

THE UNIVERSITY OF MANITOBA

PHYSIOLOGIC RESPONSE OF CROSS-COUNTRY SKI RACERS
DURING
PROGRESSIVE AND STEADY STATE SKIING
ON THE SKIMILL

by

Hugh R. Huber

Honours B.A. University of Western Ontario 1975

A Thesis

Submitted to

The Faculty of Graduate Studies

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

Faculty of Physical Education and Recreation Studies

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ISBN 0-315-71835-8

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HUGH R. HUBER

A thesis submitted to the Faculty of Graduate Studies of
the University of Manitoba in partial fulfillment of the requirements
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MASTER OF SCIENCE

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ABSTRACT

Physiologic response of cross-country ski racers during progressive and steady state skiing on the skimill. Huber, H. R. University of Manitoba.

The assessment of endurance performance has been greatly enhanced by the measurement of anaerobic threshold. The response of both gas exchange parameters and blood lactate during progressive exercise has been related to endurance capacity. However, the use of a multiplicity of tests which vary in increment length and loading rate alters the oxygen and lactate kinetics, and complicates attempts at inter-athlete and between-test comparisons.

The main purpose of this study was to compare the physiologic response of cross-country ski racers at the equivalent submaximal workload during progressive and steady state tests. A second aim was to determine whether the physiologic response during the steady state test varied between the tenth and twentieth minutes. Testing took place during diagonal skiing on the skimill using racing skis and poles. Participants were provincial junior and master skiers. Progressive test intervals were four minutes with one minute pauses between stages for blood lactate sampling. Steady state interval length was ten minutes with one minute pauses for measurement of blood lactate.

Progressive test values of minute carbon dioxide output (\dot{V}_{CO_2}), respiratory exchange ratio (RER), minute ventilation (\dot{V}_E), and breathing frequency (f), differed significantly ($p \leq 0.05$) from the steady state results at the same workload. Heart rate (HR) and arterialized blood lactate concentration ([LCT]) differed significantly between minutes ten and twenty of the steady state test ($p \leq 0.05$). Additionally, large intra-individual variation suggests that the lactate response to exercise is highly specific. As progressive tests during simulated skiing require pauses for blood lactate sampling which complicates the lactate kinetics, it is apparent that endurance performance is best monitored by the use

of constant load tests. It is recommended that such tests be at least 20 minutes in duration, and at an intensity at or below the lactate threshold.

ACKNOWLEDGEMENTS

This research and thesis owes its completion to many individuals who contributed generously in either the giving of their time, talent, or knowledge throughout its long gestation. I am a richer person because of all the people who I have had the pleasure to work and associate with during this study period.

First of all, I thank Dr. A. E. Ready, who as my main advisor guided, encouraged, and directed me during this project. I also thank Dr. E. A. Kroeger, Dr. K. Lindner, and Dr. N.L. Stephens who generously gave of their time to serve on my committee, and, who have provided invaluable assistance in the completion of this thesis.

Special thanks are directed to Mr. Ants Uin who worked above and beyond the call of duty in his commitment to the technical aspects and data collection for this research. Without his help the experiments certainly could not have been completed. Thanks to Mr. Richard Pettit, Head Coach of the Manitoba Cross Country Ski Association and the athletes who volunteered to be tested for this study. The work of the technicians who assisted in data collection often goes unnoticed but is of course vital to research success. Thank you to you all. Thank you also to Stephen and Kathrine Klassen, and many others too numerous to mention who have helped me to complete this tome.

Special thanks are also given to Mr. Theo Dubois who graciously and generously encouraged me in the completion of this thesis.

DEDICATION

This thesis is dedicated to the two people in my life who have always unwavering encouragers and faithful supporters of all my endeavours. Mom and Dad, this thesis is dedicated to you for your love and faithfulness through all the years.

Also hat Gott die Welt geliebt daß er seinen eingebornen Sohn gab, auf das alle, die an ihn glauben, nicht verloren werden, sondern daß ewige Leben haben.

Johannes 3,16

TABLE OF CONTENTS

	Page
ABSTRACT	iii
ACKNOWLEDGEMENTS	v
DEDICATION	vi
LIST OF TABLES	x
Chapter	
1. INTRODUCTION	1
Statement of the Problem	2
Assumptions	3
Delimitations	4
Limitations	4
Definition of Terms	5
2. REVIEW OF LITERATURE	7
Introduction	7
Anaerobic Threshold	7
Lactate Kinetics	10
Production	10
Removal	13
Progressive Tests	15
Ventilation Threshold	17
Lactate Threshold	18
Steady State Tests	19
Test Specificity	20

Chapter

3. METHODS AND PROCEDURES	22
Part A	22
Part B	22
Protocol.....	23
Data Collection and Instrumentation	24
Statistical Analysis	25
Part A	25
Part B	25
Experimental Design	26
4. RESULTS	27
Part A	27
Part B	30
5. DISCUSSION	33
Introduction	33
Training Status.....	34
Progressive versus Steady State Testing	35
Heart Rate Response.....	35
Lactate Response	36
Ventilation and Gas Exchange Parameters	39
Effect of Interval Length.....	42

Chapter

5. DISCUSSION (continued)	
Steady State Testing.....	43
Heart Rate Response.....	43
Lactate Response.....	43
Ventilation and Gas Exchange Parameters	44
Effect of Interval Length.....	45
Progressive and Steady State Tests as Predictors of Endurance Performance.....	45
6. SUMMARY AND CONCLUSIONS	48
REFERENCES.....	50
APPENDICES.....	78
A. Preliminary Athlete Letter.....	79
B. Information and Informed Consent Form.....	81
C. Letter of Appreciation	85
D. Athlete and Coach Feedback.....	86
E. Terms.....	87

LIST OF TABLES

Table 1. Subject characteristics (Part A) ($\bar{x} \pm \text{SEM}$).....	27
Table 2. Blood lactate and heart rate response to progressive and steady state tests at the reference workload ($\bar{x} \pm \text{SEM}$).....	28
Table 3. Respiratory response to progressive and steady state tests at the reference workload ($\bar{x} \pm \text{SEM}$).....	28
Table 4. Gas exchange response to progressive & steady state tests at the reference workload ($\bar{x} \pm \text{SEM}$).....	29
Table 5. Subject characteristics (Part B) ($\bar{x} \pm \text{SEM}$).....	30
Table 6. Blood lactate & heart rate response to steady state tests at the reference workload ($\bar{x} \pm \text{SEM}$).....	31
Table 7. Respiratory responses to steady state tests at the reference workload ($\bar{x} \pm \text{SEM}$).....	31
Table 8. Gas exchange response to steady state tests at the reference workload ($\bar{x} \pm \text{SEM}$).....	32

Chapter 1

INTRODUCTION

Endurance athletes are required to perform high intensity work for extended periods of time. Referred to as the anaerobic threshold (AT) or maximal lactate steady state, this threshold is considered to be the workload beyond which blood lactate accumulation significantly exceeds its rate of removal (Heck et al., 1985). As the AT is closely related to endurance performance (Edgren, Marklund, Nordesjo & Borg, 1976; Kumagai et al., 1982; Maughan & Leiper, 1983) it may provide an indication of cross country ski racing potential and assist in the monitoring and prescription of athlete training programs.

In order to gain the greatest benefits from assessment of AT in athletes, specificity of the test is essential (Åstrand, 1984; Edgren et al., 1976; Thoden, Wilson & MacDougall, 1982). Specificity refers to the degree of similarity, between the actual sport performance and the protocol designed to predict or measure the performance ability of that individual, from a biomechanical, motor, and physiologic perspective. For example, cyclists are tested on the bicycle ergometer (Coyle, Coggan, Hopper & Walters, 1988; McLellan & Gass, 1989b), kayakers and canoeists on upper body ergometers (Tesch, Piehl, Wilson & Karlsson, 1976; Tesch & Lindeberg, 1984) and runners on the treadmill (Withers, Sherman, Miller & Costill, 1981). Present methods of measuring anaerobic threshold measurements lack specificity. Ideally, such anaerobic threshold measurements would take place during actual skiing. This is an impractical approach since field measurements of physiologic values are subject to external influences such as temperature changes, varying snow conditions, and differing wax preparations which do not allow accurate inter- and intra-athlete comparisons. The lab test is the best compromise because it allows reproducibility and the control of the above-mentioned variables. The preferred lab

measurement would be one which most closely simulates the exact ski movement and force production pattern. The skimill used in this study incorporated upper body work which provided total body exercise in a movement pattern which simulated cross country skiing. Validation of the skimill was accomplished in another study which compared the physiologic response of ski walking on the treadmill with that of the skimill.

AT is frequently measured in endurance athletes using incremental graded tests with protocols that vary greatly in work load and stage length (Nemoto, Iwaoka, Funato, Yoshioka & Miyashita, 1988; Ribeiro et al., 1986). These tests are also referred to as intermittent, step function, or progressive tests. It is questionable whether such tests accurately reflect the steady state condition found during many endurance sports, as the physiologic response at each stage also reflects the one or two previous work intervals. Additionally, athlete response to change in work load has been shown to be quite individual (Coyle et al., 1988; Kuipers, Keizer, de Vries, van Rijthoven & Wijts, 1988). Fast and slow responders to increasing work loads may have markedly different results during progressive exercise tests (Whipp, Davis, Torres & Wasserman, 1981).

The use of fixed lactate values do not account for individual differences in physiological makeup and test response (Aunola & Rusko, 1984). Assessments which use a progressive protocol that consists of short loading intervals or long breaks between intervals may significantly alter the kinetics and affect blood and/or ventilation measurements at given workloads (Davis et al., 1983) thus impairing the test's predictive ability.

STATEMENT OF THE PROBLEM

There is a need to develop a reliable, accurate, interpretable test of endurance athlete training status. Progressive tests are commonly used to assess steady state performance

capabilities. The degree to which progressive tests reflected actual physiologic measures of performance during a 10 minute constant load test, and the extent of the similarity between 10 and 20 minute constant load tests were the primary concerns of this study. Currently there are a myriad number of protocols in use to assess anaerobic threshold (Haverty, Kenney & Hodgson, 1988; Jacobs & Sjödín, 1985b; Stegmann & Kindermann, 1982). Progressive test protocols may utilize continuous or discontinuous ramp or step functions to increase workloads. Steady state tests are typically constant load tests and may be continuous or discontinuous.

This study examined the appropriateness of the progressive test and its applicability to endurance ski racers in terms of reflecting actual physiologic responses of submaximal performance during steady state conditions designed to closely simulate competition. The purpose of the study was two-fold:

1. To determine if a discontinuous progressive protocol using four minute increments and one minute pauses was able to accurately reflect physiologic measures during the equivalent load for a constant test using ten minute intervals.

