

ABSTRACT

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This study investigated the physiological responses of cross-country skiing at 3 different speeds using the NordicSport CrossTraining System™ (NSCTS). Twenty-four healthy males (mean age = 26.6 ± 6.3 yrs) volunteered as subjects. Following practice sessions to become proficient on the NSCTS™, each subject performed 3 5-minute bouts of steady state exercise for a total of 15 minutes. The speeds of 2.0, 2.5, and 3.0 mph were used at a 9.6% grade with no resistance for arms and legs. During the exercise session, VO_2 ($L \cdot \text{min}^{-1}$, $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, METS), HR, VE, Kcal, RER, and RPE were measured each minute. It was found that as the speed increased, all physiological responses increased significantly ($p < .05$) at each stage, indicating an increase in energy cost. It was concluded that the NSCTS™ may provide a means for cardiovascular improvements and weight management.

**ENERGY COST AT THREE DIFFERENT SPEEDS
ON A CROSS-COUNTRY SKI SIMULATOR**

**A MANUSCRIPT STYLE THESIS PRESENTED
TO
THE GRADUATE FACULTY
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**IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE
MASTER OF SCIENCE DEGREE**

**BY
KATHRYN A. WEILAND**

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

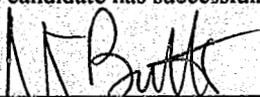
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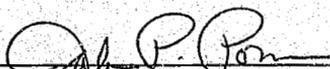
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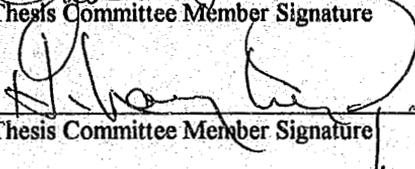
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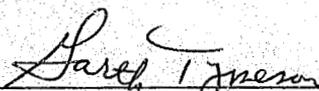


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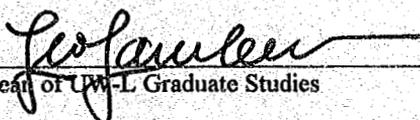


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ENERGY COST AT THREE DIFFERENT SPEEDS ON A CROSS-COUNTRY SKI SIMULATOR

INTRODUCTION

Although there has been extensive research comparing the energy cost of various modes of cardiovascular equipment currently on the market, little information is available on one of the most advertised cross-country skiing simulators - NordicSport CrossTraining System™. Cross-country skiing has been determined to have a beneficial effect on cardiovascular improvement and maintenance while reducing stress on the joints that may lead to injuries (Åstrand & Rodahl, 1977).

Cross-country skiing on an outdoor track involves a variety of factors that affect energy cost, such as changes in the weather, temperature, snow conditions, and terrain. Several researchers (MacDougall, Hughson, Sutton, & Moroz, 1979; Saibene, Cortili, Roi, & Colomini, 1989) have evaluated the energy cost of cross-country skiing using different techniques and speeds, and found as the skiing speed increased, the energy cost (VO_2) increased. MacDougall et al. (1979) tested a small number of elite skiers at subjective workloads and found a higher energy cost for skiing than for level running at similar speeds. Furthermore, the skating technique has been shown to be more efficient than the traditional inline technique, resulting in a lower energy cost at any speed (Saibene et al., 1989).

Cross-country skiing machines have been designed to simulate the combined arm/leg movements similar to those movements employed during actual skiing. These cross-country skiing machines can be used throughout the year as a means to improve and maintain cardiorespiratory fitness. The ability to control arm and leg resistance, speed, and incline provide a constant intensity for cardiorespiratory and muscular workouts. Goss et al. (1989) used an earlier version of the NordicTrack™ cross-country skiing

machine to assess the aerobic metabolic requirements while altering the arm and leg resistance and movement frequencies. This earlier machine used a direct-drive flywheel. Recently, however, NordicTrack™, Incorporated, developed the NordicSport CrossTraining System™ (NSCTS), a four-in-one exerciser for cross-country skiing, stepping, walking, and running. The NSCTS™ uses a self-propelled treadmill belt and attachable foot-glides to adapt to a cross-country skiing simulator. The purpose of this study was to assess the energy expenditure of cross-country skiing at three different speeds using the NSCTS™.

METHODS

Pilot Testing

Prior to actual data collection, two subjects participated in a pilot study to determine the increments of speed for the three progressive stages necessary to maintain a steady state. The three speeds determined from this pilot study were 2.0, 2.5, and 3.0 mph. Slower speeds were too inefficient to maintain a steady state and, at speeds faster than 3.0 mph, subjects were unable to complete a final stage before reaching their maximum levels, thus unable to maintain a steady state. At this time, using an equation to calculate the speed based on belt revolutions, it was discovered that the digital display of miles per hour on the NSCTS™'s console was faster than the actual speed. As a result, subjects were given a range of 1.8 to 2.0 mph, 2.3 to 2.5 mph, and 2.8 to 3.0 mph on the digital display to represent 2.0, 2.5, and 3.0 mph, respectively. It was also determined during the pilot study that a 5-minute exercise period was sufficient for the subjects to reach and maintain a steady state.

