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Physiological Responses of Elite Cross-Country Skiers at Selected Exercise Intensities under Laboratory and Field Conditions

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B.Sc., University of Ottawa, 1988

Thesis

Submitted to the School of Graduate Studies
in partial fulfilment of the requirements
for the degree of Master of Science in Kinanthropology
in the School of Human Kinetics,
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ABSTRACT

The purpose of this study was to compare the heart rate (HR) and blood lactate (BLa) responses of elite male and female cross-country skiers at 3 selected exercise intensities (Zones) using selected training techniques under laboratory and dryland field conditions. All were members of the Canadian Senior and Junior Cross-Country Ski Teams. The testing consisted of a progressive incremental test on a sport-specific ski treadmill (ST) on Day 1 followed by dryland field tests using 2 training techniques, running with cross-country ski poles (RP) and freestyle rollerskiing (FR), on Days 2 and 3. The dryland field tests consisted of discontinuous bouts of exercise using 3 selected exercise intensities called Zone 1, Zone 2 and Zone 3. The Zones were intended to elicit steady-state responses corresponding to the dryland training intensities of the cross-country skiers. The immediate post-exercise HRs and the one minute post-exercise BLas from the 3 Zones and the 2 training techniques were compared with the HRs and BLas on the ST.

The Zone 1 and Zone 2 HRs on the ST were significantly greater ($p<0.05$) than either of the 2 dryland techniques for the female skiers. The Zone 1 HR on the ST was significantly greater ($p<0.05$) than the RP technique while the Zone 2 HR on the ST was significantly greater ($p<0.05$) than the FR technique for the male skiers. However, there were no significant gender differences between the HRs in Zone 3.

The Zone 1 BLa on the ST was significantly greater ($p<0.05$) than the RP BLa but was not significantly different from the FR BLa for the female skiers. There were no significant differences between the BLas in Zone 1 for the male skiers. There were also no significant gender differences between the Zone 2 BLas. The Zone 3 BLa on the ST

was significantly lower ($p<0.05$) than the Zone 3 BLa values for the dryland techniques for both genders.

There were no significant HR or BLa gender differences for the dryland techniques across the 3 Zones. The females had a significantly greater HR ($p<0.05$) than the males on the ST only in Zone 1. There were no other significant gender differences across the 3 Zones or between the 3 training techniques for the HR values. There were no significant gender differences across the 3 Zones or between the 3 training techniques for the BLa values.

The results of this study suggest that there were no significant physiological differences between the dryland training techniques across the three Zones but that there were significant physiological differences when the laboratory responses were compared with the field responses.

INTRODUCTION

Elite cross-country skiers train year-round to develop the heightened aerobic endurance capacity that is required of their sport. The assessment of physiological variables pertaining to their physical performance is an important component in the development of training programs for elite cross-country skiers. Traditionally these physiological assessments have been conducted under controlled laboratory conditions using standard exercise ergometry. The development of sport-specific ergometers has allowed for an improved simulation of exercise and sport performance and an enhanced interpretation of the physiological responses to these sport-specific ergometers in the laboratory (Davies et al., 1984; Thoden, 1991). Although the sport-specific ergometers allow for a closer simulation of an exercise performance in the laboratory, the testing conditions often can not simulate the precise training conditions. An enhanced interpretation of the physiological responses to training and performance should incorporate the training and performance techniques employed by the athletes. The physiological testing of the athlete should involve actual exercise performance under field conditions. It is important to understand how these training techniques affect the physiological variables associated with aerobic endurance capacity and cross-country skiing performance. The purpose of this study was to compare the HR and BLa responses of elite male and female cross-country skiers at 3 selected exercise intensities (Zones) using selected training techniques under laboratory and dryland field conditions.

METHODOLOGY

The subjects in this study were all members of the Canadian Senior and Junior Cross-Country Ski Teams. These included 11 female and 11 male skiers between 18 and 29 years of age. The skiers were highly trained endurance athletes who had been competing at the national and international level for several years. All the athletes had prior experience with the laboratory and field skiing techniques used in this study. The skiers gave their informed consent to the physiological assessments in this study.

The testing consisted of a laboratory treadmill test on Day 1 followed by field tests on Days 2 and 3. The testing was conducted during July and August. The intent of this study was to have all the subjects participate on all 3 days of testing; however, the actual number of participants involved was affected by travel requirements, health status, etc. The testing protocols were as follows:

Laboratory Testing Procedures

The subjects performed a progressive incremental exercise test according to the Canadian Association of Sport Sciences protocol (Thoden et al., 1982) as modified by Stark (1989) on a sport-specific Posi-Trac Ski Treadmill (ST) (Blue Klister, Inc.). The protocol consisted of a 5 minute warm-up stage followed by successive 3 minute work stages until volitional exhaustion. The warm-up stage speed was 6.0 km/h for the female skiers and 6.5 km/h for the males skiers. The speed was increased to 7.0 km/h for the female skiers and to 7.5 km/h for the male skiers following the warm-up stage and was maintained for the duration of the test. The initial grade of the ST was 1 degree for the warm-up stage. The grade was increased by 1 degree for each successive stage. The

ST utilizes a rotating belt similar to standard running treadmills except that parallel tracks in the belt allow for the use of cross-country skis and poles using the classical cross-country skiing technique. The classical skiing technique was used in the laboratory since biomechanical analysis of the treadmill and on-snow skiing techniques indicated a high degree of specificity for the classical technique but not for the freestyle technique (Norman, R., unpublished data, 1986). The test-retest reliability for the ST' VO_2 max testing was comparable to other VO_2 max protocols (Thoden et al., 1982).

Expired ventilation samples were collected throughout the test. The gas analysis was performed using an open-circuit Roxon Rapid Response metabolic cart. The expired ventilation samples were analyzed by a Godart Capnograph and Oxygen Analyzer. The expired volumes were measured by a turbine ventilometer attached to a room air intake port of a one-way mouth valve. Backup samples were collected in a Collins 100 litre Tissot tank during the last 30 seconds of each stage. Where there were differences between the oxygen consumption (O_2) values of the 2 collection systems, the Tissot value was used as the maximum value since the Tissot collection of the expired ventilation is less subject to the inertial problems associated with the turbine ventilometer.

HRs were monitored throughout the test by a Polar Electro PE3000 Sport Tester (Polar Electro Co.). The HR immediately prior to the BLa sampling was used to represent the HR for that stage of the test.

Fingertip blood samples were collected during the last 30 seconds of each stage for the analysis of BLa concentration. The BLa concentration was determined using a Kontron Medical 640 Lactate Analyzer (Roche Bio-Electronics).

The criteria for the determination of the exercise intensities (Zones) on the ST was as follows: The stage where the first BLa value less than 2.0 mM occurred was considered to be the Zone 1 stage. If there was no BLa value less than 2.0 mM, the BLa value with the smallest deviation from 2.0 mM was considered to be the Zone 1 stage. The stage where the first BLa value between 2.5 and 3.5 mM occurred was considered to be the Zone 2 stage. If there was no BLa value between 2.5 and 3.5 mM, the BLa value with the smallest deviation from the 2.5 and 3.5 mM range was considered to be the Zone 2 stage. The stage where the first BLa value between 3.5 and 4.5 mM was considered to be the Zone 3 stage. If there was no BLa value between 3.5 and 4.5 mM, the BLa value with the smallest deviation from the 3.5 and 4.5 mM range was considered to be the Zone 3 stage.

Field Testing Procedures

The subjects performed 3 discontinuous bouts of exercise using 3 selected exercise intensities. Each bout consisted of approximately 5 minutes of exercise since preliminary investigation demonstrated that similarly trained athletes required a longer work interval to achieve steady-state responses under similar field conditions as in this study. It was intended that the extra two minutes at each exercise intensity would not result in significantly different BLa responses than observed in the laboratory. The 3 selected exercise intensities were called Zone 1, Zone 2, and Zone 3 and were performed in that order. The recovery time between exercise bouts was approximately 5 minutes.

The exercise intensities were performed by the subjects to elicit HRs which had previously been shown to be related to approximate BLa responses. Zone 1 exercise was intended to elicit a steady-state BLa response of 2.0 mM or less. Zone 2 exercise was

intended to elicit a steady-state BLa response between 2.5 and 3.5 mM. Zone 3 exercise was intended to elicit a steady-state BLa response between 3.5 and 4.5 mM (Reed, 1989).

The skiers were instructed to ski at exercise intensities corresponding to the previously determined HR values on the ST. The skiers were given a range (5 to 15 bpm) of HR values for each of the three Zones. The minimum value for the HR range was determined by the HR value from the ST stage before each Zone. The maximum value for the HR range was determined by the HR value from the ST stage corresponding to each Zone. The intent of the field testing was to create a sampling of low subthreshold, high subthreshold, and threshold exercise intensities.

The dryland skiing techniques employed were running with cross-country ski poles (RP) and freestyle rollerskiing (FR) using the V1 Skate technique.

HRs were monitored by a Polar Electro PE3000 Sport Tester. The HR immediately following each bout of exercise was used to represent the HR for that Zone.

Fingertip blood samples were collected 1 minute after the end of each exercise bout for the BLa determination. The post one minute sample was previously found to represent the peak BLa following the termination of an exercise bout in studies with similarly trained cross-country skiers (MacKenzie, 1989; Mansfield, 1989).

Statistical Design

The data were analyzed using the following statistical procedures where the exercise intensities (Zones), the skiing techniques, and the gender of the athletes were the independent variables and the HR and BLa values were the dependent variables:

1. Descriptive analyses of the physiological responses of the athletes by exercise intensity (Zones), by skiing technique, and by gender of the athlete were conducted.

2. Pearson product moment correlational analyses of the HR and BLa in the field and the HR, BLa, and oxygen consumption (O_2) in the laboratory were conducted.

3. A three-way analysis of variance using a General Linear Model (GLM) procedure was conducted where exercise intensity (Zone), skiing technique, and gender of the athlete were the independent variables for each of the HR and BLa values to identify if statistical significance ($P<0.05$) was achieved. Post-hoc analyses using a Least Square Means (LSM) technique were conducted to identify the sources of any observed statistical significance.

RESULTS

Table 1

Physical Characteristics of Subjects.

Variable	Females (N=11) Mean ± S.D.	Males (N=11) Mean ± S.D.
Age (years)	23 ± 4	23 ± 3
Height (cm)	167.8 ± 4.1	178.6 ± 6.1
Weight (kg)	57.1 ± 4.8	73.7 ± 5.4
VO_2 max (ml/kg/min)	58.5 ± 3.4	67.6 ± 4.3
Body Density (mg/dl)	1.066 ± 0.009	1.087 ± 0.006
Sum of Skinfolds (mm)	36.7 ± 8.8	28.8 ± 6.0

The physical characteristics of the subjects in this study are shown in Table 1. The body densities were determined by underwater weighing. The Canadian Standardized Test of Fitness (CSTF) protocol was used to determine the sum of five skinfolds. These data were collected for descriptive purposes only and no further analysis of these physical characteristics was intended.

Table 2

Comparisons of the physiological variables for the 3 skiing techniques across the 3 exercise intensities for the ***female*** skiers.

Technique Variable	Zone 1	Zone 2	Zone 3
Freestyle Rollerskiing (N=5)			
Heart Rate (bpm)	142 ± 3	160 ± 3	177 ± 4
Blood Lactate (mM)	1.36 ± 0.56	2.13 ± 0.53	5.32 ± 1.70
HR/BLa Ratio (bpm/mM)	114 ± 31	79 ± 17	35 ± 9
Running With Poles (N=9)			
Heart Rate (bpm)	145 ± 7	168 ± 7	183 ± 6
Blood Lactate (mM)	1.23 ± 0.42	2.26 ± 0.88	5.68 ± 2.43
HR/BLa Ratio (bpm/mM)	133 ± 53	84 ± 30	37 ± 15
Ski Treadmill (N=11)			
Heart Rate (bpm)	163 ± 11	179 ± 9	185 ± 8
Blood Lactate (mM)	2.24 ± 0.48	2.87 ± 0.29	4.05 ± 0.70
HR/BLa Ratio (bpm/mM)	76 ± 17	63 ± 8	47 ± 9
O_2 Consumption (ml/kg/min)	41.3 ± 7.1	50.6 ± 4.5	54.2 ± 6.0

Table 2 compares the physiological variables for the 3 skiing techniques across the 3 exercise intensities for the female skiers. Not all the subjects on the Ski Treadmill (ST) were available for the dryland testing due to travel requirements, health status, etc. The HR and BLa values increased for each successive exercise intensity; the oxygen consumption (O_2) values on the ST also increased for each successive exercise intensity. The highest HR values occurred on the ST for each of the 3 zones. The ST BLa values were higher than the two dryland techniques for Zones 1 and 2; however, the BLa value on the ST was lower than both of the dryland techniques for Zone 3. The heart rate/blood

lactate (HR/BLa) ratio was obtained by dividing the HR value by the BLa. These HR/BLa ratios decreased for each successive exercise intensity and are were included to represent the simultaneous changes in the two variables. The HR/BLa ratios were presented to supplement the absolute HR and BLa values and no further analysis of these ratios was intended.

