PHYSIOLOGICAL STRESS DURING FIVE-DAYS

OF VACATION SKIING

by

Jennifer Ann Portmann

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Health and Human Development

MONTANA STATE UNIVERSITY
Bozeman, Montana

November 2011

APPROVAL

of a thesis submitted by

Jennifer Ann Portmann

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citation, bibliographic style, and consistency and is ready for submission to The Graduate School.

Dr. John G. Seifert

Approved for the Department of Health and Human Development

Dr. Mark Nelson

Approved for The Graduate School

Dr. Carl A. Fox

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library.

If I have indicated my intention to copyright this thesis by including a copyright notice page, copying is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Requests for permission for extended quotation from or reproduction of this thesis in whole or in parts may be granted only by the copyright holder.

Jennifer Ann Portmann

November 2011

TABLE OF CONTENTS

TABLE OF CONTENTS - CONTINUED

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES – CONTINUED

LIST OF FIGURES – CONTINUED

ABSTRACT

Little research has been conducted on repeated days of recreational skiing. Repeated days of recreational skiing were thought to increase stress markers, induce fatigue, and hinder ski performance and enjoyment. PURPOSE: To examine the physiological changes that occur in recreational skiers from elevations below 460 meters over five days of vacation skiing. METHODS: Fourteen skiers, four females (Mean ±SD; Age (yrs): 41.3 ±6.2), ten males (47.9 ±11.2) participated in the study. Nine skiers were considered advanced skiers (7 males, 2 females) and five intermediate skiers (3 males, 2 females). Subjects arrived at Bridger Bowl Ski Area, Bozeman MT to ski for five days. Each subject filled out subjective scales, had their resting heart rate, systolic and diastolic blood pressure measured as well as blood drawn for creatine kinase analysis. Samples were taken on days 1, 3, and 5. Subjects skied for three hours in the morning at a self selected pace and on self selected runs. They came in for lunch and recorded their rating of perceived exertion (RPE). The researcher downloaded the data from the heart rate monitor. The subjects skied in the afternoon until a self determined end time and again recorded their RPE and gave the researcher their heart rate monitors; the researcher then gave directions for the following day. RESULTS: The variables of ski time, number of runs, heart rate, blood pressure, and subjective scales did not change significantly. However, RPE was significantly increased suggesting an increase amount of perceptual fatigue. Creatine kinase was did not increase until one outlier was removed. Significant creatine kinase (p=0.001) and RPE results strongly suggests that subjects were stressed even without a decrease in runs, or ski time. CONCLUSION: The current study supports previous research; repeated days of skiing was not a fatiguing enough event to hinder ski performance or enjoyment. Future studies should examine whether repeated days of skiing results in a positive contribution to physical fitness.

CHAPTER ONE

INTRODUCTION

Development of Problem

Recreational alpine skiing is a self-paced activity that involves a wide range of exercise intensities and can last from a few hours to an entire day. The National Ski Area Association reported that there were 58 million skier days in 2009 in the United States (National Ski Area Association, 2010). Of these 58 million skier days, many skiers only ski while on a ski vacation. Bridger Bowl Ski Area in Bozeman, MT, attracts an estimated 25,000 multi-day non-resident skiers per year who ski three to five days while on vacation (Bridger Bowl Marketing Department, 2010). While these skiers enjoy the vacation and relaxation benefits that many associate with a ski trip, some may forget the important physical aspects that affect the enjoyment, safety, and success that come with skiing (Bridger Bowl Marketing Department, 2010).

Throughout the history of skiing, the sport has gone through many changes and adaptations in an effort to enhance ski technique and to improve skiing equipment. For example, alpine skis have evolved from long straight skis, known as traditional skis, to shorter skis with deeper sidecuts. These new skis are made out of wood, aluminum, fiberglass, and carbon fiber (Volkl.com). After the development of the carving ski in the 1990's, a new technique evolved to maximize performance of the new carving skis. Each turn on the carving ski is dependent on the ski waist width, on ski edge angle, and flexion of the skis (Müller and Schwameder, 2003). The main difference between traditional and carving skis is the amount of force required by the legs and speed of impulse incurred during the turn (Müller and Schwameder, 2003). With more force and quicker impulses, people are able to perform smaller turning radii, which in turn, will cause an increase in the physical requirements of the skier (Müller and Schwameder, 2003).

Changes in heart rate, blood lactate, muscle glycogen, blood pressure, repeated submaximal and maximal voluntary contractions of the quadriceps, and blood creatine kinase levels have been measured to quantify the physical requirements and stresses during alpine skiing. Heart rate varies depending on snow conditions, skill level of skiers, skiing terrain, as well as pitch and skiing duration of the runs (Scheiber et al., 2009; Seifert et al., 2009). Seifert et al. (2009) reported that heart rate was approximately 80% of maximal heart rate during recreational self-paced runs in their three-hour free skiing study. In contrast, Karlsson and colleagues (1978) reported that heart rate values during giant slalom races in Are and Gällivare, Sweden during the winter of 1976 ranged from 160 bpm during the practice run, to over 200 bpm during the actual race and reached the subjects' maximal heart rates.

In addition to heart rate, muscle stress can be assessed by creatine kinase. Creatine kinase has been shown to increase due to skiing at a self-selected pace. Seifert et al. (2005) reported that after one day of self-paced skiing, creatine kinase levels were increased by 93% from baseline. Seifert et al. (2009) found that after three hours of skiing, blood creatine kinase levels increased 42% in recreational skiers. Coupled with creatine kinase levels after three hours of skiing, these authors also observed a significant

12% decrease in isometric endurance time pre to post skiing. This marker demonstrates that skiing can lead to increased muscular stress and fatigue in as little as three hours of self-paced skiing.

