

ABSTRACT

WESOLEK, B. J. Development of a VO_2 max protocol for cross-country ski racers for use with the NordicTrack 900. MS in Exercise and Sport Science-Human Performance, August 1996, 30pp. (W. Floyd)

The purpose of the study was to develop a VO_2 max test protocol for cross-country ski racers for use with the NordicTrack 900 (NT). It was desirable that the values obtained using the NT should compare favorably with VO_2 max values obtained from a treadmill (TM) test in order for it to be considered valid. A protocol was developed from the findings of previous studies and was compared to a modified Balke TM VO_2 max test (self-selected running speed with an increase in grade of 2.5% every 2 min). Eight female and 4 male volunteers with a minimum of 2 years of skiing experience and 1 year of racing experience served as subjects and completed both tests in random order. Maximal physiological responses were recorded for the TM and NT tests. There was no significant ($p > .05$) difference in VO_2 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (52.9 versus 51.3), VO_2 $\text{L}\cdot\text{min}^{-1}$ (3.38 versus 3.28), RER (1.20 versus 1.24), HR (189 versus 191), and RPE (18.6 versus 18.9) between the NT and TM, respectively. However, VE was significantly higher ($p < .05$) for the NT test than the TM test (124 versus 111). It was concluded that the protocol developed for this study is valid and may elicit slightly higher values than TM running.

DEVELOPMENT OF A VO_2 MAX PROTOCOL
FOR CROSS-COUNTRY SKI RACERS FOR
USE WITH THE NORDICTRACK 900

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

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

BY
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AUGUST 1996

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

THESIS FINAL ORAL DEFENSE

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Master of Science Exercise and Sport Science - Human Performance

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ACKNOWLEDGMENTS

I would especially like to thank my committee members Dr. William Floyd, Dr. Larry Terry, and Dr. Jeff Boyle for their patience and assistance in helping me to complete this paper. I would also like to thank my family and fellow students at the University of Wisconsin-La Crosse. Their support helped me relieve the anxiety and stress I confronted while completing the required course work and paper for this degree. Finally, I would like to thank my parents who instilled in me the drive to challenge myself and to continue to learn from life.

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CHAPTER I

INTRODUCTION

Maximal oxygen uptake ($VO_2\text{max}$) is an important physiological parameter in the design and revision of exercise prescriptions for aerobic athletes (Thoden, 1991). Several systematic training books (Sharkey, 1984; Sleamaker, 1989) suggest using percentages of $VO_2\text{max}$ as guidelines for training intensities. The modality used most frequently in assessing an aerobic athlete's $VO_2\text{max}$ is uphill treadmill (TM) running because it typically yields the highest values. Although highest values are usually obtained using TM running, this modality does not aid the athlete or coach in designing a training program for a sport that does not utilize running. Hence, the test must be specific to the sport in which the athlete participates.

Several studies have been conducted to determine which mode of exercise yields an individual's highest $VO_2\text{max}$ value. Much discrepancy exists in the literature concerning this issue. Most studies indicate that the amount of muscle mass involved in the exercise has an impact on $VO_2\text{max}$. For instance, arm work alone and cycling typically yield 30-40% and 10-20% lower values, respectively, than TM running (Londeree, Thomas, Ziogas, Smith, & Zhang, 1995; Myers, Buchanan, & Walsh, 1991). Several studies (Brahler & Blank, 1995; Seals & Mullin, 1982; Secher, Ruberg-Larson, Binkhorst, & Bonde-Petersen, 1974) have concluded that the fitness level of the individual tested may play a role in determining the modality that elicits the highest max values. A study by Seals and Mullin (1982) compared well trained upper body athletes (WTUB) versus nonwell trained upper body athletes. The study found that WTUB athletes were able to achieve similar $VO_2\text{max}$ values using arm cranking plus leg cycling and running; whereas the nonWTUB individuals were only able to achieve their highest VO_2 's with

running. This suggests that individuals who have trained upper bodies may have higher VO_2 max values using aerobic equipment that involves the lower and upper body.

Cross-country skiers have the highest VO_2 max values of all aerobic athletes (Astrand & Rodahl, 1986), although no practical sport specific VO_2 max test has consistently demonstrated higher values than TM running. The actual sport and the simulated form of skiing involve many large muscle groups of the upper and lower body. Theoretically, cross-country skiers should have higher VO_2 max values when tested on an apparatus that simulates the motions of cross country skiing rather than TM running because of the involvement of more aerobically trained muscle mass.

