ABSTRACT

AUDET, D. Metabolic cost of downhill ski ergometry in males. MS in Adult Fitness/Cardiac Rehabilitation, August 1994, 35pp. (J. Porcari)

This study compared the physiological responses to 20 min of simulated downhill skiing between the NordicSport™ and Skier's Edge™ downhill ski ergometers. Experienced male skiers ($\underline{N}$ = 15, age = 18-34 yrs.) volunteered as Ss. Pretest measurements included a treadmill VO_2max test and % body fat (BF) by skinfolds (VO_2max = 58.6 ml/kg/min, BF = 12.9%). Each S performed 20 min of steady state exercise, at a cadence eliciting a HR between 70-85% of HRmax (avg = 68 turns/min), on both ski ergometers in random order and on separate days. During the exercise sessions VO_2 (ml/kg/min), HR (bpm), and RPE were measured each min. Responses between conditions were analyzed with paired t-tests. Analysis revealed that all responses were significantly ($p < .05$) higher for the NordicSport™ condition. Individual regression equations were calculated from the treadmill data to investigate the HR-VO_2 relationship during downhill ski ergometry compared to that of treadmill running. Results showed that there was no significant difference between actual VO_2 measured during downhill ski ergometry and VO_2 predicted from the treadmill running prediction equations for both the NordicSport™ and Skier's Edge™ conditions, at the same HR. It was concluded that both ski ergometers can provide a sport-specific workout for downhill skiing. However, due to differences in ergometer design and resistance characteristics, the NordicSport™ elicited greater physiological responses at similar self-selected cadences and horizontal displacements.

METABOLIC COST OF DOWNHILL SKI ERGOMETRY IN MALES

A MANUSCRIPT STYLE THESIS PRESENTED

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The candidate has successfully completed her thesis oral defense.

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DEDICATION

Je dédie ce manuscript à mes parents,
Jacques et Denise Audet.

Papa, maman, merci pour tout le support
que vous m'avez donné au cours des deux dernières années
et ca, malgré les 1000 milles qui nous séparent.
Ailleurs n'est jamais loin quand on aime.

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TABLE OF CONTENTS

LIST OF TABLES

TABLE PAGE

LIST OF APPENDICES

INTRODUCTION

Skiing originated in northern Europe and Scandinavia some three to four thousand years ago. It was essentially an early form of cross-country skiing and was used as transportation, or for activities such as hunting and fighting. Downhill skiing or "slalam" as it was originally called by its Norwegian originators, was developed at the end of the nineteenth century. The sport flourished in Europe in the mid-1930s and gradually spread to the rest of the world (Karlsson, 1984).

It was not until the 1950s that downhill skiing became popular in the United States (Karlsson, 1984). Since then, many Americans have enjoyed downhill skiing as a leisure time activity or as a competitive sport. In 1989, the American downhill skier population was estimated to be more than 15 million with more than 600 ski areas in 40 states across the country (Wirth, 1989). Nationally, ski areas bring in over $1.6 billion a year (Gam, 1989).

It has been said that the average downhill skier skis 15 times per year and spends the other 350 days of the year thinking about it. If skiers want to stay conditioned in the off-season, they most often rely on running, cycling, or weight training to maintain cardiorespiratory endurance and muscular tone. Recently, downhill ski simulators have become available on the market. These skiing ergometers are designed to mimic the actions used during downhill skiing, thus providing a sport specific workout for downhill skiers. It is known that aerobic fitness and muscular strength is most effectively achieved when the exerciser trains the specific muscles involved in the desired performance (McArdle, Katch, & Katch, 1986).

It has been shown that there is a significant positive correlation between maximal oxygen consumption (VO_2max) and downhill skiing performance (Song, 1982). To optimize physical fitness and maintain proper skiing mechanics during the summer season or between ski trips, exercising on a downhill ski ergometer represents a good alternative to the real sport. It is hypothesized that increases in aerobic fitness and in lower body muscle endurance as well as increases in balance and coordination may be expected from exercising on a downhill ski ergometer. Furthermore, it may help reduce the risks of injury during the ski season since lack of physical fitness is an important predisposing factor to many ski injuries (Miller, Porcari, Audet, & Csontos, 1993).

Although no single definition of physical fitness has ever been universally accepted, many exercise physiologists consider VO_2max a major component. The American College of Sports Medicine (ACSM, 1991) recommends that individuals obtain regular aerobic exercise for the development of cardiorespiratory fitness. Any activity that uses large muscle groups, is rhythmical in nature, and is maintained continuously for extended periods of time is considered aerobic. The ACSM (1991) recommends practicing this activity 3 to 5 times per week, for 20 to 60 minutes per session, at an intensity of 60 to 90% of maximum heart rate (HRmax) or 50 to 85% of VO_2max.

While running, walking, and swimming are well documented aerobic activities, there is a need for more research to characterize the physiological responses obtained during downhill ski ergometry. Cisar (1992) showed that simulated downhill ski ergometry, using the Skier's Edge™ ergometer (Scientific Sports Systems Inc.), resulted in average relative workloads of 75.5% of HRmax and 59.5% of VO_2max. He concluded that these values are within the range of exercise intensity recommended by the ACSM (1991) for increasing cardiorespiratory fitness.