With an increased pitch of the slope and increased energy expenditure, muscle glycogen depletion may become a limiting factor in ski performance. Depending on the intensity and skill level of the skier, glycogen stores within the muscles have been reportedly depleted by 50% after a day of skiing (Tesch, 1995). Nygaard et al. (1978) found that muscle glycogen in the vastus lateralis was reduced an average of 30 mM/kg of baseline after a full day of skiing. Interestingly, these authors found no difference in the amount of glycogen depletion after skiing short slopes versus skiing long slopes. The researchers may not have found a difference because the subjects might have paced themselves or could have changed their skiing habits to ski at the same intensity whether skiing on the short slopes or the long slopes.

Based on various markers, one day of recreational skiing can cause significant stress and fatigue. Therefore, it may be hypothesized that consecutive days of skiing will increase the stress levels incurred by skiers. However, previous research on repeated days of skiing reported that different stress markers were not significantly elevated over six consecutive days of skiing. Kahn et al. (1993) reported that after six days of skiing heart rate quickly adapted to the change in skiing intensity which resulted in increased energy expenditure and increased production of lactic acid. While subjects may have experienced some fatigue due to a decreased descent time while skiing during the course of the week, the evidence shows that with some rest, including a decrease in skiing time on Day 4, the skiers were able to adapt to the conditions.

Strojnik et al. (2001) also conducted a study on repeated days of skiing and found similar results to those of Kahn et al. (1993). Strojnik and colleagues observed an overall increase of the subjects' maximal voluntary contraction (MVC) of the quadriceps with and without electrical stimulation after six days of skiing. Because of this increase in MVC, the authors suggested that the subjects did not significantly fatigue and that multiple days of skiing had conditioned the muscles. It was also reported that the skiing distance completed each day increased through the fourth day of skiing with a decrease on the fifth day. However, skiing distance returned to baseline on day six. The results of this study indicate that the subjects were able to adapt to the change in physical activity with little physical stress.

Although previous research found that the subjects adapted to the ski regimen, questions remain regarding the methodology used within the studies by Kahn et al. (1993) and Strojnik et al. (2001). Most significantly, skiing characteristics from Kahn et al. (1993) and Strojnik et al. (2001) were not reported. In addition, these authors did not account for changes in skiing load. Thus, a formula was implemented to assess the overall stress of skiing. This formula was based on Banister et al.'s (1975) training impulse (TRIMP) system where the training load can be quantified. Changes in stress markers may not only change by skier adaptation, but also by changes in intensity and duration of skiing between days. For example, subjects can change skiing velocity by taking longer, wider turns on the hill or skiing a straighter line down the hill. They can decrease the intensity by skiing with a more upright posture, by taking longer breaks, or skiing an easier run (Scheiber et al., 2009). Any of these changes could result in the slight reduction of average heart rate observed by Strojnik et al. (2001) over the course of the week. When fatigued, subjects may also choose easier runs as opposed to the steeper, advanced runs to minimize stress. This variability in skiing intensity and volume over consecutive days must be taken into account to ensure that reliable information about physical stress and fatigue can be obtained.

The current study proposed to monitor subjects' heart rates and creatine kinase levels throughout the week. This allowed changes in the subjects' physical stress to be observed and account for changes in their skiing behavior. The results of this study may aid the ski industry in making recommendations to vacation skiers. The results may also aid in the development of a pre-ski vacation workout to help minimize the stress experienced during skiing as well as add to the knowledge and understanding of skiing stress in recreational skiers. While it is understood that physiological changes may be present after repeated days of vacation skiing; there is little known about these changes and even less is known about the extent of the changes that occur over a week vacation skiing when accounting for ski load.

Statement of Purpose

The purpose of this study was to describe the changes in creatine kinase, heart rate, resting blood pressure, perceptual scales, ski time, and TRIMP scores during five consecutive days of recreational skiing.

Hypothesis

It was hypothesized that after five days of vacation skiing the subjects would experience changes in ski time, excitement of skiing, TRIMP, resting blood pressure, fatigue, soreness, rating of perceived exertion, heart rate, and creatine kinase values. The dependant variables that were expected to decrease relative to Day 1 measures were ski time, excitement of skiing, TRIMP, and resting blood pressure.

$$H_O: \mu_{D1} = \mu_{D3, D5}$$

$$H_A: \mu_{D1} > \mu_{D3, D5}$$

where μ_{D1} was Day 1 averages for ski time, enjoyment of skiing, TRIMP, and resting blood pressure and $\mu_{D3, D5}$ were Day 3 and Day 5 averages for ski time, enjoyment of skiing, TRIMP, and resting blood pressure.

The dependant variables that were expected to increase relative to Day 1 measures were subjective rating of fatigue, subjective soreness, rating of perceived exertion, heart rate, and creatine kinase.

$$H_O: \mu_{D1} = \mu_{D3, D5}$$

$$H_A: \mu_{D1} < \mu_{D3, D5}$$

Where μ_{D1} was Day 1 averages for fatigue, soreness, rating of perceived exertion, heart rate, and creatine kinase and $\mu_{D3, D5}$ were Days 3 and 5 averages for fatigue, soreness, rating of perceived exertion, heart rate, and creatine kinase.

Assumptions

It was assumed that all participants were healthy and injury free at the onset of the study. It was assumed that daily activity done before and after the ski day did not interfere with the dependent measures. It was also assumed that the participants represented avid recreational skiers across a broad age range.

Delimitations

For the duration of this study the participants were asked not to back country ski at Bridger Bowl Ski Area, in Bozeman, MT, which requires a large amount of hiking. Skiers remained among Alpine, Bridger, Pierre's Knob, and Schlassmann's Lifts. The subjects were intermediate to advanced skiers and were excluded from the study if they had any previous injury or fitness level that would hinder their ability to ski all five days. Subjects were not allowed to ski with children in an attempt to minimize any distractions from the subject's normal skiing habits. The researcher required that the subjects were between the ages of 30 years old and 60 years old. The skiers were from elevations below 460 meters as the majority of the vacation skiers that come to Bridger Bowl Ski Area are from the plains.