Ideally, the best method of assessing a cross-country ski racer's VO_2 max would be to conduct the experiment in a field setting. However, the benefits of this approach would most likely be outweighed by technical problems.

Purpose of the Study

The purpose of the study was to develop a VO_2 max test protocol for cross-country ski racers for use with the NordicTrack 900 (NT).

Hypothesis

The following null hypothesis was tested:

There is no significant difference in maximal values between simulated skiing and TM running.

Assumptions

The following assumptions were made prior to each test:

1. It was assumed that subjects had not participated in strenuous exercise 24 hours prior to the test, nor consumed food, tobacco, caffeine, or alcohol for at least 3 hours prior to the test.

2. It was assumed that the resistance of the arms and legs on the NT remained constant within and between each test.

Delimitations

The following delimitations were present in the study:

1. One of the two modalities was randomly assigned to each subject on the first testing day. The second test session was scheduled within a 4 to 14 day period of the first test.
2. The testing was performed during the off-season from late March to early June.
3. No practice sessions were performed on the NT prior to testing.

Limitations

The following limitations were present in the study:

1. The subjects used for this study were cross-country ski racers who had a minimum of 2 years of skiing experience and 1 year of racing experience.
2. The previous experience and coordination of the subjects tested on the NT could have influenced the results of the study.

Definitions of Terms

The following terms were used in this study:

Cross-Country Skiing - a sport that is performed on snow with skis and poles used to propel the body across varied terrain (Sharkey, 1984).

Diagonal Striding - a cross-country skiing technique that utilizes alternate arm and leg actions to propel the skier forward (Sharkey, 1984).

Double Poling - a cross-country skiing technique where the legs remain in a fairly extended position while hip flexion and simultaneous poling propel the skier forward (Sharkey, 1984).

NordicTrack 900 Ski Simulator - an aerobic piece of equipment that imitates the motions of the cross-country skiing technique of diagonal striding (NordicTrack, 1991).

Pole-Striding - an activity performed on dry land with poles that incorporates long strides, similar to bounding, to imitate the cross-country skiing technique of diagonal striding (Sharkey, 1984).

$\dot{V}O_2\text{max}$ - the greatest amount of oxygen that can be utilized at the cellular level for the entire body (Williams, 1994).

CHAPTER II

REVIEW OF RELATED LITERATURE

Introduction

Cross-country skiing involves the use of many large muscle groups of the lower and upper body as opposed to running or cycling which use primarily lower body muscle groups. 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 max. Therefore, if VO_2 max is largely dependent upon the amount of muscle mass involved, individuals should achieve higher VO_2 max values using apparatus that involves upper and lower body as opposed to modalities that only involve the lower body. However, research has not found this hypothesis to be totally valid. Several studies have compared combined arm and leg work to TM running and have found mixed results. The discrepancies among findings are most likely attributed to the design of the protocol and the training status of the subject tested. To date, very few studies have been conducted on cross-country ski racers to determine if higher VO_2 max values can be achieved using a ski simulator as opposed to a TM.

Role of Muscle Mass in Determining VO_2

Several investigators have studied the role of muscle mass in determining maximal oxygen uptake. Nagle, Richie, and Giese (1984) had nonarm trained males perform to maximal exertion using arm work with a push-pull motion, leg work, and combined arm and leg work on an air-braked ergometer. The combined arm and leg work consisted of 3 trials with arms contributing 10, 20, and 30% of total work. No significant differences in VO_2 max were found for the 10 and 20% combined workloads. However, the values for

the 10% combined workload were significantly higher than the values for arm work alone, leg work alone, and 30% combined workload.

Bergh, Kanstrup, and Elkbom (1976) also studied the effects of VO_2 max using various modalities. Bergh et al. (1976) had 10 males perform maximal work using uphill TM running, cycling, arm work using a cranking motion, and combined arm and leg work. The combined arm and leg work was performed four different ways with the arms contributing 10, 20, 30, and 40% of total work. VO_2 max values were similar in TM running and in combined work when arms contributed 20 and 30% of total work. However, when arms contributed 10 and 40%, VO_2 max values were 2.5 and 9.4% lower, respectively. These results agree with the findings of Nagle et al. (1984), that the contribution of arm work to total work in performing maximal exercises affects VO_2 max values.

