_2max values should be. This is the reason why the involvement of a large muscle mass is a major criteria for a VO_2max test and why treadmill work results in higher maximal values than cycle or arm ergometery work. Another criteria is the specificity of the testing mode. Athletes tend to achieve higher VO_2max values when the test mode is similar to the sport in which they compete (14). Thus, runners achieve their highest VO_2max values during a running test, cyclists during a cycle ergometery test, rowers during a rowing ergometery test, and swimmers during a flume test.

Elite cross-country skiers have obtained the highest VO_2max values recorded (2), but unlike other athletes they do not have a sport specific VO_2max test. Theoretically skiers should be able to obtain even higher VO_2max values during a simulated cross-country skiing test due to the increased muscle mass involved and the specificity of the test. The reason there is no sport specific test is that very few studies have been conducted on simulated cross-country skiing (3, 6, Hinze unpublished observations). Most of the studies that have investigated combined arm and leg work have been conducted using arm ergometers, leg ergometers, and combined arm and leg machines such as the Schwinn Airdyne (4, 7, 10, 11). Those studies that have compared treadmill running to combined arm and leg work (3, 4, Hinze unpublished observations) have not found higher VO_2max values for the combined work. There are several possible explanations for these findings. One problem is the devices used for testing. As mentioned above, most of the studies have used machines that did not simulate cross-country skiing. Additionally when studies have used simulated cross-country skiing (3, 6, Hinze unpublished observations) no standardized protocols were utilized. This is due to the confusion as to which combination of arm resistance, leg resistance, speed, and elevation is optimal. Therefore the purpose of this study was to develop a test protocol for cross-country skiers to obtain the highest VO_2max values on the NordiCare Strider ski simulator. This study was conducted in two phases. The pilot phase was used to determine the settings for resistance, speed, and elevation used in the cross-country (XC) test protocol. The testing phase compared the VO_2max values from the XC test protocol to the values obtained from a Modified Balke treadmill (TM) test.

METHODS

Pilot Study

Subjects. Two male volunteers with 30 years of skiing experience served as subjects. Following a written and verbal explanation of the procedure and potential risks, an informed consent was completed (see Appendix B).

Procedure. On the NordiCare Strider, workload can be increased by altering the resistance, speed, and elevation. The influence of these conditions on VO_2 were tested using the NordiCare Strider. Each test consisted of four stages, each 2 minutes in duration, in which one condition was altered while the other two remained constant. Upon completion of the second minute of each stage, the work load was increased until the test was terminated.

When resistance was used as the independent variable, arm work was maintained at 20% and leg work 80% of the total resistance. The resistance settings for the four stages were 3 lb/12 lb, 4 lb/16 lb, 5 lb/20 lb, and 6 lb/24 lb. The elevation was maintained at 10% and the speed at a rate of 100 strides per minute. For each increase in workload in the first three stages, an average increase of 15% (5.8 ml O_2) and 14.4% (6.4 ml O_2) was observed in VO_2. Only one subject completed stage four, with an observed increase of only 7.1% (3.6 ml O_2) in VO_2 .

When speed was used as the independent variable the elevation was set at 5% and the resistance was set at 4 lbs for the arms and 16 lbs for the legs. The stride rates for the four stages, as set by a metronome, were 80, 100, 120, and 138 strides per minute. The 20 stride per minute increase between each of the first three stages resulted in an average increase of 23% (8.8 ml O_2) and 17.3% (8.1 ml O_2), respectively. Only one of the subjects completed the last stage, with a resulting 10% (5.7 ml O_2) increase in VO_2 for the 18 stride per minute increase in speed.

The last variable tested was elevation. To allow for rapid increases in elevation the NordiCare Strider was mounted on the treadmill. The resistance was set at 4 lbs for the arms and 16 lbs for the legs. The speed was set at 100 strides per minute. The elevations for the four stages were 5, 10, 15, and 20%. The average increases in VO_2 between the stages were 8.6% (4.8 ml O_2), 8.1% (3.7 ml O_2), and 3.3% (1.5 ml O_2) respectively. Both subjects stated that they felt like they were falling backwards during the last two stages.