Limitations

The following study was limited because the participants of this study were vacation skiers, which limited the number of available participants. Each participant was able to select a self-paced skiing speed for the duration of the study and was able to choose which type of run they skied. Since the study was be conducted while the mountain was open for business, the lift lines could have added some time to the participants "off hill" time. No measurements were collected on ski Days 2 and 4. However, subjects still skied, but their ski habits were unknown. The snow and weather conditions may have limited the amount of time the subjects were able to spend on the mountain each day.

Funding

This study was part of a larger funded study. Upon subject approval each subject received one Bridger Bowl lift ticket when they arrived at Bridger Bowl each of the five days during the study. Once the subject completed the required five days of skiing the subject received an Osprey hydration backpack specific for winter sports.

Definitions

The following definitions were adapted for the purpose of this study:

Chronic Fatigue — A condition of prolonged and severe tiredness or weariness that is not relieved by rest.

Creatine Kinase — An enzyme found within the skeletal muscle and released into the blood when muscle damage occurs and creatine kinase (CK) leaks into the blood stream.

Down Day	A reduction in ski time and ski runs.
Eccentric Contraction	Any muscle contraction that develops tension and causes the sarcomere to increase in length.
Fall Line	The path a ball would take rolling down the mountain.
Hypoxia (hypoxic environments)	A decrease in the partial pressure of oxygen in the environment due to increased elevation or oxygen desaturation within the muscle tissue.
Isometric Contraction	Any muscle contraction that develops tension while the sarcomere remains the same length.
Isometric Endurance Time	The amount of time a muscle is able to maintain an isometric contraction.
Kinetic Energy	The work needed to accelerate the body of a given mass from rest to its current velocity.
Load	Consists of the intensity, duration, and frequency of the exercise.

Maximal Voluntary Contraction	The maximal amount of force exerted by a muscle during an isometric contraction as measured by joint torque.
Mean Arterial Pressure (MAP)	The pressure of blood against the walls of blood vessels. Formula: MAP = [(2 x diastolic) + systolic] / 3
Muscular Fatigue	The physiological inability of muscle tissue to maintain the required force levels at a given activity level.
On-Edge Angle	The degree at which the outside ski is angled to achieve a turn radius.
Pressure	Governed by the weight of the skier (m), their velocity (v), and the radius of the pitch of the slope (r). Equation for pressure = mv^2/r.
Physiological Fatigue	The reduction in the capacity to carry out functions due to physiological overwork and strain.
Repeated Days	Consecutive days of doing the same type of activity.
Ski Descent Time	The amount of time it takes to get from the top of the ski run to the bottom of the

ski run once the skier started skiing down the hill.

Ski Flexion	The amount of flex the ski must achieve to maintain contact to the snow through the whole turn.
Ski Waist Width	The maximum width under the binding at the center of the ski; measured in centimeters.
Skier Days	The number of skiers multiplied by the by the number of days each skier skied during one season. Example: 2 skiers x 20 days = 40 skiers days.
Sidecut	The width of the ski under the binding at the center of the length of the ski in relation to tip and tail width.
Training Impulse (TRIMP)	The overall load of a training bout. TRIMP = multiplying average skiing heart rate, average run difficulty, and the average descent time together and dividing by the number of runs.
Up-unweighting	Occurs when there is slight extension of the ankles, knees, and hip in order to facilitate weight transfer from one ski to the other ski.

CHAPTER TWO

LITERATURE REVIEW

Introduction

Skiing started 3,000 to 4,000 years ago as a way of transportation for Northern Europe and Scandinavia (Karlsson, 1984). Prior to 1900, the only mode of skiing was Nordic skiing (Karlsson, 1984). While skiing began in the Scandinavian countries, Austria quickly became the cradle of downhill skiing where many of the technical advances came about. The origin of competitive alpine skiing began in the Scandinavian countries shortly after 1900 (Andersen and Montgomery, 1988). In the United States, ski racing didn't become popular until the 1950's (Andersen and Montgomery, 1988).

Since the creation of skiing, researchers have worked on ways to improve the equipment used as well as how to improve the physiological aspects of skiing. However, once ski racing became popular much of the previous ski research has focused on the different biomechanical and physiological aspects of racing. It was found that about 60% of the energy demands of racing were met through anaerobic metabolism; more specifically, 40% of the total energy contribution came from lactic acid metabolism from the anaerobic pathway (Tesch, 1995). Previous research seems to have been primarily focused on how to improve the racer's ability to ski and maximize performance on a race course (Tesch, 1995). However, researchers have recently turned their attention to recreational skiing which involves a combination of low and high intensity efforts and can range from short to long durations (Turnbull et al., 2009). The focus of ski research is evolving from maximizing racing performance to what physiological changes occur during recreational skiing.

Turning Technique

Recreational skiers encounter variable terrain when skiing and therefore need to be able to efficiently adapt to this changing terrain in order to minimize physical stress. They gain velocity and kinetic energy due to the snow conditions, the skiers' body mass, and technical skill as they turn while skiing down the hill (Berg et al., 1995). Karlsson et al. (1978) reported that the pressure decreases, due to resistance forces, when progressing from a flatter to a steeper slope. The pressure the skier experiences is composed of the skiers mass, the velocity of the skier, and the radius of the pitch of the slope. The resistance forces the skier encounters are from gravity, friction between the snow and the skis, and air resistance. Conversely, skiers will feel an increased amount of pressure going from a steeper slope to a flatter slope. While Karlsson et al. (1978) does not specify which type of pressure the skier feels, the pressure could be due to an increased muscular force, increased centrifugal force in a turn or a change in the ground reaction force from the turn radius or slope pitch. Thus, skiing speed, turning radius, pitch, and body mass of the skier will determine the required muscle demand at any given point during a turn (Berg et al., 1995).