2. To ascertain if significant changes in physiologic response occurred between the tenth and twentieth minute of constant load exercise while cross-country skiing on the skimill.

ASSUMPTIONS

It was assumed that the individuals involved in the testing were sufficiently motivated and at a competitive level which necessitated their continued training in the period prior to the testing period which occurred at the beginning of the racing season. Since all athletes were from the same provincial association it was also assumed that they undertook a common manner of preparation due to climatic and racing season similarities.

For the purpose of the progressive test the lactate threshold was assumed to be equivalent to the exercise intensity producing a significant departure from linearity of the blood lactate response over time. The chosen or standard reference grade of the skimill was the elevation corresponding to the interpolated lactate value from the lactate response curve and confirmed by subjective assessment.

DELIMITATIONS

The study focused entirely on the submaximal index of performance (anaerobic threshold) of competitive cross-country ski racers as measured during discontinuous progressive step tests and constant load steady state tests. Therefore results were only applicable to ski racers and similarly trained endurance athletes.

LIMITATIONS

The absence of the control of the time of the test was a limitation in this study. Another limitation, albeit a necessary one, was the test order. The progressive test always preceded the steady state test. This, however, was necessary since the predicted workload for the steady state test was based on a determination made from measurements during the progressive test. Validation of the skimill was accomplished in a study which compared the physiologic response of ski walking on the treadmill with that of the skimill. Differences in the friction coefficient between snow and carpet meant that the skiing technique varied although the contribution of total body musculature to both activities was similar. Another limitation in this study was the use of a random, not randomized, testing schedule. Athletes were tested when it was convenient for them as long as adherence to other testing requirements was maintained.

DEFINITION OF TERMS

Threshold:

Refers to a significant departure from linearity or a non-linear increase in certain physiologic measures.

Ventilation Threshold:

(VT) Either the oxygen uptake at which a significant and continual non-linear increase in minute ventilation occurs or the minimum oxygen uptake at which carbon dioxide release increases abruptly.

Lactate Threshold:

(LT) The maximum oxygen uptake beyond which a significant increase in blood lactate accumulation occurs.

Anaerobic Threshold:

(AT) Refers to either the VT or the LT as commonly measured during a progressive test.

Individual Anaerobic Threshold:

(IAT) The maximum oxygen uptake at which rate of lactate diffusion from the muscle to the blood is in equilibrium with the rate of elimination as determined from individual blood inclination rates (Stegmann, Kindermann & Schnabel, 1981).

Onset of Blood Lactate Accumulation:

(OBLA) The maximum workload at which lactate reaches $4\text{-mMol}\cdot\text{L}^{-1}$ for a continuous, progressive test with 4 minute stages (Jacobs, Sjödin & Scheele, 1983).

Standard Reference Grade:

The elevation determined in the progressive test and used in the steady state format which corresponded to the location of significant departure from linearity for the

blood lactate response with time. This grade was also considered to be equivalent to the anaerobic threshold and was determined by interpolation (Heck et al., 1985; Stegmann et al., 1982), and confirmed by subjective assessment.

Chapter 2

REVIEW OF LITERATURE

INTRODUCTION

Metabolic parameters are measured routinely in exercise physiology research. To facilitate comparisons between various studies and to make plasma lactate values more meaningful, attention must be given to the effects of different protocols on the physiologic response to exercise as it relates to endurance performance. The following review describes research pertinent to cardiac and metabolic measures in order to ascertain implications for the testing and training of elite cross-country ski racers and other endurance athletes. Particular emphasis will be given to the lactate response to exercise since this area has not been addressed in previous research in the same depth as the ventilation and gas exchange reaction to various exercise procedures as they pertain to endurance capacity.

ANAEROBIC THRESHOLD

The AT concept evolved as a result of scientific desire to understand human endurance capacity. Hill first noted a relationship between blood lactate and oxygen uptake during muscular work in 1924 (Hollmann, 1985; Stremel, 1984). Before the next decade Owles discovered the existence of an individual, activity specific blood lactate threshold value during exercise (Stremel, 1984). The development of rapid gas analysis instrumentation prompted the use of gas measurements simultaneous with lactate testing in exercise.

Naimark et al. (1964) first defined 'anaerobic threshold' as the abrupt increase in the respiratory exchange ratio from linearity during a progressive test. Since that time many definitions of AT and methods of measuring the same have been used (Hollmann, 1985;

Kindermann, Simon & Keul, 1979). Controversy surrounding the term AT is significant (Brooks, 1985b; Davis, 1985b; Gardner, Yeh, Crapo, Yanowitz & Adams, 1984). Research which contributes to a greater understanding of the physiologic response during submaximal exercise may clarify the issue.

The idea that a single, or fixed, blood lactate value could represent a common response to exercise first found favour because of its possible association with an endurance threshold. Different lactate values, ranging from one to four $\text{mMol}\cdot\text{L}^{-1}$, were used by various researchers and came to portray different states of endurance capacity. The use of a fixed lactate threshold, initially popular for its simplicity and apparent reflection of human physiologic response to endurance work (Heck et al., 1985; Sjödín, Jacobs & Svedenhag, 1982), has largely been supplanted by more individually sensitive approaches (Stegmann et al., 1981). The fact that the anaerobic threshold and fixed lactates are not related (Buchanan & Weltman, 1985; Davis, Bassett, Hughes & Gass, 1983; Davis et al., 1983) has been well documented. Furthermore, Tanaka and Matsuura (1984a), have shown that the running velocity at the AT was significantly better at predicting marathon running velocity than the running velocity at 4 $\text{mMol}\cdot\text{L}^{-1}$ lactate. The shift in emphasis from a fixed lactate threshold to individual determinations acknowledges that the lactate response to exercise is a complex phenomenon which includes many constituents (Von Lehmann, Wybitul, Schmid & Keul, 1983). Some of the accepted elements include the effect of nutrition (Quirion et al., 1988), glycogen depletion by exercise or diet (Greenhaff, Gleeson & Maughan, 1988; Jacobs, 1986), training status (Jacobs, 1986), the severity of work performed in the days prior to testing (Foster, Snyder, Thompson & Kuettel, 1988; Saltin, 1981; Vøllestad & Blom, 1985), altering the work interval (Heck et al., 1985), velocity (Buchanan et al., 1985; Hughson & Green, 1982a) or mode of exercise (Costa et

al., 1989; Jacobs et al., 1985b). The lactate threshold will vary with type of training (Sprynarova, 1980) and years of training (Coyle et al., 1988).

Several other factors which can affect the measurement of blood lactate include the site of sampling (Jacobs, 1986; Yoshida, 1984; Yoshida, Suda & Takeuchi, 1982a; Yoshida, Takeuchi & Suda, 1982b), alterations in pedal frequency (Hughes, Turner & Brooks, 1982), the type of exercise test and conditions under which it was performed (Hartley & Saltin, 1969; Heck et al., 1985; Wong et al., 1985), the rate of work increase (Jacobs, 1986) as well as the composition of the active muscle bed (Ivy, Withers, Van Handel, Elger & Costill, 1980; Kelso, Hodgson, Visscher & Gollnick, 1987; Tesch & Karlsson, 1985), its blood flow, and sampling time (Graham, 1978). In addition, the training state (Denis et al., 1988; Poole & Gaesser, 1985; Yoshida et al., 1982b), muscle capillarization (Jacobs et al., 1983), muscle enzyme levels (Aunola et al., 1988; Macková et al., 1983; Rusko, Rahkila & Karvinen, 1980; Sprynarova, 1980), muscle fibre type (Jacobs et al., 1983; Tesch et al., 1976), mitochondrial levels (Von Schön, Hollmann, Liesen & Waterloh, 1980) can all vary greatly between individuals.

Although both the lactate and ventilatory thresholds have been used to determine AT, they are distinct and separate events (Scheen, Juchmes & Cession-Fossion, 1981) that can be dissociated by training (Costa et al., 1989; Fric et al., 1988; Kuipers et al., 1988), glycogen depletion due to exercise or diet (Greenhaff et al., 1988; Jacobs, 1986), changing the interval length (Heck et al., 1985), velocity (Buchanan et al., 1985; Hughson et al., 1982a) or mode of exercise (Costa et al., 1989; Jacobs et al., 1985b).

LACTATE KINETICS

Blood lactate measurements at rest or during exercise reflect net lactate values – the difference between lactate production and removal (Brooks, 1985a; Connor, Woods, Ledingham & Murray, 1982; Heck et al., 1985).

Production

In the transition from rest to exercise the initial energy requirements turn over free adenosine triphosphate (ATP) rapidly. This stimulates ATP production via the transfer of a phosphate group from phosphocreatine to adenosine diphosphate (ADP). Depletion of phosphocreatine initiates glycolysis which produces pyruvate. The regulatory link between glycolysis and the electron transport system is a result of O₂ limited maximum mitochondrial respiration (Hochachka, 1988). Katz (1988) proposed that the increases in P_i and ADP stimulate glycolysis and the resultant increase in cytosolic NADH will shift LDH equilibrium toward an increased lactate production.

Stainsby (1986) studied muscle fibres and proposed that activation of glycolysis exceeded that of oxidative phosphorylation and caused a temporary increase of cytoplasmic NADH in the presence of pyruvic acid and a net formation of lactic acid. Katz et al. (1986), also studied glycolysis at the muscle fibre level and made several observations. He discovered that muscle fiber composition is a major determinant of the ATP turnover rate. Secondly he noted that the increase in prephosphofructokinase intermediates is important for stimulating glycolysis during contraction, the enzymes for which are pH sensitive (Alberti & Cuthbert, 1982). Finally, Katz and his colleagues reported that low creatine phosphate content contributed more to fatigue than high lactate content.

Research involving in situ red muscle contraction has shown (Connett, Gayeski & Honig, 1986) that the efflux of lactate cannot be explained by the intracellular P_{O₂} since the

drop in P_{O_2} would not be significant for a maximally respiring mitochondrion. Connett (1987) also found that changes in cytosolic pH and free [ADP] and [AMP] can account for the initial burst of glycolysis during the rest to work transition in red muscle. Researchers who argue that cellular metabolism, not respiration, is P_{O_2} dependent must recognize that P_{O_2} drops only a few hundredths of a Torr between cytosol and mitochondrion (Clark, Clark, Connett, Gayeski & Honig, 1987). O_2 delivery in normal working muscle is not rate limited by a single step but is better regarded as a family of steady states (Wittenberg & Wittenberg, 1989). P_{O_2} greater than or equal to 0.5 Torr is sufficient to support a maximal \dot{V}_{O_2} and energy demand (Gayeski, Connett & Honig, 1987). \dot{V}_{O_2} over a wide range of P_{O_2} was well correlated with the concentration ratio of phosphocreatine to free creatine.