The results of the pilot study agree with the findings of Goss, Robertson, Spina, Auble, Cassinelli, Silberman, Galbreath, Glickman, and Metz (6), that an increase in speed has the greatest influence on VO_2 values. In addition it appears that a 10% grade is the optimal setting because it increases VO_2 without causing the "falling" sensation associated with steeper grades. These findings in conjunction with those of Nagle, Richie, and Giese (11), that a ratio of arm work to total work of 20% or less is optimal for increasing VO_2max values, were used to develop the XC test protocol presented in Table 1.

Table 1. XC test protocol

Stage	Minutes	Grade	Speed strides/minute	Resistance Arm (lbs)	Resistance Legs (lbs)
I	0-2	10%	80	4	16
II	2-4	10%	100	4	16
III	4-6	10%	100	4	20
IV	6-8	10%	120	4	20
V	8-10	10%	140	4	20
VI	10-12	10%	160	4	20

* Increase resistance on legs by 4 lbs every 2 minutes as needed after stage VI

Testing Protocol

Subjects. Fourteen male volunteer cross-country skiers between the age of 22 and 41 years, and with at least two years of skiing experience served as subjects. Subjects were solicited from local cross country ski teams or clubs. Subjects were randomly assigned the order in which the XC test and treadmill tests were taken.

Treadmill test. American College of Sports Medicine (ACSM) guidelines (1) for exercise testing were followed for all tests (i.e. patients should abstain from food, tobacco, alcohol, and caffeine for at least 3 hours prior to testing, etc.). The tests were performed on the Quinton model 24-72. The subjects' height and weight were taken prior to the test and entered into the Q-Plex (Q-Plex 1, Quinton Instrument Company, Seattle, WA). The test was preceded by a warm-up that consisted of walking up a 10% grade at 3 mph. A Modified Balke test protocol (self-selected running speed with an increase in grade of 2.5% every 2 minutes) was utilized. Physiological responses were recorded at the end of each minute during the tests and the subject's Rating of Perceived Exertion (RPE) was recorded at the end of each stage.

An automated metabolic cart, Q-Plex, was used to assess the subjects' expired air for the determination of absolute and relative oxygen consumption, 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 3.002 liter syringe pump at various flow rates. Heart rates were determined using a heart rate monitor (Polar-CIC INC, Port Washington, NY). The subjects RPE was determined using the Borg 15 point scale (5).

A test was determined to be a true VO_2max test if two of the following criteria were met: 1) a plateau or decrease in oxygen consumption with an increase in workload (13), 2) a heart rate no less than 10 beats below age-predicted maximal heart rate (8), and 3) a RER value greater than 1.0.

XC test. The XC test was performed on the NordiCare Strider. The test was preceded by a 5 minute warm up (self-selected speed, 10% grade, and resistance of 2 lbs and 12 lbs on the arms and legs, respectively). The XC test protocol from Table 1 was followed. Physiological responses were recorded as stated above. RPE's were recorded for the arms alone, the legs alone, and the overall perception of effort at the end of each stage. The same criteria for determining a true VO_2max as the TM test were used.

Statistical analysis. Descriptive statistics were run to characterize the subjects. A paired t-test was used to compare the maximal values obtained during the XC and TM test. The level of significance was set at $p < 0.05$.

RESULTS

The subjects' ages ranged from 22 to 41 years, with a mean height of 179.2 ± 5.5 cm, and mean weight of 75.0 ± 9.8 kg. The TM test and the XC test were valid maximal tests because at least two of the three criteria (a plateau or decrease in VO_2 with an increase in work, heart rate no lower then 10 beats below age predicted max, and a RER over 1.0) for a true VO_2max test were met by all subjects. There were no significant ($p > 0.05$) differences in VO_2max (relative and absolute), maximal RER, maximal HR, and maximal RPE values between the TM test and the XC test (see Table 2).