Subjects

After all procedures and time commitments were explained and all questions answered, 24 healthy males volunteered to participate in this study. Since the subjects had varying ability and experience both on the ski machine and cross-country skiing, they were required to practice prior to the actual testing. Their average age, height, and weight are in Table 1.

Table 1. Physical characteristics of subjects (n = 24)

Variables	Mean	Standard Deviation	Range
Age (yr)	26.6	6.3	18 - 40
Height (cm)	176.7	5.9	167.6 - 191.0
Weight (kg)	76.8	12.1	59.7 - 103.6

Protocol

The NSCTS™ consists of a self-propelled treadmill belt, attachable foot-glides, adjustable hip pad, and an arm pulley system for an upper-body workout (see Figure 1). The base of the machine was at its lowest incline which was an elevation of 9.628% grade and was held constant for all tests. The treadmill belt was 110.23 inches long and was lubricated prior to each test with Snap Silicone Spray for 3 seconds to reduce friction. The hip pad was adjusted and held in place by the detent pin so the pad rested at hip level below the navel as recommended by NordicTrack™, Incorporated (1993). All tension was released from the arms and legs by turning the resistance dials counterclockwise. The

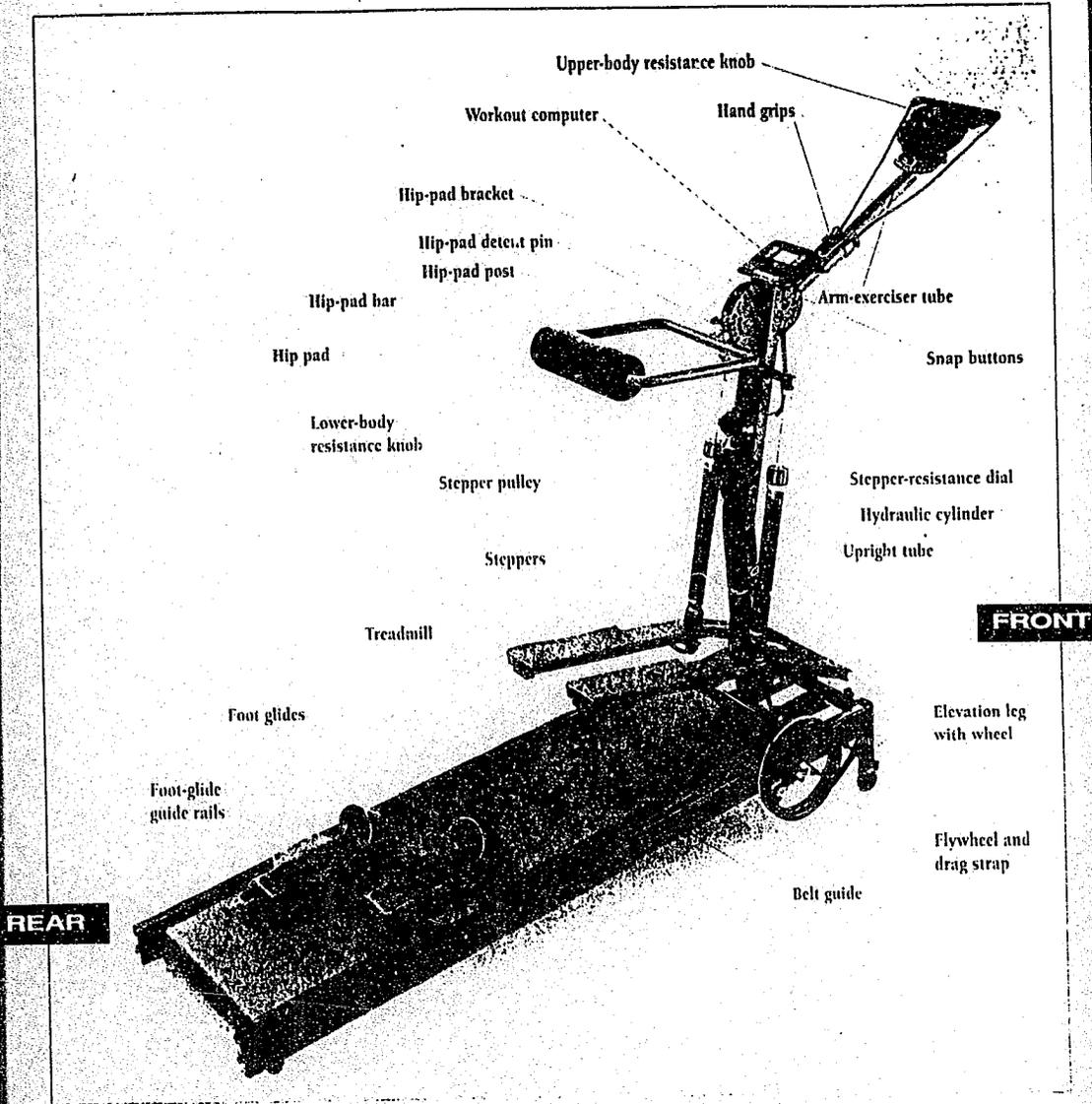


Figure 1. NordicSport CrossTraining System™ by NordicTrack™, Incorporated.

mode for miles per hour (mph) was selected on the electronics monitor to provide feedback to each subject and assist in maintaining the required speed for each phase.