The ratio of lactate to pyruvate production has come to indicate the degree of glycolysis occurring. The ratio is affected by both the rate of production and rate of removal of lactate, which not only depends on events outside of the reaction but on levels of lactate dehydrogenase (LDH). When considering specific workloads, data regarding the lactate-pyruvate ratio is contradictory. Bhattacharya et al. (1983) found that the lactate-pyruvate ratio increased in short and long distance runners but not in middle distance runners following treadmill exercise. Hollmann and Kastner (1969), however, noted that in endurance trained subjects that after an initial fall the ratio rises but not to the same extent as in untrained subjects. Wasserman et al. (1986), reported that lactate concentration increased during work at constant rates, and that above a threshold value increases in the lactate-pyruvate ratio occurred. He also noted that for work loads below the AT changes in lactate were due to an increased rate of glycolysis, while above the threshold the change in cell redox state was the primary determinant. The sub threshold lactate adjustments were due to substrate concentrations and those above AT were because of a reduction in free electrons.

Performance with respect to hyper-, hypo-, and normoxia has been extensively studied. Adams (1980) has recorded longer exercise times for hyperoxia than normoxia or hypoxia. The higher inspired oxygen fractions were associated with decreases in lactic acid concentrations and pH, while at the same time, P_{CO_2} and HCO_3 concentrations increased. Contrary to Adams, Yoshida (1989) found pH decreased more markedly during hypoxia. While studying hyperoxic, normoxic, and hypoxic conditions individually, Hogan et al. (1983) found that \dot{V}_{O_2} was not significantly different at any work rate during cycle ergometry. However, lactate concentrations were significantly lower during hyperoxia and significantly higher during hypoxia compared with normoxia. Findings by Bouissou (1987) included similar peak blood lactate concentrations in both normoxia and in hypoxia following 30 minutes of exercise. By the end of the exercise, however, lactic acid concentration was significantly higher in hypoxic than in normoxic conditions. Graham (1978) contradicted this view by demonstrating that hypoxia was not the cause of the lactate production during exercise. His position has been supported by others who have shown that lactate efflux is not due to anoxia or hypoxia (Clark et al., 1987; Gayeski, Connett & Honig, 1985) but depends on blood flow (Connett, Gayeski & Honig, 1985).

There is considerable debate in the current literature regarding the relationship between the oxygen kinetics, P_{O_2} , and lactate accumulation. Contributors to the viewpoint that decreasing O_2 stores accelerate O_2 kinetics include Di Prampero (1983) who found that \dot{V}_{O_2} on-responses were faster in hypoxic situations than while air breathing and Paganelli (1989) whose research supported the view that the local depletion of O_2 and/or phosphate stores played an important role in determining the kinetics of \dot{V}_{O_2} adjustment to exercise by significantly decreasing the half time of the \dot{V}_{O_2} on-response. The opposing position states that the effect of exercise on oxygen content prior to activity delays the oxygen uptake kinetics for step-wise increases in power output (Hughson & Morrissey, 1982b). The

reduced time for the \dot{V}_{O_2} on-response is paralleled by an early lactate accumulation which is both variable and transient. Training shortens the response time and reduces early lactate release (Cerretelli, Rennie & Pendergast, 1980).

Removal

To ensure optimal performance the body must deal with excess lactates. The heart (Drake, Haines & Noble, 1980; Gertz et al., 1981; Rose & Goresky, 1977), the kidney (Davis, 1985a; Yudkin & Cohen, 1975), the liver (Lloyd et al., 1973; Rowell, Blackmon & Bruce, 1964), and skeletal muscle (Brooks, 1985b; Brooks, 1986; Ozolin, 1986) are able to metabolize lactate. A major factor affecting lactate uptake by these organs is a declining pH (Alberti et al., 1982). Yudkin and Cohen (1975) showed that as acidity of the blood increased the kidney contributed significantly to lactate removal. The effect of declining pH on the liver was the opposite to that of the kidney below pH 7.0. At this level the liver began producing lactate (Lloyd et al., 1973). Rowell et al. (1964) discovered great individual differences in both liver clearance rates and estimated hepatic blood flow (EHBF). They found EHBF corresponded with the relative metabolic demand and noted it occurred at about 50% of the \dot{V}_{O_2} max in sedentary man, approximately the level of the AT (Blachura, Emmerich, Stoklosa & Plucinska, 1984; Nemoto & Miyashita, 1980).

Jorfeldt et al. (1978) noted that lactate release from muscle peaked at approximately $4\text{-}5 \text{ mMol}\cdot\text{L}^{-1}\cdot\text{min}^{-1}$. The plateau which follows indicates a maximal rate of lactate release that is impeded by translocation hindrances within the exercising muscles themselves. Tesch et al. (1982) determined that great variability in the muscle-blood lactate gradient exists among individuals when submaximal steady-state exercise is performed at a fixed blood lactate level. Green et al. (1983) confirmed what Hermansen and Stensvold had shown (1972), i.e., that the blood lactate response lags significantly behind the muscle

lactate response to exercise. The time lapse varies from 2-7 minutes (Stainsby, 1986; Tzankoff & Norris, 1979). Considerable inter-individual variability is also apparent between subjects. Exercise at levels up to 70% $\dot{V}_{O_2 \max}$ showed declining muscle lactates, but at 90% $\dot{V}_{O_2 \max}$ lactate accumulated intramuscularly (Jorfeldt et al., 1978). The reason for lactate storage suggested by Sacks and Sacks (Jorfeldt et al., 1978) was that the intracellular region is the most efficient buffering system for acids. Therefore a very significant volume of lactate could be stored during periods of severe exercise.

Catecholamines have been shown to significantly affect the accumulation of blood lactate during exercise under hypoxic and normoxic conditions. Bouissou (1987) found the effect of infused catecholamines to be similar for both conditions however, the higher [LCT] during hypoxic exercise seemed to reflect the rate of removal rather than the rate of production. Heart rate, \dot{V}_E , RER, and [LCT] increased after the infusion of epinephrine although no significant changes in \dot{V}_{O_2} occurred (Scheen & Lemaire, 1983). Scheen also found that the ventilation threshold appeared at a lower intensity, and for a higher plasma lactate level, following infusion of epinephrine. Since it has been found that plasma levels of endogenous catecholamine are positively related to active muscle mass (Lewis et al., 1983) it can be inferred that lactate levels will also be increased. Significant rises in epinephrine and norepinephrine levels have been demonstrated to occur throughout 50 minutes of exercise (Schnabel, Kindermann, Schmitt, Biro & Stegmann, 1982).

Lactate extraction also takes place in skeletal muscle (Ozolin, 1986). Hermansen and Stensvold (1972) have demonstrated that this is the primary site of removal during exercise, the principal form of removal being oxidation (Brooks, 1986; Mazzeo, Brooks, Schoeller & Budinger, 1986). Brooks (1986) measured the lactate shuttle during exercise and recovery. He noted that the turnover rate of lactate during exercise at 50% and 75% $\dot{V}_{O_2 \max}$ was a linear relationship. At exercise levels causing significant increases in

arterial lactate the inactive arm muscles (cycling exercise) extracted lactate (Brooks, 1986). About half the lactate produced in a working muscle by fast glycolytic fibres is oxidized by slow twitch or fast oxidative glycolytic fibers. Hollman (1985) and Essen (Davis, 1985a) have shown that non-exercising muscle can also metabolize lactate. Lactate turnover, it appears, is related to metabolic rate. Normal individuals have optimal lactate clearance rates of 25% \dot{V}_{O_2} max while trained subjects demonstrate the best removal of lactate at work rates of (30-40)% \dot{V}_{O_2} max (Connor et al., 1982). These values represent approximately 50% of the anaerobic threshold values in both untrained and trained individuals.

PROGRESSIVE TESTS

Progressive exercise tests, which have long been popular for the determination of maximal performance and the prediction of running performance at short distances (Haverty et al., 1988), are also commonly used to evaluate endurance performance (Orok, Hughson, Green & Thomson, 1989). The many protocols in use make comparisons difficult as differing work loads, exercise intervals and loading rates yield disparate lactate curves and threshold values in graded exercise tests (Heck et al., 1985).

Subject response to exercise is strongly related to the length of the work interval. Progressive test stages can take the form of ramp loading (Whipp et al., 1981) or increments which vary from 15 seconds (Fairshier et al., 1983; Whipp et al., 1981) up to six minutes (Hollmann et al., 1969) in duration. The use of short stages reduces interval length and increases the rate of loading. The increase in loading rate produces a distinct dissociation of the lactate and respiratory responses (Acevedo & Goldfarb, 1989; Poole et al., 1985; Scheen et al., 1981). Such procedures yield gas exchange values which are neither reproducible nor comparable to peak blood lactate (Busse, Muller, Boning & Bocker, 1984). Protocols which use short incrementation intervals will result in non-steady

state values that lag behind equilibrium values (Whipp & Wasserman, 1986b). Ignoring the effect of loading length results in temporary CO₂ storage in body tissues which complicates gas exchange parameters even at sub anaerobic threshold workloads. In spite of this, Yoshida (1984), found no significant differences between one and four minutes incremental test for ventilatory or lactate concentration for the same workload. By increasing the length of intervals from three to five and one-half minutes the work at the AT decreases by 4-6% (Kindermann, Schramm & Keul, 1980; Yoshida, 1984) revealing that significant manipulations of the AT are possible and result in threshold dissociation.

Insertion of a rest period between exercise intervals can dramatically affect the metabolic and cardiac response to exercise. Fardy and Hellerstein (1978) found a diminished \dot{V}_{O_2} and cardiac response with intermittent tests at both moderate and heavy exercise intensities. Pauses also result in the accumulation of lactate during progressive tests (Rieu, Miladi, Ferry & Duvallat, 1989). For example, Rodahl and colleagues (1964) found that the response to intermittent work was a slight increase in lactate compared to continuous activity but, contrary to expectations, a greater free fatty acid (FFA) release. The increase in FFA release appears to indicate that lactate removal was affected by the progressive protocol and not lactate production. The length of the rest period has also been found to affect lactate accumulation. Progressive incremental tests result in an overproportional lactate increase at submaximal-maximal workloads for cumulative versus discontinuous exercise protocols (Lehmann, Schmid & Keul, 1985) but no significant lactate differences are found at moderate workloads. Although ten second pauses yield lactates similar to continuous work, the inclusion of 30 second rest periods following swimming exercise of the equivalent velocity and interval length result in significant declines in lactic acid (Olbrecht, Madsen, Mader, Liesen & Hollmann, 1985). Fardy et al. (1978) found significantly lower oxygen uptake, heart rate, and \dot{V}_E , and RER for

intermittent than for continuous treadmill tests in the first and second minutes of three minute stages but greater during all three minutes at moderate and strenuous loads.