Müller and Schwameder (2003) and Hintermeister et al. (1995) have broken down the conventional turn into four phases: initiation, steering, completion, and up-unweighting. The initiation phase is marked by force change from the downhill ski to the uphill ski with an increase load on the uphill ski. During the steering phase of the turn, the greatest force is on the outside ski while skiing into the fall line. Muscular forces can reach upwards of 100-150% of the skiers' maximal voluntary contraction as measured by electromyography (EMG) (Berg et al., 1995; Hintermeister et al., 1997). The completion phase of the turn is established by increased tail pressure and the skiers body being in a more upright and balanced position as compared to the lower stance while turning (Hintermeister et al., 1995). Lastly, the up-unweighting phase occurs when the skiers' ski changes to a different ski edge and body weight (force) is changing from one ski to the other with the skis pointing toward the direction of the new turn. The carving turn can be distinguished from the traditional turn by the co-loading of both skis throughout the turn along with a relatively short steering phase and a longer initiation phase (Müller and Schwameder, 2003).

Skiers utilize muscular strength and power to act on the skis throughout the entire turn in order to properly execute a turn (Karlsson et al., 1978). The primary muscle contraction used during skiing is the eccentric contraction. This is due to resisting the forces produced by the vertical drop the skier encounters when descending the mountain as well as within the turn (Berg et al., 1995). The quadriceps are activated in the later part of the steering phase and through the completion phase at a higher intensity than the hamstrings while the skiers' hamstrings are activated through the steering phase (Kröll et al., publication in process). The hamstrings are also utilized at the up-unweighting phase to help stabilize the knee and develop force for the steering phase (Hintermeister et al., 1995). However, during prolonged skiing the rectus femoris compensates for the vastus lateralis and contracts at higher intensities to complete each turn (Kröll et al., publication in process). The quadriceps and hamstrings are contracted through the majority of each turn which requires ample leg strength and endurance to counteract the velocity and forces the skier experiences while turning. With ample leg strength, skiers will successfully be able to overcome many different pitches, snow conditions, and obstacles.

Intensities of Skiing

Few skiers maintain the high intensity level when skiing all day (Interview with Bridger Bowl Marketing Department, 2010). A change in skiing intensity could be due to fatigue, pitch of the hill, terrain, weather conditions, or the style of skiing. Scheiber et al. (2009) examined four different intensities of skiing which were a flat run at low intensity, flat run at high intensity, a steep run at low intensity, and a steep run at high intensity. Low intensity skiing was categorized by the parallel ski steering technique while the high intensity skiing used carving in long radii turns. The flat slope was 2,700 meters in length with a vertical change of 474 meters, while the steep slope was 1,400 meters long with a vertical drop of 474 meters. The researchers reported that when the skiers skied at a high intensity on a flat slope, lactate concentration ranged from 0.8 to 3.8 mmol/L with an estimated group average of 2.0 mmol/L. However, when skiers skied at a high intensity on a steep slope, lactate concentration ranged from 0.9 to 6.0 mmol/L with an estimated average of 3.0 mmol/L. These data were interpreted from graphs provided since raw data were not available. These authors concluded that skiing at higher intensities on both the flat and steep slopes led to increases in oxygen uptake, heart rate, and perceived exertion (see Table 1).

Table 1. Mean physiological changes between velocity and pitch of slope (Scheiber et al., 2009).

	Low Intensity			High Intensity		
Physiological Measures	HR (bpm)	VO_2 (ml/kg/min)	Borg's RPE	HR (bpm)	VO_2 (ml/kg/min)	Borg's RPE
Flat Slope	105	14	8.5	115	16.5	10.5
Steep Slope	120	16	12	134	18	13.5

*The data was interpreted from graphs as no numerical data provided

Blood lactate values, when taken one minute post skiing, can be a good determinate of skiing stress (Seifert et al., 2009). Tesch et al. (1987) reported that the mean blood lactate value of a ski racer was 13.4 mmol/L after one minute of maximal intensity skiing. However, with prolonged time between exercise and sampling, or with an active recovery, the majority of the accumulated lactate is removed; therefore blood lactate may not be a good indicator for chronic muscle stress and fatigue (Richardson et al., 1993). There is a substantial difference in lactate concentration between elite ski racers and less skilled racers. The elite skiers had an average lactate value of 12.4 mmol/L while the less skilled skiers had a lactate concentration of 8.8 mmol/L after self-paced skiing (Veicsteinas et al., 1984). This is possibly due to the elite skier being able to produce and maintain a higher degree of muscular force than the less skilled skier which is possibly the result of greater levels of ischemia and hypoxia. In contrast to values obtained from racers, Nygaard et al. (1978) and Seifert et al. (2009) reported that the average recreational skier skied at a self-paced intensity eliciting blood lactate levels ranging from 2.0 to 5.0 mmol/L.

Recreational skiers typically ski at an intensity corresponding to 60-80% of their maximal heart rate and at approximately 50% of their maximal oxygen uptake (VO_{2MAX}) when skiing on smooth, groomed runs at a self selected pace (Scheiber et al. 2009; Seifert et al. 2009). As the ski terrain changes, so to does the energy required to maintain proper ski technique and ski through varying conditions. As snow conditions change from well maintained slopes to bumpy and unmaintained slopes, heart rate and oxygen uptake can increase to 90% and 60% of their maximal values, respectively (Karlsson, 1978).

Heart rate responds to different stressors throughout the day; these stressors can include the type of food or fluid ingested, various environmental factors, or a change in physical activity. In regards to skiing, heart rate varies depending on snow conditions, skill level of skiers, skiing terrain, duration of skiing runs, and pitch of the run (Scheiber et al., 2009; Seifert et al., 2005). Seifert et al. (2005) reported that recreational skiers skied at 82% of their maximal heart rate while skiing self-selected runs and at self-selected paces. During that study, the participants were able to self select their skiing paces and runs and therefore could accommodate for any fatigue they experienced. This accommodation can be accomplished by changing their skiing velocity or duration of time spent skiing. In comparison, Szmedra et al. (2001) reported ski racers trained at approximately 86% of their age predicted maximal heart rate during practice runs on a giant slalom course.