Table 3

Comparisons of the physiological variables for the 3 skiing techniques across the 3 exercise intensities for the ***male*** skiers.

Technique Variable	Zone 1	Zone 2	Zone 3
Freestyle Rollerskiing (N=8)			
Heart Rate (bpm)	145 ± 19	161 ± 18	178 ± 11
Blood Lactate (mM)	2.11 ± 0.47	3.00 ± 0.81	5.60 ± 1.19
HR/BLa Ratio (bpm/mM)	71 ± 17	57 ± 15	33 ± 9
Running With Poles (N=8)			
Heart Rate (bpm)	140 ± 11	163 ± 14	181 ± 7
Blood Lactate (mM)	2.01 ± 1.18	2.58 ± 1.55	6.35 ± 1.28
HR/BLa Ratio (bpm/mM)	85 ± 31	80 ± 34	30 ± 7
Ski Treadmill (N=11)			
Heart Rate (bpm)	151 ± 17	172 ± 14	182 ± 7
Blood Lactate (mM)	2.07 ± 0.76	3.15 ± 0.64	4.48 ± 0.41
HR/BLa Ratio (bpm/mM)	81 ± 29	56 ± 11	41 ± 3
O_2 Consumption (ml/kg/min)	43.6 ± 6.7	54.7 ± 5.8	60.0 ± 4.4

Table 3 compares the physiological variables for the 3 skiing techniques across the 3 exercise intensities for the male skiers. For the same reasons noted for the female skiers not all the male subjects on the Ski Treadmill (ST) were available for the dryland testing. The HR and the BLa values increased for each successive exercise intensity; the O_2 values on the ST also increased for each successive exercise intensity. The highest HR values occurred on the ST for each of the 3 zones. The trend for the BLa values was less clear for the males than for the females. The highest BLa value in Zone 1 occurred during the Freestyle Rollerskiing (FR). The ST BLa value was the highest in Zone 2. However, as was the case for the females, the BLa on the ST was lower than both of the dryland techniques for Zone 3.

Table 4

Statistically significant Pearson correlation coefficients for the variables investigated for the ***female*** skiers.

Running With Poles - Zone 1 (N=9)	
	BLa (mM)
HR (bpm)	r=0.74, p<0.05
Running With Poles - Zone 2 (N=9)	
	BLa (mM)
HR (bpm)	r=0.69, p<0.05
Ski Treadmill - Zone 1 (N=11)	
	O_2 Consumption (ml/kg/min)
HR (bpm)	r=0.79, p<0.01

All the statistically significant correlations for the female skiers are shown in Table 4. There were positive correlations between HR and BLa for the Running With Poles (RP) technique in Zones 1 and 2. There was a positive correlation between HR and O_2 on the ST in Zone 1.

Table 5

Statistically significant Pearson correlation coefficients for the variables investigated for the ***male*** skiers.

Freestyle Rollerskiing - Zone 2 (N=8)	
	BLa (mM)
HR (bpm)	r=0.73, p<0.05
Ski Treadmill - Zone 1 (N=11)	
	O_2 Consumption (ml/kg/min)
HR (bpm)	r=0.80, p<0.01
Ski Treadmill - Zone 2 (N=11)	
	O_2 Consumption (ml/kg/min)
HR (bpm)	r=0.87, p<0.01
Ski Treadmill - Zone 3 (N=11)	
	O_2 Consumption (ml/kg/min)
BLa (mM)	r=0.62, p<0.05

All the statistically significant correlations for the male skiers are shown in Table 5. There was a positive correlation between HR and BLa for the FR technique in Zone 2. There were positive correlations between HR and O_2 on the ST in Zones 1 and 2. There was also a positive correlation between the BLa and O_2 on the ST in Zone 3.

Table 6

Summary of General Linear Models (GLM) Results for Heart Rate (HR).

Source	Sum of Squares	Degrees of Freedom	F Value	PR > F
GENDER	384.06	1	3.07	0.0818
ZONE	27523.14	2	110.14	0.0001 *
TECHNIQUE	3760.98	2	15.05	0.0001 *
GENDER*ZONE	126.27	2	0.51	0.6044
GENDER*TECHNIQUE	442.21	2	1.77	0.1742
ZONE*TECHNIQUE	865.82	4	1.73	0.1463
GENDER*ZONE*TECHNIQUE	140.14	4	0.28	0.8903

The General Linear Models (GLM) procedure is a statistical analysis-of-variance procedure utilized when the cell sizes are unequal. Table 6 summarizes the GLM results for the HR variable. There were no statistically significant differences between the genders for the HR variable. There were statistically significant differences for the Zone and Technique effects on HR. There were no statistically significant differences for the interactions of the 3 independent variables.

Table 7

Summary of General Linear Models (GLM) Results for Blood Lactate (BLa).

Source	Sum of Squares	Degrees of Freedom	F Value	PR > F
GENDER	7.98	1	7.72	0.0062 *
ZONE	307.03	2	148.64	0.0001 *
TECHNIQUE	1.28	2	0.62	0.5390
GENDER*ZONE	0.01	2	0.00	0.9953
GENDER*TECHNIQUE	1.73	2	0.84	0.4348
ZONE*TECHNIQUE	36.64	4	8.87	0.0001 *
GENDER*ZONE*TECHNIQUE	2.11	4	0.51	0.7279

The GLM results for the BLa variable are summarized in Table 7. There were statistically significant differences for the Gender and Zone effects on BLa. There was no statistically significant difference for the Technique effect on BLa. There was a statistically significant difference for the Zone and Technique interaction effects on BLa. There were no statistically significant differences for the other interactions of the 3 independent variables.

Table 8

Least Square Means (LSM) test for ZONE effect on Heart Rate (HR).

Variable	Least Squares Mean	Significance Zone 1	Zone 2	Zone 3
Zone 1	147		0.0001	0.0001
Zone 2	167			0.0001
Zone 3	181			

The Least Squares Means (LSM) test is a post-hoc analysis technique for the GLM procedure to identify where there were statistically significant differences between the different levels of a variable. Table 8 shows the LSM results for the Zone effect on HR. There were statistically significant differences between the HR values across the 3 Zones. These significant differences support the use of the criteria for the determination of the exercise intensities (Zones) on the ST to produce three separate exercise intensities or Zones. These results indicate a statistically significant sampling of exercise intensities from low subthreshold to threshold was accomplished.

Table 9

Least Squares Means (LSM) test for TECHNIQUE effect on Heart Rate (HR).

Variable	Least Squares Mean	Significance Freestyle	Running	Treadmill
Freestyle	161		0.2718	0.0001
Running	163			0.0001
Treadmill	172			

The LSM results for the Technique effect on HR are presented in Table 9. The HR values for FR and for RP were not significantly different. There were significant differences between the ST HR values and the FR and RP HR values. The ST HR value was greater than both the FR and RP HR values.

Table 10

Least Square Means (LSM) test for GENDER effect on Blood Lactate (BLa).

Variable	Least Squares Mean	Significance Female	Male
Female	3.02		0.0062
Male	3.49		

There were significant gender differences between the BLa values as represented by the LSM results in Table 10.

Table 11

Least Squares Means (LSM) test for ZONE effect on Blood Lactate (BLa).

Variable	Least Squares Mean	Significance Zone 1	Zone 2	Zone 3
Zone 1	1.84		0.0001	0.0001
Zone 2	2.67			0.0001
Zone 3	5.25			

Table 11 shows the LSM results for the Zone effect on BLa. There were statistically significant differences between the BLa values across the 3 Zones.

Table 12

Significant differences between the 3 skiing techniques across the 3 Zones for the ***female*** skiers.

Variable	Zone 1	Zone 2	Zone 3
Freestyle Rollerskiing (N=5)			
Heart Rate (bpm)	142	160	177
Blood Lactate (mM)	1.36	2.13	5.32
Running With Poles (N=9)			
Heart Rate (bpm)	145	168	183
Blood Lactate (mM)	1.23	2.26	5.68
Ski Treadmill (N=11)			
Heart Rate (bpm)	163 ***a,b***	179 ***a,b***	185
Blood Lactate (mM)	2.24 ***b***	2.87	4.05 ***a,b***

a Significantly different from Freestyle Rollerskiing
b Significantly different from Running With Poles

Table 12 shows the significant differences between the 3 skiing techniques across the 3 Zones for the female skiers. The Zone 1 and Zone 2 HRs on the ST were significantly greater ($p<0.05$) than either of the 2 dryland techniques. However, there were no significant differences between the HRs in Zone 3. The Zone 1 BLa on the ST was significantly greater ($p<0.05$) than the RP BLa but was not significantly different from the FR BLa. There were no significant differences between the BLas in Zone 2. The Zone 3 BLa on the ST was significantly lower ($p<0.05$) than each of the dryland techniques. There were no significant differences between the HR and BLa values across the 3 Zones for the 2 dryland techniques.

Table 13

Significant differences between the 3 skiing techniques across the 3 Zones for the ***male*** skiers.

Variable	Zone 1	Zone 2	Zone 3
Freestyle Rollerskiing (N=8)			
Heart Rate (bpm)	145	161	178
Blood Lactate (mM)	2.11	3.00	5.60
Running With Poles (N=8)			
Heart Rate (bpm)	140	163	181
Blood Lactate (mM)	2.01	2.58	6.35
Ski Treadmill (N=11)			
Heart Rate (bpm)	151 *b*	172 *a*	182
Blood Lactate (mM)	2.07	3.15	4.48 *a,b*

a Significantly different from Freestyle Rollerskiing
b Significantly different from Running With Poles

Table 13 shows the significant differences between the 3 skiing techniques across the 3 Zones for the male skiers. The Zone 1 HR on the ST was significantly greater ($p<0.05$) than the RP techniques but was not significantly different than the FR technique. The Zone 2 HR on the ST was significantly greater ($p<0.05$) than the FR technique but was not significantly different than the RP technique. There were no significant differences in the Zone 3 HRs. There were also no significant differences between the Zone 1 and Zone 2 BLas. However, the Zone 3 BLa on the ST was significantly lower ($p<0.05$) than either of the 2 dryland techniques. There were no significant differences between the HR and BLa values across the 3 Zones for the 2 dryland techniques.

Table 14

Comparison of gender differences between the 3 skiing techniques across the 3 Zones for the HR variable.

Variable	Zone 1	Zone 2	Zone 3
Freestyle Rollerskiing			
Females	142	160	177
Males	145	161	178
Running With Poles			
Females	145	168	183
Males	140	163	181
Ski Treadmill			
Females	163 *c*	179	185
Males	151	172	182

c Significantly different from Males

Table 14 compares the HR differences between the genders. The females had a significantly greater HR ($p<0.05$) than the males on the ST in Zone 1. There were no other significant gender differences across the 3 Zones or between the 3 skiing techniques.

Table 15

Comparison of gender differences between the 3 skiing techniques across the 3 Zones on the BLa variable.

Variable	Zone 1	Zone 2	Zone 3
Freestyle Rollerskiing			
Females	1.36	2.13	5.32
Males	2.11	3.00	5.60
Running With Poles			
Females	1.23	2.26	5.68
Males	2.01	2.58	6.35
Ski Treadmill			
Females	2.24	2.87	4.05
Males	2.07	3.15	4.48

There were no significant BLa differences between the genders across the 3 Zones or between the 3 skiing techniques as presented in Table 15.

DISCUSSION

The physical characteristics of the cross-country skiers in this study are presented in Table 1. The results were comparable to similar elite cross-country skiers for height, weight, and body composition (Haymes and Dickinson, 1980) although the body densities and sum of skinfolds were not converted into percent body fat values. The skiers were lean, highly trained endurance athletes who were highly experienced with the skiing techniques and exercise conditions performed in this study.