The regional RPE values for each stage of the XC test are presented in Table 3. It was found that there was no significant ($p > 0.05$) difference between the 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 VO_2max testing protocol for cross-country skiing using the NordiCare Strider. It was believed that a properly developed protocol should compare favorably to the results obtained during a treadmill VO_2max test because a treadmill test is considered to produce the highest VO_2max values. It was found that there were no significant differences between the XC test and TM test in VO_2 (absolute

Table 2. Maximal physiological responses obtained during TM and XC tests.

	Treadmill	NordiCare	t (p)
VO_2 L·min⁻¹	4.29 ± 0.45	4.17 ± 0.48	1.31 (0.21)
VO_2 ml·kg⁻¹·min⁻¹	57.7 ± 8.6	56.2 ± 9.3	1.36 (0.20)
RER	1.13 ± 0.06	1.15 ± 0.07	-1.32 (0.21)
HR	184 ± 10	183 ± 8	0.29 (0.77)
RPE	17.9 ± 1.3	17.8 ± 1.8	0.41 (0.68)

* significant difference between means ($p < 0.05$)
Note: all values represent mean ± standard deviation

Table 3. Regional RPE values for each stage of the XC test.

Stage	Overall	Arms	Legs
I	9.3 ± 1.3	8.9 ± 1.4	9.2 ± 1.5
II	12.0 ± 1.5	11.0 ± 1.6	11.4 ± 1.6
III	13.3 ± 1.7	12.0 ± 1.7	13.3 ± 2.0
IV	15.3 ± 1.5	14.3 ± 1.8	15.0 ± 1.6
V	17.2 ± 1.8	16.4 ± 2.2	17.0 ± 1.6
VI	17.6 ± 1.2	16.3 ± 1.5	17.0 ± 0.0
VII	18.0 ± 0.0	18.0 ± 0.0	18.5 ± 0.7

* significant difference between means ($p < 0.05$)
Note: all values represent mean ± standard deviation

and relative), maximal RER, maximal heart rate, and maximal RPE. The findings of the present study agree with those of Bart, Dorsen, and Leon (3) in finding no difference between a maximal simulated skiing test and a maximal treadmill test. However, the present findings disagree with those of Hinze (unpublished observations), who found the values from a maximal NordicTrack test to be lower than those from a maximal treadmill test (52.3 $ml \cdot kg^{-1} \cdot min^{-1}$ versus 56.6 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively). Possible explanations for this disagreement include the ratio of arm work to total work, the method of testing, the machine utilized, and the characteristics of the subject population.

In studies comparing arm work to leg work (4,11), the ratio of arm work to the total work was found to be an important factor influencing VO_2max. Bergh, Kanstrup, and Ekblom (4), who used a cranking motion for arm work, compared treadmill running to combined arm and leg work. It was found that when the arms contributed 20 and 30% of the total work there was no significant difference in VO_2 (4.34 $L \cdot min^{-1}$ and 4.27 $L \cdot min^{-1}$) compared to treadmill running (4.44 $L \cdot min^{-1}$). However, the VO_2 was significantly lower when the arms contributed 10 and 40% of the total work (4.32 $L \cdot min^{-1}$ and 4.01 $L \cdot min^{-1}$, respectively). In contrast, Nagle, Richie, and Giese (11) compared combined arm and leg work with leg work on an Airdyne. This machine employs a push-pull motion for the arms that resembles the poling motion of cross-country skiing. It was found that there was no significant difference between 10% arm work (4.086 $L \cdot min^{-1}$) and 20% arm work (3.775 $L \cdot min^{-1}$). However leg work alone (3.580 $L \cdot min^{-1}$), arm work alone (2.522 $L \cdot min^{-1}$), and arm work contributing 30% of the total work (3.402 $L \cdot min^{-1}$) were significantly lower than 10% arm work. These results are supported by the findings of the present study and those of Bart, Dorsen, and Leon (3). Both the present study and Bart, Dorsen, and Leon (3) utilized a protocol in which the arm resistance corresponded to 20% or less of the total work load and found no difference between a treadmill test and a ski test. In