The first purpose of this investigation was to determine the energy cost (ml/kg/min and kcal/hr) and relative intensity (percent of HRmax and percent of VO_2max) of exercising on the NordicSport™ (NordicTrack, Inc.) and Skier's Edge™ downhill ski ergometers and therefore investigate their ability as a mode of exercise to potentially induce changes in cardiorespiratory fitness as recommended by ACSM (1991) guidelines. The second purpose of this study was to compare the physiological responses between machines at a similar cadence and horizontal displacement, to determine which ergometer would provide a more time efficient workout. The third purpose of this study was to investigate the HR-VO_2 relationship during downhill ski ergometry compared to that of treadmill running.

METHODS

Fifteen male recreational alpine skiers were tested at the Human Performance Laboratory at the University of Wisconsin-La Crosse. Before participation, all subjects signed an informed consent form (see Appendix A) and completed the Physical Activity Readiness Questionnaire (Government of Canada Fitness and Amateur Sport, 1986) (see Appendix B).

Physiological Testing Protocol

The research protocol was divided into training and testing phases. During the training phase, each subject practiced skiing on both downhill ski ergometers. The purposes of the practice sessions were to assure proper mechanical efficiency (the ability to perform rhythmical and large amplitude movements without loss of balance) while skiing and to eliminate possible training effects. All subjects skied with poles to help with balance and were instructed to use a loose grip to avoid a pressor response. Each subject completed a minimum of two training sessions.

The testing phase included four sessions. For each session, the subjects were instructed to refrain from smoking, eating, and drinking (except water) for 3 hours preceding the testing, and to avoid physical activity on the day of testing. During session one, anthropometric measurements, VO_2max, and HRmax were obtained. Percent body fat was estimated from the umbilical and thigh skinfold measurements using the equation of Wilmore and Behnke (1970). Maximal oxygen consumption and HRmax were determined using a modified

Balke treadmill test. The subject ran at a self-selected speed (mph) which was held constant throughout the test. The grade was increased by 2.5% every 2 minutes until the subject reached volitional exhaustion. Maximal oxygen consumption was established as the highest 1-minute value attained for VO_2 during the test. To establish that valid VO_2max values had been attained, two of the three following criteria had to be met: 1) a rise in oxygen consumption of less than 0.15 L/min with a further increase in power output (Shephard, 1984); 2) a respiratory exchange ratio equal to or greater than 1.10 (McArdle et al., 1996); and 3) a heart rate no less then 10 beats below the predicted HRmax (Shephard, 1984).

During the second session, a cadence eliciting a heart rate between 70 and 85% of HRmax was determined for each subject while exercising on the NordicSport™ downhill ski ergometer. This cadence was later used during both the NordicSport™ and Skier's Edge™ protocols. The cadence was paced by an electronic metronome. To determine the appropriate cadence, the subject began to ski at a self-selected cadence for a 4-minute period following the protocol described below:

(A) The mean heart rate for the third and fourth minute of the first workload had to range from 70 to 85% of HRmax as determined from the maximal treadmill test. If the mean heart rate did not lie within the target range, step (B) was followed if less than 70% of HRmax or step (C) was followed if greater than 85% of HRmax.

(B) If the subject's mean heart rate for the third and fourth minute of a new workload was less than 70% of HRmax, the cycle cadence was increased by 4 turns/min and step (A) was repeated.

(C) If the subject's mean heart rate for the third and fourth minute of a new workload was greater than 85% of HRmax, the cycle cadence was decreased by 4 turns/min and step (A) was repeated.

The skiing cadence ranged from 80 to 100 turns/min, with an average of 88 turns/min. The resistance (band tension) on the ski ergometers was adjusted to allow a horizontal displacement of approximately 145 cm.

The third and fourth testing sessions involved measurements of the subject's submaximal VO_2 (ml/kg/min), RPE, caloric expenditure (kcal/hr), and HR (bpm) responses during 20 minutes of steady-state exercise on both the NordicSport™ and the Skier's Edge™ downhill ski ergometers. Testing order was randomized and the cadence and horizontal displacement were kept constant while exercising on both ski ergometers. A 10-minute warmup period preceded each of the experimental protocols. The warmup consisted of 5 minutes of light cycling at a resistance of 0.5 kp and 5 minutes of stretching for the major muscle groups (gastrocnemius, soleus, hip flexors, hamstrings, quadriceps, back, chest, shoulders, and triceps).

Data Collection

Expired gas volumes and concentrations were analyzed during the VO_2 max test and the submaximal trials using a Quinton Q-Plex I metabolic cart with software revision E (Quinton Instruments Co., Seattle, WA). The volume was calibrated using a 3.0 L calibration syringe and the gas analyzers were calibrated before and after each test using calibration gases verified by the Micro-Scholander technique (Scholander, 1947). The subjects' heart rates were continually monitored using a Polar Vantage XL model heart rate monitor (Polar USA, Inc., Stamford, CT.). Throughout all tests, measurements (V_E, VO_2, VCO_2, and HR) were recorded every 15 seconds. Ratings of perceived exertion (RPE) were recorded at the end of each stage during the VO_2max test and every 2 minutes during the experimental protocols using the 15 point Borg Scale (Borg, 1982).