Generally speaking, the ability of the skier may influence the absolute intensity of the skiing. The more experienced skiers may ski at a higher velocity than inexperienced skiers on the steeper terrain which will increase their heart rate and amount of muscle stress. Additionally, a more experienced skier may also choose to ski off the groomed runs and ski through the trees or powder (Interview with Bridger Bowl Marketing Department, 2010). These situations will increase the intensity and result in increased energy expenditure which could result in muscle stress or fatigue sooner than a skier that stays on the groomed runs and decreases their intensity on the steeper slopes. In conclusion, recreational skiers generally ski at approximately 60%-80% of their maximal heart rate and a blood lactate concentration from 2 to 5 mmol/L.

Training Impulse

Skiing intensities change throughout a skier's day and therefore the amount of force the skier is subject to also changes. Thus far a way of quantifying skiing load has not been established. Banister et al. (1975) proposed an athletic performance model comprised of a number of factors that contribute to physical performance. These researchers determined that athletic performance is based on multiple aspects of physical fitness as well as emotion and fatigue. While the fitness aspect can be quantified easily, Banister and associates were interested in quantifying the fatiguing and emotional components that influences performance. Any form of fatigue could negatively affect the performance, this includes fatigue from the amount of training as well as the fatigue that results from daily routines, should be taken into account (Banister et al., 1975). Banister and colleagues also wanted to take into account the emotional aspect of an individual and how that may impact performance; this ranges from acute crises to chronic stress. The resulting model was a way to quantify any changes in the level of performance in both the physical fitness aspects (such as heart rate and the duration of the activity) as well as the emotional and fatiguing aspects of the activity.

Those researchers developed a model for training impulse (TRIMP) which is the product of the training intensity (measured by average heart rate), the training volume (number of minutes exercising), and/or the perceived exertion or difficulty of a specific activity (easy and moderate = 2, difficult = 3) (Banister et al., 1975). The TRIMP score is a method to quantify the aerobic training load and can be used to determine the total effort the person exerting to complete a certain task (Banister et al., 1975; Foster et al., 2001). However, that measurement left out high intensity workouts because Banister et al. (1975) did not account for the intensity changes during the training bouts (Foster et al., 2001).

Foster et al. (2001) developed a modified TRIMP equation that uses Rating of Perceived Exertion (RPE) as a marker of training intensity. The researchers were interested in examining how close RPE was related to summated heart rate zones during a cycle ergometery trial. Foster et al. (2001) found that the RPE was significantly higher at a given summated heart rate zone; however after performing a regression analysis the two scores were highly consistent throughout the different stages. From these results, Foster et al. (2001) concluded that the consistency between the objective (summated heart rate zone) and subjective methods (RPE scales) of monitoring during different types of exercises show that subjective scales may be useful over a wide range of exercise sessions, even non-steady state, high intensity exercise. The TRIMP model could be implemented in determining the load the skier is under at any given point during day or can be used to determine an average for the entire day.

Stresses Encountered During Skiing

Skiing causes many different physiological changes due to the stress and hypoxic conditions that are normally associated with skiing. Oxygen uptake, glycogen depletion, and muscle stress (assessed by creatine kinase and myoglobin) change with an increase or decrease in skiing intensity, slope, and skiing velocity (Scheiber et al., 2009; Seifert et al., 2005, 2009). It would be expected that these stresses are amplified when examining racers versus recreational skiers; however, the generalized results of these stresses still occur in the same manor between the two types of skiers.

Evidence suggests that muscle fatigue starts at the cellular level of the muscle; therefore muscle fatigue appears to be related to cellular metabolism (Allen et al., 2002; McLester, 1997; Sirikul et al., 2007). During exercise, depletion of glycogen and other energy stores, and/or a buildup of metabolites such as lactate, calcium, hydrogen ions, and inorganic phosphate increase fatigue in the muscle. With the change in muscle and cellular metabolism the skier may experience slower reaction/response time along with a greater hip and knee extension during the turning phase (Scheiber et al., 2009; Seifert et al., 2005). When these modifications occur due to changes in muscle metabolism there is a negative impact on force production, a decrease in response time, decreased balance, and a longer time period to regain balance.

The majority of skiing in the western United States occurs in the mountains at elevations in excess of 2,000 meters; therefore hypoxia could also be factor in the development of fatigue. Performance decreases in hypoxic environments; this includes a hypoxic environment as well as hypoxic conditions within the muscles. Szmedra et al. (2001) reported that junior alpine racers experienced significant oxygen desaturation in both giant slalom and slalom racing. After completing a giant slalom (long radius turns) course the racers experienced a decrease in oxygen saturation from 100% to 79.2% and from 100% to 65.7% during the slalom (short radius turns) course. The decrease in performance is attributed to the decrease in oxygen delivered to the muscle as well as muscle contractility (Millet et al., 2009). Millet at el. (2009) found that the number of isometric muscle contractions of the leg decreased significantly from 21.5 repetitions to 15.6 repetitions in the normoxic environment compared to the controlled hypoxic environment. Repeated eccentric contractions, such as repeated turns down the mountain, lead to increased muscle damage, which results in increased creatine kinase and soreness and loss of force (Mackey et al., 2008). Mackey et al. (2008) reported that soreness, force loss, and creatine kinase levels peaked three days following exercise consisting of isometric contractions.