Comparisons of the two dryland skiing techniques demonstrated no significant HR differences within each Zone for both genders. The HR responses were not significantly different within each Zone for the female and male skiers. The above findings are in agreement with similar studies of the physiological responses of elite cross-country skiers to different dryland training techniques. Pekkarinen et al. (1984) evaluated the intensity of dryland running and rollerskiing training by HR telemetry and concluded that the HRs in slow and moderate running did not differ significantly from rollerskiing but in running performed at maximum speed the HRs were significantly higher than in rollerskiing. The authors did not mention whether the rollerskiing was performed using a freestyle or a classical technique. Higgins et al. (1989) compared classical and skating-style rollerskiing at moderate and high intensities and found that there were no significant HR differences between the techniques and intensities. Hoffman et al. (1990) compared the physiological responses to different roller skiing techniques at two speeds chosen to represent submaximal training intensities. There were no significant differences in the HR values at the two speeds between the kick double pole technique, chosen to represent the classical technique, and the V1 Skate technique, chosen to represent the freestyle

technique. Although there are differences between the dryland techniques evaluated in this study and the techniques used in the aforementioned studies, there were no significant differences in the HR responses of different dryland training techniques at submaximal exercise intensities.

There were however significant HR differences between the laboratory and the field responses for the first 2 Zones. The HR values on the ST for Zones 1 and 2 were significantly higher than the 2 dryland techniques for both genders. The elevated HRs may have been caused by anticipatory responses in an artificial environment. While the skiers were familiar with the laboratory testing, a greater proportion of their training and experience involved situations away from the laboratory setting.

The differences in the HR values in the laboratory and the field were diminished for Zone 3 exercise. There were no significant differences between the laboratory and field HR responses in Zone 3 for both genders. Since Zone 3 was achieved several minutes into the progressive ST test, the early anticipatory responses were likely diminished by this phase of the laboratory testing. In addition, as the ST grade was progressively increased it more closely simulated the grades of the dryland testing. The dryland testing was conducted on an uphill course that varied in grade from 8 to 11 degrees. The similarity of the grades of the laboratory and field testing in Zone 3 exercise may have resulted in similar muscle recruitment and skiing performance styles which were reflected in the non-significant differences in HR responses.

Comparisons of the two dryland skiing techniques demonstrated no significant BLa differences within each Zone for both genders. The BLa responses were not significantly different within each Zone for the female and male skiers. These findings

of this study are in agreement with Hoffman et al. (1990). They found no significant differences in BLa responses at two submaximal speeds for kick double pole, V1 Skate, and double pole technique rollerskiing. The findings of Higgins et al. (1989) differed from the findings of this study. They found significant plasma lactate differences at moderate and high exercise intensities for classical and skating-style rollerskiing.

The BLa trend was opposite to the HR trend when the laboratory responses were compared with the dryland responses. Although there was a statistically significant difference between the ST Zone 1 BLa and the RP Zone 1 BLa values for the female skiers, there were no other significant BLa differences when the ST responses were compared with the dryland techniques for Zones 1 and 2 for both genders. The ST Zone 3 BLa values were significantly lower than either of the dryland techniques for both female and male skiers.

The protocol differences between the laboratory and the dryland testing may have affected the Zone 3 BLa differences. The dryland Zone 3 BLa values following a 5 minute work interval were significantly higher ($p<0.05$) than the laboratory Zone 3 BLa values following 3 minute work intervals. These findings are in agreement with Heck et al. (1985) who found highly significant differences between the maximal steady state BLa values following 3 and 5 minute work intervals. The BLa values following the 5 minute work intervals (4.05 mmol/l) were significantly higher ($p<0.01$) than the BLa values following the 3 minute work intervals (3.5 mmol/l) (Heck et al., 1985). The different work durations between the laboratory and the dryland testing may have been responsible for the elevated BLa responses following the longer exercise bouts in the dryland testing. However, the discontinuous nature of the dryland testing required longer exercise bouts

since the highly trained athletes in this study recovered very quickly at the end of the 5 minute work intervals and they required a longer exercise time to achieve steady-state responses at each of the selected exercise intensities.

The elevated dryland BLa values in Zone 3 may have also reflected the training state of the athletes at the time of the testing. The low BLa values in Zones 1 and 2 were consistent with the training emphasis of the skiers at the time of the testing. The training programs for these athletes during the late spring and early summer months involved long training sessions at Zone 1 and 2 exercise intensities to develop endurance fitness. Less time was devoted to Zone 3 threshold endurance training. Endurance training has been shown to result in decreased BLa values at submaximal exercise intensities (Gollnick et al., 1986; Hurley et al., 1984). It is likely that the Zone 3 BLa responses were reflective of the less-trained state of the athletes at that exercise intensity at the time of the testing.

The differences between the laboratory and field Zone 3 BLa responses may have also been influenced by the selection criteria for the determination of exercise intensities (Zones) following the ST test. Stark (1989) concluded that the BLa threshold on the ST occurred across a range of BLa concentrations from 2.51 to 5.53 mM. The Zone 3 BLa responses on the ST from this study did occur within this range of values following the criteria for the determination of Zones of exercise intensity (Reed, 1989). While the selection criteria reflected the laboratory situation, it did not reflect the field situation for Zone 3 BLa responses. The high Zone 3 BLa responses in the field may reflect the "actual" Zone 3 BLa responses since the athletes were training under similar environmental conditions and were using the "actual" training techniques in the field testing, unlike the conditions and "testing" technique in the laboratory. When comparing

physiological responses between laboratory and field settings, caution must be employed since, no matter how sport-specific the laboratory ergometer, the environmental conditions in the field cannot be controlled and may have contributed to the disparity in the results.

Another design consideration was the selection of subjects for this study. There is a need for further investigations where both genders are involved to determine if there are physiological differences between similarly trained male and female cross-country skiers. Notwithstanding the differences in the Zone 1 ST HR values, there was no pattern of gender differences in this study. Although the BLa differences were not significantly different across the Zones and between the skiing techniques, the trend was for the male skiers to have higher BLa values than the females was in agreement with previous investigations (MacKenzie, 1989; Mansfield, 1989). However, the lack of significant gender differences in this study may be attributed to the limited statistical power due to the small sample sizes.

The results of this study suggest that there were no significant physiological differences as indicated by the HR and BLa responses between the two dryland training techniques across the three Zones but that there were significant physiological differences when the laboratory responses were compared with the dryland responses. In light of these findings, discretion must be used when comparisons between simulated laboratory exercise and actual exercise performance are made.

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APPENDIX A

RAW DATA & DESCRIPTIVE STATISTICS

PHYSICAL CHARACTERISTICS

Gender=Female

Subject	Age (yrs)	Height (cm)	Weight (kg)	Skinfolds (mm)	Body Density (g/mL)	VO_2 max (ml/kg/min)
AM	19	164.0	56.6	45.8	1.057	58.4
MJP	18	168.8	52.5	40.2	1.053	55.2
LS	20	170.6	53.2	34.3	1.070	58.1
CG	24	176.9	67.2	47.3	1.057	60.1
MAM	25	167.8	57.6	34.6	1.068	56.9
LP	21	164.3	59.1	50.3	1.055	53.3
RD	24	167.0	52.3	28.7	1.077	65.4
JV	23	162.5	54.2	33.1	1.067	62.8
JM	25	168.0	54.3	21.5	1.077	59.5
LS	29	165.0	56.7	29.0	1.075	56.5
ASF	29	171.2	63.8	38.6	1.071	56.9
Mean	23	167.8	57.1	36.7	1.066	58.5
S.D.	4	4.1	4.8	8.8	0.009	3.4
Minimum	18	162.5	52.3	21.5	1.053	53.3
Maximum	29	176.9	67.2	50.3	1.077	65.4

Gender=Male

Subject	Age (yrs)	Height (cm)	Weight (kg)	Skinfolds (mm)	Body Density (g/mL)	VO_2 max (ml/kg/min)
DG	20	178.8	70.6	31.5	1.085	66.9
BL	22	183.0	77.9	24.9	1.090	64.3
CP	22	174.8	70.5	41.6	1.088	63.4
LT	20	180.0	73.2	21.1	1.095	73.6
HW	20	171.2	67.1	33.8	1.080	61.6
DB	21	177.3	76.7	30.6	1.083	66.9
WD	23	186.8	84.2	32.2	1.076	65.5
AP	24	178.8	72.2	24.7	1.099	75.0
YB	27	169.7	67.3	28.4	1.085	66.6
AM	28	174.9	70.5	22.1	1.082	68.1
FF	25	189.3	79.9	25.7	1.089	72.1
Mean	23	178.6	73.7	28.8	1.087	67.6
S.D.	3	6.1	5.4	6.0	0.006	4.3
Minimum	20	169.7	67.1	21.1	1.076	61.6
Maximum	28	189.3	84.2	41.6	1.099	75.0

APPENDIX B

RAW DATA, DESCRIPTIVE STATISTICS, & CORRELATIONAL ANALYSES

LABORATORY AND FIELD TESTING

Gender=Female Zone=1 Technique=Freestyle Rollerskiing

Subject	HR (bpm)	BLa (mM)
LP	143	1.14
LS	139	1.08
AM	141	2.36
MJP	146	1.18
LS	142	1.06
Mean	142	1.36
S.D.	3	0.56
Minimum	139	1.06
Maximum	146	2.36

Pearson Correlation Coefficients & Levels of Significance

	BLa
HR	-0.19081
	0.7585

Gender=Female Zone=1 Technique=Running With Poles

Subject	HR (bpm)	BLa (mM)
CG	148	1.52
MAM	153	1.44
JM	154	1.32
ASF	133	0.52
AM	140	1.02
MJP	145	1.04
LS	137	0.82
RD	145	1.88
JV	150	1.50
Mean	145	1.23
S.D.	7	0.42
Minimum	133	0.52
Maximum	154	1.88

Pearson Correlation Coefficients & Levels of Significance

	BLa
HR	0.73535
	0.0240

Gender=Female Zone=1 Technique=Ski Treadmill

Subject	HR (bpm)	BLa (mM)	O_2 Consumption (ml/kg/min)
CG	161	1.98	33.4
MAM	164	2.16	43.0
JM	184	1.82	47.9
LP	151	2.86	33.1
LS	164	2.48	49.4
ASF	167	1.90	45.5
AM	150	1.64	34.6
MJP	154	1.98	35.4
LS	164	2.88	37.7
RD	177	1.94	53.4
JV	156	3.00	40.8
Mean	163	2.24	41.3
S.D.	11	0.48	7.1
Minimum	150	1.64	33.1
Maximum	184	3.00	53.4

Pearson Correlation Coefficients & Levels of Significance

	BLa	O_2 Consumption
HR	-0.31046 0.3528	0.79407 0.0035
BLa		-0.18203 0.5922

Gender=Female Zone=2 Technique=Freestyle Rollerskiing

Subject	HR (bpm)	BLa (mM)
LP	160	1.86
LS	160	1.70
AM	157	3.02
MJP	161	1.84
LS	164	2.22
Mean	160	2.13
S.D.	3	0.53
Minimum	157	1.70
Maximum	164	3.02

Pearson Correlation Coefficients & Levels of Significance

	BLa
HR	-0.48390
	0.4088

Gender=Female Zone=2 Technique=Running With Poles

Subject	HR (bpm)	BLa (mM)
CG	167	2.32
MAM	172	2.78
JM	182	3.40
ASF	162	1.40
AM	168	3.72
MJP	162	1.18
LS	162	1.86
RD	166	1.64
JV	173	2.06
Mean	168	2.26
S.D.	7	0.88
Minimum	162	1.18
Maximum	182	3.72

Pearson Correlation Coefficients & Levels of Significance

	BLa
HR	0.69312
	0.0384

Gender=Female Zone=2 Technique=Ski Treadmill

Subject	HR (bpm)	BLa (mM)	O_2 Consumption (ml/kg/min)
CG	187	3.04	57.8
MAM	168	2.88	48.5
JM	190	2.40	51.7
LP	171	3.00	42.9
LS	167	2.96	51.6
ASF	174	2.46	48.4
AM	177	3.24	47.1
MJP	192	2.74	50.0
LS	179	3.30	47.5
RD	183	2.70	56.5
JV	177	2.82	54.9
Mean	179	2.87	50.6
S.D.	9	0.29	4.5
Minimum	167	2.40	42.9
Maximum	192	3.30	57.8