Prior to testing, each subject signed a consent form (see Appendix A) and was required to practice the arm and leg motion to become comfortable on the cross-country ski simulator. Proper technique included keeping hips in contact with the hip pad, swinging the arms in opposition to the legs, lifting the heel up while keeping the ball of the foot in the foot-glide as the leg extended back, and maintaining an upright position. The arm pulley was attached to the self-propelled treadmill and subjects were instructed to use an extended arm motion, pulling past the vertical midline of the body.

A Q-Plex I (Quinton Instruments Co., Seattle, WA.), an open circuit metabolic system, was used to determine energy costs. The room temperature, relative humidity, and barometric pressure were recorded before each test. The oxygen and carbon dioxide analyzers were calibrated using gases previously determined using the Micro-Scholander technique. The volume flow meter was calibrated at various flow rates using a 3.002 syringe pump. The Q-Plex I monitored the expired gas volumes and recorded minute values for pulmonary ventilation (VE), oxygen consumption ($L \cdot \text{min}^{-1}$, $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, and METS), respiratory exchange ratio (RER), and caloric cost (kcal) each minute throughout the test.

A Polar Vantage XL heart rate monitor (Polar Electro Oy, Kempele, Finland) was strapped to the chest to measure the heart rate response during the test and recorded during the last 15 seconds of each minute. The Borg Scale for the rating of perceived exertion (RPE) (see Appendix B) was explained before each test. The RPE was determined by the investigator pointing to the numbers on the Borg Scale and progressing from six up to the appropriate number indicated by the subject nodding his head. The responses for RPE were recorded in the last minute of each stage.

Velocities of 2.0, 2.5, and 3.0 mph were predetermined in a pilot test and a 5-minute interval at each stage was determined to be sufficient to reach a steady state. A steady state for this study was defined as the leveling off of the oxygen consumption (i.e., less than $1 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ between two consecutive minutes). Once the subject reached the initial speed of 2.0 mph, a timer was started and each speed was maintained for at least 5 minutes or until the $\dot{V}O_2$ leveled off before increasing to the next phase.

During the final 2 minutes of each stage, the investigator timed the completion of 20 belt revolutions in seconds to determine the actual mph using the following equation:

$$\frac{110.23 \text{ inches}}{1 \text{ revolution}} \times \frac{20 \text{ revolutions}}{\text{seconds}} \times \frac{3600 \text{ seconds}}{1 \text{ hour}} \times \frac{1 \text{ foot}}{12 \text{ inches}} \times \frac{1 \text{ mile}}{5280 \text{ feet}}$$

$$\text{or } \frac{125.26136}{\text{seconds}} = \text{mph}$$

The computed mph were compared to the speeds reported on the digital display provided on the NSCTS™'s console in Table 2.

Table 2. Calculated mph compared to console values indicated on the NSCTS™ console

Speed (mph)	Calculated Speed (mph)
2.0	2.12 ± .13
2.5	2.60 ± .12
3.0	3.09 ± .18

STATISTICAL ANALYSIS

A one-way ANOVA with repeated measures was calculated for all dependent variables (VE, VO_2 , kcal, HR, RER, and RPE) to determine if there were significant differences among the speeds. A Tukey's posthoc test was computed for those variables which the ANOVA indicated were significant. An alpha level of .05 was used.

RESULTS

The means and standard deviations for VE, VO_2 ($L \cdot \text{min}^{-1}$, $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, METS), kcal, HR, RER, and RPE for the three speeds are presented in Table 3. All physiological responses progressively increased with increasing speeds. These increases were significantly ($p < .05$) different among all speeds with 2.5 mph significantly ($p < .05$) higher than 2.0 mph and 3.0 mph significantly ($p < .05$) higher than 2.5 mph.

The average VO_2 values ($L \cdot \text{min}^{-1}$, $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ & METS) increased 24% from 2.0 to 2.5 mph and 26% from 2.5 to 3.0 mph. Heart rates increased 13.7 and 10%, respectively, as the speed increased. Kcal expenditure also showed an increase of 25.7 and 27.5%, respectively. The largest differences were in VE, increasing 33.9% between 2.0 and 2.5 mph and 41.8% between 2.5 and 3.0 mph. With increasing speed, the RER increased 4.3 and 6.1% and the RPE increased 26.6 and 24.1% between 2.0 mph to 2.5 mph and 2.5 mph to 3.0 mph, respectively.