Ventilation Threshold

There is a lack of consensus regarding the value of that the progressive ventilation threshold measure as a good predictor of endurance performance (Powers, Dodd & Garner, 1984). It is believed, however, that long term ventilation threshold determinations are superior to short term measures as indicators of endurance ability (Ghesquiere et al., 1982; Reybrouck, Ghesquiere, Cattaert, Fagard & Amery, 1983). The usefulness of the AT as a predictor of endurance performance has also been demonstrated in several studies (Kumagai et al., 1982; Tanaka et al., 1984b; Tanaka et al., 1983). Measures of the ventilation threshold have been demonstrated to be dissociated from the lactate threshold (Powers et al., 1984). Reybrouck et al. (1986) consider long term ventilatory threshold measures superior to maximum oxygen uptake determinations. McLellan (1985) places equal value on both ventilation threshold and $\text{VO}_2 \text{ max}$ measures as indicators of endurance ability although Hurley et al. (1984) consider adaptations to the training of both to be somewhat independent of those responsible for lower blood lactate levels during submaximal exercise. It is concluded that the ventilation threshold for long term exercise is a more specific measure of accounting for running performance than is the threshold during graded exercise. McLellan (1985) notes that the first and second ventilation thresholds are not influenced by the duration of step increment whereas the determination of IAT may be misinterpreted with a fast incremental test. Poole and Gaesser (1985) showed that although interval training is more effective in improving the ventilation threshold, both continuous and interval training are equally effective in improving the lactate threshold. Training therefore causes a dissociation between VT and LT.

Lactate Threshold

Although the majority of studies have employed progressive exercise protocols to measure AT, there is increasing evidence that steady state tests are more effective (Reybrouck et al., 1986) since progressive tests are subject to significant individual response variation (Hughson & Inman, 1986). The short duration typical of progressive tests does not provide adequate time for either the attainment of gas exchange or lactate equilibrium, therefore true measures of physiologic responses are not available. Constant load intervals yield initial rises in lactates which then stay relatively constant for the duration of exercise, while cardiac frequency exhibits a small steady increase throughout (Kindermann et al., 1979). The lactate threshold (Boutcher et al., 1989) occurs at a higher work rate after training. Chwalbinska-Moneta et al. (1989b) noted that muscle and blood lactate concentrations are highly correlated, reporting muscle-to-blood lactate ratios at below-OBLA stage; at OBLA, and above-OBLA stages to be 0.74, 0.63, and 0.96, respectively. The lactate threshold is significantly affected by the proportion of slow twitch fibres and muscle respiratory capacity (Ivy et al., 1980). Over 92% of endurance performance variance was related to the $\% \dot{V}_{O_2 \max}$ at LT and to the muscle capillary density (Coyle et al., 1988). Slow twitch fiber composition varies directly with training level, yet in spite of equal maximum oxygen uptakes the endurance performance can differ significantly (Coyle et al., 1988).

STEADY STATE TESTS

Lactate threshold measurement during steady state exercise is valuable since it mirrors the metabolic and ventilatory responses (Reybrouck et al., 1986; Ribeiro et al., 1986). The use of long term exercise thresholds therefore, provides a measure of running

performance superior to those obtained during graded tests (Haverty et al., 1988; Reybrouck & Ghesquiere, 1984; Reybrouck et al., 1983). Ghesquiere et al. (1982) showed that the threshold determined during steady state work is a better predictor of endurance performance than the threshold measured during progressive tests.

The length of time required to reach steady state is directly related to work intensity (Whipp, Ward & Wasserman, 1972). Although steady state for O_2 uptake can be attained within three minutes for moderate exercise (Casaburi, Storer, Ben-Dov & Wasserman, 1987), three minutes is insufficient time for equilibration at heavier workloads (Casaburi et al., 1987; Whipp, Ward & Wasserman, 1986a). The relationship between \dot{V}_E and \dot{V}_{O_2} is unchanged at workloads below steady state (Davis, Whipp & Wasserman, 1980).

In response to steady state exercise, blood lactates increase initially and then gradually decline. In one study, 30 minutes of constant load exercise at 65-70% of $\dot{V}_{O_2 \max}$ resulted in blood lactate elevations which peaked within five minutes and then gradually declined to the end of the interval (Hollmann et al., 1969). Rowell et al. (1966), found that arterial venous lactate peaked in the first 10 minutes of prolonged exercise (>1 hr). Orok et al. (1989) found that lactates were consistently higher during prolonged exercise at both 60% and 80% $\dot{V}_{O_2 \max}$ than those observed at the same work rate during progressive exercise. He noted a continuing increase in lactate uptake across resting muscle at work rates above threshold some of which was attributable to sink-like properties. Schnabel et al. (1982) reported that subjects exercising at threshold for 50 minutes had constant arterial glucose levels, and an increase in free fatty acid blood levels, between minutes 25 and 50 in the face of stable elevated lactates. Blood lactate declines have also been noted after 40 minutes of constant velocity treadmill exercise (Gass et al., 1983). Kindermann et al. (1979), found that during 30 minute work intervals at a load where lactates were held constant, cardiac frequency drifted from 165 up to 175 beats per minute.

That elevated lactates remain stable in the face of rising FFA has been demonstrated (Schnabel et al., 1982) since glycerol increases of 157% above the pre-exercise values were noted.

TEST SPECIFICITY

The use of steady state tests should, where possible, closely match the demands of the sport activity of the athlete and reduce the effects of outside influences. The applicability of the AT demonstrated for runners, cyclists, kayakers, rowers, and other endurance athletes has been shown to depend on the specificity of the sport (Niinimaa, Shephard & Dyon, 1979), type of training (Simon et al., 1979), and the level of training (Coyle et al., 1988). The importance of test specificity cannot be ignored (Åstrand, 1984; Edgren et al., 1976) whether one is measuring ventilation (Bunc, Heller, Leso, Sprynarova & Zdanowicz, 1987; Gray, 1981), activity with varying contributions of lower and upper body work, (Bergh, Kanstrup & Ekblom, 1976; Boutcher et al., 1989; Secher, Clausen, Klausen, Noer & Trap-Jensen, 1977) or highly sport-specific activities (Ridge, Pyke & Roberts, 1976; Vrijens, Hoekstra, Bouckaert & Van Uytvanck, 1975; Withers et al., 1981).

The contribution of upper body work and additional equipment use introduces complications to the measurement of the submaximal threshold in skiers (Von Lehmann et al., 1983). For example, Von Simon (1979) found lower heart rates for cross country skiers during progressive treadmill exercise at the AT compared to roller-skiing and cross-country ski training due to the additional upper body work. Niinimaa et al. (1979) showed that skill is also an important factor since only the most experienced skiers were able to operate at an intensity approaching maximal oxygen uptake. The type of training significantly affects aerobic capacity as well. For example endurance capacity declines

significantly at the end of the competitive season compared to summer training due to the lack of endurance work during competitions. The sensitivity of the metabolic and cardiac responses to the sport-specific activities described above underscores the importance of conducting athlete testing in conditions and activities that mimic the sport as closely as possible.

Chapter 3

METHODS AND PROCEDURES

This chapter contains sections describing subjects, protocol, experimental design, methodology, instrumentation and data collection, and statistical analysis. Data from all skiers were not complete; in order to obtain maximal information for each test it was necessary to report test data separately as Part A and Part B. Sixteen athletes were common to both parts. Part A was a comparison of a progressive discontinuous interval and a longer steady state simulated skiing test. Part B compared the physiologic response of simulated nordic skiing at ten and twenty minutes of constant load exercise. The communication to the subjects found in the appendices contains details and procedures not followed in this study but which were relevant to another study performed with the same group of subjects.

PART A

Sixteen competitive skiers took part in the study, 13 males and 3 females. The subjects included provincial (9), and master (7) athletes. Provincial athletes were recommended by the coach and master athletes volunteered. All subjects completed an informed consent form and were screened using a Physical Activity Readiness Questionnaire (Par-Q). The physical characteristics of the subjects, and ski racing experience are listed in Table 1.

PART B

Nineteen competitive skiers took part in this study, 14 males and 5 females. The subjects included provincial (11), and master (8) athletes. Provincial athletes were

recommended by the coach and master athletes volunteered. All subjects completed an informed consent form and were screened using a Physical Activity Readiness Questionnaire (Par-Q). The physical characteristics of the subjects, and ski racing experience are listed in Table 2.

PROTOCOL

Participants refrained from alcohol, caffeine, and smoking for at least two hours prior to testing. Height, weight and the sum of four skinfold thicknesses (biceps, triceps, subscapula, and suprailiac crest (Fitness and Amateur Sport Canada, 1986)), were recorded. Body density was measured by underwater weighing using at least three trials and body fat was calculated using the equation of Brozek (1963). Residual volume was estimated from vital capacity (Wilmore, 1969). These tests were conducted on the first visit to the laboratory. Tests were conducted in October and November and the training emphasis prior to trials centered on ski-specific training. Some athletes were involved in summer competitive cycling, rowing, or canoeing which resulted in a higher training intensity in the prior preparation phase.

After a familiarization session on the skimill each subject performed a progressive and a steady state test. Tests were separated by 7 ± 1 days, and did not take place immediately after races or hard training in order to minimize lactate threshold changes. The progressive test was conducted at a constant velocity of $7.25 \text{ km} \cdot \text{hr}^{-1}$ and consisted of 4% increments every four minutes beginning at 0% elevation. Blood lactate samples were taken from the hyperemized ear (Heck et al., 1985) immediately after each interval and post-exercise.

The standard reference elevation determined from the progressive test was used for the steady state test. Work intervals for the steady state test were ten minutes and elevation

increments ranged from 0 to 1% after the completion of two stages provided that lactate measures were not increasing. Velocity was constant at 7.25 km·hr⁻¹. Ventilation, heart rate, and blood lactate measurements were taken at the end of the ten minute stages. If the second lactate measurement at the same workload did not exceed the first then the slope was increased by 1%. This was repeated until the lactate climbed steadily and the subject was not able to proceed for the complete interval. Although only the first two steady state intervals were compared steady state skiing lasted between 40 and 55 minutes to ensure that athletes were not working beyond their submaximal threshold.