Pearson Correlation Coefficients & Levels of Significance

	BLa	O_2 Consumption
HR	-0.28767 0.3910	0.44085 0.1747
BLa		-0.24350 0.4706

Gender=Female Zone=3 Technique=Freestyle Rollerskiing

Subject	HR (bpm)	BLa (mM)
LP	180	5.06
LS	171	4.04
AM	174	8.22
MJP	182	4.14
LS	177	5.16
Mean	177	5.32
S.D.	4	1.70
Minimum	171	4.04
Maximum	182	8.22

Pearson Correlation Coefficients & Levels of Significance

	BLa
HR	-0.25528
	0.6785

Gender=Female Zone=3 Technique=Running With Poles

Subject	HR (bpm)	BLa (mM)
CG	185	5.80
MAM	183	6.54
JM	192	6.44
ASF	177	3.34
AM	174	11.18
MJP	185	2.70
LS	177	4.96
RD	185	5.14
JV	185	5.04
Mean	183	5.68
S.D.	6	2.43
Minimum	174	2.70
Maximum	192	11.18

Pearson Correlation Coefficients & Levels of Significance

	BLa
HR	-0.29920 0.4341

Gender=Female Zone=3 Technique=Ski Treadmill

Subject	HR (bpm)	BLa (mM)	O_2 Consumption (ml/kg/min)
CG	191	3.90	58.9
MAM	184	4.30	52.2
JM	193	3.30	54.2
LP	179	4.00	44.9
LS	171	3.80	54.9
ASF	178	3.48	51.4
AM	183	4.88	49.0
MJP	197	3.04	51.8
LS	181	4.70	51.1
RD	188	5.34	65.4
JV	188	3.78	62.3
Mean	185	4.04	54.2
S.D.	8	0.70	6.0
Minimum	171	3.04	44.9
Maximum	197	5.34	65.4

Pearson Correlation Coefficients & Levels of Significance

	BLa	O_2 Consumption
HR	-0.24124	0.33045
	0.4748	0.3209
BLa		0.21669
		0.5222

Gender=Male Zone=1 Technique=Freestyle Rollerskiing

Subject	HR (bpm)	BLa (mM)
WD	153	2.26
FF	143	1.92
AM	123	1.86
DG	129	1.18
BL	126	2.64
CP	154	2.42
LT	146	2.10
HW	182	2.52
Mean	145	2.11
S.D.	19	0.47
Minimum	123	1.18
Maximum	182	2.64

Pearson Correlation Coefficients & Levels of Significance

	BLa
HR	0.47147
	0.2383

Gender=Male Zone=1 Technique=Running With Poles

Subject	HR (bpm)	BLa (mM)
YB	130	1.36
DB	153	1.58
AP	135	1.82
DG	137	4.58
BL	129	1.06
CP	135	1.12
LT	139	1.66
HW	160	2.88
Mean	140	2.00
S.D.	11	1.18
Minimum	129	1.06
Maximum	160	4.58

Pearson Correlation Coefficients & Levels of Significance

	BLa
HR	0.29334 0.4807

Gender=Male Zone=1 Technique=Ski Treadmill

Subject	HR (bpm)	BLa (mM)	O_2 Consumption (ml/kg/min)
YB	132	1.54	40.4
DB	150	1.58	40.8
WD	147	1.76	46.3
FF	156	1.42	46.9
AM	123	2.26	35.1
AP	136	0.98	41.7
DG	148	2.46	34.9
BL	175	1.74	54.7
CP	144	2.90	38.3
LT	171	2.50	53.7
HW	175	3.62	46.3
Mean	151	2.07	43.6
S.D.	17	0.76	6.7
Minimum	123	0.98	34.9
Maximum	175	3.62	54.7

Pearson Correlation Coefficients & Levels of Significance

	BLa	O_2 Consumption
HR	0.38132 0.2472	0.80086 0.0031
BLa		-0.04677 0.8914

Gender=Male Zone=2 Technique=Freestyle Rollerskiing

Subject	HR (bpm)	BLa (mM)
WD	172	4.02
FF	170	3.46
AM	144	3.32
DG	143	1.58
BL	144	2.26
CP	166	2.84
LT	158	2.76
HW	193	3.80
Mean	161	3.00
S.D.	18	0.81
Minimum	143	1.58
Maximum	193	4.02

Pearson Correlation Coefficients & Levels of Significance

	BLa
HR	0.73451
	0.0380

Gender=Male Zone=2 Technique=Running With Poles

Subject	HR (bpm)	BLa (mM)
YB	153	2.58
DB	173	4.40
AP	175	5.44
DG	154	1.22
BL	144	1.40
CP	162	1.74
LT	153	1.42
HW	186	2.42
Mean	163	2.58
S.D.	14	1.55
Minimum	144	1.22
Maximum	186	5.44

Pearson Correlation Coefficients & Levels of Significance

	BLa
HR	0.62221
	0.0995

Gender=Male Zone=2 Technique=Ski Treadmill

Subject	HR (bpm)	BLa (mM)	O_2 Consumption (ml/kg/min)
YB	160	2.42	53.5
DB	184	3.08	61.9
WD	169	2.58	52.9
FF	183	3.42	63.5
AM	143	2.72	44.4
AP	178	2.20	55.2
DG	166	3.82	47.9
BL	183	3.44	58.2
CP	158	3.34	49.5
LT	178	3.20	58.4
HW	185	4.40	56.1
Mean	172	3.14	54.7
S.D.	14	0.64	5.8
Minimum	143	2.20	44.4
Maximum	185	4.40	63.5

Pearson Correlation Coefficients & Levels of Significance

	BLa	O_2 Consumption
HR	0.36957 0.2633	0.87690 0.0004
BLa		0.13625 0.6896

Gender=Male Zone=3 Technique=Freestyle Rollerskiing

Subject	HR (bpm)	BLa (mM)
WD	183	6.58
FF	180	5.32
AM	168	5.08
DG	168	3.00
BL	167	5.86
CP	180	6.02
LT	178	6.38
HW	201	6.60
Mean	178	5.61
S.D.	11	1.19
Minimum	167	3.00
Maximum	201	6.60

Pearson Correlation Coefficients & Levels of Significance

	BLa
HR	0.60385
	0.1129

Gender=Male Zone=3 Technique=Running With Poles

Subject	HR (bpm)	BLa (mM)
YB	170	5.70
DB	182	7.60
AP	181	7.46
DG	180	4.24
BL	180	6.82
CP	182	7.22
LT	179	4.80
HW	196	7.00
Mean	181	6.36
S.D.	7	1.28
Minimum	170	4.24
Maximum	196	7.60

Pearson Correlation Coefficients & Levels of Significance

	BLa
HR	0.37295
	0.3629

Gender=Male Zone=3 Technique=Ski Treadmill

Subject	HR (bpm)	BLa (mM)	O_2 Consumption (ml/kg/min)
YB	176	4.66	62.4
DB	188	5.24	63.8
WD	180	4.40	60.9
FF	186	4.94	66.8
AM	165	3.86	53.8
AP	186	4.26	64.5
DG	181	4.18	54.6
BL	188	4.72	61.1
CP	181	4.20	54.8
LT	187	4.12	61.5
HW	192	4.72	56.7
Mean	183	4.48	60.1
S.D.	7	0.41	4.4
Minimum	165	3.86	53.8
Maximum	192	5.24	66.8

Pearson Correlation Coefficients & Levels of Significance

	BLa	O_2 Consumption
HR	0.58262	0.44933
	0.0600	0.1656
BLa		0.61967
		0.0420

APPENDIX C

TRADITIONAL FIRST THREE CHAPTERS

Heart Rate and Blood Lactate Responses of Elite Cross-Country Skiers at Selected Exercise Intensities Under Laboratory and Field Conditions

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presented to the University of Ottawa
in partial fulfilment of the
thesis requirement for the degree of
Master of Science
in
Kinanthropology

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CHAPTER ONE

INTRODUCTION

The measurement of physiological variables pertaining to exercise and sport performance is a commonly employed practice in the field of exercise physiology. Traditionally the measurements of exercise performance have been conducted under controlled laboratory conditions. The traditional laboratory tests typically involved stair-stepping, cycling and running ergometers. However, the development of sophisticated sport-specific ergometers has allowed for improved simulation of exercise and sport performance and an enhanced interpretation of the physiological responses to these movement-specific modalities.

Although the sport-specific ergometers allow for a close simulation of an exercise performance in the laboratory, the testing conditions often can not simulate the precise t' ining conditions. The ideal interpretation of the physiological responses to exercise and sport performance should incorporate the training and performance techniques employed by the athletes. The physiological testing of the athlete should involve actual exercise performance under field conditions. The indicators of exercise responses under field testing conditions should also permit the athletes to perform with a minimum of interference from the testing equipment.

Two of the most commonly used indices of exercise intensity are heart rate (Karvonen and Vuorimaa, 1988) and blood lactate concentration (Jacobs, 1986). Variations in heart rate and in blood lactate concentration correlate well with changes in intensity during subthreshold exercise (Jacobs, 1986; Karvonen and Vuorimaa, 1988). With the development of portable heart rate microcomputers (Karvonen et al., 1984; Léger

and Thivierge, 1988) and the ease and reliability of blood lactate determination using micro-assay techniques (Jacobs, 1986), the use of heart rate and blood lactate as indicators of the exercise intensity of specific exercise performances under field conditions has contributed to the interpretation of the physiological parameters associated with exercise and sport performance. These developments in testing specificity allow the exercise physiologist to investigate new sports techniques that otherwise would not be possible using even the most sophisticated of laboratory ergometers.

Cross-country skiing is an example of a sport that is witness to a recent revolutionary technique. The freestyle skiing technique has resulted in 10-30% faster race times when compared with the classical technique (Clifford and Hoffman, 1989; Stray-Gundersen and Ryschon, 1987). These two techniques place different physical demands on the cross-country skier; thus, the physiological responses to the classical and freestyle skiing techniques should be investigated (Eisenman et al., 1989).

Rationale

Elite cross-country skiers train year-round to develop the heightened aerobic endurance capacity that is required of their sport. Their training involves different techniques and equipment for dryland and for on-snow conditions. It is important to understand how these training techniques affect the physiological variables associated with aerobic endurance capacity on a year-round basis.

Studies that have investigated the effects of skiing technique under different conditions on the heart rate and blood lactate responses have reported conflicting results. Stray-Gundersen and Ryschon (1987) reported higher heart rate and blood lactate values for the freestyle technique than for the classical technique while rollerskiing on a modified treadmill. Higgins et al. (1989) reported increased plasma lactate values for freestyle rollerskiing than for classical rollersking on pavement. However, the classical technique during on-snow exercise resulted in higher heart rate and oxygen uptake values when compared to the freestyle technique (Zupan et al., 1988). Karvonen et al. (1987) found no significant differences in heart rate and blood lactate values when the two techniques were compared at different intensities during on-snow exercise. Thus further investigation is required to determine how the physiology of heart rate and blood lactate responses are affected by the skiing technique utilized and by the mode of exercise employed.

Purpose of the Study

The purpose of the study was to compare the heart rate and blood lactate responses of elite male and female cross-country skiers at three selected exercise intensities using selected skiing techniques under laboratory and dryland exercise conditions.

Null Hypothesis

It is hypothesized that the skiing technique used and the gender of the athlete will have no statistically significant effect on the heart rate or blood lactate responses within the three selected exercise intensities.

Definition of Terms

Zone One: A level of low aerobic subthreshold exercise in which the steady-state blood lactate concentration is intended to be 2.0 mM or less. These blood lactate values are not significantly different from resting values.

Zone Two: A level of high aerobic subthreshold exercise in which the steady-state blood lactate concentration is intended to be between 2.5 and 3.5 mM.

Zone Three: A level of lactate threshold exercise in which the steady-state blood lactate concentration is intended to be between 3.5 and 4.5 mM (Reed, 1989).

Classical Technique: The classical technique is also referred to as diagonal striding. This technique involves contralateral limbs moving synchronously, a pattern similar to walking or running. This technique relies on a stationary ski providing a platform

from which the diagonal stride of the opposing ski is made (Smith, 1990).

Freestyle Technique: The freestyle technique is also referred to as skating. Although there is more than one skating technique, the V1 Skate is the predominant pattern used in racing (Smith, 1990). The V1 Skate involves an asymmetrical cycle with a double poling action associated with the skating motion of one 'strong' side. The 'weak' side is not accompanied by poling (Smith, 1989).