Another potential stress encountered during skiing is muscle glycogen depletion. During a slalom turn, the isometric force the legs experience range from 48% to 172% of the maximal voluntary contractions of the quadriceps (Zeglinski et al., 1998). Therefore, it would be to no surprise that the leg muscles can experience rapid glycogen depletion after a few hours of skiing. Tesch (1995) reported that after competition, a racer’s glycogen content was depleted, on average, by 50% with slow twitch fibers being depleted by 100%. Tesch (1995) reported no difference between muscle fiber types I and II in muscle glycogen depletion after two days of race practice. Although these results were obtained from racers, it is assumed that recreational skiers would also experience a significant amount of glycogen depletion after a full day of skiing. Skiing intensity, skiing velocity, the pitch of the slope, skiing duration, and the skiers ability will determine the magnitude of stress during a day of skiing.

Creatine Kinase

Creatine kinase (CK) is an enzyme found within the muscle (Armstrong, 1984). Once skeletal muscle damage occurs, creatine kinase diffuses from the muscle to the blood stream. Skeletal muscle damage occurs after a disruption of the z-line and myofibril tears as a result of mechanical stress, metabolic stress, or a combination of both during and after exercise (Armstrong, 1984).

Mechanical stress, such as eccentric contractions, strenuous exercise, or brief repeated hard impact exercise is thought to be responsible for the loss of intracellular enzymes and increases the activity of various serum enzymes, in particular, creatine kinase (Clarkson et al., 1982; Haralambie et al., 1976; Sirikul et al., 2007). During eccentric exercise, the muscle lengthens as it produces force causing micro-tears along the z-line of the myofibril. The end result is that creatine kinase diffuses into the blood (Armstrong, 1984). Isometric contractions were also found to increase levels of creatine kinase in the circulation because of the high fiber tension (Clarkson et al., 1982). Both eccentric and isometric contractions occur when skiing. Isometric contractions normally occur around the core to help stabilize the upper part of the body while the skier's legs are experiencing eccentric contractions when maneuvering down the hill. As the intensity of the exercise increases, the amount of force the muscles are subject to increase linearly causing more micro-tears and therefore cause a higher increase of serum creatine kinase circulating around in the blood (Clarkson et al., 1982).

Seifert et al. (2005) reported an increase in creatine kinase during recreational skiing. Ten intermediate and expert skiers skied any six runs from a high speed quad chairlift at a self selected pace and were asked to avoid stopping during the run. Skiers skied approximately 19,000 vertical feet during the three hours. All the selected runs were groomed the night before or the morning of the study. Blood samples were taken from a forearm vein the night before the study, ten minutes after the final run of the day, and again two hours after skiing was completed. Those authors reported that two hours post skiing creatine kinase levels increased from 126.0 $\pm$23.2 U/L to 243.2 $\pm$34.3 U/L.

Additionally, Seifert et al. (2009) found that after three hours of skiing by intermediate level skiers, blood creatine kinase levels increased from 40.4 +19.3 $U \cdot L^{-1}$ pre-skiing to 57.3 +25.4 $U \cdot L^{-1}$ post skiing. Coupled with creatine kinase levels after three hours of skiing, these authors found a significant decrease in isometric endurance time and peak force from pre to post skiing. The subjects' average pre-skiing isometric endurance time was 106.1 $\pm$29.6 seconds with a peak force of 1151.6 $\pm$202.1 N; while the post-skiing isometric endurance time decreased to 93.2 $\pm$24.0 seconds with a peak force of 1112.4 $\pm$187.7 N. These markers demonstrate that three hours of skiing caused muscle stress and fatigue during self-paced runs due to magnitude of the load on the legs. While it is important to note that the subjects in this study did not knowingly pace themselves, they would have experienced some degree of pacing because each subject would most likely have skied within their desired comfort zone range just as a skier skiing over repeated days would do. These values were established during three hours of recreational skiing; therefore, it would be expected that these stress markers would be amplified during a five day ski excursion if the skiers maintained their intensity, skiing technique, and amount of time they spend on the mountain.

Hubal et al. (2010) found that strength loss coupled with high levels of circulating creatine kinase within the blood are due to the exercise-induced muscle damage as a product of strain-induced structural defects that occurred immediately during the exercise. After an isometric maximal voluntary contraction (MVC) test of the elbow flexors, Hubal et al. (2010) found that creatine kinase activity continued to increase from an average of 115 IU until it peaked on day seven at 3,057 IU. Levels of creatine kinase continued to circulate within the blood through day ten where the creatine kinase levels decreased to 491 IU (Hubal et al, 2010). From this data it is apparent that recovery from severe exercise takes approximately ten days; although creatine kinase levels peak a few days after the unaccustomed exercise (Hubal et al., 2010).

Hubal et al. (2010) concluded that repeated days of exercise and Seifert et al. (2005) concluded that after three hours of self paced skiing that creatine kinase levels rose as a direct result of exercise. With the increased serum creatine kinase levels it is apparent that muscle stress is present within the subjects. The increased muscle stress could cause muscle soreness and fatigue and therefore lead to a decreased ability to perform the task from the onset of exercise.

Impact of Altitude on the Body

Reductions in oxygen uptake and an increase in heart rate are observed as the barometric pressure decreases with an increase of altitude (Makowski et al., 2006). At an altitude from 2,000 to 2,200 meters, Makowski et al. (2006) found that there was a decrease in maximal oxygen uptake and an increase in physiological costs in response to hypoxia, and low humidity. These atmospheric factors reduce exercise tolerance, maximal power output, and maximal oxygen uptake (Makowski et al., 2006). Oxygen uptake is lower due to the decrease in the partial pressure of oxygen which decreases the pulmonary diffusion of oxygen.