Hinze's (unpublished observations) protocol, arm resistance varied from 15 to 25% and a difference between the tests was found. These findings suggest that the optimal ratio of arm work for cross-country skiing is with the arms contributing 10 to 20% of the total work. This also suggests that there is a point at which the increase in oxygen demand by the arms is counteracted by the difficulty in perfusing the arms with blood . If this is the case, there may be a point at which the influence of an increase in muscle mass will be detrimental.

Since there is no established protocol for simulated cross-country skiing, the present study's testing methods differed from those of previous researchers (3, Hinze unpublished observations). The major difference was in the protocol utilized. Hinze used an arm resistance that increased from 2 kg to 3 kg after stage four. The leg resistance varied for each subject because the resistance was determined by multiplying the subjects weight (kg) by a different constant for each stage (see Table 4, Appendix C). In contrast, the present study and the study by Bart, Dorsen, and Leon (3) employed constant arm resistance settings of 4 pounds and 1 kg, respectively, for the duration of the test. The leg resistance was not based on the subjects weight, but was rather an absolute value that increased during the test. As stated previously, the resistance settings utilized by Hinze would vary the ratio of arm work to total work for each subject and may have caused the arm work to be a limiting factor.

The testing methods also differed in the model of ski simulator utilized for the test. Bart, Dorsen, and Leon (3) and Hinze (unpublished observations) used the NordicTrack Achiever, while the present study used the NordiCare Strider. The Achiever model has two wooden skies that slide in channels over the drive shaft of the resistance flywheel, while the Strider has foot pads that glide on rails. These foot pads are attached to a belt that drives the flywheel. The latter system provides a constant resistance throughout the backward stroke of the "ski." The subjects in the present study, who were familiar with both NordicTrack models, stated that the Strider provided a smoother stride action than the Achiever.

The chosen subject population can also influence a maximal test. As stated by Thoden (14), athletes tend to achieve higher VO_2max values when tested in the mode in which they compete. This statement is supported by the results of the present study, and those of Bart, Dorsen, and Leon (3). Both the present study and Bart, Dorsen, and Leon (3) used cross-country skiers as subjects, where as Hinze (unpublished observations) used nonskiers as subjects. Thus the subjects who were familiar with skiing as a mode of exercise had similar treadmill and skiing VO_2max values , while those unfamiliar with skiing as a mode of exercise had lower skiing than treadmill VO_2max values.

The present study also found that a subject's style of cross-country skiing may influence the test results. The four subjects who obtained a higher VO_2max on the XC test versus TM test (63.9 ml·kg^{-1}·min^{-1} and 60.7 ml·kg^{-1}·min^{-1}, respectively) were familiar with the classic style, diagonal stride, of skiing (i.e., they raced or trained 50% of the time or more using the classical style). The rest of the subjects used predominantly the newer skating style. This suggests that this protocol is most appropriate for classical style cross-country skiers but can be used for all cross-country skiers.

In conclusion, the protocol devised in this study is a viable alternative to a maximal treadmill test for use with cross-country skiers, especially those who use the classical style of skiing. However, it is recommended that the first stage of the protocol be eliminated and the test begin with stage II. This is recommended because the VO_2 values for the first stage of the XC test were an average 6.9 ml lower than the first stage of the treadmill test. The XC test times also averaged 3 minutes longer than the treadmill tests. Further research should be conducted using the developed XC test protocol on nonskiing

populations to determine if the findings of the present study were the result of the test protocol or the subject population.