DATA COLLECTION AND INSTRUMENTATION

Respiratory data was determined from mixed gases during the final 30 seconds of each workload for the progressive and steady state tests. \dot{V}_{O_2} STPD, RER, \dot{V}_E BTPS, f , \dot{V}_T , and fraction of expired oxygen (FE_{O_2}) and carbon dioxide (FE_{CO_2}) were measured using the Sormedics Metabolic Measurement Cart (Horizon[®] System). Resting, exercise, and post-exercise heart rates (HR) were obtained from an electrocardiograph recorder (Cambridge VS4) using a CM5 lead, or from a portable heart rate recorder (Polar Electro 3000). Lactate concentration was determined by the YSI Model 27 Industrial Analyzer. Blood lactates were measured at the ear lobe hyperemized with Finalgon salve (Heck et al., 1985). Analysis of blood lactates was performed immediately after sampling by a technician on the YSI Model 27 Industrial Analyzer which combines immobilized enzyme technology with a linear electrochemical sensor. Hydrogen peroxide produced from substrates, catalyzed by a thin film of oxidase enzyme, is measured by electrochemical oxidation at the platinum anode (Yellow Springs Instrument Co., 1984). Calibration of the metabolic and lactate measurement systems was performed prior to and after each test .

Lactate analysis supplies included the L-Lactate Standard (R7230-7), and (R7230-9), buffer (B6042-6), L-lactate membranes (R7230-9) and potassium ferrocyanide (B6042-9) from American Scientific Products. The Skimill was an alpine skimill modified for nordic skiing with a medium shag carpet (1.8 M X 3.6 M) track surface. Shampooing before testing ensured a consistent surface with minimal friction. The belt was driven at $7.25 \text{ km}\cdot\text{hr}^{-1}$ by a 220 volt 5 H.P. electric motor (1750 rpm) with a 10:1 gear reduction. Grade was accurately controlled by two hydraulic rams using a slope meter. Classic racing skis and bamboo poles (125-157 cM) with specially milled nylon tips were used.

STATISTICAL ANALYSIS

Part A

A two-tailed t-test was used to determine differences between means for [LCT], HR, \dot{V}_{O_2} , \dot{V}_{CO_2} , and \dot{V}_E for the progressive and steady state tests at the reference elevation. A two-tailed t-test was also used to examine the difference between the progressive and steady state mean lactate values and OBLA. Tests were considered significant at the 0.05 level. A two-tailed test was selected because of disagreement in the literature about the difference between lactates measured during the progressive and steady state tests.

Part B

A one-tailed t-test was used to determine differences between means for [LCT], HR, \dot{V}_{O_2} , \dot{V}_{CO_2} , and \dot{V}_E for the tenth and twentieth minutes of the steady state tests at the reference elevation. A one-tailed t-test was also used to examine the difference between the mean lactate values and OBLA. Tests were considered significant at the 0.05 level. A

one-tailed t-test was used here since the lactates for the longer interval were hypothesized to be significantly lower than those measured during the first stage.

EXPERIMENTAL DESIGN

The research design met the criteria of the ethics committee and was approved by the "Committee on Research Involving Human Subjects". Specific instructions describing pre-test procedures were given to each athlete in order to reduce complications caused by the variables described in the immediately preceding introduction. The factors controlled were: 1) temperature, 2) intensity, duration, and proximity of previous workouts to the test, 3) proximity of food intake to test commencement, and, 4) convective air flow past the athlete during the test.

Chapter 4

RESULTS

Since lactate concentration did not differ significantly during either the progressive or the steady state testing and no significant differences between males and females were found for measurements during the progressive test, it was therefore decided to group data for both sexes. Some data are missing due to technical difficulties. Static electricity produced on the skimill resulted in a loss of some ventilatory and heart rate data. The loss of some lactate measures was due to lactate samples which had to be rejected when post-calibration tests on the analyzer revealed it was out of calibration.

PART A

Table 1.
Subject characteristics.

Parameter	Males	Females
Number (n)	13	3
Age (yr)	29.5±3.6	15.7±0.3
Experience (yr)	4.4±0.7	3.3±0.9
Height (cm)	174.5±2.0	163.2±6.1
Weight (Kg)	69.3±2.1	55.7±4.1
Body Fat (%) ¹	12.2±1.4	18.8±0.2

(\bar{x} ±SEM)¹ Estimated by skinfold and body density measurements (See Chapter 3 Methods and Procedures, p. 23).

Blood lactate and heart rate response to progressive and steady state tests at the reference workload.

Test Parameter	Progressive	Steady State
Elevation (%)	9.6±0.8	9.6±0.8
[LCT] (mMol·L ⁻¹)	5.66±0.83 (n=13)	4.42±0.53 (n=13)
HR (beats·min ⁻¹)	175.9.1±3.5 (n=10)	176.6±4.0 (n=10)

Two directional t-test (\bar{x} ±SEM; n=16).

Table 3.

Respiratory response to progressive and steady state tests at the reference workload.

Test Parameter	Progressive	Steady State
\dot{V}_E BTPS (L·min ⁻¹)	97.3±5.3	83.5±3.0*
f (breaths·min ⁻¹)	38.7±2.3	34.3±1.8*
\dot{V}_T (L)	2.58±0.14	2.48±0.13

* Sig. difference between P and SS ($p \leq 0.05$) Two directional t-test. (\bar{x} ±SEM; n=14).

Table 4.

Gas exchange response to progressive and steady state tests at the reference workload.

Test Parameter	Progressive	Steady State
$\dot{V}O_2$ STPD (L·min ⁻¹)	3.50±0.15	3.20±0.14
$\dot{V}CO_2$ STPD (L·min ⁻¹)	3.58±0.17	3.26±0.14*
RER	1.02±0.01	0.99±0.01*

* Sig. difference between P and SS ($p \leq 0.05$) Two directional t-test ($\bar{x} \pm SEM$; n=14).

The reference grade for the progressive (P) and steady state (SS) tests occurred at the mean elevation of $9.6 \pm 0.8\%$ ($\bar{x} \pm SEM$). The physiologic response at the reference elevation during the P and SS test is summarized in Tables 3 to 5. Progressive mean arterialized blood lactate ($[LCT]_P$) did not differ significantly from the SS value ($[LCT]_{SS}$). The two-tailed t-test for the difference between $[LCT]_P$ and OBLA and $[LCT]_{SS}$ and OBLA was not significant. The differences however between progressive and steady state RER, \dot{V}_E , and f were significant ($p \leq 0.05$). The chosen workload was within the submaximal range (aerobic to anaerobic threshold) as demonstrated by the ability of subjects to perform 4 ten minute intervals at the initial load or greater during the SS test.

PART B

Table 5.
Subject characteristics.

Parameter	Males	Females
Number (n)	14	5
Age (yr)	27.6±3.1	15.8±0.3
Experience (yr)	4.2±0.6	3.25±0.6
Height (cm)	172.8±2.3	164.6±4.5
Weight (Kg)	67.3±2.5	55.5±2.9
Body Fat (%)	12.2±3.1	19.4±0.6

(\bar{x} ±SEM).

The reference grade for Part B tests differed from the reference grade for Part A due to the addition of three athletes to the subject pool. [LCT]_{SS10} differed significantly from [LCT]_{SS20}. The HR_{SS10} versus HR_{SS20} was also significantly different. The physiologic response following 10 and 20 minutes at the reference elevation is compared in Tables 6 to 8. The one tailed t-test for the difference between [LCT]_{SS10}, [LCT]_{SS20} and OBLA was not significant. The chosen workload was within the submaximal range (aerobic to anaerobic threshold) as demonstrated by the ability of subjects to perform 4 ten minute intervals at the initial load or greater during the SS test.

Table 6.

Blood lactate and heart rate response to steady state tests at the reference workload.

Parameter	Steady State 10'	Steady State 20'
Elevation (%)	9.1±0.7	9.1±0.7
[LCT] (mMol·L ⁻¹)	4.51±0.47 (n=15)	4.12±0.50* (n=15)
HR (beats·min ⁻¹)	176.9±3.5 (n=13)	179.4±3.4* (n=13)

* Sig. diff. between SS 10' and SS 20' (p≤0.05) One directional t-test (\bar{x} ±SEM; n=18).

Table 7.

Respiratory responses to steady state tests at the reference workload.

Parameter	Steady State 10'	Steady State 20'
\dot{V}_E BTPS (L·min ⁻¹)	80.4±2.9	81.2±2.9
<i>f</i> (breaths·min ⁻¹)	34.5±1.7	35.5±1.8
\dot{V}_T (L)	2.39±0.13	2.39±0.15

One directional t-test (\bar{x} ±SEM; n=18).

Table 8.

Gas exchange response to steady state tests at the reference workload.

Parameter	Steady State 10'	Steady State 20'
\dot{V}_{O_2} -STPD (L·min ⁻¹)	3.14±0.15	3.10±0.15
\dot{V}_{CO_2} STPD (L·min ⁻¹)	3.10±0.14	3.04±0.14
RER	0.99±0.01	0.98±0.01

One directional t-test ($\bar{x} \pm \text{SEM}$; n=18).

Chapter 5

DISCUSSION

INTRODUCTION

Two main points will be discussed in this chapter: the first point is the relationship between the progressive tests, also referred to as an intermittent, incremental, or graded test, and the steady state or constant load test; this relationship has important implications for the use of progressive tests as a predictive device for steady state performance. The apparent agreement between the progressive and steady state test data for [LCT], heart rate, \dot{V}_T , and \dot{V}_{O_2} would suggest that progressive tests are acceptable protocols for predicting actual endurance performance. Second, the discussion considers the minimum constant-load interval-length which reflects actual steady state values for endurance performance.

The reliability and accuracy of the progressive test as a measure of actual steady state performance has not been tested by previous research for total body work during cross country skiing. Blood lactate, heart rate, and gas exchange values obtained during progressive tests are often used to establish training regimens for athletes preparing for competitions ranging in length from ten minutes to more than an hour. It is unclear, however, whether the submaximal measures obtained during progressive discontinuous tests reflect the physiologic response at the same load for a longer, steady state interval.

To prevent other factors from confounding the measurements of lactate concentration and ventilation, tests were conducted within 7 ± 1 days of each other. Athletes did not perform either a hard workout or competition within 24-48 hours of the trials, and they maintained a diet sufficiently high in carbohydrates, since it has been demonstrated

that glycogen depletion by exercise or dietary means can affect the lactate response to exercise (Greenhaff et al., 1988; Jacobs, Scheele & Sjödín, 1985a). Overproportional lactate and catecholamine increase (Lehmann et al., 1985) and complications in lactate and oxygen uptake kinetics occur for workloads greater than the anaerobic threshold (Hughson et al., 1986; Whipp et al., 1986b); therefore subjects exercised at the reference grade or greater for at least forty minutes (Schnabel et al., 1982; Stegmann et al., 1982; Stegmann et al., 1981) to ensure that workloads were less than or equal to the anaerobic threshold. The nordic skiers in this study produced lactate levels with a larger range than subjects who previously participated in either treadmill or cycle ergometer tests conducted at the anaerobic threshold (Buchfuhrer et al., 1983; Jacobs et al., 1985b; Stegmann et al., 1981). Although some lactates were higher than anticipated, the levels were not due to machine errors or time delay in analyzing the sample, since the equipment was well calibrated and lactate assessment took place immediately. The higher lactate levels were probably due to the fact that total body work was involved (Ang, 1984; Gleser, Horstman & Mellow, 1974; Vokac, Bell, Bautz-Holter & Rodahl, 1975), and that several of the athletes had performed a large amount of velocity training (Sprynarova, 1980).