A study conducted by Seals and Mullin (1982) investigated the differences in VO_2 max among well trained upper body (WTUB) athletes and untrained individuals using arm cranking, legs only cycling, TM running, and combined arm cranking and leg cycling. The results from this study indicated that 1) WTUB athletes were able to achieve 85% of their leg only VO_2 max using arm cranking whereas untrained athletes could only reach 60 to 70%, 2) WTUB athletes attained 120 to 130% of their leg only VO_2 max in combined exercise where the untrained group only achieved 110 to 115%, and 3) WTUB athletes were able to attain their highest values using combined exercise and TM running whereas untrained subjects could only achieve their highest values using TM running.

These findings suggest that WTUB athletes (i.e., cross country ski racers) may achieve their highest VO_2 max values using a modality that incorporates upper body work.

Simulated Skiing Compared to Treadmill Running

Several studies have been performed comparing VO_2max values during simulated skiing and TM running. Austen (1994) tested 14 cross country skiers who had at least two years of skiing experience, ranging in age from 22 to 41, using a NordiCare Strider and TM running. The NordiCare Strider protocol consisted of 2-minute stages with elevation and arms resistance held constant at 10% and 4 pounds, respectively (see Appendix A). The stride frequency and leg resistance were each increased throughout the test. A modified Balke protocol with a 5-minute self-selected warm-up was used for the TM test. The results showed that there was no significant difference in VO_2max between the simulated skiing test ($56.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) and the TM running test ($57.7 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$).

Bart, Dorsen, and Leon (1990) compared VO_2max values of 6 men and 5 women using simulated skiing on a NT and TM running. All subjects were members of a national collegiate cross-country ski team. The NT test utilized a discontinuous protocol consisting of 3 minute stages with increasing leg resistance, elevation, and speed, interspersed with 3 minute rest periods. The arms remained constant at 1 kg throughout the test. The modified Bruce protocol was used for the TM test with 3 minute recovery periods after stage 3 and thereafter. The results demonstrated that there was no significant difference in VO_2max between the NT ($57.0 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) and the TM test ($59.0 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$).

A study by Haug (1995) also compared VO_2max values during simulated skiing using a NT and TM running. However, subjects used in this study were nonskiers. The NT protocol consisted of 2 minute stages with elevation held constant at 5%. Stride frequency and arm and leg resistance were increased throughout the test (see Appendix B). A Bruce protocol with a 5-minute self-selected warm-up was utilized for the TM test.

The VO_2max values achieved during the NT test ($42.5 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) were not significantly different from those of the TM test ($42.6 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$).

While the previous studies found no significant differences in VO_2max between TM running and simulated skiing, a study by Hinze (unpublished observation) found simulated skiing to yield significantly lower VO_2max values than TM running. Hinze's study involved 14 healthy male volunteers between the ages of 21 and 34. The NT protocol consisted of seven, 3 minute stages with the grade held constant at 5%. The speed increased in uneven increments during each stage from 96 strides per minute in the first stage to 184 strides per minute in the last stage (see Appendix C). Arm resistance was held constant during stages I-IV at 2 kg and then increased to 3 kg until subjects were exhausted. 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 VO_2max attained during the NT test ($52.3 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) was statistically lower than the TM test ($56.5 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$).

The differences in results between Hinze's study and the three studies that showed no difference in VO_2max between simulated cross-country skiing and TM running may be attributed to different training levels of the subjects tested, protocols used, or a combination of each. Hinze's study used nonskiers as subjects whereas Austen (1994) and Bart et al. (1990) used skiers. However, the study conducted by Haug (1995) which used nonskiers as subjects, demonstrated no significant difference in VO_2max between modalities.

Another reason for the different findings may be attributed to different protocols used. Hinze (unpublished observation) used a protocol that increased leg resistance relative to the subject's body weight whereas the other studies did not. This may have placed some of the subjects over the optimal arm work to total work load ratio of 10 to 30% (Bergh et

al., 1976; Nagle et al., 1984). Bart et al. (1990) also used a discontinuous protocol as opposed to a continuous protocol. Each of these factors may describe why Hinze found lower VO_2max values for simulated skiing than TM running.