DISCUSSION

The purpose of this study was to determine the energy expenditure at three different speeds using the cross-country ski simulator of the NordicSport CrossTraining System™ (NSCTS). As expected, the data indicate that as speed increased, the corresponding physiological responses increased proportionately.

The heart rates recorded for 2.0, 2.5, and 3.0 mph increased proportionately from 140 to 159 to 175 bpm as the speed increased. According to the American College of

Table 3. Physiologic results to skiing on the NSCTS™ at three different speeds (n = 24)

Variable	Speed (mph)		
	2.0	2.5	3.0
Ve (L·min ⁻¹)	55.2*	73.9**	104.8
	11.9	14.1	19.1
VO ₂ (L·min ⁻¹)	2.170*	2.702**	3.405
	.474	.446	.366
VO ₂ (ml·kg ⁻¹ ·min ⁻¹)	28.7*	35.6**	44.8
	.7	6.2	5.2
Kcal	10.81*	13.59**	17.33
	2.40	2.31	1.96
METS	8.19*	10.17**	12.8
	1.91	1.78	1.49
HR (beats·min ⁻¹)	139.6*	158.7**	174.5
	16.1	15.8	15.6
RER	.94*	.98**	1.04
	.04	.05	.06
RPE	8.46*	10.71**	13.29
	2.11	2.77	3.09

* p < .05 between 2.0 and 2.5

** p < .05 between 2.5 and 3.0

Sports Medicine (ACSM, 1991), this linear rise in heart rate reflects the increased oxygen uptake. Ready and Huber (1990) reported a similar increase in heart rates for submaximal testing on a skimill compared to treadmill tests at a speed of 7.25 km/h. Goss et al. (1989) reported the lowest heart rate of 118 bpm for five trained skiers moving at 40 cycles per minute on a NordicTrack™ ski machine with no arm or leg resistance. The highest heart rate of 168 bpm was achieved at 60 cycles per minute with arm resistance at 1.0 and leg resistance at 6.0. Although the NSCTS™ does not allow adjustments for arm and/or leg resistance, the movement of the arms and legs contributed to the increase of the heart rate. The range of heart rate from 140 to 175 bpm would be classified by Åstrand and Rodahl (1977) as very heavy to extremely heavy work.

Lawrence (1994) used the NSCTS™ as a treadmill and found higher heart rates compared to similar speeds while working on a motorized treadmill. The self-propelled treadmill yielded a heart rate of 116 bpm at 2.0 mph, 130 bpm at 2.5 mph, and 145 bpm at 3.0 mph compared to heart rates of 103, 112, and 119, respectively, at the same speeds on a motorized treadmill. The self-propelled treadmill put a greater demand on the legs to keep the belt moving, resulting in an increased energy expenditure and increased heart rates. At the same speeds, the heart rates in the present study increased even more when the NSCTS™ was used for skiing. The skiing motion required arm movements. Åstrand and Rodahl (1977) reported that the increase in heart rate is linear with an increase during work and is higher for work performed by the arms than with the legs. The results of the present study support this.

Several studies incorporating the use of arm movement and hand weights during walking and/or running have found increases in energy expenditure. Maud, Stokes, and Stokes (1990) reported a heart rate of 105 for a normal walk at 4.0 mph. An exaggerated arm swing raised it to 111 bpm and increased to 127 bpm with a 3-lb weight added to

each hand. Walking with the addition of hand weights resulted in increases from 7.3 to 13 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ at 2.0 mph and from 10.6 to 17.7 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ at 3.0 mph (Miller & Stamford, 1987). The extended arm swing on the NSCTS™ placed an energy demand on the upper body which involved more muscle mass, resulting in an elevated heart rate at each stage.

As with the heart rates, the oxygen uptake in both absolute ($\text{L}\cdot\text{min}^{-1}$) and relative ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) terms increased in response to each speed increase. Goss et al. (1989) investigated the energy cost of exercising on a NordicTrack™ at 12 different arm and leg resistances and movement frequencies, and concluded that as the limb movement increased, the VO_2 increased over a range of 21.6 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ to 44 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. In this present study, a similar increase in oxygen uptake ranged from 28.7 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ at 2.0 mph to 44.8 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ at 3.0 mph.