Statistical Analyses

Means and standard deviations were calculated for subject characteristics and anthropometric measurements. Means and standard deviations were also calculated for HR (bpm and percent of HRmax), VO_2 (ml/kg/min and % of VO_2max), RPE, and energy expenditure (kcal/hr) responses obtained during the experimental protocols. The physiological responses obtained during the two experimental protocols were compared using paired t-tests.

Individual regression equations were calculated from the treadmill data to investigate the HR-VO_2 relationship during downhill ski ergometry compared to that of treadmill running. Heart rate was chosen as the independent variable to predict VO_2. The mean HR achieved during the NordicSport™ condition for every subject was then inserted into each respective individual regression equation to yield a predicted VO_2. The predicted VO_2 values were compared to the actual VO_2 values obtained during the NordicSport™ condition using a paired t-test. The same procedure was used for the Skier's Edge™ condition. An a priori probability level of .05 was selected for significance for all analyses.

RESULTS

Selected demographic characteristics of the subjects are presented in Table 1. The skiers were more fit (95th percentile) and leaner (85th percentile) compared to subjects in a similar age-group (Pollock, Wilmore, & Fox, 1978).

Table 1. Anthropometric measurements and characteristics of the subjects

Variable	Mean ± SD	Range
Age (yrs)	25.3 ± 4.6	18.0 - 34.0
Height (in)	70.3 ± 1.6	68.0 - 73.0
Weight (lbs)	170.8 ± 18.3	135.0 - 197.0
Body fat (%)	12.9 ± 2.2	7.5 - 15.1
VO_2max (L/min)	4.52 ± 0.47	3.61 - 5.42
VO_2max (ml/kg/min)	58.6 ± 4.0	49.6 - 63.7
HRmax (bpm)	196 ± 7.8	165 - 212

Responses to the two submaximal skiing trials are reported in Table 2. All subjects reached a steady state by minute 5 thus data were averaged for minutes 6-20. Analyses revealed that all measured variables (VO_2, %VO_2max, HR, %HRmax, RPE, kcal/hr, and RER) were significantly ($p < 0.05$) higher for the NordicSport™ condition compared to the Skier's Edge™ condition. The group mean VO_2 (ml/kg/min) and energy expenditure (kcal/hr) were 29% higher in the NordicSport condition. Also, HR (bpm) responses were 18% greater when exercising on the NordicSport™ ski ergometer.

Table 2. Physiological responses to 15 minutes of steady-state exercise on the NordicSport™ and Skier's Edge™ downhill ski ergometers

Variable	NordicSport™ Mean ± SD	Skier's Edge™ Mean ± SD
VO_2 (ml/kg/min)	32.4 ± 5.50	25.2 ± 5.00*
%VO_2max	55.2 ± 7.10	43.0 ± 7.90*
HR (bpm)	155 ± 12.5	131 ± 13.90*
%HRmax	78.7 ± 5.90	66.7 ± 7.40*
RPE	12.00 ± 2.20	9.90 ± 2.20*
kcal/hr	740 ± 169.60	569 ± 115.90*
RER	0.91 ± 0.04	0.88 ± 0.03*

* significantly different ($p < 0.05$) from NordicSport™ condition

The use of target heart rate to assess the intensity of aerobic type activities is based on the assumption that HR increases proportionately to increases in VO_2. While this relationship is essentially linear and proportional during running and cycling (Parker, Hurley, Hanlon, & Vaccaro, 1989), it has not been established for downhill ski ergometry.

Individual regression equations of HR vs VO_2 were calculated for each subject from the treadmill data (see Table 3). The actual HR's obtained for the NordicSport™ and Skier's Edge™ conditions were then inserted into these equations to get a predicted VO_2. These predicted VO_2 values were compared to the actual VO_2 values measured during skiing ergometry using paired t-tests. It was found that there was no significant ($p > .05$) difference between the actual and predicted VO_2 values for both the NordicSport™ and Skier's Edge™

conditions. Thus similar HR-VO_2 relationships exist for treadmill running and downhill ski ergometry indicating that HR can be used as an accurate guide for exercise prescription.