Abbreviations of Terms

ATP - Adenosine triphosphate

bpm - beats per minute

HR - Heart rate

kg - kilograms

La - Blood lactate

ml - millilitres

mM - millimoles per litre

OBLA - Onset of blood lactate accumulation

Limitations of the Study

The conclusions of this study can only be generalized to a group of similarly trained athletes of the same age during similar laboratory and field exercise.

While it is considerably easier to maintain consistent laboratory conditions, it is more difficult to control for the environmental conditions during field testing. The variations in wind and temperature conditions were a limitation of this study in that they were carefully recorded but not controlled.

The performance of the roller skis during the dryland exercise may have differed from the laboratory exercise since the friction of the roller skis on the pavement may have differed from the friction of the skis on the laboratory ski treadmill.

Skiing with roller skis and running with ski poles are two of many dryland training techniques used by cross-country skiers. The results of the testing may not reflect on other dryland training techniques.

The field testing involved at least five minutes of work at each exercise intensity while the laboratory testing involved a progressive incremental treadmill exercise test where each successive stage involved three minutes of work. The testing protocols required were different and therefore are a limitation of this study.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

Introduction

There is a wide spectrum of exercise intensities from the low intensity, long duration aerobic to the very high intensity, short duration anaerobic exercise. Although some exercise and sport performances are predominantly one type of intensity or another, many exercise and sport performances involve a combination of the two in varying degrees. Of prime importance to the exercise physiologist is the understanding of the physiological responses to these varying exercise intensities. This understanding will allow for a specific description of the physiological characteristics of a sport or exercise performance and ultimately a prescription of training strategies that will enable the athlete to enhance his or her physical abilities.

The purpose of the study was to compare the heart rate and blood lactate responses of elite male and female cross-country skiers at three selected exercise intensities using selected training techniques during laboratory, dryland and on-snow exercise.

This review of literature will be comprised of the following sections:

1. Measurement of Intensity of Exercise
2. Using Intensity Measurements to Classify Aerobic Exercise Responses
3. Specificity of Aerobic Exercise Effects
4. Physiology of Cross-Country Skiing

Measurement of Intensity of Exercise

As the athlete moves from rest to a maximal exercise intensity, a number of physiological changes occur. These changes may be described by several physiological variables. Three of the most common physiological indices of exercise intensity are heart rate, oxygen consumption, and blood lactate concentration.

Heart Rate

The cardiac output is the primary indicator of the functional capacity of the circulatory system to meet the demands of physical activity (McArdle et al., 1986). The cardiac output is a product of two variables: The stroke volume and the heart rate. The stroke volume is the amount of blood pumped by the heart per stroke or beat while the heart rate is the number of times the heart beats per minute (Fox et al., 1988).

The resting upright stroke volume of untrained males averages between 70 and 90 millilitres (ml) per beat with maximal values ranging between 100 and 120 ml per beat (Fox et al., 1988). The resting and maximal values are higher for trained men, averaging about 100 to 120 ml and 150 to 170 ml, respectively (Fox et al., 1988). The stroke volumes are generally lower for women than for men. The resting stroke volume of untrained women averages between 50 and 70 ml with maximal values ranging between 70 and 90 ml (Fox et al., 1988). The resting and maximal values are higher for trained women, averaging about 80 to 100 ml and 100 to 120 ml, respectively (Fox et al., 1988). The maximal stroke volume for the highly trained male endurance athlete may reach or even exceed 200 ml per beat (Fox et al., 1988). Endurance athletes exhibit increased cardiac outputs due primarily to the increased stroke volumes since the maximal heart

rates are similar in trained and untrained individuals (Fox et al., 1988).

Stroke volume increases during the progression from rest to moderate work but does not necessarily increase from moderate to maximal work. In most cases, stroke volume becomes maximal at a submaximal workload when oxygen consumption is only about 40% of maximal (Fox et al., 1988). This phenomenon applies to both trained and untrained individuals. This plateauing of the stroke volume response to incremental exercise, in addition to the invasive practices required to determine stroke volume, result in the use of the heart rate to monitor changes in the circulatory responses to exercise in many non-clinical situations.

The resting heart rate values of untrained individuals range from 70 to 90 beats per minute (bpm) (Astrand and Rodahl, 1986; Fox et al., 1988). The maximal heart rate values of untrained individuals may reach or exceed 200 bpm (Fox et al., 1988).

Physical training, particularly endurance training, has profound effects on heart rate. It is not unusual for endurance trained athletes of either gender to exhibit resting heart rates as low or lower than 40 bpm (Fox et al., 1988). Training also decreases the heart rate response to a given submaximal level of exercise (Brooks and Fahey, 1984). Although the metabolic requirements of a given activity remain the same, the decreased heart rate response does not reduce the cardiac output due to an increase in the stroke volume response to training (Brooks and Fahey, 1984). Training has only a small effect on maximal heart rate, usually decreasing it by about 3 to 10 bpm (Brooks and Fahey, 1984; Fox et al., 1988). Because maximal heart rate is relatively stable, only tending to decrease with age, it can be used as a reference point for judging the relative intensity of exercise (Brooks and Fahey, 1984).

As exercise begins, the heart rate elevates very rapidly. If the exercise is light, a plateau of the heart rate response is observed in thirty to sixty seconds (DeVries, 1986). The heart rate will increase in a linear fashion in response to a progressive linear increase in exercise intensity from light to approximately maximal intensity (Astrand and Rodahl, 1986). There will be a deflection from linearity in heart rate near maximal exercise intensity as the heart rate begins to plateau (Skinner and McLellan, 1980). Any further increase in exercise intensity will not result in a further increase in heart rate (Astrand and Rodahl, 1986).

The use of heart rate as an indicator of exercise intensity is a widely used method for exercise prescription due to the relative ease of determining the heart rate response during exercise (Karvonen and Vuorimaa, 1988) and due to the linearity of its response to submaximal workloads (Astrand and Rodahl, 1986). Exercise prescriptions will often recommend training intensities with respect to the maximum heart rate achieved during a progressive exercise test (Karvonen and Vuorimaa, 1988). The relative percent concept (Katch et al., 1978) for determining training intensities from heart rate responses is valid as long as the linearity of the heart rate response is maintained (Katch et al., 1978). The deflection in the linearity of the heart rate response may indicate a transition from aerobic to anaerobic metabolism (Katch et al., 1978) referred to as the anaerobic threshold (Wasserman and McIlroy, 1964).

There is disagreement in the literature as to whether the deflection from linearity of the heart rate response does reflect a transition from aerobic to anaerobic metabolism. While some investigators (Conconi et al., 1982; Droghetti et al., 1985; Parkhouse et al., 1982) conclude that heart rate may be a good indicator of the anaerobic threshold, others

conclude that heart rate may not be a good indicator of the anaerobic threshold (Dwyer and Bybee, 1983; Sady et al., 1980). Ribeiro et al. (1985) concluded that while the heart rate break point may be a good indicator of the anaerobic threshold, half of the subjects failed to demonstrate a heart rate break point. They further stated that the heart rate break point may not be a generalizable physiological measurement (Ribeiro et al., 1985).

Thus, while heart rate may be a useful indicator of exercise intensity where its response is linear to the exercise intensity, it may not be an accurate indicator near maximal intensity once the heart rate response breaks from linearity and begins to plateau.

Oxygen Consumption

The oxygen utilized to fuel the tissues of the body is provided by the interplay of the respiratory, circulatory, and muscular systems. The oxygen that diffuses from the alveoli of the lungs to the pulmonary-capillary blood is transported to the tissues of the body where it is consumed. The carbon dioxide produced by these tissues diffuses into the tissue-capillary blood and is transported to the alveoli where it is exhaled. The transport of these gases is the primary function of the respiratory-circulatory or cardiorespiratory system (Fox et al., 1988).

The average resting oxygen consumptions for males and females are approximately 250 and 200 ml per minute, respectively (McArdle et al., 1986). The highest oxygen consumptions have been observed in endurance-trained athletes, particularly cross-country skiers (Astrand and Rodahl, 1986). Elite female cross-country skiers have demonstrated maximal oxygen consumptions ranging from 3.5 to 4.4 litres per

minute whereas elite male cross-country skiers have demonstrated maximal oxygen consumptions in excess of 5.5 litres per minute (Astrand and Rodahl, 1986).

The oxygen consumption during exercise at a given submaximal load is the same or slightly lower following training (Fox et al., 1988). This decrease may be due to an increase in skill and mechanical efficiency. The maximal oxygen consumption is increased following training; the improvements range from 5 to 20% following endurance training (Fox et al., 1988). These increases in maximal oxygen consumption are a result of two main physiological changes: An increased oxygen delivery through an increased cardiac output and an increased oxygen extraction from the blood by the trained musculature (Fox et al., 1988).

Oxygen consumption rises rapidly during the first minutes of exercise. By the third to fourth minute, the oxygen consumption remains relatively stable if there is no change in the intensity of the exercise. This plateau of the oxygen consumption response is referred to as the steady state (McArdle et al., 1986). As with heart rate, the rate of oxygen consumption will increase in a linear fashion in response to a progressive linear increase in exercise intensity from light to approximately maximal intensity (Astrand and Rodahl, 1986). There will be a deflection from linearity in oxygen consumption near maximal exercise intensity as the oxygen consumption begins to plateau (Skinner and McLellan, 1980). Any further increase in exercise intensity will not result in a further increase in oxygen consumption (Astrand and Rodahl, 1986).

It has been well documented that oxygen consumption and heart rate are highly correlated during light to moderate exercise (Astrand and Rodahl, 1986). The quantification of training intensity usually involves the expression of a percentage of

maximum oxygen consumption with a percentage of maximum heart rate (Sady et al., 1980). However, near maximal intensity, the relationship between oxygen consumption and heart rate becomes less predictable since the oxygen consumption may increase relatively more than the heart rate (Astrand and Rodahl, 1986).

While the linearity of the oxygen consumption-heart rate relationship may be a useful indicator of exercise intensity during light to moderate exercise, the predictability of the relationship becomes less accurate as the intensity nears maximal and the variables each begin to plateau.

Blood Lactate

The blood lactate concentration can be described as an index of the anaerobic metabolism during physical activity. Increased lactate levels, in blood and in muscle, indicate an anaerobic supplement to the aerobic production of adenosine triphosphate (ATP) (Astrand and Rodahl, 1986). During light exercise, the oxygen store in the muscle plus the oxygen supplied as the respiration and the circulation adapt to the demands of the exercise will completely cover the oxygen need (Astrand and Rodahl, 1986). During exercise of moderate intensity, anaerobic processes contribute to the energy output at the beginning of the exercise until the aerobic processes begin to cover the energy demands of the activity (Astrand and Rodahl, 1986). Lactate diffuses into the venous blood draining the muscle and eventually into the arterial blood when the quantity of lactate produced by the working muscles is high enough (Astrand and Rodahl, 1986). The blood lactate levels may decrease during continuous activity if the consumption of lactate by the muscles, liver, and heart exceeds the production of lactate by the muscles at this moderate exercise intensity. As the exercise intensity increases from moderate to maximal the

production far exceeds the consumption and the blood lactate concentration increases exponentially until the termination of the exercise. The blood lactate concentration continues to increase following the termination of a maximal exercise bout as excess lactate produced and stored in the muscles diffuses across the tissue-capillary blood barrier. Peak blood lactate concentration may occur during the first five to ten minutes of the recovery period (Astrand and Rodahl, 1986).

Training does not appear to affect the resting blood lactate levels (Fox et al., 1988). The average resting blood lactate levels occur around 1 mM (Astrand and Rodahl, 1986). However, training does affect the blood lactate responses to submaximal and maximal exercise. The increase in the concentration of lactate in muscle and blood is lower at the same absolute power production in endurance trained persons as compared with nontrained individuals (Gollnick et al., 1986). The curves generated by plotting the blood lactate concentration against the absolute and relative intensities of exercise are shifted to the right following endurance training (Gollnick et al., 1986). Training at maximal intensity results in an increased production of lactate as a result of increased glycolytic activity (Fox et al., 1988). More ATP energy can be generated through this metabolic pathway thereby improving the performance of activities that rely on this energy system (Fox et al., 1988).