REFERENCES

1. American College of Sports Medicine: Guidelines for exercise testing and prescription. Philadelphia: Lea & Febiger, 1991

2. *Astrand P. O., Rodahl K.:* Applied sports physiology, in Astrand P. O., Rodahl K. (eds.): Textbook of work physiology: physiological base of exercise. New York, McGraw-Hill, 1986, pp 661-665.

3. *Bart B. A., Dorsen P. J., Leon A. S.:* Maximal oxygen uptake (VO_2max) by ski ergometry in men and women collegiate champion cross-country skiers. Med. Sci. Sports Exerc. 22: S65, 1990.

4. *Bergh U., Kanstrup I. L., Ekblom B.:* Maximal oxygen uptake during exercise with various combinations of arm and leg work. J. Appl. Physiol. 41: 191-196, 1976.

5. *Borg, G. A. V.:* Psychological basis of perceived exertion. Med. Sci. Sports Exerc. 14: 377-387, 1982.

6. *Goss F. L., Robertson R. J., Spina R. J., Auble T. E., Cassinelli D. A., Silberman R. M., Galbreath R. W., Glickman E. L., Metz K. F.:* Aerobic metabolic requirements of simulated cross-country skiing. Ergonomics 32: 1573-1579, 1989.

7. *Hagan R. D., Gettman L. R., Upton S. J., Duncan J. J., Cummings J. M.:* Cardiorespiratory response to arm, leg, and combined arm and leg work on an air-braked ergometer. J. Cardiac Rehabil. 3: 689-695, 1983.

8. *Kline G. M., Porcari J. P., Hintermeister R., Freedson P. S., Ward A., McCarron R. F., Ross J., Rippe J. M.:* Estimation of VO_2 from a one-mile track walk, gender, age, and body weight. Med. Sci. Sports Exerc. 9: 253-259, 1987.

9. *Lamb D. R.:* Physiology of Exercise: Responses and adaptations (2nd ed.). New York, Macmillan, 1984.

10. *Mostardi R. A., Gandee R. N.:* Exercise training using arms and legs versus legs alone. Arch. Phys. Med. Rehabil. 62: 332-335, 1981.

11. *Nagle F. L., Richie J. P., Giese M. D.:* VO_2max responses in separate and combined arm and leg air-braked ergometer exercise. Med. Sci. Sports Exerc. 16: 563-566, 1984.

12. *Shepard, R. J.:* Tests of maximal oxygen intake: A critical review. Sports Med. 1: 99-124, 1984.

13. *Taylor H., Buskirk E., Henschel A.:* Maximal oxygen intake as an objective measure of cardiorespiratory performance. J. Appl. Physiol. 8: 73-85, 1955.

14. *Thoden J. S.:* Testing aerobic power, in MacDougall J. D., Wenger H. A., Green H. J. (eds): Physiological testing of the high performance athlete. Champaign, Il, Human Kinetics Books, 1991, pp 131.

APPENDIX A

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Why do cross-country skiers have the highest VO_2max values (1) of any athlete? The theory is that it is the result of the increased muscle mass involved in the sport. Since working muscle demands oxygen to metabolize energy, more working muscle mass would result in a higher demand for oxygen and thus a higher VO_2max. Research conducted to investigate this theory have not found this hypothesis to be totally valid. When combined arm and leg work is performed, the VO_2max values are greater than that of arm work alone and leg work alone, but typically do not exceed the VO_2max values of treadmill work (3, 5, 6). The major difference between these studies and cross-country skiing is the combination work was performed on machines, such as the Schwinn Airdyne, which do not use the same motion as cross-country skiing. The few studies that have used simulated cross-country skiing to investigate the role of muscle mass on VO_2 have had conflicting results (2, 4, 7, Hinze unpublished observations).