Sport Specific VO_2max Tests

Several studies have attempted to quantify differences in peak physiological responses of specific maximal exercise for cross-country skiing. Watts et al. (1993) compared the peak physiological responses to pole-striding, double poling, and diagonal striding on roller skis during maximal exercise. Six expert cross-country ski racers, 3 males and 3 females, were used as subjects. The pole-striding test involved striding in running shoes while using ski poles in a manor similar to diagonal striding. The TM speed for this test was set at 2.46 and 2.91 $\text{m}\cdot\text{sec}^{-1}$ for women and men, respectively. The elevation was set at 0.0% and increased 5.0% every 2 minutes thereafter. Diagonal striding involved using the diagonal stride cross-country technique utilizing the same protocol as the pole-striding test. Double poling involved the double poling cross-country skiing technique. The protocol for this test was similar as the previous tests except women skied at 2.68 $\text{m}\cdot\text{sec}^{-1}$. It was concluded that double poling elicits significantly lower VO_2max values than pole-striding and diagonal striding on roller skis during maximal exercise. Again, this suggests that amount of muscle mass involved in the exercise has an impact on VO_2max .

A study by Ready and Huber (1990) also evaluated the physiological responses of specific maximal exercise for cross-country skiing. Eight racers completed a ski-walking test, ski-walking with arm resistance provided by a pulley system, and simulated skiing on a TM with a modified belt that was covered with carpet. Speed of the TM remained constant at 7.25 km/h for each of the 3 tests. Elevation began at 0% and increased by 4% every 4 minutes until subjects reached exhaustion. It was concluded that there was no

significant difference in VO_2 max between each of the sport specific exercises. However, time to exhaustion for simulated skiing was significantly less than the other two modes. This was attributed to the added weight of the equipment and decrease in efficiency due to slippage during simulated skiing. These are similar problems skiers are faced with during skiing and may explain why cross-country skiers have higher VO_2 max values.

Summary

The most important finding from the review of related literature was that no combination of arm and leg work elicited higher VO_2 max values than TM running. However, there seems to be an optimal ratio of arm work to total work around 10 to 30%.

While most studies used upper body trained athletes or skiers to demonstrate similar VO_2 max values for simulated skiing and TM running, it is interesting to note that nonskiers can achieve similar values as well (Haug, 1995).

CHAPTER III METHODS AND PROCEDURES

Pilot Study

A pilot study was undertaken to determine the optimal flywheel resistance, elevation, arm resistance, and rate of strides per minute for each stage of the NT protocol. The pilot study included one male and one female skier with 32 and 13 years of skiing experience, respectively. Following a written and verbal explanation of the procedures and potential risks, an informed consent was completed (see Appendix D). Each subject completed a VO_2 max test on the NT with a protocol determined by the thesis committee (see Table 1). Physiological data and subjective responses of the four variables that influence intensity were collected during each stage of the test. A second protocol would have been developed if one or both of the subjects felt there needed to be a change in the initial protocol. Subjects would then have completed another VO_2 max test on the NT with a revised protocol within a 4 to 10 day period of the initial test. However, the subjects concurred that the initial protocol was satisfactory. Therefore, a second protocol was not needed.

Testing Procedures

Subject Selection

Twelve cross-country ski racers with a minimum of 2 years of skiing experience and 1 year of racing experience were used as subjects for the study. All subjects signed an informed consent form prior to participating in the study.

Table 1. VO_2 max test protocol

Stage	Minutes	Grade	Strides/Minute	Resistance	
				Arms (lb)	Legs (lb)
I	0-2	5%	100	4	16
II	2-4	5%	106	4	16
III	4-6	5%	118	4	20
IV	6-8	5%	134	4	20
V	8-10	5%	150	4	24
VI	10-12	5%	162	4	24
VII	12-14	5%	166	4	24
VIII	14-16	5%	170	4	24
IX	16-18	5%	174	4	24

Note. Increase strides/minute by 4 as needed after stage IV.

Testing Schedule

Each subject was randomly assigned the order for the TM and the NT tests. All subjects were tested within a 2 week time period of their first test with at least 4 days rest between tests.