The energy expenditure expressed in METS for cross-country skiing in the present study was 8.2 METS at the slowest speed and 12.8 METS at the fastest speed, which falls into the range of 6 to 12 METS given by ACSM (1991) and Howley and Franks (1992) for cross-country skiing. Compared to the METS required for other aerobic activities (i.e., walking, running, and cross-country skiing), the cross-country ski machine obtained the highest METS at similar speeds. Walking on a treadmill at 9% incline required 5 METS at 2 mph, 6 METS at 2.5 mph, and 7 METS at 3 mph, and running at 3.0 mph demanded 7.4 METS (Howley & Franks, 1992). On a nonmotorized treadmill, the METS ranged from 6.6 to 8.0 to 9.6 for walking speeds of 2.0, 2.5, and 3.0 mph, respectively (Lawrence, 1994). Goss et al. (1989) reported a range of 6.2 to 12.7 METS for the energy expenditure of 12 different exercise conditions on their NordicTrack™ and suggested the MET level on a cross-country skier may be increased by increasing the arm or leg resistance and/or increasing the frequency of movements of the arms and legs. This

current study only altered the speed of the arm and leg movements to increase the intensity, but resulted in a significant difference in MET levels at all three speeds.

The METS in this current study increased 1.98 from 2.0 to 2.5 mph, but had a larger increase of 2.63 when the speed increased to 3.0 mph. As the subject reached the last stage, the continuous motion to maintain the faster speed put a greater demand on the cardiovascular system, so a larger increase in METS was observed.

The energy cost of running compared to walking is about double due to the inefficiency of running (ACSM, 1991). The ACSM equation for estimating METS corrects this difference by multiplying the vertical component by 0.5. The comparison of running at 5 mph to cross-country skiing is very similar, with a range of 8.6 METS at 0% grade to 12.0 METS at 10% grade for running. This would imply that the energy expenditure for a cross-country ski simulator would be twice that of walking.

Similar studies involving the use of different modes of exercise have found significant increases in a number of physiological responses. Butts, Knox, and Foley (1994) examined the responses to walking on a dual action treadmill with and without arm activity. They reported that incorporating the arms resulted in significant increases in metabolic responses as the walking speed increased indicating a higher energy expenditure. For example, they reported that walking at 4 mph at 3% incline with arm activity resulted in a VE of 70.8 L·min⁻¹, VO₂ of 2.8 L·min⁻¹ and 35.8 ml·kg⁻¹·min⁻¹ and 10.2 METS. All values obtained in the present NSCTS™ study at 3 mph were higher than those reported during walking on the cross-walk at 4 mph. Neither study altered the arm resistance, but the ski simulator was set at an incline of 9.6%, placing a higher demand on the energy costs which could account for the higher values.

Allen and Goldberg (1986b) compared the energy cost during exercise on the NordicTrack™ and Fitness Master™ at similar submaximal heart rates. They concluded

the NordicTrack™ to be a better cardiorespiratory machine because it resulted in higher oxygen consumption at the three different submaximal heart rate levels. Reite (1991) concluded there were no significant differences in oxygen costs for submaximal exercise between the NordicTrack™ and a Fit-One™ ski machine, yielding $2.4 \text{ L}\cdot\text{min}^{-1}$ and $2.1 \text{ L}\cdot\text{min}^{-1}$, respectively. These values were similar to those obtained in the present study at 2.0 and 2.5 mph.

Allen and Goldberg (1986a) also compared the NordicTrack™ to a bicycle and a rower at two submaximal workloads and reported the energy costs were greater for the NordicTrack™. They concluded that a greater cardiorespiratory workout was possible on the NordicTrack™ than on the bicycle or rower. The energy costs for the NSCTS™ of the present study were $2.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ expended at 2.0 mph, classified as a very heavy level of intensity, and 2.7 and $3.4 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ at the higher speeds, classified as unduly heavy intensity according to McArdle, Katch, and Katch (1986).

In this study, the caloric expenditure ranged from $10.8 \text{ kcal}\cdot\text{min}^{-1}$ at 2.0 mph to $17.3 \text{ kcal}\cdot\text{min}^{-1}$ at 3.0 mph. A recommended aerobic period by ACSM (1991) of 15 to 60 minutes yielded a minimum of 162 kcal to a maximum of 1038 kcal for an exercise bout on this machine. These data indicate the use of a NSCTS™ as a possible means for a weight loss or maintenance program. Goss et al. (1989), reporting a caloric expenditure of 223 to 622 kcal for 30 minutes of exercise on a NordicTrack™ for 7 of the 12 different arm and leg resistances and movement frequencies, recommended using it for weight management. Howley and Franks (1992) gave a range of $7 \text{ kcal}\cdot\text{min}^{-1}$ to $14 \text{ kcal}\cdot\text{min}^{-1}$ for cross-country skiing, so the caloric expenditure on the NSCTS™ fell at the high end of the range and exceeded it at 3.0 mph. Both the NordicTrack™ and the Fit-One™ machines in Reite's 1991 study expended similar calories of 11.9 and 10.6, respectively.