<u>The Role of Muscle Mass in Determining VO_2</u>

Most studies which have investigated the role of muscle mass on VO_2 have involved the comparison of treadmill work to work performed on ergometers (3, 5). Bergh, Kanstrup, and Ekblom (3) compared arm ergometery, leg ergometery, and combined arm and leg ergometery, with uphill treadmill running. Subjects performed a maximal exercise test for each condition. The arm and leg ergometery were performed on separate ergometers. There were four different trials for the combined work, with the arms contributing 10, 20, 30, or 40% of the total work for each trial. The VO_2max values for arm ergometery, leg ergometery, combined work of 10%, and combined work of 40% were significantly lower than treadmill running. The VO_2max values for combined work of 20%, and combined work of 30% (4.34 $L \cdot min^{-1}$, and 4.27 $L \cdot min^{-1}$, respectively) were lower, but not significantly different than treadmill running (4.44 L·min-1). This suggests that the ratio of arm work to total work may be an important factor influencing VO_2.

Hagan, Gettman, Upton, Duncan, and Cummings (5) found similar results, but there were several methodological differences between the studies. One was the use of an air-braked ergometer (Schwinn Airdyne) for the arm work, leg work, and combination work. The Airdyne employs a push-pull motion for the arm work as opposed to the cranking motion used by Bergh, Kanstrup, and Ekblom (3). The second difference was the use of a walking protocol instead of a running protocol for the treadmill tests. Maximal exercise tests were performed by the subjects, 15 men and 15 women, for each of the test conditions (treadmill work, arm work, leg work, and combination work). No significant difference was found between the treadmill work and the combination work, with the combination work being about 4% (0.07 L·min-1) lower than the treadmill work. Thus again it was concluded that the addition of arm work to leg work does not increase VO_2 even though more muscle mass is involved.

The data of Nagle, Richie, and Giese (6) support the earlier findings of Bergh, Kanstrup, and Ekblom (3) that the ratio of arm work to total work is an important factor influencing VO_2. Nagle, Richie, and Giese (6) had subjects perform maximal arm work alone, leg work alone, and combination 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. It was found that there was no significant difference in the VO_2max values between the 10% combined (4.086 L·min-1) and 20% combined (3.775 L·min-1) work loads, but the values for the 10% combined workload were significantly higher than the values for arm work alone (2.522 L·min-1), leg work alone (3.580 L·min-1), and the 30% combined (3.402 L·min-1) workload. This disagrees with Bergh, Kanstrup, and Ekblom (3) as to which ratio of arm work to total work produced the highest values. Bergh, Kanstrup, and Ekblom (3) found that the 20 and 30% combination work was not significantly different from treadmill work, but that the 10 and 40% combination work was significantly lower. The only value they agreed on was the 20% combination work load.

Simulated Cross-Country Skiing

Simulated cross-country skiing involves the arms and legs in motions similar to those used in cross-country skiing. There have been few studies done on simulated cross-country skiing. Those that have been done usually involve the use of the NordicTrack or a system of pulleys used in conjunction with a treadmill. Most studies have shown equal or lower values for simulated cross-country skiing tests compared to treadmill tests (2, Hinze unpublished observations). A possible reason for this, and the results of the combined arm and leg work cited in the previous section, is the increased difficulty of perfusing the arms while they are working. When the muscles in the arms contract during work they exert pressure on blood vessels which may occlude blood flow. This pressure increases the peripheral vascular resistance in the arms which results in a decreased blood flow and oxygen supply to the working muscles of the arms. An example of this occurs during arm ergometery where a 43% increase in the peripheral resistance accounts for the 30% reduction in VO_2 for arm work compared to treadmill work (8). It appears that the increased difficulty in perfusing the arms counteracts the increased oxygen demand that is created by the larger muscle mass involved in combined arm and leg work. Thus arises the question is there a work load for the arms that is high enough to increase oxygen demand, but low enough to prevent or diminish the counteracting effect of the increased difficulty in perfusion?