Testing Sessions

Subjects weight and height were measured prior to each test. These data were entered into the metabolic cart to determine relative and absolute VO_2 's, respiratory exchange ratio (RER), and ventilation (VE). The gas analyzers were calibrated prior to each test using gases of known percentages 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 (HR) monitor (Polar-CIC INC, Port Washington, NY).

Treadmill Test

The test was performed on a Quinton model 24-72 TM (Q-plex 1, Quinton Instrument Company, Seattle, WA) using a modified Balke test protocol (self-selected speed with an increase in grade of 2.5% every 2 minutes). All subjects received a 5 minute self-selected warm-up prior to the TM test (self-selected speed with 5% grade). Physiological responses were collected during the last minute of each stage and at maximal exertion.

Cross-Country Test

The test was performed on the NT 900 model. Rate of stride was controlled using a Seiko digital metronome (DM-10, Hattori Seiko Company, LTD, Mahwah, NJ). Subjects were permitted to use a 5 minute self-selected warm-up prior to the test (self-selected speed, 5% grade, with a resistance of 4 lbs and 14 lbs on the arms and legs, respectively). The NordicTrack test protocol (see Table 1) was followed. Physiological responses were collected during the last minute of each stage and at maximal exertion.

The tests were considered valid if two of the three criteria were met: 1) a plateau or decrease in VO_2 with an increase in work load; 2) a heart rate of no less than 10 beats below age predicted max heart rate, and lastly; 3) a RER of greater than 1.0 was reached.

Statistical Treatment

Descriptive statistics were run to characterize the subjects. A paired t-test was used to compare the maximal values obtained during each modality tested. The level of significance was set at $p < .05$.

CHAPTER IV RESULTS AND DISCUSSION

Introduction

The purpose of the study was to develop a VO_2 max protocol for cross-country ski racers using the NordicTrack 900 ski simulator. Because TM tests typically elicit an individual's highest VO_2 max values, it was desirable that the maximal values obtained on the NT test should compare favorably to the results of a TM test in order for it be considered valid.

Results

Eight female and 4 male subjects completed both the NT and TM tests. The subjects' ages ranged from 16 to 41 years, with a mean height of 169 (SD = 11cm) and a mean weight of 63.5 (SD = 11kg). The NT and TM tests were valid VO_2 max tests because at least two of the three criteria (a RER over 1.0, heart rate no lower than 10 beats below age predicted, and a plateau or decrease in VO_2 with an increase in intensity) for a true VO_2 max were met by all subjects. There were no significant ($p > .05$) differences in VO_2 max (relative or absolute), maximal HR, maximal RER, maximal RPE values between the NT and the TM tests (see Table 2). However, maximal VE was significantly ($p < .05$) higher for the NT test than the TM test. The average time to exhaustion was 11:08 and 10:26 for the NT and TM, respectively.

Discussion

The findings of the present study agree with Austen (1994), Haug (1995), and Bart et al. (1990) in finding no difference in VO_2 max between simulated skiing and TM running. However, the present study disagrees with Hinze (unpublished observation), who found simulated skiing VO_2 max values to be lower than TM VO_2 max values.

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

	NordicTrack		Treadmill		t (p)
	M	SD	M	SD	
VO ₂ L·min ⁻¹	3.38	.98	3.28	.84	1.65 (0.13)
VO ₂ ml·kg ⁻¹ ·min ⁻¹	52.9	11.3	51.3	9.5	1.65 (0.13)
RER	1.20	.07	1.24	.07	-1.25 (0.24)
VE	124.1	25.6	111.4	23.1	5.24 (0.00)*
HR	189	9	191	10	-1.28 (0.23)
RPE	18.6	1.5	18.9	1.7	-0.39 (0.67)

* (p < .05)

(52.3 ml·kg⁻¹·min⁻¹ versus 56.0 ml·kg⁻¹·min⁻¹). The differences in values may be attributed to the subject population tested, the method of testing, and the ratio of arm work to total work during simulated skiing.