Other significant increases in this study were VE, RER (respiratory exchange ratio), and RPE (rating of perceived exertion). An increase in VE from 55 to 73 to 104 L·min⁻¹ at each stage illustrated that the ventilation increased as the work load increased (Åstrand & Rodahl, 1977). The RER values from .94 to 1.04 indicated that as the intensity of skiing increased, more carbon dioxide was blown off in the expired air (McArdle et al., 1986). The gradual increase in RPE at each stage paralleled the increase in the other physiological responses, supporting ACSM (1991) that the RPE progresses linearly as the exercise intensity increases.

In conclusion, this study determined the energy expenditure at three different speeds using the cross-country ski simulator of the NSCTS™. The data indicate that as speed increased, the variables indicating energy cost increased. A significant problem in this investigation was the inability to calibrate and control the resistance for the arms and legs. Goss et al. (1989) also reported this concern and recommended that the NordicTrack™ be used for recreational or rehabilitation purposes and not for research until a precise and reproducible method of calibration is developed.

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APPENDIX A
INFORMED CONSENT DOCUMENT

Comparison of Energy Cost at Three Different Speeds Using a Cross-Country Ski Simulator, a Self-Propelled Treadmill and a Motorized Treadmill

I, _____, volunteer to participate in a study investigating the energy cost of exercising on a cross-country ski simulator, a self-propelled treadmill of the NordicSport CrossTraining System™, and a motorized treadmill. I understand each test will consist of three 5-minute stages of exercise at increasing speeds of 2.0, 2.5, and 3.0 miles an hour. I realize that a headgear with a mouthpiece and a nose clip will be used during the test so that expired air may be analyzed. My heart rate will be recorded throughout the tests with a heart rate monitor strapped to the chest. I also am aware that I will complete each test in a randomly assigned order.

I understand that my participation in this research study will require a minimum of 3 days consisting of practice sessions, two submaximal tests on two different treadmills and one submaximal test on the cross-country ski simulator. All practice/testing sessions will be scheduled at my convenience and conducted by Kathryn Weiland and Lisa Lawrence in the Human Performance Laboratory in Mitchell Hall of the University of Wisconsin-La Crosse under the direction of Dr. Nancy K. Butts.

As with any exercise, there exists the possibility of adverse changes occurring (i.e., dizziness, staggering, difficulty in breathing, etc.) during the test. In addition, I may feel tired at the end of the exercise. If any abnormal observations are noted, the test will be immediately terminated.

I consider myself to be in good health and to my knowledge I am not infected with a contagious disease or have any limiting physical condition or disability, especially with regard to my heart, that would preclude my participation in the exercise tests as described above. I have read the foregoing and I understand what is expected of me. Any questions which may have occurred to me have been answered to my complete satisfaction. I, therefore, voluntarily consent to be tested. Furthermore, I know I may withdraw from these tests at any time.

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, administration, employees or anyone acting on behalf of them.

Signed: _____ Date: _____

Witness: _____ Date: _____

APPENDIX B

BORG RATING OF PERCEIVED EXERTION SCALE

Borg RPE Scale

6-

7-**Very, Very Light**

8-

9-**Very Light**

10-

11-**Fairly Light**

12-

13-**Somewhat Hard**

14-

15-**Hard**

16-

17-**Very Hard**

18-

19-**Very, Very Hard**

20-

APPENDIX C
REVIEW OF RELATED LITERATURE

REVIEW OF RELATED LITERATURE

Introduction

Research has been conducted to compare the energy cost of various modes of aerobic equipment. There is a need to evaluate new equipment on the market for safety, adaptability to individual needs, and health benefits achieved through exercise prescriptions. Companies attempt to model machines after cardiovascular activities, such as walking, running, and cross-country skiing. Studies have looked at factors that influence the energy expenditure and the physiologic responses to submaximal exercise. A review of these responses to cardiovascular activities and equipment is presented below.

Physiological Responses

Oxygen Uptake

Thomas, Feiock, and Araujo (1989) compared steady state exercises on a bicycle, rower, cross-country skier, and treadmill and found similar energy expenditure for all four modalities. At a level of 65% maximal heart rate, the cross-country machine yielded 2.26 L·min⁻¹ at a heart rate of 120 bpm. Faulkner, Roberts, Elk, and Conway (1971) compared the metabolic responses to submaximal and maximal cycling and running in eight men. The only significant difference was submaximal heart rate on the bicycle was lower. Allen and Goldberg (1986a) reported the oxygen uptake on a NordicTrack™ was greater at two submaximal workloads than on a bicycle or rower and concluded that a greater cardiorespiratory workout is possible on the NordicTrack™ than on the bicycle or rower.

Pulmonary Ventilation

Pulmonary ventilation (VE) during submaximal exercise increases as blood lactate accumulates and the blood pH becomes acidic (ACSM, 1991). Ready and Huber (1990) compared submaximal tests on a skimill and a treadmill and reported that the minute ventilation was significantly higher during the skimill test. Also, VE was significantly

higher on the treadmill when ski-walking with an arm pulley system for resistance than when ski-walking with no arm resistance. The reason given by the researchers for these differences was an increase in respiratory frequency while the tidal volume remained the same. During submaximal exercise, McArdle, Katch, and Katch (1986) suggested that tidal volume can be increased and the breathing frequency reduced so there is a longer period of time to extract more oxygen from the inspired air in the lungs.