Bart, Dorsen, and Leon (2) used cross-country ski racers to study the effects of increased muscle mass on VO_2max using simulated cross-country skiing. Six men and five women, 18 to 21 years of age, who were members of a university ski team served as subjects. Subjects completed a maximal exercise treadmill test and a maximal exercise test on a NordicTrack in random order. The treadmill test used a modified Bruce protocol with a 3 minute rest period occurring after the third stage, and after each stage thereafter. For the NordicTrack test a discontinuous protocol was used with 3 minute stages followed by 3 minute rest periods. The speed, leg resistance, and e vation were changed while arm resistance remained constant at 1 kg. There were no significant differences between the treadmill test and ski test in maximal values for VO_2 (59.0 $ml \cdot kg^{-1} \cdot min^{-1}$ and 57.0 $ml \cdot kg^{-1} \cdot min^{-1}$,respectively), heart rate, and VE.

Another study that used cross-country ski racers compared ski walking tests to a skimill test (7). The ski walking tests were performed on a treadmill in two ways. One test involved walking without poles but with the arms simulating the motions of pole use. The second test employed the use of poles, attached to pulleys to provide resistance, while walking on the treadmill. The skimill test involved the use of a treadmill with a modified belt that was covered with carpet. The subjects performed the test using classic racing skies and nylon tipped poles. There were no significant differences between the tests in the maximal responses to the exercise, but the submaximal values were greater for the skimill test. This increase was attributed to the added weight of the equipment and a decrease in efficiency due to slippage, friction between surfaces, and recruitment of accessory muscle groups for stabilization. These are the same forces that are encountered while skiing on snow and may be the reason that cross-country skiers have a higher VO_2max.

Goss, Robertson, Spina, Auble, Cassinelli, Silberman, Galbreath, Glickman, and Metz (4) investigated the aerobic requirements of simulated cross-country skiing using the NordicTrack. Five college age males were randomly assigned to 12 separate, 6 minute, exercise bouts. Three arm resistance settings, two leg resistance settings, and two speed settings were used to allow for the 12 separate exercise bouts. It was found that there were significant increases in VO_2 with increases in speed regardless of the resistance settings. When the speed was maintained and the other variables altered, the response in VO_2 was similar.

In a study comparing uphill running to simulated cross-country skiing on the NordicTrack, Hinze (unpublished observations) found that there were significant differences between the mean VO_2max values and maximal heart rate for the two exercise modes. The 14 subjects ranged in age from 21 to 34 years. Subjects participated in three practice sessions prior to performing a maximal exercise test on the treadmill and the NordicTrack, and were randomly assigned the order in which the tests were taken. The NordicTrack test protocol involved seven, 3 minute stages. The speed was increased in uneven increments from 96 strides per minute in stage I, to 186 strides per minute in stage VII. The arm resistance was set at 2 kg for stages I-IV and at 3 kg for the remaining stages. The leg resistance was calculated based on 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. When the NordicTrack and treadmill tests were compared, the results showed that the VO_2max and maximal heart rate (52.3 $ml \cdot kg^{-1} \cdot min^{-1}$ versus 56.5 $ml \cdot kg^{-1} \cdot min^{-1}$, and 188 bpm versus 193 bpm, respectively) were significantly lower for simulated cross-country skiing. These results differ from those obtained by Bart, Dorsen, and Leon (2) who found that there was no significant difference between the maximal treadmill test and the maximal NordicTrack test. Possible reasons for this are the subjects, racers versus nonracers, and the test protocol for the NordicTrack. The test protocols for the NordicTrack differed in three ways. First, Hinze's protocol utilized a higher initial arm load (2 kg) and increased the load during the test while Bart, Dorsen, and Leon (2) maintained a constant arm load of 1 kg. Second, Bart, Dorsen, and Leon (2) utilized a discontinuous test protocol as opposed to a continuous protocol. Third, Hinze calculated leg resistance based on the subjects' body weight. This would result in variations in the ratio of arm work to total work from subject to subject, with it possibly going above the 20% ratio that appears to be optimal (3,6). All of these factors may explain why Hinze found a significantly lower VO_2max for the NordicTrack test compared to the treadmill test.