Since there is no established protocol for simulated cross-country skiing, the present study differed from previous studies with regard to testing methods. One of the major differences among these studies and the current study was the protocol used. Haug (1995) utilized a protocol in which the arm resistance increased from 4 to 6 lb after stage five, whereas the present study maintained a constant arm resistance of 4 lb throughout the duration of the test. Studies by Bart et al. (1990) and Austen (1994) also differed

from the present study. Bart et al. used a discontinuous protocol consisting of 3 minute stages with increasing leg resistance, elevation, and speed, interspersed with three minute rest periods, whereas Austen utilized a continuous protocol with elevation held constant at 10%. In contrast, Hinze (unpublished observation) utilized 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. Since the arm resistance setting used by Hinze may have varied the ratio of arm work to total work for each subject, arm work could have been a limiting factor.

The subject population tested may have also influenced VO_2 max values. Seals and Mullin (1982) discovered that individuals who are upper body trained tend to elicit similar VO_2 max values on combined arm/leg tests and TM test, whereas individuals who are not upper body trained tend to have lower values on combined arm/leg tests. The present study, along with Bart et al. (1990) and Austen (1994), used cross-country skiers as subjects and found no significant difference in VO_2 max between modalities tested.

According to Thoden (1991), athletes tend to achieve higher VO_2 max values when tested in the mode in which they compete. This statement held true for 8 of the 12 subjects tested in the present study with 3 out of the 8 subjects achieving $5.0 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ or higher during the simulated skiing test than on the TM test.

In contradiction to Seals and Mullin's (1982) research, Haug (1995) VO_2 max tested nonskiers on a NT and a TM and found no significant differences between modalities. This suggests that it is not necessary for an individual to be upper body trained to achieve a valid VO_2 max test on an exercise requiring arm and leg work. In contrast, Hinze's study (unpublished observation) which also used nonskiers as subjects, found VO_2 max values during simulated skiing to be lower than TM VO_2 max values.

Several researchers have investigated combined arm and leg work and have found that the proportion the arms and legs contribute to total power output can influence $VO_2\text{max}$. Nagle, Richie, and Giese (1984) had nonarm trained males perform to maximal exertion using arm work with a push-pull motion, leg work, and combined arm and leg work on an air-brake ergometer. The results indicated that there was no significant differences in $VO_2\text{max}$ for the 10 and 20% combined workloads. However, the $VO_2\text{max}$ values for the 10% combined workload were significantly higher than the values for arm work alone, leg work alone, and 30% combined workload. Bergh, Kanstrup, and Elkblom (1976) also investigated the effects of $VO_2\text{max}$ using uphill running, cycling, arm work using cranking motion, and combined arm and leg work. The study revealed that $VO_2\text{max}$ values were similar in running and in combined work when arms contributed 20 to 30% of total work. However, when arms contributed 10 and 40%, values were significantly lower.

These studies suggest that if the arms contribute less than 10% or greater than 30% of leg work, $VO_2\text{max}$ values could be compromised. The present study generally maintained arm work near 20% of the total power output which may explain the findings.

In conclusion, the protocol developed in this study for cross-country ski racers using the NT is a viable alternative for $VO_2\text{max}$ testing and may elicit higher values than TM running. It is interesting to note that there were no practice sessions performed prior to the NT testing. Moreover, four of the subjects had never been on a simulated ski machine. Of these four subjects, three achieved higher values on the NT ski simulator.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The purpose of this study was to develop a VO_2 max test protocol for cross-country ski racers using a NordicTrack 900 (NT) ski simulator. Because TM tests typically elicit an individual's highest VO_2 max values, it was desirable that the maximal values obtained on the NT test should compare favorably to the results of the TM test in order for it to be considered valid.

Twelve cross-country ski racers with a minimum of 2 years of skiing experience and 1 year of racing experience completed a VO_2 max test on the NT with the developed protocol and on a TM using a modified Balke protocol. Maximal physiological responses were obtained on each modality for the variables VO_2 (relative and absolute), VE, HR, RPE, and RER. There was no significant ($p > .05$) difference for VO_2 (relative and absolute), HR, RER, and RPE between modalities. However, VE was significantly ($p < .05$) higher for the NT test.

Conclusions

While many human performance laboratories lack the large and expensive TM often needed for cross-country ski specific VO_2 max testing, the NT cross-country ski simulator offers a viable alternative for coaches and athletes.

Since the NT mimics the motions of the classical style, diagonal stride, of cross-country skiing to a greater degree than the newer skating style, those who predominately race or train using the classical style may achieve higher values on the NT. This suggests that the protocol is most appropriate for those who classical ski but can also be used for all cross-country skiers.