The rate of muscle fatigue is exacerbated during hypoxic exposure since there is a reduced pressure gradient to move oxygen (Katayama et al., 2010). In addition to the already increased fatigue rate during hypoxia, skiing consists of intermittent isometric contractions which may also increase the rate of fatigue faster in hypoxic environments as compared to normoxic environment (Katayama et al., 2010). During isometric contractions, the force within the muscle increases causing the arteriole and capillary vessels to compress, which in turn causes a rapid ejection of venous blood out of the muscle and restricts the blood from re-entering the muscle (Katayama et al., 2010). Because of the high pressure during isometric contractions, blood pressure will also increase in order to push the blood through the narrowed vessels (Foster et al., 2010).

In addition to muscle fatigue and increased blood pressure at altitude, Katayama et al. (2010) found that inspired minute ventilation increased to 13.8 ±0.6 L/min during hypoxia, compared to 12.9 ±0.6 L/min in normoxia during repeated intermittent isometric contractions. The researchers also reported that heart rate in a hypoxic condition was significantly greater than in normoxia, 88.9 ±5.9 bpm versus 75.1 ±4.9 bpm. Due to the increased inspired minute ventilation and increased heart rate in hypoxic conditions, the intermittent isometric endurance time decreased significantly, approximately 375 ±25 seconds in normoxic conditions to approximately 225 ±25 seconds in hypoxic conditions (Katayama et al., 2010).

Creatine kinase may also be influenced in hypoxic conditions. There is an increased stress on the muscles during physical activity when the body is exposed to hypoxic environments (Katayama et al., 2010). Therefore, it is possible that stress the muscles are under while skiing may be greater in hypoxic environments. With the increased muscle stress, the legs could fatigue sooner and also experience more muscle damage. However, this has not been thoroughly researched.

From these results it is apparent that skiing in hypoxic conditions, such as mountain skiing, may cause an increased ventilatory rate which in turn will increase the minute ventilation, and therefore increase oxygen uptake. In addition to the increased oxygen uptake while skiing, heart rate will also increase due to hypoxia and increased metabolic demands to allow for proper oxygenation of the blood and an increased oxygen delivery to the muscles. Because of increased physiological demands, the body expends more energy and may cause a decrease in the amount of time it can perform a specific task, such as skiing (Katayama et al., 2010).

Repeated Days of Exercise

Stresses that occur during repeated days of exercise have been thoroughly examined. Stewart et al. (2008) found that untrained cyclists, after cycling for three consecutive days at a moderate intensity, demonstrated a decrease in their maximal voluntary contraction (MVC) force. There was a significant decrease in the isometric force production, compared to their pre-test values on Day 1 (Pre-value: 527 ±31 N; Post-value: 451 ±40 N) and Day 3 (Pre-value: 546 ±35 N; Post-value: 391 ±42 N) (Stewart et al., 2008). The researchers found that by recovery Day 1, force production was partially recovered to 460 ±46 N ($p < 0.05$); however, the forces were still below the pre-test values. Stewart et al. (2008) noted possible mechanisms for the decrease in the subjects' MVC is the loss of membrane excitability causing a loss of action potentials reaching the muscles and impaired signal transmission between t-tubules, sarcoplasmic reticulum, and calcium releasing channels.

The physiological changes that occur in diverse training regimens for different sports programs have been examined as well. Duffield et al. (2008) examined 14 rugby players over five weeks of their normal training program which included rugby-specific training, strength training, and one game each week. Creatine kinase, heart rate, skin temperature, perceived muscle soreness, and lactate values were measured during each of the separate training sessions throughout the week. The researchers found that heart rate and skin temperature spontaneously adapted to the exercise intensity of the training day.

As the heart rate increased from 75 bpm to 175 bpm, there was also an increased body temperature, from 29°C to 33°C, and a faster onset of sweating. Lactate also increased immediately after the specified training session was completed and slowly decreased over a few hours post exercise. The researchers found that creatine kinase increased after the training sessions, and was highest after the rugby game with the pre creatine kinase value at 307 ±191 UL and post game creatine kinase values at 630 ±298 UL. Along with the creatine kinase values, perceived muscle soreness also increased significantly after the rugby game, as compared to training and practice days.

Repeated days of exercise can cause multiple adaptations as well as a certain amount of muscle damage and fatigue. There was significant muscular fatigue reported by Stewart et al. (2008) and Duffield et al. (2008) which were observed by the decreased maximal voluntary contraction tests after biking and increased muscle soreness and creatine kinase values after the rugby game. Heart rate was reported to spontaneously adapt to the repeated exercises, however heart rate increased once fatigue and muscle damage were present.