TRAINING STATUS

All but one of the athletes in this study had actively endurance-trained on an annual basis for several years and had skied competitively for at least a year. Chwalbińska-Moneta et al. (1989b), Wasserman et al. (1985), and Hollman and Kastner (1969) found that muscle lactate concentrations reached a threshold for untrained individuals at approximately 50% of maximum \dot{V}_{O_2} and rose suddenly beyond that level. The group of subjects in this study demonstrated their training level since the lactate threshold response occurred at

greater than 75% of peak $\dot{V}O_2$ (Denis et al., 1988; Heck et al., 1985; Wasserman et al., 1985).

PROGRESSIVE VERSUS STEADY STATE TESTING

Exercise of varying intensities and durations places changing demands upon the organism. Unlike continuous tests, progressive tests with discrete load increases at set intervals allow the organism periods of metabolic adjustment. Obviously, the larger the increase in workload and the shorter the work interval the greater the metabolic stress of the activity.

The time to reach the standard reference elevation for the progressive test varied with the individual but the mean exercise time, including pauses, was 16.3 ± 1.0 minutes. This was considerably longer than the steady state exercise time of ten minutes. The major differences between the two tests were the discontinuity of the progressive test versus the continuous protocol of the steady state test, the duration of the interval used, and the rate of loading.

Heart Rate Response

The mean heart rates at the reference work load for P and SS tests did not vary significantly. Although the extended length of the P test would be expected to result in a higher heart rate due to the calorogenic effect (Chwalbinska-Moneta & Hänninen, 1989a; Sawka, Toner, Francesconi & Pandolf, 1983; Wyndham, McPherson & Munro, 1964), the discontinuity of the shorter exercise intervals plus the fact that the total work was less during the P test would result in a heart rate lower than measured for steady state exercise. Perhaps the sympathetic response was greater for the P test because of the shorter work intervals separated by pauses (Lehmann et al., 1985; Pluto et al., 1988). The SS interval of

only ten minutes was not long enough to require significant thermoregulatory adaptations, resulting in similar heart rates for both progressive and steady state tests at the reference workload (See Table 2).

Lactate Response

Mean lactate values for the progressive and steady state test did not differ significantly, yet there are numerous competing mechanisms manifesting themselves in the phenomena of a decreased rate of production for the progressive test and an increased rate of removal for the steady state test (See Table 2).

Phosphate regeneration, a lower total work, and a lower rate of work contribute to reduced production, whereas the increased removal rate appears to be due to the increased pause to work ratio and the lactate storage capacity of non-exercising muscle, as discussed in the review of literature.

Lactate levels are affected by increased catecholamines (Reed, 1985; Schnabel et al., 1982; Therminarias, Flore, Oddou-Chirpaz, Pellerei & Quirion, 1989), increased glycolysis as a response to demands for increased phosphate (Hultman, Sjöholm, Sahlin & Edström, 1981; Pluto et al., 1988; Wasserman et al., 1985), or a decreased removal rate (Boileau, Misner, Dykstra & Spitzer, 1983; Freund et al., 1989; Oyono-Enguelle et al., 1989). The lactate removal by exercising and non-exercising muscle (Cerretelli, Pendergast, Marconi & Piiper, 1986; Ozolin, 1986) is more likely greater for the steady state test than the progressive test since blood flow for the SS test exceeds the P test. Orok et al. (1989) found that lactate was consistently higher during prolonged exercise at both 60% and 80% $\dot{V}O_2$ max than for that observed at the same work rate during progressive exercise. The inactive muscle appeared to have lactate storage capacity as well.

The pauses during progressive tests normally result in early lactate accumulation (Rieu et al., 1989; Rodahl et al., 1964) compared to continuous activity. It should be noted here that increment lengths are often significantly shorter than the exercise stages of four minutes used in the present study. Olbrecht et al. (1985) found that for equal intervals of work each lasting two to three minutes, 10 second pauses resulted in lactate values resembling continuous activity, but 30 second pauses yielded lower lactates. The progressive test in the present study used one minute pauses, which, when combined with the relatively long work interval of four minutes would provide more than sufficient time for significant lactate removal to occur. Lactate production would also be lower than expected as recovery periods have been demonstrated to allow time for phosphocreatine regeneration (Olbrecht et al., 1985) and restoration of the ATP pool (Adolf, Nelson & Valentini, 1982; Katz et al., 1986; Sahlin & Ren, 1989). Indeed, the importance of the $[ATP]/([ADP] \cdot [Cr])$ ratio has been shown to be a significant factor with incremental tests (Stainsby, 1986; Von Mader, Heck, Liesen & Hollmann, 1983) as well as the ratio of $[NAD]/[NADH]$ (Stainsby, 1986).

The one minute pause and the shorter work interval of four minutes would be expected to result in lower lactate levels for the work than if it was performed continuously (Ferry, Duvallet & Rieu, 1988). Previously active but now non-exercising muscle mass obtains the opportunity to metabolize some of the lactate during the rest period (Ozolin, 1986). Any factor serving to increase the definite lag between the muscle lactate production and its release into the blood (Jorfeldt et al., 1978) could also contribute to lower blood lactate levels for intermittent as compared to continuous work.

The importance of considering the interval length cannot be overlooked. Increasing interval length from three to five and one-half minutes resulted in a decrease of AT by 4% to 6% (Kindermann et al., 1980). Progressive incremental tests result in an

overproportional lactate increase at submaximal-maximal workloads for cumulative versus discontinuous exercise protocols (Lehmann et al., 1985) but no significant lactate differences are found at moderate workloads. A similarity in ventilation parameters \dot{V}_E and f might have indicated a reduced breathing frequency (Yamamoto, Takei, Mutoh & Miyashita, 1988) which would be expected to result in a lower lactate concentration than that expected for incremental tests (See Table 3). Reduced ventilatory frequency may be due to a decreased drive to breathe which will occur as a result of pauses necessary for drawing blood samples. The fact that this phenomenon was not observed for the progressive tests in this study would indicate that other factors such as catecholamines (Reed, 1985; Schnabel et al., 1982; Therminarias et al., 1989) may have influenced ventilation since four minute intervals would be expected to provide sufficient time to allow physiologic values to approximate steady state at sub threshold levels (Whipp et al., 1986a) (See Table 3).

The release of muscle lactate into the blood varies greatly with the individual (Tesch et al., 1982; Tzankoff et al., 1979). Endurance training is positively related to a lowered lactate production (Denis et al., 1988; Tesch et al., 1984), a reduced hormonal and adrenergic response, and glycogenolysis more in line with actual needs (Gollnick, Bayly & Hodgson, 1986). The glycogen sparing effect and reduced lactate is a direct result of training (Favier, Constable, Chen & Holloszy, 1986). Discontinuous step function tests enhance threshold dissociation (Ferry et al., 1988). Given that there is a maximal rate of lactate release (Jorfeldt et al., 1978), altering the work interval length or inserting pauses between stages can seriously affect the lactate kinetics. Heck et al. (1985) showed that a two minute difference in work interval length significantly altered the velocity at the $4 \text{ mMol}\cdot\text{L}^{-1}$ threshold. Freund et al. (1989), considered lactate kinetic data to vary with time during exercise and that this must be taken into consideration when interpreting lactate

data. Short increment progressive tests (Buchfuhrer et al., 1983; Casaburi et al., 1987; James, Adams & Wilson, 1989; Kindermann et al., 1980; McLellan, 1985; McLellan & Gass, 1989a) or fast ramp protocols (Whipp et al., 1986b) are not capable of reliably measuring anaerobic threshold.

In spite of the significantly shorter total work period during the steady state test, there was greater time for adaptation at each constant workload. An initial very sharp rise in lactate production declined as metabolic adjustments were made to accommodate changing requirements. Lactate diffusion from the muscle compartment into the circulatory system allowed eventual removal by exercising and non-exercising muscle to occur (Cerretelli et al., 1986; Hollmann, 1985; Ozolin, 1986). The continuous activity of this single exercise interval insured adequate circulation for lactate uptake. Thus at the end of 10 minutes lactates were declining from their early abrupt increase.

Ventilation And Gas Exchange Parameters

The length of the work interval for the P test also would not allow attainment of SS ventilation (Whipp et al., 1986b), therefore the stimulus to increase \dot{V}_E , resulted in a significantly higher f than for the SS test (See Tables 3 and 4). The faster gas exchange versus lactate kinetics (Roca et al., 1989) can explain the lack of a parallel in the significant differences between the P and SS test for measures of \dot{V}_E , f , \dot{V}_{O_2} , and \dot{V}_{CO_2} . In other words, the difference in the time required to attain equilibration explains why gas exchange measures were significantly different between the P and SS tests while the mean lactate values were not.

The one minute pause to allow blood lactate sampling between intervals of the progressive test helps to explain the significant differences in the mean respiratory and gas exchange responses between the incremental and steady state tests. \dot{V}_E , f , \dot{V}_{CO_2} , and RER

were all significantly greater for the progressive test than for the constant load test. In the face of a non-significant reduction in \dot{V}_{O_2} between the progressive and steady state tests, the fact that the \dot{V}_{CO_2} was significantly greater for the progressive test reflected the considerable glycolysis, concomitant $[H^+]$ production, and attendant bicarbonate buffering which resulted in an increased CO_2 release to maintain pH. The increased $[H^+]$, and CO_2 production stimulated baroreceptors and chemoreceptors to address the metabolic demands of exercising muscle (Gollnick et al., 1986; Wasserman, 1986). Respiration, cardiac output, and blood flow to previously exercising muscle was given an opportunity to decline during the rest interval, which also allowed continued albeit reduced lactate diffusion out of the muscle compartment into the circulation (Jorfeldt et al., 1978; Tzankoff et al., 1979). The continued lactate efflux in the face of a diminished ventilation during the rest interval of the progressive test (Ferry et al., 1988) resulted in a dissociation between the ventilation and lactate thresholds. This partially explains the significant difference between ventilation responses for the progressive and steady state tests while lactate measures did not differ significantly.