Kilocalories

The number of kilocalories expended during an aerobic bout of exercise is usually of interest to the general population. The ACSM (1991) recommends an exercise program that can be sustained for a long period of time at a low intensity for a caloric expenditure of 300 kcal or more a day, be used when the individual is interested in weight control. Goss et al. (1989) suggested using the NordicTrack™ as a weight management exercise mode since it can require 223 to 622 kcal to complete a 30-minute exercise. Howley and Franks (1992) gave a range of 7 to 14 kcal·min⁻¹ for actual cross-country skiing. In Reite's 1991 study, both the NordicTrack™ and the Fit One™ machines required similar calories of 11.9 and 10.6, respectively. A 30-minute bout of walking on a self-propelled treadmill resulted in 321 kcal expended at 2.5 mph and 384 kcal at 3.0 mph (Lawrence, 1994). These types of exercise equipment provide a sustained activity for a high rate of energy expenditure for weight loss purposes (ACSM, 1991).

Respiratory Exchange Ratio

The RER indicates the exercise intensity and the proportional utilization of carbohydrates and fats (ACSM, 1991). Thomas et al. (1989) found no significant difference in RER during steady-state exercises on four pieces (i.e., bicycle, rower, cross-country skier, and treadmill) of cardiovascular equipment. Lawrence (1994), however, reported contrasting results. She found significantly higher differences in the RER at 2.5

and 3.0 mph on a nonmotorized treadmill compared to a motorized treadmill, as well as a difference for RPE at the same speeds.

Bart (1989) found an increase in RER on a treadmill at submaximal level for conditioned skiers, but not on a ski simulator, indicating an influence for specificity of training. Butts, Knox, and Foley (1994) used a cross walk machine to compare the RER in a steady state. Walking at 3.0 mph at 3% incline yielded an RER value of .87 using the arms and .86 with no arms for men and women. McArdle and Mogel (1970) reported a higher RER on a bicycle at submaximal heart rates than walking on a treadmill at 3.4 mph.

Rating of Perceived Exertion

Bart (1989), using cross-country skiers on a treadmill and ski ergometer, reported the RPE increased more at submaximal workloads on the treadmill. Howley (1986) compared RPE responses from eight subjects using a Monarch™ cycle ergometer, Concept II™ rower, Stairmaster 4000™, treadmill, and a NordicTrack™. He reported a faster rise in RPE scales with an increased intensity for the NordicTrack™ than for the other four pieces of equipment.

Influencing Factors

Stride Length and Frequency

There are a number of factors that influence the energy expenditure of any activity. For example, Workman and Armstrong (1963) reported that the step frequency is the most important factor to determine the energy cost of walking, using the equation $VO_2 = \text{oxygen consumption/step} \times \text{number of steps/minute}$. They determined energy was needed for accelerating and decelerating the motion of walking, particularly the legs. They found the step frequency was the reciprocal of body height, indicating shorter subjects take more steps, thus use more oxygen (i.e., energy) to walk (Workman & Armstrong, 1986).

Holt, Hamill, and Andres (1991) compared the energy cost of a subject's preferred stride frequency for a comfortable pace on a treadmill to a predetermined pace set by a force-drive harmonic oscillator. These authors found a higher metabolic cost for slow frequency and longer strides than for faster frequency and shorter strides. A curvilinear relationship between stride length and frequency was reported by Bobbert (1960). He reported an increase in energy expenditure which corresponded to the increasing speed and with an increased gradient. The rising speed resulted in an increase in stride length as well as an increase in the number of strides per minute.

Friction

Friction has been determined to be an influence on the energy cost of cross-country skiing outdoors. In 1990 Hoffman, Clifford, Bota, Mandli, and Jones investigated the effect of body mass on the measured oxygen consumption of cross-country skiing and roller skiing and the effect of body mass. They reported a decrease of 1.0% in oxygen consumption for each kilogram increase in body mass for six male racers as well as a difference in energy cost to overcome friction for these exercises.

The study of Saibene, Cortili, Roi, and Colombini (1989) also used six skiers to determine their oxygen consumption and the influence of friction during skiing. Friction on the skis was affected by the snow temperature. As the friction increased there was a corresponding resulting increase in oxygen consumption. Ready and Huber (1990) investigated the energy expenditure on a skimill and found higher values when compared to two ski-walking tests on a treadmill. The friction between the skis and the skimill resulted in a higher oxygen cost during the glide phase and increased as the elevation increased.