Table 3. Individual regression equations

S's	Individual Regression Equations	NordicSport™ HR	NordicSport™ PVO_2	NordicSport™ AVO_2	Skier's Edge™ HR	Skier's Edge™ PVO_2	Skier's Edge™ AVO_2
1	Y = -12.33 + 0.38 * X	153	45.8	35.0	131	37.4	26.4
2	Y = -54.23 + 0.58 * X	153	34.1	32.4	144	29.3	31.3
3	Y = -62.56 + 0.61 * X	177	45.4	33.6	126	14.3	24.9
4	Y = -63.36 + 0.62 * X	163	37.7	29.3	138	22.2	22.4
5	Y = -64.28 + 0.67 * X	174	52.3	47.2	141	30.2	34.7
6	Y = -61.63 + 0.60 * X	145	25.4	29.0	124	12.8	17.7
7	Y = -78.56 + 0.66 * X	153	22.4	28.8	133	09.2	18.8
8	Y = -80.03 + 0.68 * X	157	26.8	29.5	159	28.1	28.2
9	Y = -35.79 + 0.53 * X	140	38.4	37.6	118	26.8	28.4
10	Y = -18.03 + 0.39 * X	151	40.9	34.0	128	31.9	25.7
11	Y = -49.95 + 0.59 * X	163	46.2	27.2	115	17.9	22.0
12	Y = -51.47 + 0.51 * X	152	26.1	34.0	133	16.4	19.7
13	Y = -51.48 + 0.54 * X	160	34.9	35.7	108	06.8	24.1
14	Y = -30.47 + 0.48 * X	130	31.9	28.3	148	40.6	32.2
15	Y = -38.86 + 0.39 * X	154	21.2	24.8	119	07.6	21.8
Mean		155	35.3	32.4	131	25.0	25.2

X = actual HR, Y = predicted VO_2, PVO_2 = predicted VO_2, AVO_2 = actual VO_2

DISCUSSION

The American College of Sports Medicine (1991) recommends that individuals obtain regular aerobic exercise for the development of cardiorespiratory fitness. The ACSM (1991) recommends that this activity be performed 3 to 5 times per week, for 20 to 60 minutes per session, at an intensity of 60 to 90% of maximum heart rate (HRmax) or 50 to 85% of VO_2max. While running, walking, and swimming are well documented aerobic activities, more research was needed to characterize the physiological responses obtained during downhill ski ergometry.

The first purpose of this study was to determine the energy cost and relative intensity of downhill ski ergometry, using the NordicSport™ and Skier's Edge™ downhill ski ergometers, and therefore investigate their ability as a mode of exercise to potentially induce changes in cardiorespiratory fitness. The mean VO_2 while exercising on the NordicSport™ was 32.4 ml/kg/min and the HR averaged 155 bpm. These values represent relative intensities of 55.2% of VO_2max and 78.7% of HRmax, respectively. The mean VO_2 while exercising on the Skier's Edge™ was 25.2 ml/kg/min and the HR averaged 131 bpm. These values represent relative intensities of 43.0% of VO_2max and 66.7% of HRmax, respectively. Based on these results, it appears that downhill ski ergometry has the potential to induce changes in cardiorespiratory fitness. A list of energy expenditures for selected sports activities is presented in Table 4 (adapted from McArdle, Katch, & Katch, 1986). Based on this table, it appears that downhill ski ergometry is comparable to other forms of aerobic exercise performed at a moderate exercise intensity.

A second purpose of this study was to determine which ergometer would provide a more time efficient workout at a similar cadence and horizontal

Table 4. Energy expenditure for selected sports activities

Activity	kcal/min/kg
Aerobic dance - medium	0.103
Aerobic dance - intense	0.135
Cross-country skiing - medium	0.143
Cross-country skiing - intense	0.274
Cycling at 9.4 mph	0.100
Cycling - racing	0.169
Downhill skiing - leisure	0.100
Running at 9 min per mile	0.193
Running at 7 min per mile	0.228
Swimming freestyle slow	0.128
Swimming freestyle fast	0.156
Walking - normal pace	0.080

Adapted from McArdle, Katch, & Katch, 1986

displacement. It was found that the NordicSport™ condition yielded significantly ($p < .05$) higher VO_2 and HR responses compared to the Skier's Edge™ condition. On average, VO_2 responses were 29% greater and HR responses 18% greater when exercising on the NordicSport™ ski ergometer. The subject's mean energy expenditure was 740 kcal/hr (0.159 kcal/kg/min) and 569 kcal/hr (0.122 kcal/kg/min) for the NordicSport™ and Skier's Edge™ conditions, respectively. The skiers expended significantly more kcal/hr (29%) in the NordicSport™ condition. It can be concluded, therefore, that when compared to the Skier's Edge™, exercising on the NordicSport™ downhill ski ergometer would provide a more time efficient workout at a similar cadence and horizontal displacement. Cisar (1992) reported an energy expenditure of 528 kcal/hr (0.12 kcal/kg/min) using the Skier's Edge™ downhill ski ergometer at an intensity of 75.5% of HRmax or 59.5% of VO_2max. The energy expenditure reported in Cisar's study is similar to that found in the present investigation.

The higher metabolic cost of exercising on the NordicSport™ compared to the Skier's Edge™, despite a similar cadence and horizontal displacement, may be due to differences in machine design. The NordicSport™ downhill ski ergometer is built with a forward slant and places a greater challenge on balance. In a different study, Miller et al. (1993) found that knee flexion was significantly greater when skiing on the NordicSport™ in comparison to the Skier's Edge™ downhill ski ergometer. Miller et al. (1993) hypothesized that the greater knee flexion may have been in response to greater balance requirements. Better balance is acquired by lowering one's center of mass. Greater knee flexion requires more muscle fiber recruitment and therefore may have contributed to the greater metabolic cost of skiing on the NordicSport™ in comparison to skiing on the Skier's Edge™. It can be hypothesized that downhill ski ergometry has the potential not only to improve VO_2max but also balance, an important physiological characteristic of downhill skiers (Andersen & Montgomery, 1988).