The longer work intervals in this study compared to the many shorter loading protocols in use (Ribeiro et al., 1986; Schnabel et al., 1982), produce lactate and ventilatory responses which better reflect steady state performance (Whipp et al., 1986a). Whether one considers the oxygen uptake kinetics to be delayed (Fardy et al., 1978; Hughson et al., 1982b) or accelerated (Di Prampero et al., 1983) by prior exercise, the longer interval allows more time for accommodation to the load and a reduction in the effect of the lag time. And indeed, the lack of a significant difference between the incremental and constant load lactate concentrations appears to confirm this hypothesis.

The \dot{V}_E and f , however, were significantly greater for the progressive test. The increasing demands of cellular respiration necessitated central and peripheral adjustments

during the four minute exercise intervals. Abrupt momentary cessation of work to allow for sampling allowed respiration to decline towards resting levels. This was observed but not systematically documented. The increased breathing frequency during the P test was probably due to an amplified chemoreceptor drive triggered by increased CO₂ production (Gollnick et al., 1986; Wasserman, 1986). According to Hughson and Inman (1985), immediate CO₂ storage at the onset of exercise below 60% to 70% $\dot{V}_{O_2 \max}$ is significant for every increase in work rate. Thus, short interval discontinuous protocols result in CO₂ storage which delays its release and contributes to an uncertainty about the accuracy of the measure of \dot{V}_{CO_2} relative to \dot{V}_{O_2} increases. It should be noted here that the \dot{V}_{CO_2} was significantly greater for the P than the SS test. The lack of an increase in \dot{V}_{O_2} indicates that a significant portion of energy contribution was as a result of anaerobic work. The lactate production from the P test buffered by bicarbonates was still being evolved by the lungs since four minutes was too short a period to allow steady state at the reference workload (Whipp et al., 1972). The steady state test, on the other hand, thrust metabolic demands on the subject from the outset which remained constant throughout the exercise period. Therefore metabolic adjustments made during the SS test caused aerobic energy production to increase in order to attempt to meet total energy requirements in an asymptotic fashion, approaching it from the side of an insufficient aerobic energy production. The significantly reduced carbon dioxide output and \dot{V}_E mirror the body's adjustments to the imposed stress and indicated the approaching of an equilibrium between muscle and blood compartments (Sejersted, Medbo, & Hermansen, 1982; Simon et al., 1986).

The SS test \dot{V}_{CO_2} was lower, since 10 minutes were available for CO₂ reductions and workload adaptation. SS RER was also significantly less than P RER since it is the ratio of \dot{V}_{CO_2} production to \dot{V}_{O_2} uptake. Steady state \dot{V}_E was significantly less than progressive ventilation due to a significantly lower breathing frequency in the SS test. This

is probably due to the increased drive to hyperventilation which occurs during the progressive test as a result of chemical and neural signals (Gollnick et al., 1986; Wasserman, 1986).

Effect of Interval Length

Although the athlete exercised at threshold longer for the SS test, the progressive test time to completion of the reference load was significantly greater. However, because interval length for the progressive test was only four minutes and the workrate increased by four percent grade per stage the rate of loading was lower. Unlike the P test, rest periods did not occur for the SS test and the same final reference load was maintained continuously for ten minutes.

The rate of work increase appears to be more significant than the absolute work load in causing the body to make rapid adjustments centrally and at the tissue level (Hansen, Casaburi, Cooper & Wasserman, 1988). The progressive test required adjustments to match every increase in workload. The differences between steady state and progressive intervals were partly due to the contribution of the anaerobic component for the steady state test and a balance between \dot{V}_{O_2} and the anaerobic component for the progressive test.

Significant differences between mean \dot{V}_{CO_2} and \dot{V}_E without similar significant differences for lactate concentrations for the P and SS tests have been described earlier on the basis of interval length and discontinuous protocols. Others have also found a dissociation between \dot{V}_{CO_2} and lactate concentrations based on the rate of loading. Although gas exchange measurements between fifteen and sixty second incremental tests are similar (Fairshter et al., 1983), fast protocols result in significantly higher oxygen uptakes (Ribeiro et al., 1986) normalized for fixed blood lactates than do slow protocols.

Ramp slopes of a $100 \text{ W}\cdot\text{min}^{-1}$ prevent valid measures of the anaerobic threshold using gas-exchange criteria (Davis et al., 1982). Fast incremental tests result in non-steady state measures of ventilatory responses and cause difficulties when attempting to identify breakpoints (James et al., 1989) and estimate IAT (McLellan, 1985).

STEADY STATE TESTING

Heart Rate Response

The small but significant difference between mean heart rates measured at minutes 10 and 20 of the steady state test (See Table 6) was likely a result of metabolic adjustments to compensate for the increased thermal load of the extended exercise period (Chwalbinska-Moneta et al., 1989a; Kindermann et al., 1979; Sawka et al., 1983). However the response could also have been due to catecholamine effects (Schnabel et al., 1982).

Lactate Response

The significant decrease in mean lactate between minutes 10 and 20 (See Table 7) can possibly be attributed to increased uptake by exercising and non-exercising muscle (Hollmann, 1985; Ozolin, 1986) or a decline in production due to system equilibration by the time of arrival of the later stage. Differences between the blood lactate concentrations at minute ten and twenty of the steady state test reveal that the body is still metabolizing (Jorfeldt et al., 1978) and redistributing lactate efflux (Mason, Mainwood & Thoden, 1986; Stegmann et al., 1981; Tzankoff et al., 1979) from the active muscle compartments to other compartments (Rieu, Duvallet, Scharapan, Thieulart & Ferry, 1988). Significant reductions in lactate concentration at the end of the second long interval are possibly due to the diffusion of lactate (Jorfeldt et al., 1978, Tesch, 1982 #246; Tzankoff et al., 1979) into the

circulatory system which allowed its uptake by exercising muscle, the redistribution of lactate (Sejersted et al., 1982), or a reduction in lactate production.

A second reason for a decrease in measured lactate occurring during endurance work is due to an increased FFA metabolism after approximately 25 minutes of steady state exercise (Buono & Roby, 1982; Lehmann et al., 1985; Schnabel et al., 1982). Glycogen depletion is not a factor for the decline in blood lactate response (Scheele, Herzog, Ritthaler, Wirth & Weicker, 1979) and the possibility that reduced lactic acid levels measured at minute 20 in this study reflect increased energy provided by free fatty acid oxidation is doubtful (Buono et al., 1982; Lehmann et al., 1985; Schnabel et al., 1982).

Steady state values of respiratory and gas exchange responses did not differ significantly between minutes ten and twenty (See Tables 7 and 8) because of faster kinetics for ventilatory versus lactate responses (Simon et al., 1986). Hollmann and Kastner (1969) noted that for thirty minutes of constant work at 40% to 50% of aerobic capacity lactate peaked at the fifth minute and declined slowly to the end of the period. The pH value mirrored the movement of lactate. For work at 65% to 70% of the maximum \dot{V}_{O_2} the arterial blood lactate rose in most subjects. Both lactate and pH dropped by the fifth minute and rose again up to the thirtieth minute. The fact that lactates in this study dropped significantly between minutes 10 and 20 indicates the group was well trained aerobically (See Table 6).

Ventilation And Gas Exchange Parameters

The fact that no significant differences in the \dot{V}_E , f , \dot{V}_T , \dot{V}_{O_2} , and \dot{V}_{CO_2} between the tenth and twentieth minute of the SS test (See Tables 7 and 8) revealed that the O_2 and CO_2 , unlike the lactate, had ample time within the first ten minute interval to reach steady state (Roca et al., 1989; Simon et al., 1986; Whipp et al., 1986b). The respiratory

exchange ratio was not significantly different between the tenth and twentieth minute of the steady state test. FFA release had likely not yet begun to increase significantly. Increased free fatty acid blood levels begin to occur by the twenty-fifth minute of constant load exercise (Schnabel et al., 1982).

Effect of Interval Length

No significant differences between gas exchange responses between the tenth and twentieth minute had occurred since the gas exchange kinetics are much faster than lactate kinetics (Roca et al., 1989) and adaptation had taken place by minute ten. The storage of lactates in the exercising muscle volume to maintain pH (Hermansen et al., 1972; Simon et al., 1986; and Sacks and Sacks in Jorfeldt et al., 1978) in the face of metabolic demands results in a blood lactate level which lags behind actual production (Jorfeldt et al., 1978) therefore postponing the reduction of blood lactate levels by oxidation (Brooks, 1986; Mazzeo et al., 1986) and redistribution until the twentieth minute (Sejersted et al., 1982).

PROGRESSIVE AND STEADY STATE TESTS AS PREDICTORS OF ENDURANCE PERFORMANCE

This study focused on the relationship between the arterialized blood lactate measured during the predictive test (P) and the actual steady state performance (SS) at a reference grade. Although many studies have been performed using progressive tests to predict endurance capacity from gas exchange and ventilatory measures, (Haverty et al., 1988; Orok et al., 1989; Tanaka et al., 1984a) test protocol can significantly influence the response to such exercise (Acevedo et al., 1989; Busse et al., 1984; Whipp et al., 1986b). Less is known of the ability of lactate, as measured during progressive tests to predict

endurance performance (Stegmann et al., 1982). Even small errors in progressive tests can result in significant under- or over-estimations of maximal steady state work.

The non-significant differences between the blood lactate measurements for the progressive and steady state tests would initially appear to indicate that the progressive test is a good predictor of endurance performance. However, previous studies have shown that the ventilatory response to exercise, since it is a faster responder than lactate (Roca et al., 1989), can act as an indicator of an increasing lactate production. Therefore, since $P\dot{V}_{CO_2}$ is greater than $SS\dot{V}_{CO_2}$ and the kinetics for CO_2 is faster than lactate, changes in ventilation measures are indicative of other metabolic changes taking place (Davis et al., 1980). Therefore, despite the apparent lack of difference between P and SS [LCT], the \dot{V}_{CO_2} demonstrates that a lactate equilibrium has not been achieved. The measurement of progressive lactates after four minutes is of questionable value as it reflects the previous work interval (Davis, Gass, Eager & Bassett, 1981).

The lactates which are released into the circulation are signals of an event which occurred several minutes earlier (Green et al., 1983; Jorfeldt et al., 1978) and therefore cannot be considered representative of steady state events for the load in question for such a short interval (Whipp et al., 1972). A one minute pause is a long interval between the work stages and disrupts the oxygen uptake kinetics of the exercising individual (Whipp & Ward, 1982; Whipp et al., 1986b). The significant difference between the ventilation measures of the \dot{V}_{CO_2} for the P and the SS test reveals that the organism is not in steady state during such an exercise protocol. The disruption of gas exchange significantly alters the lactate kinetics. Without assurance that this value is steady state one cannot make any accurate representations about the progressive lactate measure for the P test is not representative of a steady state response to exercise at that particular workload since the metabolic flux is substantial.