The blood lactate concentration follows an approximate exponential curve with at least one (Wasserman and McIlroy, 1964) but more likely two distinguishable break points from rest to maximal intensity during a progressive exercise bout (Kindermann et al., 1979; Skinner and McLellan, 1980). There is a slight increase in blood lactate from rest to light intensity exercise. The first distinguishable break point occurs when the

blood lactate concentration reaches approximately 2 mM. The first break point is referred to as the aerobic threshold. The blood lactate concentration then increases at an increased rate until the second break point. The second break point occurs when the blood lactate concentration reaches approximately 4 mM. The second break point is referred to as the anaerobic threshold. There follows a steep exponential increase in blood lactate concentration beyond the anaerobic threshold until exhaustion (Kindermann et al., 1979; Skinner and McLellan, 1980).

Some researchers have developed mathematical models to describe the blood lactate responses to progressive incremental exercise. Beaver et al. (1985) used logarithmic transformations of the lactate and oxygen uptake responses to incremental exercise to identify a single threshold point. Their lactate threshold was identified as the abrupt transition between a phase of slow increase to a phase of rapidly increasing increase (Beaver et al., 1985). Hughson et al. (1987) concluded that the change in blood lactate during incremental exercise is best described as a continuous function rather than as a threshold response. There is presently no definitive mathematical model of the blood lactate responses to progressive incremental exercise.

The ability to determine optimal training intensities is of paramount importance to the athlete since deviations above or below a particular intensity may result in reduced training effects (Jacobs, 1986). Other studies indicate that lactate-related variables account for a larger proportion of the variation in exercise performance than other variables traditionally determined in the exercise laboratory (Jacobs, 1986; Williams and Eston, 1989). The use of blood lactate accumulation as a more specific indicator of exercise intensity is of particular importance to the cross-country skier since they typically perform

at 85-90% of their maximum aerobic capacity in competitive situations for extended periods of time (Bergh, 1982; Jetté et al., 1976; Niinimaa et al., 1978). At these elevated aerobic intensities, heart rate and oxygen consumption may not accurately identify small changes in exercise intensity since these variables are beginning to plateau. Therefore, prescribing training intensities as a function of blood lactate concentration may prove to be a more accurate method of obtaining a homogeneous adaptation to training in a group of similarly trained athletes than is obtained by prescribing training intensities as a function of maximal heart rate or percentage of maximal oxygen consumption (Jacobs, 1986). While blood lactate concentration would serve to determine the optimal exercise intensities and since the sampling of blood lactate during each training session is not necessarily practical, the use of the heart rates corresponding to the blood lactate concentrations as regulatory parameters of the training intensities is recommended (Kindermann et al., 1979).

Using Intensity Measurements to Classify Aerobic Exercise Responses

Several investigators have tried to quantify the intensities of aerobic exercise primarily on the basis of blood lactate concentration.

Wells et al. (1957) suggested that blood lactate concentration during steady-state aerobic exercise could be used to standardize exercise intensity. The classification system involved three levels of intensity expressed as multiples of resting blood lactate concentration. Light work was defined as causing no increase in blood lactate concentration. Heavy work was defined as causing a 1.5- to 2-fold increase in blood lactate above resting levels. Severe work was defined as causing greater than a 5-fold

increase in blood lactate above resting levels.

Kindermann et al. (1979) established two threshold criteria to be used to individually determine the workload intensities for different forms of endurance training. The first threshold criteria was called the aerobic threshold. The aerobic threshold corresponded to the first significant elevation of blood lactate concentration above resting levels and occurred at a lactate concentration of approximately 2 mM. They concluded that endurance training would maintain the state of conditioning when performed in the range of the aerobic threshold. The second threshold criteria was called the anaerobic threshold. The anaerobic threshold corresponded to the steep part of the exponential increase in blood lactate concentration and occurred at a lactate concentration of approximately 4 mM. They also observed an average heart rate of 170 beats per minute (bpm) when seven cross-country skiers of national level ran on a treadmill at the anaerobic threshold intensity. They concluded that endurance training would increase the exercise capacity when performed in the range of the anaerobic threshold. They concluded that the anaerobic threshold represented the upper limit of an exclusively aerobic metabolism.

Skinner and McLellan (1980) were in agreement with the blood lactate criteria for determining different levels of exercise intensity as developed by Kindermann et al. (1979) but they introduced a three phase model to quantify work intensities from rest to maximum oxygen uptake. Phase I involved the transition from rest to the aerobic threshold corresponding to a blood lactate concentration of approximately 2 mM. The predominant type of metabolism was aerobic metabolism in Phase I. The aerobic threshold was further defined as occurring at a relative work intensity of between 40 and

60% of maximum oxygen uptake and at heart rates between 130 and 150 bpm. Phase II involved the transition from the aerobic threshold to the anaerobic threshold corresponding to a blood lactate concentration of 4 mM. The predominant type of metabolism in Phase II was also aerobic metabolism. The anaerobic threshold was further defined as occurring at a relative work intensity of between 65 and 90% of maximum oxygen uptake and at heart rates between 160 and 180 bpm. Phase III involved the transition between anaerobic threshold and maximum oxygen uptake. The predominant type of metabolism in Phase III was anaerobic metabolism.

Stark (1989) conducted a study to determine the physiological responses of elite cross-country skiers on a sport-specific ski treadmill during a progressive incremental exercise test. He concluded that blood lactate concentration, heart rate and oxygen consumption responded to a progressive incremental exercise test in three distinct compartments. The first compartment, the subthreshold phase, was associated with blood lactate concentrations from resting values to 2.5 mM. He determined that the first statistically significant increase in blood lactate occurred at a blood lactate concentration between 2.51 and 3.01 mM. The second compartment, the threshold phase, was associated with blood lactate concentrations between 2.5 and 5.5 mM. The third compartment, the suprathreshold phase, was associated with blood lactate concentrations above 5.5 mM.

Specificity of Aerobic Training Effects

Training specificity usually involves the manipulation of one or more aspects of physical performance: the mode of exercise employed, the intensity of exercise performed, the frequency of training and the duration of training bouts. This section will deal with

the specificity of aerobic exercise effects as a result of physical training.

Mode of Exercise

In the traditional exercise laboratory, the three modes of exercise employed to produce standardized work outputs are the step test, the bicycle ergometer, and the running treadmill. The traditional indicator of exercise performance in the exercise laboratory is the determination of the maximal oxygen uptake as a result of a progressive incremental exercise test using one of the three modes of laboratory exercise (Astrand and Rodahl, 1986). Many researchers have attempted to answer the question as to which of these exercise modalities will result in the highest oxygen uptake (Astrand and Rodahl, 1986).

Running uphill on a treadmill at a greater than three degree incline is usually considered the best exercise modality used to produce the highest oxygen uptake when compared with the other traditional exercise modalities (Astrand and Rodahl, 1986). Running on a horizontal treadmill resulted in 95-98% of the maximal oxygen uptake achieved when running uphill on a treadmill (Astrand and Rodahl, 1986). In comparison, a step test resulted in 97% while upright cycling on a bicycle ergometer resulted in 92-96% of the maximal oxygen uptake achieved when running uphill on a treadmill (Astrand and Rodahl, 1986). However, a study conducted where ski-walking with ski poles on a running treadmill was the exercise modality employed resulted in a significantly higher maximal oxygen uptake than achieved in uphill treadmill running (Astrand and Rodahl, 1986).

The above findings suggest that the more closely a laboratory test can simulate the specific muscular actions involved in training, the more objective and valuable the maximal oxygen uptake assessment (Davies et al., 1984). Moreira-Da-Costa et al. (1984) investigated the maximal oxygen uptakes in trained runners, trained cyclists and untrained individuals to compare trained to untrained muscle groups. The non-athletes and trained runners had 11% and 12% greater maximum oxygen uptake values during treadmill running when compared to leg ergometry while the trained cyclists obtained 7% greater maximum oxygen uptake values during the leg ergometry. They concluded that an ergometer which requires approximately the same muscular activity as is usually performed by the athlete should always be employed to evaluate the quantitative effects of training on cardiovascular and respiratory functions (Moreira-Da-Costa et al., 1984).

Although the determination of the maximal oxygen uptake is an important consideration in many athletic performances, the determination of the anaerobic threshold is of paramount importance to the endurance athlete. This threshold represents the greatest exercise intensity attained without the rapid and continuous accumulation of blood lactate that could limit the endurance exercise performance (Costill et al., 1973; Farrell et al., 1979).

Withers et al. (1981) examined the specificity of maximum aerobic power and anaerobic threshold in endurance-trained cyclists and runners. The subjects performed progressive work tests on a bicycle ergometer and on a running treadmill. They found that the cyclists had a higher anaerobic threshold on the bicycle ergometer than the runners although the maximal oxygen uptakes were not statistically different for both groups. Conversely, the runners had a higher anaerobic threshold on the running treadmill

than the cyclists. The runners also had significantly higher maximal oxygen uptakes on the running treadmill than the cyclists. They concluded that the adaptive responses to exercise are in part a function of the specific movement patterns executed in training (Withers et al., 1981). They further sta' 'hat the laboratory tests of anaerobic threshold and the maximal oxygen uptake should simulate movement patterns of training if maximum values are to be attained (Withers et al., 1981).

Millerhagen et al. (1983) conducted a study on a nordic ski simulator designed to test the specific muscle groups used during cross-country skiing. A set of wall pulley weights were attached to a running treadmill to provide an effective load for the arms during simulated cross-country skiing performance. Arm ergometry, leg ergometry, and combined arm and leg ergometry were the modalities employed to test the maximal oxygen uptake. While the leg and combined ergometry resulted in significantly higher maximal oxygen uptakes than the arm ergometry, there was no significant differences between the leg and the combined ergometry. However, the oxygen uptakes at submaximal work rates were significantly lower during the combined ergometry. The anaerobic threshold during the combined ergometry was significantly delayed with respect to time and work rate when compared with the leg ergometry although it was not significantly higher than in leg ergometry. They concluded that if oxygen consumption can be reduced relative to the exercise level by sharing the energy burden over a greater muscle mass, the anaerobic threshold will be relatively delayed but the absolute value of the oxygen consumption at the anaerobic threshold may not be significantly altered (Millerhagen et al., 1983).

Aerobic Training Effects

There is general agreement that training is an efficient stimulus for improvements in cardiovascular and muscular endurance only if higher work intensities are maintained for prolonged periods of time (Katch et al., 1978; Kindermann et al., 1979). Of particular interest is how varying intensities of training affect varying indices of physiological performance, particularly the effects of exercise intensity below, at and above the anaerobic threshold in endurance trained athletes.

Kindermann et al. (1979) stated that endurance training would maintain the state of conditioning when performed in the range of the aerobic threshold corresponding to a blood lactate concentration of approximately 2 mM. Rusko (1987) investigated the effects of training on aerobic power characteristics of young cross-country skiers. He stated that low intensity distance training was more effective in producing improvements in anaerobic threshold than training at the anaerobic threshold. He further concluded that distance training at a relatively low intensity was the most effective method for producing improvements in submaximal work capacity (Rusko, 1987).

Kindermann et al. (1979) stated that training at the anaerobic threshold of approximately 4 mM would increase the exercise capacity at the anaerobic threshold exercise intensity. They concluded that the optimal training intensity for endurance performance should be in the range of the anaerobic threshold (Kindermann et al., 1979).

Sjodin et al. (1982) investigated the changes in onset of blood lactate accumulation (OBLA) corresponding to a blood lactate concentration of 4 mM and in muscle enzymes after training at OBLA in well-trained runners. They concluded that the

training effect was greatest when a steady-state blood lactate concentration of approximately 4 mM could be maintained throughout the training sessions. They also stated that those runners with the lowest rate of blood lactate accumulation during the training sessions exhibited the greatest increases in running velocity at OBLA following training. They concluded that the training at OBLA resulted in measurable local metabolic adaptations in the active skeletal musculature of the runners without a significant change in maximal aerobic power (Sjodin et al., 1982).

Yoshida et al. (1982) investigated the effects of endurance training based upon the anaerobic threshold corresponding to a blood lactate concentration of 4 mM. They concluded that after training, the anaerobic threshold and the maximal oxygen uptake were both significantly improved. They also observed that the heart rates, oxygen consumptions, and blood lactate concentrations were significantly reduced during the replication of the submaximal exercise test following training.

Rusko (1987) concluded that intensive training at the intensity of the anaerobic threshold corresponding to a blood lactate concentration between 3 and 4 mM or higher was most effective in producing improvements in maximal oxygen uptake of endurance athletes although training at this high intensity may negatively influence the capacity for prolonged work.