Another difference in machine design relates to the band tension. The resistance on both machines was controlled by a resistive elastic band. Although the degree of elasticity of each band was not measured, the band on the NordicSport™ ski ergometer seemed less elastic than that of the Skier's Edge™. A lower degree of elasticity may have accounted for a loss of momentum and therefore the subjects may have needed a greater push-off to travel from side to side. This also may have accounted for the greater metabolic cost of skiing on the NordicSport™.

Another variable measured during the testing phase was the rating of perceived exertion (RPE). The RPE scale (see Table 5) has become a valid tool as an adjunct to heart-rate monitoring for determining exercise intensity (Van Gelder, 1987). This is based on the strong, positive relationship demonstrated between rating of perceived exertion and relative metabolic demand (Williams & Eston, 1989).

In the present study, the RPE was significantly higher in the NordicSport™ condition (RPE = 12) compared to the Skier's Edge™ condition (RPE = 9). Therefore, not only were the subjects working at a significantly higher metabolic workload in the NordicSport™ condition, but they also perceived it as such.

Table 6 describes the relationship between relative intensity based on percentage of HRmax, percentage of HRmax reserve, percentage of VO_2max, and RPE (ACSM, 1991). According to this table, a RPE of 12 corresponds to a relative intensity of approximately 50-60% of VO_2max. Therefore, the RPE of 12 in the NordicSport™ condition was an accurate reflection of the actual metabolic demand (55.2% of VO_2max). According to the same table, a RPE of 9 corresponds to a relative intensity of less than 30% of VO_2max. In the Skier's

Edge™ condition, the RPE was 9 and therefore the skiers tended to slightly underestimate the metabolic demand (43.0% of VO_2max). It has been shown that RPE is a more valid predictor of exercise intensity at higher intensities. Eston et al. (in Williams & Eston, 1989) instructed subjects to run at constant exercise intensities that they perceived corresponded to 9, 13, and 17 on the RPE scale. It was found that RPE was at least as good a predictor of exercise intensity as heart rate particularly at the two higher RPE levels. In conclusion, RPE seems to be a valid tool for estimating exercise intensity in downhill ski ergometry especially at moderate intensities.

Table 5. Rating of perceived exertion scale (RPE)

Rating	Description
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	

Table 6. Classification of intensity of exercise based on 20-60 minutes of endurance training (ACSM, 1991).

Relative Intensity (%) HRmax	VO_2max or HRmax reserve	Rating of Perceived Exertion	Classification of Intensity
<35%	<30%	<10	Very light
35-59%	30-49%	10-11	Light
60-79%	50-74%	12-13	Moderate (somewhat hard)
80-89%	75-84%	14-16	Heavy
>89%	>84%	>16	Very Heavy

The third purpose of this study was to investigate the HR-VO_2 relationship during downhill ski ergometry compared to that of treadmill running. The establishment of a training intensity from measures of VO_2 is accurate, but impractical without sophisticated equipment. Consequently, the intensity of an aerobic activity is usually calculated from a percentage of HRmax. The use of target heart rate to assess the intensity of aerobic type activities is based on the assumption that HR increases proportionately to increases in VO_2. While this relationship is essentially linear and proportional during running and cycling (Parker et al., 1989), it has not been established for downhill ski ergometry. Furthermore, downhill skiing is an interval-type exercise and is usually classified among the anaerobic events (Saibene, Cortilli, Gavazzi, & Magiciri, 1985).

Results showed that there was no significant difference between actual VO_2 measured during downhill ski ergometry and VO_2 predicted from the treadmill running prediction equations for both the NordicSport™ and Skier's Edge™ conditions, at the same HR. Actual VO_2 and predicted VO_2 were 32.4 ml/kg/min and 35.3 ml/kg/min for the NordicSport™ condition and 26.2 ml/kg/min and 25.0 ml/kg/min for the Skier's Edge™ condition, respectively. This indicates that HR and VO_2 during downhill ski ergometry and treadmill running have essentially the same linear relationship. In conclusion, the use of a target heart rate to determine exercise intensity during downhill ski ergometry is warranted.

In summary, based on the results found in the present study, it can be concluded that exercising on the NordicSport™ and Skier's Edge™ ski ergometers can elicit physiological responses that are within the guidelines recommended by the ACSM for improving and maintaining cardiorespiratory endurance. Also, when compared to the Skier's Edge™, exercising on the NordicSport™ downhill ski ergometer would provide a more time efficient workout at a similar cadence and horizontal displacement. Furthermore, this study has shown that the use of a percentage of HRmax and the use of the RPE scale are both valid methods to estimate exercise intensity during downhill ski ergometry. Finally, it can be said that to optimize VO_2max and to maintain proper skiing mechanics during the summer season or between ski trips, exercising on a downhill ski ergometer represents a good alternative to the real sport. Further research is needed to identify how downhill ski ergometry simulates actual downhill skiing on snow from a biomechanical perspective.