The most important finding from this review of literature is that no form of combined arm and leg work was able to produce a higher VO_2max value than a treadmill test. Secondly the ratio of arm work to total work utilized influences VO_2max. For a push-pull arm motion, a ratio of 10 to 20% of total work appears to be optimal. When a cranking motion is used the optimal ratio appears to be 20 to 30% of total work. Third, an increase in speed has the greatest influence on VO_2 when the NordicTrack is utilized as the testing mode. The choice of subjects also influences VO_2 values for combined work. Subjects who are familiar or accustomed to doing arm work or combined work perform better than those who are unaccustomed to arm or combined work.

REFERENCES

1. *Astrand P. O., Rodahl K.:* Applied sports physiology, in Astrand P. O., Rodahl K. (eds.): Textbook of work physiology: physiological base of exercise. New York, McGraw-Hill, 1986, pp 661-665.

2. *Bart B. A., Dorsen P. J., Leon A. S.:* Maximal oxygen uptake (VO_2max) by ski ergometry in men and women collegiate champion cross-country skiers. Med. Sci. Sports Exerc. 22: S65, 1990.

3. *Bergh U., Kanstrup I. L., Ekblom B.:* Maximal oxygen uptake during exercise with various combinations of arm and leg work. J. Appl. Physiol. 41: 191-196, 1976.

4. *Goss F. L., Robertson R. J., Spina R. J., Auble T. E., Cassinelli D. A., Silberman R. M., Galbreath R. W., Glickman E. L., Metz K. F.:* Aerobic metabolic requirements of simulated cross-country skiing. Ergonomics 32: 1573-1579, 1989.

5. *Hagan R. D., Gettman L. R., Upton S. J., Duncan J. J., Cummings J. M.:* Cardiorespiratory response to arm, leg, and combined arm and leg work on an air-braked ergometer. J. Cardiac Rehabil. 3: 689-695, 1983.

6. *Nagle F. L., Richie J. P., Giese M. D.:* VO_2max responses in separate and combined arm and leg air-braked ergometer exercise. Med. Sci. Sports Exerc 16: 563-566, 1984.

7. *Ready A. E., Huber H. R.:* Physiologic responses of nordic ski racers to three modes of sport specific exercise. Can. J. Sport Sci. 15(3): 213-217, 1990.

8. *Shepard, R. J.:* Tests of maximal oxygen intake: A critical review. Sports Med. 1: 99-124, 1984.

APPENDIX B

INFORMED CONSENT

Informed Consent for NordicTrack VO_2max Study

Project: A VO_2max test for simulated cross-country skiing.
Principle Investigator: John P. Porcari, Ph.D. and Scott Austen, graduate student

Explanation of the Exercise Tests

As a subject in this thesis you will perform a maximal exercise test on a motorized treadmill and a NordicTrack ski simulator. 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. 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.

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. The results may also help you in formulating a training program for future seasons.

Inquiries

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.

Signed ______________________________ Date__________________

______________________________ __________________

APPENDIX C

NORDICTRACK MAXIMAL EXERCISE TEST PROTOCOL

(HINZE UNPUBLISHED OBSERVATIONS)

Table 4. NordicTrack maximal exercise test protocol (Hinze unpublished observations).

Time (min)	Arm Resistance (kg)	Leg resistance (kg)	Elevation (%)	Speed Strides/min
3	2	.10xW(kg)___	5	96
6	2	.12xW(kg)___	5	112
9	2	.12xW(kg)___	5	126
12	2	.14xW(kg)___	5	144
15	3	.14xW(kg)___	5	160
18	3	.16xW(kg)___	5	176
21	3	.16xW(kg)___	5	184

Note: W = subjects body weight