Henritze et al. (1985) investigated the effects of training at and above the lactate threshold on the lactate threshold and maximal oxygen uptake. They concluded that training above the lactate threshold results in an improvement in lactate threshold while training at the lactate threshold did not result in an improvement in lactate threshold. They further stated that improvements in maximal oxygen uptake were not necessary for

improvements in lactate threshold (Henritze et al., 1985).

Physiology of Cross-Country Skiing

Physical Characteristics

Cross-country skiing is considered a highly oxidative, weight-supported endurance activity. The elite cross-country skier is typically a lean athlete with a low percentage of body fat (Eisenman et al., 1989). Females typically have body fat percentages between 15 and 17% while males typically have body fat percentages between 5 and 9% body fat (Eisenman et al., 1989). Niinimaa et al. (1978) concluded that a low body fat percentage made a significant contribution as reflected by statistically significant factor analysis to the competitive endurance performance of trained intercollegiate cross-country skiers.

Body composition may not be as important a determinant of cross-country skiing performance as concluded by Niinimaa et al. (1978). Bergh (1982) concluded that cross-country skiing differed from running in that the total rise of the body's centre of gravity is not as great as in running. Thus, increases in body mass should not increase the energy costs of cross-country skiing to the same extent as they do in running (Bergh, 1982). Bergh (1987) conducted a study on the influence of body mass on cross-country skiing and concluded that the relative per body weight cost of moving a body on skis decreases as the body mass increases. He further stated that skiing performance would be independent of body mass on race courses that contained a varied terrain (Bergh, 1987). The heavier skier would be at an advantage on the downhill, flat, and low grade uphill sections while the lighted skier would be at an advantage on steeper uphill sections (Bergh, 1987). In this study, proven elite world class male skiers ranged from 65 to 95

kilograms in body mass. This large variation in body mass would not be present if skiing performance was closely associated with body mass (Bergh, 1987) to the same extent that body mass has been shown to affect performance in endurance running (Eisenman et al., 1989). Body mass has proven not to be as critical a determinant of cross-country skiing performance as a highly developed oxidative capacity (Eisenman et al., 1989).

The highest maximal oxygen uptakes have traditionally been recorded in cross-country skiers (Astrand and Rodahl, 1986). The average maximal oxygen uptakes of elite male cross-country skiers are 5.5 litres/minute or 80 ml/kg/minute (Bergh, 1982). The average maximal oxygen uptakes of elite female cross-country skiers are 3.5 litres/minute or 70 ml/kg/minute (Bergh, 1982). Bergh (1982) concluded that a high maximum aerobic power was definitely a requirement for cross-country ski racing but was not an absolute assurance of world class performance.

Successful ski racers must be able to perform at a high percentage of their maximal oxygen uptake for long periods of time (Eisenman et al., 1989). The oxygen transport system rarely operates below 85% of the maximum oxygen uptake during competitive ski racing (Bergh, 1982). Some well-trained ski racers frequently perform at 90% of their maximum oxygen uptakes for extended periods of time (Jetté et al., 1976; Niinimaa et al., 1978). These findings support the use of blood lactate concentration as an indicator of exercise intensity at very high levels of aerobic performance.

Effect Of Technique On Heart Rate And Blood Lactate Responses

While it is important to determine the physiological responses of the cross-country skiing techniques in the exercise laboratory, it may be of equal or greater importance to

determine the specific physiological responses to cross-country skiing and training techniques under actual field and performance conditions.

There are two cross-country skiing techniques presently utilized in competitive situations: The classical technique and the freestyle technique. The classical technique is also referred to as diagonal striding. This technique involves contralateral limbs moving synchronously, a pattern similar to walking or running. This technique relies on a stationary ski providing a platform from which the diagonal stride of the opposing ski is made (Smith, 1990). The freestyle technique is also referred to as skating. Although there is more than one skating technique, the V1 Skate is the predominant pattern used in racing. The V1 Skate involves an asymmetrical cycle with a double poling action associated with the skating motion of one 'strong' side. The 'weak' side is not accompanied by poling (Smith, 1989).

There are any number of off-season training techniques employed by cross-country skiers to maintain and improve their aerobic conditioning. Among these techniques are running with ski poles and rollerskiing. Running with ski poles allows the athlete to train the upper body musculature involved in cross-country skiing as they maintain and develop their overall aerobic conditioning during running activities. Roller skis allow the skier to approximate both the classical and freestyle techniques on pavement. These techniques allow the athlete to train the specific musculature involved in cross-country skiing during the off-season.

Recent studies have examined the effects of different training and skiing techniques on the heart rate and blood lactate responses.

Pekkarinen et al. (1984) evaluated the intensity of dryland running and rollerskiing training by heart rate telemetry. Nine competitive cross-country skiers were asked to run 1.2 kilometres at three different speeds on a hilly asphalt road and then roller ski on the same road using similar speeds. The speeds were determined to be slow, moderate, and fast. They concluded that the heart rates in slow and moderate running and rollerskiing did not differ significantly but in running performed at maximum speed the mean heart rates were significantly higher than in rollerskiing. They also stated that there were no differences between running and rollerskiing times at the same intensity. Pekkarinen et al. (1984) concluded that the work intensity of rollerskiing training at maximum speed was not as heavy as that of running at maximum speed. They concluded that rollerskiing should not replace normal running for anaerobic training but can be used in pure aerobic training and in training the skiing technique. They further stated the athletes could quite well self-determine the appropriate training pace (Pekkarinen et al., 1984).

Karvonen et al. (1987) investigated the effects of freestyle and classical techniques during on-snow exercise. Nine junior cross-country skiers skied on the same varying terrain track of 2.5 kilometres for four laps, first twice at a moderate training intensity (approximately 80% of maximal performance capacity) and then twice at maximum competitive speed. There was a recovery period of ten minutes between each of the four laps. The study was randomized so that every second skier performed the first and the third laps using the freestyle technique and the second and the fourth laps using the classical technique. The rest of the skiers performed the first and the third laps using the classical technique and the second and the fourth laps using the freestyle technique. Heart rates were measured using Sport Tester PE3000 monitors. The heart rate values for each workload were obtained by calculating the mean heart rate values measured at 15 second

intervals during the physical performance of each lap. Fingertip blood samples were taken at two and three minutes after the end of each lap for the determination of lactic acid concentration in capillary blood. They found that there were no significant differences between heart rate values measured when skiing at moderate and at maximum intensity for both the freestyle and the classical techniques. They also found that there were no significant differences between lactic acid values measured when skiing at moderate and at maximum intensity for both the freestyle and the classical technique. However, the times for the freestyle technique were significantly less than the classical technique for both the moderate and the maximum work intensity. They concluded that the same level of energy consumption resulted in a greater efficiency with the freestyle technique as compared to the classical technique (Karvonen et al., 1987).

Stray-Gundersen and Ryschon (1987) compared the economy of freestyle and classical rollerskiing during treadmill exercise. Five national level skiers rollerskied at 5 miles per hour up a 5% grade on a motor-driven treadmill designed to allow rollerskiing. The heart rates were determined by telemetry. The lactate concentration in capillary blood was measured immediately after each exercise bout. The freestyle technique resulted in significantly higher heart rates and blood lactate concentrations than the classical technique. They concluded that the freestyle technique is less economical than the classical technique. They suspected that the removal of kick wax and the ability to use the arm and trunk muscles to a greater extent may explain the improved performance of the freestyle technique on snow with respect to improved race times (Stray-Gundersen and Ryschon, 1987).

Zupan et al. (1988) conducted an on-snow field study to determine the differences between the classical and the freestyle techniques. Fifteen elite skiers performed eight submaximal trails between 200 and 300 metres per minute. They concluded that the heart rate values were significantly higher with the classical technique (Zupan et al., 1988).

The findings of Clifford and Hoffman (1989) where in agreement with those of Zupan et al. (1988). Nine nordic ski racers skied around a groomed snow track at an average speed of 14.2 kilometres per hour using six different skiing techniques. They found that the classical technique resulted in significantly higher heart rate values than the freestyle technique (Clifford and Hoffmann, 1989).

Higgins et al. (1989) compared plasma lactate levels in elite cross-country skiers during classical and freestyle rollerskiing at moderate and high exercise intensities. Twenty-one subjects skied one trial at moderate and one trial at high intensity for each of the rollerskiing techniques. They found that there were no significant differences between the heart rate values for the two techniques at each exercise intensity. However, they found that the lactate levels were significantly higher during the freestyle rollerskiing at each exercise intensity. They concluded that for a given exercise heart rate, plasma lactate is higher during freestyle rollerskiing than during classical rollerskiing (Higgins et al., 1989).

Karvonen et al. (1989) investigated the effects of freestyle and classical technique on skiing speed and energy metabolism at various skiing intensities during on-snow exercise. Seven elite skiers skied 0.9 kilometre laps at increasing speed using one technique on the first day and the other technique on the second day. There was a recovery time of ten minutes between laps. They found that at the same speeds the heart

rates were significantly lower for the freestyle technique. Significant differences appeared in the capillary blood lactic acid concentrations only above the anaerobic threshold of 4 mM. They found that the ratios of heart rate to blood lactic acid concentration were not significantly different when using either the freestyle or the classical technique. They concluded that when the skating technique is used during training to improve endurance, the speed of skiing must be higher than with the classical technique or else the exercise intensity will be too low (Karvonen et al., 1989).

Summary

Three of the most common physiological indices of exercise intensity are heart rate, oxygen consumption, and blood lactate concentration. While the heart rate and oxygen consumption may be useful indicators of exercise intensity where their responses are linear to the submaximal exercise intensity, they may not be accurate indicators near maximal exercise intensity once their responses break from linearity and begin to plateau. However, identifying exercise intensities as a function of blood lactate concentration may prove to be a more accurate method for training prescription in a group of similarly trained athletes than is obtained by prescribing training intensities as a function of maximal heart rate or oxygen consumption. While the blood lactate concentration would serve to determine the optimal exercise intensity, the heart rate corresponding to the blood lactate concentration would serve as the regulatory parameter during training.

Several investigators have identified phases of aerobic exercise primarily on the basis of blood lactate concentration. These investigators have proposed compartmental models of the responses to progressive incremental exercise. The aerobic and the anaerobic thresholds have been identified as the primary physiological landmarks of these

compartmental models. Thus, only two phases of exercise intensity exist below the anaerobic threshold. As the specificity of exercise training and performance increase, there is a need to further identify and delimit the phases of exercise intensity below the anaerobic threshold.

There is a common belief that the more closely a test can simulate the specific physical actions involved in training and sport performance, the more objective and valuable the assessment of those physical actions. Laboratory assessments of physical and physiological performances have become increasingly more accurate and sophisticated. However, there is an increasing need to assess the physical and physiological performances during actual training and sport performances.

The assessment of the physiological parameters associated with cross-country skiing is an example of improving the specificity of the testing procedures. The laboratory testing of the physiological capacities of the cross-country skier has been improved by the development of the cross-country ski treadmill. However, cross-country ski training and performance must ideally be evaluated during actual field training and performance.

CHAPTER THREE

METHODOLOGY

Introduction

This chapter outlines the methodology used for detecting changes in the dependent variables associated with this study. The following sections are included in this chapter:

1. Introduction
2. Subjects
3. Laboratory Testing Procedure
4. Field Testing Procedure
5. Heart Rate Determination
6. Lactate Analysis Procedure
7. Statistical Design

Subjects

Twelve male and eleven female elite cross-country skiers were involved in this study. The skiers comprised a senior national and a junior national team. The skiers were highly trained endurance athletes who had been competing at the national and international level for several years.

Laboratory Testing Procedure

The subjects performed a progressive incremental exercise test according to the Canadian Association of Sport Sciences protocol (Thoden et al., 1982) as modified by Stark (1989). The protocol consisted of a five minute warm-up stage followed by successive three minute work stages until volitional exhaustion. The warm-up stage speed was 6.0 or 6.5 km/h for females and males respectively. The speeds were increased to 7.0 or 7.5 km/h for females and males respectively following the warm-up stage. The final speeds were maintained for the duration of the exercise test. The initial grade of the treadmill was one degree for the warm-up stage. The grade was increased by one degree for each successive workload.

The ergometer used was a sport-specific Posi-Trac ski treadmill (Blue Klister, Inc.). The ski treadmill utilizes a rotating belt similar to standard running treadmills although parallel inlaid tracks allow for the use of cross-country skis and poles. The ski treadmill is a motorized, hydraulic ergometer with a central fulcrum that allows for a maximum of 15 degrees of both positive and negative incline.