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APPENDIX A

INFORMED CONSENT

ENERGY COST OF DOWNHILL SKI ERGOMETRY

INFORMED CONSENT

Your written consent is needed prior to your participation in this study. Please read this consent document carefully and sign your name in the space provided below.

In accordance with the general guidelines on the rights and welfare of human subjects, approved by the Faculty Senate of the University of Wisconsin-La Crosse, the following informed consent document is presented to each subject. This procedure is in compliance with policies formulated by the U.S. Department of Health, Education, and Welfare, and is described in detail in Senate Document 79-012.

PURPOSE: To determine the energy cost and relative intensity of exercising on the NordicSport downhill ski ergometer and hence investigate its ability as a mode of exercise to potentially induce changes in cardiorespiratory fitness.

PROCEDURES: Fifteen experienced male downhill skiers between 18 and 30 years of age will be recruited to participate in this study. Each subject will be required to take part in four testing sessions in the Human Performance Laboratory in Mitchell Hall at UW - La Crosse. The first session will consist of a treadmill VO_2max test and anthropometric measurements which will include: height, weight, and skinfolds. During the second session, each subject will be given ample time to practice on each of the downhill ski simulators. The purpose of the practice session is for each subject to get acquainted with the simulators. Once the investigators feel that the subject is competent, a cadence eliciting a heart rate between 70 to 85% of HRmax will be determined while exercising on the NordicSport downhill ski ergometer. During the third and fourth sessions, heart rate and oxygen consumption responses will be measured during 20 minutes of steady-state exercise on both the NordicSport and the Skier's Edge downhill ski ergometers. A 10-minute warm-up period will precede each of the experimental protocols. The total test time for each of the 4 sessions will be approximately 45 minutes, a total of 3 hours for the entire testing.

DISCOMFORT OR RISKS: There exists the possibility of adverse changes occurring during the VO_2max test. They could include abnormal blood pressure, fainting, disorders or heart rhythm, and very rare instances of heart attack or even death. Every effort will be made to minimize those risks by having you complete the Physical Activity Readiness Questionnaire and by observations during testing. Trained personnel are available to deal with the unusual situations which may arise.

BENEFITS: Your participation in this study will serve to contribution to the advancement of science in the field of human performance research and training. By participating, you will find out your VO_2max and your percentage of body fat.

PHYSICAL INJURY: In the event your participation results in any physical injury medical treatment will be made available. However, no compensation will be provided by the University of Wisconsin-La Crosse for any injury occurring in connection with the conduct of this research.

QUESTIONS AND ANSWERS: Questions you may have regarding any of the procedures are welcomed and encouraged. If you have any doubts or concerns, please ask any of the investigators for further explanation.

WITHDRAWAL: You are free to withdraw consent and discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled. However, if you have any doubt about your ability to adhere to this study, please do not participate.

CONFIDENTIALITY: All data obtained will be kept confidential. No data will be identified by name or any other means in any summaries, publications, or reports that result from testing.

____ Date:____________________

Investigator's Signature

I acknowledge that I have read and understand the Informed Consent Document in its entirety. I have also been informed and understand the foreseeable discomforts, risks, and benefits. I, the undersigned, give my consent for participation in the Energy Cost of Downhill Ski Ergometry Study.

Date: ________ Signed: ______________________________________

Address: ______________________________________

Telephone: ______________________________________

APPENDIX B

PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

PHYSICAL ACTIVITY READINESS QUESTIONNAIRE (PAR-Q)*

YES NO 1. Has your doctor ever said you have heart trouble?
YES NO 2. Do you frequently suffer from pains in you chest?
YES NO 3. Do you often feel faint or have spells of dizziness?
YES NO 4. Has your doctor ever said your blood pressure was too high?
YES NO 5. Has your doctor ever told you that you have a bone or joint problem such as arthritis that has been aggravated by exercise, or might be made worse with exercise?
YES NO 6. Is there a good physical reason not mentioned here why you should not exercise?

The above questions have been answered truthfully and to the best of my knowledge. I am not withholding any information regarding my health status which would place me at an increased risk of injury or cardiovascular problems by participating in this research experiment.

Signed: ______________________________ Date: ____________

* Government of Canada Fitness and Amateur Sport, 1986

APPENDIX C

REVIEW OF RELATED LITERATURE

REVIEW OF RELATED LITERATURE

Introduction

This review of literature will concentrate on downhill skiing "on snow" since there is no published research on downhill ski ergometry. It is important to note that the study of the energy cost of downhill skiing presents many difficulties. The condition of the course, its length and steepness, the intervals between runs, and the radius of the turns are factors that affect the intensity of downhill skiing (Karvonen, Rauhala, Chwalbinska-Moneta, & Hänninen, 1985). Furthermore, though the slope may be the same for all skiers, differences in skill, technique, and mechanical work result in large differences in energy expenditure (Veicsteinas, Ferretti, Margonato, Rosa, & Tagliabue, 1984). Also, downhill skiing is not easily reproducible in the laboratory. The combination of these factors makes the analysis of the energy cost of downhill skiing a difficult task and therefore has been little studied.