Soft Belt

Williams, Hone, and Carter (1992) investigated the difference a soft belt on a treadmill can make in physiological responses compared to a hard belt. They reported significant differences in oxygen costs and heart rates while walking on the two treadmills. The soft belt treadmill resulted in $29.0 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and heart rate of 141 bpm at 3.5 mph and 7.5% incline compared to the hard belt treadmill responses of $24.5 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and a heart rate of 128 bpm at a similar speed and incline.

Other Activities

Arm and Leg Movements

Toner, Glickman, and McArdle (1990) used six male subjects for leg and arm crank exercises at submaximal efforts. They found no differences at the low intensities for heart rate, stroke volume, and rate-pressure product, but the heart rate was significantly higher when using the arms at a higher intensity. They concluded that the leg musculature aided the venous return by the muscle pump activity of the legs and reduced the blood volume in the lower body. Vokac, Bell, Bautz-Holter, and Rodahl (1975) also used arm cranking and cycling to compare VO_2 , HR, and VE. At a given submaximal workload, arm cranking resulted in higher VO_2 , HR, and VE than cycling whether the subjects were standing or sitting. Åstrand and Rodahl (1977) reported that the increase in heart rate is linear with an increase during work and is higher for work performed by the arms than with the legs.

Other studies have examined the oxygen uptake by varying demands placed on the upper body, such as arm swinging, hand weights, and pulley systems while walking. Maud, Stokes, and Stokes (1990) reported an increase of energy cost from 18.9 to $24.8 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ by adding weights to an exaggerated arm swing during walking. The addition of hand weights while walking at 3 mph on a treadmill resulted in an increase

from 10.6 to 17.7 ml·kg⁻¹·min⁻¹ (Miller & Stamford, 1987). Ready and Huber (1990) used a pulley system on a treadmill while ski-walking to demonstrate a significantly higher oxygen expenditure than ski-walking only.

Running

Energy costs for running can be increased by the air resistance when running outdoors, an increased body temperature resulting in an increase in the circulation, ventilation rate, and sweating mechanism, and by additional weight, especially by heavy shoes (Daniels, 1985). Bourdin, Pastene, Germain, and Lacour (1993) reported a negative relationship of height to energy cost, indicating that taller subjects have lower energy costs for running. They also stated that training can improve running economy at a maximal level, but Daniels (1985) reported that training made no difference at submaximal workloads. Due to biomechanical and metabolic differences between the sexes, Bhambhani and Singh (1985) reported that females expended more energy to run than males. Bourdin et al. (1993), reporting a negative relationship of height and energy cost, confirmed that taller and heavier subjects had a lower energy cost when running. However, when Miller and Stamford (1987) looked at the energy cost per kilogram, they found no differences between the sexes for running. Falls and Humphrey (1976) agreed that there was no difference in the oxygen uptake between men and women for both running and walking.

Cross-Country Skiing

The energy expenditure for cross-country skiers testing in the outdoors is influenced by different factors, such as snow conditions, temperature changes, techniques, and friction. MacDougall, Hughson, Sutton, and Moroz (1979) compared the oxygen cost of cross-country skiing with poles and running on a level surface at the same speed. They reported that skiing resulted in 10 to 12 ml·kg⁻¹·min⁻¹ higher energy costs than

running and gave the following reasons for the difference: additional weight of clothing and equipment, wind resistance, snow conditions, lower skill level of the subjects, and use of upper body muscles as well as lower body muscles. Saibene et al. (1989) looked at skiing techniques and their effect on VO_2 , concluding that the skating technique at 18 to 22 $km \cdot hr^{-1}$ was the most advantageous (i.e., most efficient) and resulted in a lower VO_2 than diagonal stride technique. The relationship of body mass and aerobic power was explored by Bergh (1987), who concluded that heavier skiers have lower relative VO_2 .

The elite cross-country skiers in a MacDougall et al. (1979) study skied on an outdoor snow track at 50, 75, and 100% of their race pace. Heart rates ranged from 157 bpm at the slowest speed to 176 bpm at the fastest speed. None reached their maximal heart rates as determined from a treadmill running test. However, four novice skiers attained their maximal heart rates during the fastest skiing speed (MacDougall et al., 1979). The long glide phase of actual cross-country skiing may account for the failure of the elite skiers to reach their maximal heart rates, according to MacDougall et al. (1979). On a cross-country ski simulator, there is no glide phase and, therefore, the constant pace ensures that the subjects maintain a steady state.

Summary

Participation in cardiorespiratory activities is available in many modes, from walking and running to a wide variety of exercise equipment on the market. Many factors influence the energy expenditure by increasing the workload. These factors must be considered when designing exercise prescriptions so the subject will receive the optimal benefits in a safe manner. Recommended components for an exercise program given by ACSM (1991) are mode, intensity, duration, frequency of exercise, and rate of progression. By evaluating the exercise machines available on the market, a wise and safe

decision may be made for a personalized fitness program, and improvements for future equipment may result in better possibilities for the consumer.

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