Expired ventilation samples were collected throughout the test. The gas analysis was performed using an open-circuit Roxon Rapid Response metabolic cart. The expired ventilation samples were analyzed by a Godart Capnograph and Oxygen Analyzer. The expired volumes were measured by a turbine ventilometer attached to a room air intake port of a one-way mouth valve. Backup samples were collected in a Collins 100 litre Tissot tank during the last 30 seconds of each stage. Where there were differences between the oxygen consumption values of the two collection systems, the Tissot value was used as the maximum value since the Tissot collection of the expired ventilation is

less subject to the inertial problems associated with the turbine ventilometer.

Heart rates were monitored by a Polar Electro PE3000 Sport Tester (Polar Electro Oy). Fingertip blood samples were collected during the last 30 seconds of each stage.

Field Testing Procedure

The protocol for the dryland field testing was as follows: The subjects performed three discontinuous bouts of exercise using three selected exercise intensities. Each bout consisted of approximately five minutes of exercise. The three selected exercise intensities were called Zone One, Zone Two, and Zone Three. Each subject performed Zone One exercise followed by Zone Two exercise followed by Zone Three exercise. The recovery time between exercise bouts was approximately five minutes.

The exercise intensities were performed by the subjects to elicit heart rates which had previously been shown to be related to approximate blood lactate responses. Zone One exercise was intended to elicit a steady-state blood lactate response of 2.0 mM or less. Zone Two exercise was intended to elicit a steady-state blood lactate response between 2.5 and 3.5 mM. Zone Three exercise was intended to elicit a steady-state blood lactate response between 3.5 and 4.5 mM (Reed, 1989).

The dryland testing was conducted during July and August. The field testing was conducted the day after the laboratory testing. The dryland exercises were running with poles and freestyle rollerskiing.

Heart rates were monitored by a Polar Electro PE3000 Sport Tester. Fingertip blood samples were collected one minute after the end of each exercise bout.

Heart Rate Determination

The heart rates were monitored and recorded throughout the laboratory and field testing by a Polar Electro PE3000 Sport Tester (Polar Electro Oy, Oulu, Finland). The Sport Tester digitally recorded the heart rate values at five second intervals. The heart rate data were downloaded from memory either manually or by a Polar Electro computer interface to an IBM PC/XT microcomputer and stored on 5.25 inch diskettes. The heart rate values from heart rate microcomputers (Sport Tester PE3000) have been shown to be non-significantly different from the heart rate values obtained by electrocardiography and by holter monitors (Karvonen et al., 1984; Léger and Thivierge, 1988).

Blood Lactate Analysis

The blood lactate analysis procedure for the laboratory testing was as follows: Forty microlitres of mixed venous blood was taken from the middle fingertip during the last thirty seconds of each stage. A Monojector Lancet device was used to puncture the skin after the skin was cleaned with 70% isopropyl alcohol and dried with lint-free paper wipes. One heparinized capillary tube was half-filled with blood. The fingertip incision was covered with surgical tape. A twenty microlitre sample was hemolyzed in 380 microlitres of sample diluting solution in a hemolyzing test tube prepared prior to the testing. The hemolyzed blood was analyzed for blood lactate concentration in 100 microlitre aliquotes with a Kontron Lactate Analyzer 640 (Kontron Medical Equipment, Inc., Switzerland). The electrical current generated by the oxidation of lactate to pyruvate was proportional to the lactate concentration of the sample. The electrical current was converted to a digital signal that was recorded as the sample blood lactate concentration (Racine et al., 1975). The experimental error involved in the blood lactate determination

using this technique has been demonstrated to be +/- 0.05 mM (Geyssant et al., 1985).

The blood lactate analysis procedure for the dryland testing was identical to the laboratory testing with the exception that blood sampling occurred one minute following the end of each exercise bout.

Statistical Design

The data were analyzed using the following statistical procedures where the exercise intensity, the skiing techniques, and the gender of the athletes were the independent variables and the heart rate and blood lactate values were the dependent variables:

1. Descriptive analyses of the physiological responses of the athletes by exercise intensity, by skiing technique, and by gender of the athlete were conducted.

2. Pearson product moment correlational analyses of the dependent variables, the heart rate and the blood lactate, were conducted.

3. A three-way analysis of variance (ANOVA) was conducted where exercise intensity, skiing technique, and gender of the athlete were the independent variables of the heart rate and blood lactate values to identify if statistical significance was achieved. Post-hoc analyses using a Tukey technique were conducted to identify the sources of statistical significance.

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APPENDIX D

SCHOOL OF HUMAN KINETICS
THESIS RESEARCH CONSENT FORM

Studies involving human subjects require written consent of the participants. I, _____, authorize Jeff Fitzgerald (225-9996) of the School of Human Kinetics, University of Ottawa, to administer and conduct the laboratory, dryland, and on-snow testing. This study will be conducted under the supervision of Dr. A. Reed, School of Human Kinetics (564-9123).

I understand that the purpose of this study is to compare the heart rate and blood lactate responses as indicators of exercise intensity of elite cross-country skiers at three selected exercise intensities during laboratory, dryland, and on-snow exercise and that the information obtained is confidential and will be used for no purpose other than Jeff Fitzgerald's thesis. The information obtained from this study will be useful for the design of specific training programs for cross-country skiers. This study has been requested by Dr. A. Reed and Jeff Fitzgerald (University of Ottawa) and approved and funded by Sport Canada and Cross-Country Canada.

I understand that prior to the laboratory, dryland, and on-snow testing I will undergo a complete physical warm-up through general exercises. I understand that the laboratory testing involves a progressive incremental exercise test on a cross-country ski treadmill. The laboratory testing protocol consists of a five minute warm-up stage followed by successive three minute stages until volitional fatigue. I understand that the dryland and on-snow exercise involve the performance of skiing-specific training techniques at three selected exercise intensities. The dryland and the on-snow protocols will involve three (3) exercise trials. Each trial will involve approximately five (5) minutes of exercise with approximately five (5) minutes of recovery between trials. The laboratory testing will involve one (1) day of testing. The dryland testing will involve two (2) consecutive days of testing immediately following the laboratory testing. The on-snow testing will involve two consecutive days of testing within two (2) weeks of the laboratory testing. Each subject will be tested for approximately one (1) hour each day. The laboratory testing will be conducted in July and November. The dryland testing will be conducted in July. The on-snow testing will be conducted in November.

The heart rate and the blood lactate responses will be monitored during and following the laboratory, dryland, and on-snow exercise. The Sport Tester PE3000 will be used to monitor the heart rate and will be attached around my chest throughout the testing. Capillary blood samples will be drawn by micropuncture from a fingertip. The skilled technician will take one small blood sample every exercise stage during the laboratory testing and every one (1) minute following each exercise trial during the dryland and on-snow exercise. Blood samples will be taken every one, two, and three minutes following the laboratory testing and every one and three minutes following the dryland and on-snow testing. I will experience a slight pricking sensation when the blood samples are collected. I understand that I may experience some local muscular fatigue similar to what is experienced during cross-country ski training and performance. However, I understand that there are potential risks to some individuals while performing

an exercise test, these include episodes of transient lightheadedness, fainting, chest discomfort, leg cramps and very rarely, heart attacks. I am a healthy, active subject, under the age of 35, who has had an annual medical examination within the last 12 months. I do not suffer from any chronic medical problems and am physically active. I further understand that it is my responsibility to inform the testing personnel of any injury, illness, infection, or other condition, which would prevent me from fully participating in this session.

I understand all information collected will be kept confidential and presented in an anonymous form in the final report. I understand that I will personally be informed of my fitness in relation to the sport of cross-country skiing.

I understand that I have the right to withdraw from this study at any time and that refusal to participate or withdrawal from this study will have no effect on my continued membership with the National Cross-Country Ski Team.

SUBJECT: _____ DATE: _____

WITNESS: _____

APPENDIX E

Thesis Proposal of Jeff Fitzgerald, School of Human Kinetics
Appendix for University Human Research Ethics Committee Questionnaire

This study will involve three testing sessions: A laboratory treadmill test, a dryland training test, and an on-snow training test. All the testing sessions will be supervised by a Certified Fitness Appraiser (CFA). The subjects will undergo a warm-up session consisting of general exercises prior to each testing session.

The laboratory testing will involve a progressive incremental exercise test on a cross-country ski treadmill. The protocol consists of a five minute warm-up stage followed by successive three minute stages until volitional fatigue. The warm-up stage speed is 6.0 and 6.5 km/h for females and males, respectively. The speed is increased to 7.0 and 7.5 km/h for females and males, respectively following the warm-up stage. The final speeds are maintained for the duration of the exercise test. The initial grade of the treadmill is one degree for the warm-up stage. The grade is increased by one degree for each successive stage. Expired ventilation samples are collected throughout the test. The gas analysis is performed using an open-circuit Roxon Rapid Response metabolic cart. The expired ventilation samples are analyzed by a Godart Capnograph and Oxygen Analyzer. The expired volumes are measured by a turbine ventilometer attached to a room air intake port of a one-way mouth valve. Backup samples are collected in a Collins 100 litre Tissot tank during the last 30 seconds of each stage. The heart rates are monitored by a Polar Electro PE3000 Sport Tester throughout the test. Fingertip blood samples are collected during the last 30 seconds of each stage and at one, two, and three minutes following the termination of the test.

The protocols for the dryland and on-snow field testing are as follows: The subjects perform three discontinuous bouts of exercise using three selected exercise intensities. Each bout consists of approximately five minutes of exercise. The three selected exercise intensities are called Zone One, Zone Two, and Zone Three. Each subject performs Zone One exercise followed by Zone Two exercise followed by Zone Three exercise. The recovery time between exercise bouts is approximately ten minutes. The exercise intensities are performed by the subjects to elicit heart rates which have previously been shown to be related to approximate blood lactate responses. Zone One exercise is intended to elicit a steady-state blood lactate response of 2.0 mM or less. Zone Two exercise is intended to elicit a steady-state blood lactate response between 2.5 and 3.5 mM. Zone Three exercise is intended to elicit a steady-state blood lactate response between 3.5 and 4.5 mM. These blood lactate responses represent a range from mild to moderate exercise intensities. The field testing is conducted during different seasons of the year. The dryland testing is conducted during the late spring and summer months while the on-snow testing is conducted during the winter months. The field testing is conducted on two successive days. One technique is employed on each successive day. The dryland exercises are running with poles and rollerskiing. The on-snow exercises are classical and freestyle cross-country skiing. The heart rates are monitored by a Polar Electro PE3000 Sport Tester throughout the testing. Fingertip blood samples are collected one minute after the end of each exercise bout and one and three minutes after the end of the third exercise bout.

The heart rates are monitored and recorded throughout the laboratory and field testing by a Polar Electro PE3000 Sport Tester. The Sport Tester PE3000 digitally records the heart rate values at five second intervals. The Sport Tester PE3000 apparatus includes an adjustable belt with a transmitter and a watch-like receiver. The belt is secured around the subject's chest at the level of the sternum. Two surface electrodes on the belt conduct the weak electrical signals of the heart to a transmitter attached to the front of the belt. The transmitter sends the digital signal to the receiver worn on the wrist. The signal is stored in the memory of the receiver. The Sport Tester PE3000 is an accurate instrument for the determination of heart rate data that involves minimal contact with the subject and is comfortable for the subject to wear for long periods of time.

The analysis of the blood lactate concentrations require small blood samples from the fingertip of the subject. All blood samples are taken under the supervision of a Certified Medical Technologist. The technician sampling the blood is required to wear surgical gloves. The used surgical gloves are discarded following each subject and new gloves are worn for each new subject. The fingertip sampling site is cleaned with alcohol and wiped dry with lint-free paper wipes prior to each sample. A Monojector lancet device is used to puncture the skin. The lancets are sterilized and are discarded after each sample. Approximately twenty (20) microlitres of mixed venous blood is collected in a capillary tube for each sample. The fingertip sampling site is cleaned with alcohol and covered with surgical tape after each sample during the testing and a sterile bandage following the testing. The subjects are instructed to keep the fingertip sampling site covered for twenty-four (24) hours following the testing. This method of blood lactate determination is considered to be the least invasive method and causes less discomfort to the subject than the method that previously involved steel lancets for the sampling of blood.