Andersen and Montgomery (1988) reviewed the physiological characteristics of elite downhill skiers. They found that elite skiers display high levels of anaerobic power, anaerobic endurance, aerobic endurance, muscular strength, coordination, agility, balance, and flexibility. The present review of literature focuses on the contribution of different energy sources during downhill skiing.

VO_2max of Elite Downhill Skiers

The physiological characteristics of elite athletes practicing a given sport often determine the performance demands of that sport. Many researchers have reported that elite downhill skiers have a high VO_2max (see Table 7). The great mitochondrial enzyme activity of elite skiers also demonstrates the aerobic nature of downhill skiing (Eriksson, Nygaard, & Saltin, 1977). Some studies have also reported a significant correlation between skiers' VO_2max and downhill skiing performance. Song (1982) found a significant correlation ($r = -.62$) between the VO_2max of junior downhill skiers and skiing performance. Song combined the time for two runs in the downhill and giant slalom events as the measure of skiing performance. Andersen, Montgomery, and Turcotte (1990) also found a significant correlation ($r = -.63$) between giant slalom time and aerobic endurance as measured by the Leger shuttle run test. On the other hand, White and Johnson (1991) reported no correlation between VO_2max and downhill ski performance. They found that there was no difference between the VO_2max of regional, national, and international skiers for both males and females (see Table 7). They argued, however, that the aerobic capacity of the skiers in their study may have been above some minimum level necessary for performance. Brown and Wilkinson (1983) also found that VO_2max did not discriminate between national and divisional skiers.

The attempt to extrapolate the physiological demands of downhill skiing from the characteristics of elite downhill skiers may be problematic. The high

VO_2max of elite downhill skiers may not reflect the actual demands of the sport. Instead, it may be the result of intense endurance training programs during the off-season (Andersen & Montgomery, 1988; Karlsson, 1984). In a study

Table 7. VO_2max values of various groups of elite downhill skiers

References and group classifications	Males (N)	Males ml/kg/min	Females (N)	Females ml/kg/min
Andersen & Montgomery (1991)				
Divisional	9	56		
Bergh et al. (1978)				
Top athletes	4	65		
Brown & Wilkinson (1983)				
National	10	63		
Haymes & Dickinson (1980)				
National	12	67	13	53
Karlsson et al. (1978)				
International	17	71	7	54
Saibene et al. (1985)				
National	8	59		
Song (1982)				
Junior	9	66		
Veicsteinas et al. (1984)				
International	6	52		
White & Johnson (1991)				
International	12	53	17	47
National	8	53	6	45
Regional	11	51	7	43

by Haymes and Dickinson (1978), 10 women from the U.S. Alpine ski team were tested at the beginning and the end of the skiing season. During the skiing season, very little emphasis was placed on aerobic training. It was found that VO_2max dropped significantly from 53.1 to 48.6 ml/kg/min. The author concluded that the decline in VO_2max may reflect the lower demand placed on the cardiorespiratory system in downhill skiing compared with dry-land training. In another study, Andersen and Montgomery (1991) found no change in VO_2max from the start (60.2 ml/kg/min) to the end (59.3 ml/kg/min) of the skiing season. However, dry-land training supplemented the daily on-snow practices and weekly races. This might have helped in the maintenance of VO_2max achieved during the summer training program. Karvonen et al. (1985) trained 23 subjects for 3 months, 3-5 times per week, 124-184 minutes per session during which the subjects ran a slalom course 15-22 times at 5-8 minutes intervals. Those who had been previously active in some other field of sports were allowed to continue. It was found that the female skiers' VO_2max significantly increased from 38.0 to 41.2 ml/kg/min but remained unchanged for the male skiers. Physical performance capacity on the cycle ergometer significantly increased in both male and female skiers. Another finding was that blood lactate concentrations were significantly higher after the training period for both males and females (from 6.7 to 11.5 mmol/L and 6.4 to 10.9 mmol/L, respectively). The authors attributed the increase in physical performance to an increase in anaerobic endurance. From these limited data, it seems that

VO_2max decreases during the competitive season unless maintained by dry-land training.