Recommendations for Future Study

1. All testing should be performed within a 2 to 3 week period with the developed protocol to limit the variability in fitness levels of subjects tested during the testing period.
2. Subjects should be given practice sessions on the NT prior to testing to familiarize themselves with the apparatus.
3. Elite level skiers (skiers with more than 5 years of racing experience) should be used as the subject population and tested with the developed protocol in combination with the recommendations listed above.

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APPENDIX A

NORDICARE MAXIMAL EXERCISE PROTOCOL

(AUSTEN - UNPUBLISHED MASTER'S THESIS)

Table 3. NordiCare maximal exercise protocol (Austen - unpublished master's thesis)

Stage	Minutes	Grade	Strides/Minute	Resistance	
				Arms (lb)	Legs (lb)
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

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

APPENDIX B

NORDICTRACK MAXIMAL EXERCISE PROTOCOL

(HAUG - UNPUBLISHED MASTER'S THESIS)

Table 4. NordicTrack maximal exercise protocol (Haug - unpublished master's thesis)

Stage	Minutes	Grade	Strides/Minute	Resistance	
				Arms (lb)	Legs (lb)
I	0-2	5%	88	4	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 begin at stage I and men at stage II.

APPENDIX C

NORDICTRACK MAXIMAL EXERCISE PROTOCOL

(HINZE - UNPUBLISHED OBSERVATION)

Table 5. NodricTrack maximal exercise protocol (Hinze - unpublished observation)

Stage	Minutes	Grade	Strides/Minute	Resistance	
				Arms (kg)	Legs (kg)
I	0-3	5%	96	.10xW(kg)	2
II	3-6	5%	112	.12xW(kg)	2
III	6-9	5%	126	.12xW(kg)	2
IV	9-12	5%	144	.14xW(kg)	2
V	12-15	5%	160	.14xW(kg)	3
VI	15-18	5%	176	.16xW(kg)	3
VII	18-21	5%	184	.16xW(kg)	3

Note. W = subjects body weight.

APPENDIX D
INFORMED CONSENT FORM

Informed Consent for Treadmill and NordicTrack VO₂ max Tests

Project Title: Development of a VO₂max protocol for cross-country ski racers for use with the NordicTrack 900

Principal Investigator: Brent Wesolek, graduate student

Project Chairperson: Dr. William Floyd (608) 785-8188

Explanation of Testing Procedures

As a subject for this study you will perform a maximal exercise test on a NordicTrack 900 and on a motorized treadmill. You will be given instructions on treadmill running and simulated skiing on the NordicTrack 900. You will then be fitted with headgear that will allow the collection and analysis of your expired air. Lastly, a heart rate monitor will be strapped to your chest to continually analyze your heart rate during the testing procedure. The test may be terminated at any time due to signs of excessive fatigue or other physiological abnormalities. Also, you are able to stop the test at any time if you feel you can not continue.

Risks or Discomforts

As with any exercise, there exists the certain possibility of abnormal changes occurring during the testing procedure. They include abnormal blood pressures, fainting, disorders with the heart rhythm, and in rare instances, cardiac arrest, stroke, or even death. Every effort will be made to minimize those risks by provision of appropriate supervision during the testing period.

Benefits of Participating

The information obtained from these exercise tests can be used to assess the effectiveness of your past training program and help you to design future training programs. Your test results obtained from this study will not be shared with any outside party unless your consent has been given.

Inquires

If you have any questions or concerns regarding the exercise testing, please feel free to ask.

I, _____, being of sound mind and _____ years of age, do
(Signature of Subject)

hereby consent to, authorize and request the person named above (and co-worker, agents, and employees) to undertake and perform on me the proposed procedure, treatment, research or investigation (herein called "Procedures").

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 hereby acknowledge that no representations, warranties, guarantees or assurances of any kind pertaining to the Procedure have been made to me by the University of Wisconsin-La Crosse, the officers, and administration, employees or by anyone acting on behalf of any of them.

I understand that I may withdraw from the study at any time.

Signed at _____ this _____ day of _____, 19____.

(Subject)

I, _____, (husband, wife, parent, other) of the above-named subject _____, have read the foregoing consent and the document attached hereto and made a part of such consent, and I hereby consent to said Procedures.

Signature