Significant differences in [LCT] between minutes 10 and 20 of the steady state test preclude the use of a single 10 minute interval to determine the endurance performance using the blood lactate response. However, the faster \dot{V}_{CO_2} kinetics and the non-significant differences obtained between the tenth and twentieth minute for \dot{V}_{CO_2} suggests that ventilatory threshold measures of endurance performance can be obtained from a single 10 minute exercise interval (Ghesquiere et al., 1982; Haverly et al., 1988; Reybrouck et al., 1986).

Chapter 6.

SUMMARY AND CONCLUSIONS

A progressive discontinuous four minute interval test was compared to a 10 minute steady state constant load test (Part A) to determine if significant differences in the physiologic response existed as determined by heart rate, arterialized blood lactate, gas exchange, and ventilation measures. The responses between minutes ten and twenty of a steady state test were also compared (Part B) to determine if they differed significantly.

Progressive test values of minute carbon dioxide output (\dot{V}_{CO_2}), respiratory exchange ratio (RER), minute ventilation (\dot{V}_E), and breathing frequency (f), differed significantly ($p \leq 0.05$) from the steady state results at the same workload. Heart rate (HR) and arterialized blood lactate concentration ([LCT]) differed significantly between minutes ten and twenty of the steady state test ($p \leq 0.05$).

It was concluded that:

- 1) progressive tests do not reflect steady state exercise gas exchange or lactate kinetics,
- 2) steady state tests of 20 minutes in duration are preferable to 10 minute tests when measuring blood lactate.

As progressive tests during simulated skiing require pauses for blood lactate sampling which complicates the lactate kinetics, it is apparent that endurance performance is best monitored by the use of constant load tests. It is recommended that such tests be at least 20 minutes in duration, and at an intensity at or below the lactate threshold. For tests which only require gas exchange measurements the recommended test length is at least ten minutes for endurance trained athletes. To save time a possible solution is to couple a graded warmup phase of ten minutes directly with the test phase and reduce the constant load portion in order to effect a reduction in total experiment time.

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APPENDICES

APPENDIX APRELIMINARY ATHLETE LETTER

April 15, 1986
Exercise Science Research Institute,
Max Bell Performance Center,
University of Manitoba,
Winnipeg, Manitoba.
R3T 2N2

Dear

Congratulations on a fine competitive season. I am sure you are even now preparing for the next year of races. To enable you to better plan your summer program I am pleased to share with you the upcoming opportunity for physiological testing. Tentatively scheduled for June we are planning to perform a study comparing the anaerobic threshold measurements of cross country skiers using 3 different protocols. The test methods include the National team test using the treadmill and ski pulley, the National test without the ski pulley, and the same test procedure using a skimill. The different tests will help you to assess the state of your upper body conditioning and enable you to compare previous results to future tests -- which will probably utilize the skimill. The anaerobic threshold is considered to be the best indicator of endurance performance. This type of information therefore should prove invaluable to you in the development of your training program.

As a recipient of this letter you are in a select group of individuals who have been considered to be either sufficiently competitive presently or possess the potential to be competitive at the provincial or national level.

As well the testing will comprise part of the research of the thesis on the anaerobic threshold and the overall results and implications for training and testing of ski racers will be made known to known to Manitoba athletes and coaches, and also national team coaches and sport scientists.

If you are interested in learning more about this opportunity please return the completed form in the stamped, self-addressed envelope provided by the 25th of April. Thank you for your interest and cooperation.

Sincerely,

Hugh R. Huber,

Graduate Student Exercise Physiology.

I, _____(First and surnames), am interested in being tested to determine my anaerobic threshold for cross country skiing.

I am available for testing in Winnipeg from June 1-7 (___), June 8-14 (___), June 15-21 (___), June 22-28 (___). (Check available times and number the best to worst from 1 to 4.)

I, _____(First and surnames), am interested in being tested; please send more information regarding the protocol.

I understand that I am under no obligation and response to this letter is a declaration of interest only.

APPENDIX B.

INFORMATION AND INFORMED CONSENT FORM

THE ANAEROBIC THRESHOLD RESPONSE OF CROSS COUNTRY SKI RACERS DURING THREE TEST PROTOCOLS:

The Relationship to Performance and the Correlation of Individual Anaerobic Threshold and 4 mMol Lactate to Endurance Performance

1. INFORMED CONSENT

1.1 Introductory Information

The following is a detailed description of the procedures to be performed by subjects in a research study entitled above. Your time commitment as a subject will include the completion of survey sheets, informed consent sheet and three experimental treatment sessions. Please feel free to ask any questions regarding the procedures at any time.

1.2 Screening Session

After reporting to the exercise physiology laboratory at the Max Bell Centre you will complete a Par-Q Questionnaire in order to screen for any obvious contraindications to participation in the experiment. You will then be asked to read and sign this conformed consent. Remember that even after signing you are not committed to completing the entire experiment as you are free to withdraw from this experiment at any time.

You will then complete a survey to determine previous family activity and performance in sports. Age and anthropometric measures will then be taken. Height and weight will be recorded and body composition will be determined by immersion and by using the sum of skinfolds method. Skinfolds will be measured using fat calipers at sites on the arm, back, hip, and calf.

Bring your racing skis (all wax removed), poles, boots, (and roller blades if applicable) to the preliminary and testing sessions. For the body composition sessions please bring a bathing suit. Familiarization on the skimill usually requires about 15-20 minutes. Refrain from eating within 2 hours of the body composition test or the ski test. Also do not smoke or consume alcoholic or caffeinated beverages 2 hours prior to testing. If you have asthma bring your ventilator and inform your testor. Please do not perform an intense or long workout within 48 hours of the test. During the week prior to testing ensure that you are taking in sufficient fluids to match losses incurred while training. Drink plenty of liquids. (Your urine should be nearly clear.) Also ensure that you are obtaining adequate sleep/rest during the week of testing.

1.3 Experimental Procedures

After successfully completing the Par-Q and the body composition portion of the experiment you will have the opportunity to become accustomed to the skimill in a 15-20 minute practise session. Then you will be prepared for the progressive stage test on either the skimill or the treadmill based on random selection. Three EKG electrodes will be applied to the chest area. Heart rate and oxygen uptake will be monitored using the Beckman Gas Analyzer. After preliminary stretching a baseline lactate measurement will be taken prior to exercise. You will perform a progressive stage test consisting of 4 minute work intervals with 60 second pauses to allow the collection of blood lactate from the hyperemized ear. The sample size for lactates is 10 microlitres which amount to a total volume used in measurement of 5 or 6 drops of blood. The test will continue until your maximum oxygen uptake has been reached. After stopping the exercise blood lactate samples will be taken at 1, 2, 5, 10 and 20 minutes post exercise. Ski walking on the treadmill, diagonal stride and skating technique (roller blades) on the skimill will be performed with at least 48 hours between tests.

If you are a member of group two, you will then perform a progressive stage test using the skating technique as described above. The workloads reached using the Individual Anaerobic Threshold measurement and the 4 mMol lactate concentration will comprise the next test. You will ski continuously on the skimill at the workloads that your lactate levels reached IAT and 4 mMol. This will mean two separate tests at least 48 hours apart with a random order of selection. You will attempt to ski for a period of 45 minutes or as close to this time as possible. Lactate samples will be taken 1 minute pre-exercise and at 1, 2, 5, 10, and 20 minutes post exercise.

The second group will perform the skating technique during the progressive test and based on the lactate measurements made during the submaximal portion of the test will ski at two different intensities for a period of 45 minutes in order to determine the better of two measures of anaerobic threshold.

Brief portions of the skiing technique during the various protocols will be recorded on video tape to allow technique analysis and a comparison with snow skiing.

The testing experience will be uncomfortable and can be compared to the intensity used in medium to hard practices and some races you have raced in last year and will race in this year. The duration however will be shorter than many of your practices and races. During the test you will be attended by a technician and technologist qualified to perform lactate sampling.

1.4 Risks

During this exercise test there is a possibility that you will have an irregular heart rate consisting of extra or skipped beats or a rate much higher or lower than normal.

2. Consent

I have read this entire 4 page 'informed consent' and agree to voluntarily take part in the experiments to be carried out for this master's thesis project and realize that I am free to withdraw from this study at any time.

I have answered the Par-Q Questionnaire truthfully and know of no physical or medical reason why I should not partake in this study.

The information that is obtained during the experimental sessions will be treated as privileged and confidential. It may, however, be used for statistical or scientific purposes with your right to privacy retained. Your results will be made available to yourself and your coaches to help you in your training for the coming racing season. Parts of this experiment may be video taped for educational or publicity reasons. If you do not want to be photographed your wish will be signified by not signing the second part of this document.

I have read the foregoing form and understand it. Any questions that have arisen or occurred to me have been answered to my satisfaction.

I consent to take part in this experiment.

Signature _____
(Athlete)

Signature _____
(Parent or guardian)

Witness _____ Date _____

I consent to be photographed during the experiment.

Signature _____
(Athlete)

Signature _____
(Parent or guardian)

Witness _____ Date _____

APPENDIX C.LETTER OF APPRECIATION

November 20, 1986

Faculty of Physical Education
Frank Kennedy Building
University of Manitoba
Winnipeg, Manitoba
R3T 2N2

Dear _____,

Thank you for your participation and involvement in Phase I of Anaerobic Threshold Testing of Cross Country Skiers. In order to celebrate the completion of Phase I and also to provide an opportunity for athletes, families, and testers to obtain an overview of the results of testing, we have scheduled a smorgasbord at Shakey's Pizza on Pembina Highway. The cost is \$5.75 per person and begins at 7:30 p.m.

Specific test results will be discussed in order to help the athletes understand the importance of improving the anaerobic threshold and ways to effect an improvement of that value. A video presentation of testing and ski technique will be presented. There will also be an opportunity to answer questions which you may have as well.

Sincerely,

Rich Pettit

Technical Director

APPENDIX D.

ATHLETE AND COACH FEEDBACK

The coach was provided with immediate results and a discussion of the ramifications of the test results on the training program followed. The athlete was informed in a more general way of the test results and any questions that the athlete posed were answered. A special evening was set aside for parents, athletes, and coaches to present the test data and give a discussion of anaerobic threshold and other significant training factors for optimal cross country ski racing performance. A summary sheet, letter and description of terms was provided for coaches and athletes to enable them to monitor the training of the athletes more accurately.

APPENDIX E.**TERMS**

- \dot{V}_{O_2} STPD Oxygen uptake in litres per minute measured at standard temperature and pressure dry.
- RER The respiratory exchange ratio is the ratio of carbond dioxide output to the oxygen uptake.
- \dot{V}_E BTPS The minute ventilation under conditions of body temperature and pressure saturated.