Aerobic Demands of Downhill Skiing

Actual measurements of VO_2 during downhill skiing show that the skier uses a high percentage of his VO_2max. Karlsson, Ericksson, Forsberg, Kallberg, and Tesch (1978) analyzed the metabolic workload of downhill skiing in elite and recreational skiers. In the elite skiers, they found that on a giant slalom course that took approximately 85 seconds to cover, the mean VO_2 for eight runs was 88% of VO_2max (3.6 L/min or 1080 kcal/hr). The subjects reached 95% of VO_2max in the last run (3.9 L/min or 1170 kcal/hr). Heart rates were not reported. Saibene, Cortili, Gavazzi, and Magistri (1985) found that during an 82-second giant slalom event, the VO_2 corresponded to 80% of the skiers' VO_2max, which is similar to Karlsson's results. These results suggest that the skier competing in giant slalom uses a high percentage of VO_2max. Karlsson et al. (1978) also found that when recreational skiers skied on their own at a pace that was maximal for them, VO_2 reached levels of 50-70% of VO_2max. A possible explanation for the lower percentage of VO_2max in unskilled skiers is that many perform more static contractions than elite skiers. This reduces blood flow to the muscles which are forced to work anaerobically with the formation of lactic acid as a byproduct (Saibene et al., 1985). Similarly, Eriksson et al. (1977) reported that beginner skiers reached 40-50% of their VO_2max during a course in downhill skiing. The concomitant heart rates were 140-150 bpm (at 40% of VO_2max) and 150-160 bpm (at 50% of VO_2max). The authors stated that the heart rate response was higher than expected from the VO_2 values. Elite skiers, on the other hand, showed a closer correlation between VO_2 and HR, (i.e., maximal values are attained simultaneously). Like Karlsson et al. (1978), Eriksson et al. (1977) attributed those results to the greater static contractions displayed by the beginner skiers. Therefore, these results show that downhill skiing for the recreational skier provides some training of the cardiorespiratory system. Furthermore, the intensity of skiing (percent of VO_2max) increases with the skier's level of proficiency, approaching maximal values in the elite skier.

These results support the importance of a high VO_2max in downhill skiing and support the need and benefits of an endurance training program. A high VO_2max allows a longer use of energy from aerobic metabolism sparing the use of energy from anaerobic metabolism (Song, 1982). Also, a high VO_2max allows for a faster recovery from high intensity tasks that require the use of anaerobic energy reserves.

Anaerobic Demands of Downhill Skiing

Downhill skiing is an interval-type exercise usually classified among the anaerobic events (Saibene et al., 1985). Several investigators have said that downhill skiing requires both aerobic and anaerobic endurance. Saibene et al. (1985) measured the energy cost of a giant slalom event in eight skiers of national level. Energy cost analysis showed an aerobic contribution of 46.4%

and an anaerobic contribution of 53.6% (25.3% by the lactic acid production and 28.3% by the alactic debt). The sum of the net VO_2, gross alactic debt, and the oxygen equivalent of the lactic acid production was equivalent to 89.4 ml/kg/min (about 120% of the average VO_2max). From these results, Saibene et al. concluded that the aerobic and the anaerobic sources share the same contribution to the energy cost of a ski run. In a study by Veicsteinas et al. (1984), the sum of both aerobic and anaerobic contribution of a 55-second special slalom event was 99.2 ml/kg/min (almost 200% of the average VO_2max). During a 70-second giant slalom event the sum was 82.9 ml/kg/min (about 160% of the average VO_2max). In both the special slalom and giant slalom, the aerobic and anaerobic contribution was about 30-35% and 65-70% (≈40% by lactic acid production and 25-30% by the alactic debt), respectively.

Downhill skiers have high levels of muscle and blood lactate following race runs and training which shows that the anaerobic energy system is used extensively during downhill skiing (White & Johnson, 1991). Blood lactate concentration is around 10 mmol/L after intense downhill skiing for elite skiers. Beginners, on the other hand, seldom reach lactate levels higher than 4 or 5 mmol/L (Eriksson et al., 1977). Karlsson et al. (1978) found that elite skiers' muscle lactate concentration was 9.6 mmol/kg of muscle and in recreational skiers 5.2 mmol/kg of muscle. When skiing at top speed, the best skier had a muscle lactate concentration of 22.0 mmol/kg of muscle. In a study by Karvonen et al. (1985), maximal blood lactate values significantly increased after 3 months of on-snow training for both male and female skiers. The blood lactate values increased from 6.7 to 11.5 mmol/L and from 5.7 to 10.9 mmol/L in males and females, respectively.

Studies have found that racing performance of elite skiers is significantly correlated to anaerobic endurance as measured by the Wingate test. Song (1982) found that giant slalom performance was significantly correlated ($r = -.63$) to a 30-sec Wingate test. Andersen et al. (1990) reported a significant correlation ($r = -.53$) between a 60-sec Wingate test and performance on a giant slalom course. In a study by White & Johnson (1991), the international level skiers exhibited significantly higher Wingate endurance compared to national and regional groups.

Summary

In summary, downhill skiing requires both aerobic and anaerobic endurance. The importance of a high VO_2max in downhill skiing performance and the decrease in VO_2max observed during the skiing season when on-snow training is not supplemented by dry-land training denotes the importance of aerobic training as part of every skier's conditioning program. A high VO_2max allows for a faster recovery from high intensity tasks that require the use of anaerobic energy reserves. Furthermore, a high level of physical fitness may help reduce the risks associated with fatigue in skiing. Injuries often occur at the end of the skiing day when skiers are fatigued (Andersen & Montgomery, 1991).

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