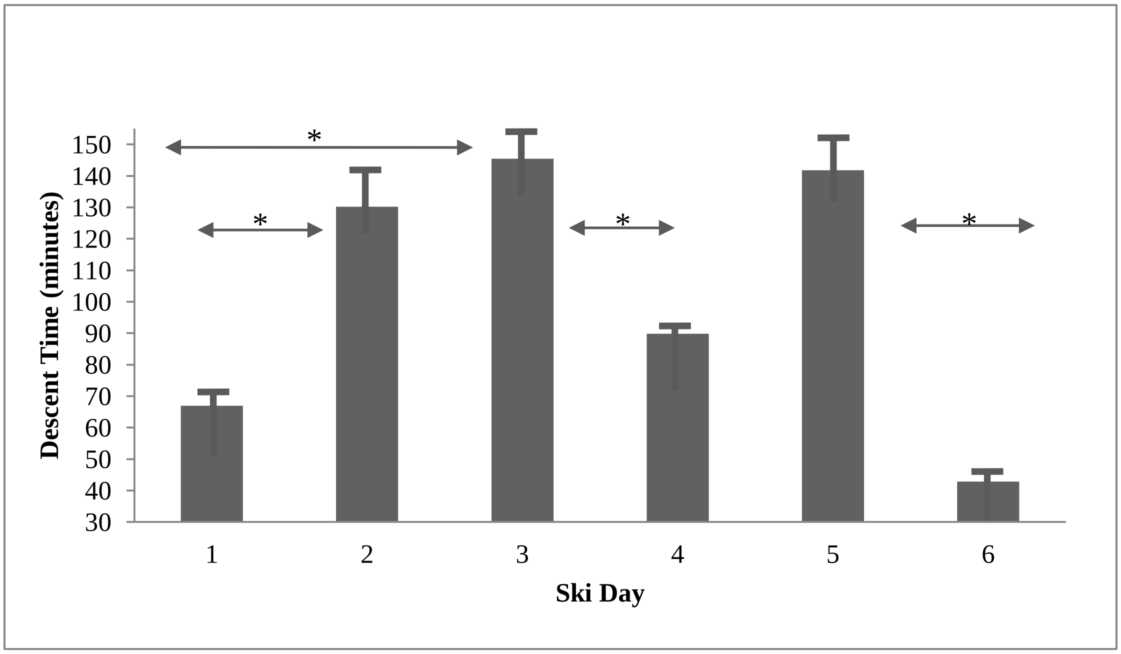
Repeated Days of Skiing

Research on repeated days of skiing has been limited. Kahn et al. (1993) and Strojnik et al. (2001) reported on the physiological changes that occurred from repeated days of skiing. Kahn and colleagues (1993) were the first to report on the physiological responses during repeated days of skiing. Ten healthy males age 51.0 ±1.3 years old, who participated in light physical activities, skied at leisure paces for six days. Each participant went through an exercise stress test the week before skiing and the week after skiing. Subjects were instructed to ski all six days as the weather allowed, four to five hours per day without any mandated pattern, and ski either in groups or individually. Each subject was required to record the number of descents, the difficulty level of the runs and time of descent, and whether skiing was delayed due to weather or breaks.

Kahn et al. (1993) collected resting heart rate, maximum skiing heart rate, mean skiing heart rate, systolic blood pressure (SBP), and diastolic blood pressure (DBP) from each participant in the morning and evening. The researchers reported a decrease in resting heart rate from 80 ±4 bpm on Day 1 to 75 ±4 bpm on Day 6. Diastolic blood pressure also decreased from 83 ±2 mmHg on Day 1 to 77 ±3 mmHg on Day 6; however the systolic blood pressure remained stable over the six days ranging from 130 ±6 mmHg to 132 ±3 mmHg. The authors also reported that the descent time increased from Day 1 (66.9 ±7.6min) to Day 3 (145.5 ±10.1 minutes). Skiers experienced a decrease in descent time to 89.8 ±4.8 minutes on Day 4 (Figure 1)

There was a linear decrease in maximum skiing heart rate from Day 1 to Day 6, 141 ±5 bpm to 130 ±4 bpm, and mean skiing heart rate, 131 ±5 bpm to 118 ±4 bpm. Researchers accounted for the drop in heart rate to be a direct result of physical and mental relaxation, as well as a certain degree of acclimatization to altitude. From these findings, the researchers concluded that normally sedentary people are able to spontaneously adapt to a regimen of prolonged physical activity with only a slight increase in fatigue (Kahn et al., 1993). However, data on skiing characteristics (volume, vertical meters, style, or velocity) were not presented.

Figure 1. Average ski descent time per day (Kahn et al., 1993).



* = Significantly Different

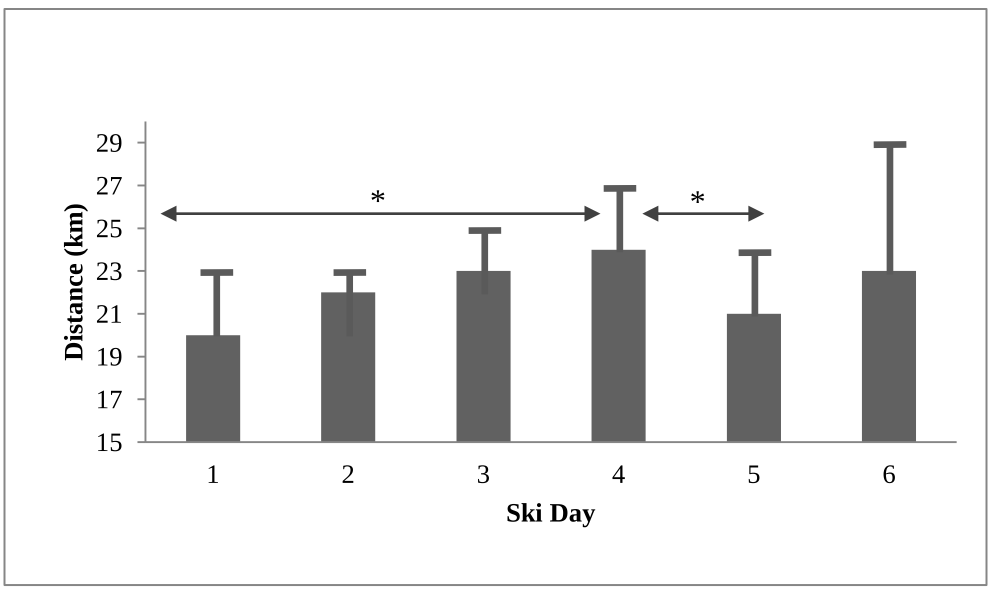
Strojnik et al. (2001) also concluded that a week of self-paced skiing did not cause significant levels of physiological fatigue. These researchers hypothesized that both peripheral and central fatigue would be present after one week of recreational skiing. Ten healthy male subjects, who were not involved in any regular activity, participated in the study. The subjects skied for one week and stayed at a hotel next to the ski resort. The subjects chose what type of slope they skied, recorded chairlifts ridden, and runs completed each day. The researchers used the information gathered from the chairlift to estimate ski distance each subject skied each day. Interestingly, the researchers treated all lifts as equally demanding, even though the runs ranged from easy expert. Again, it is important to note that these researchers did not give any information regarding vertical ascents of the chairlifts or the skiing terrain.

The subjects were put into groups for the week of skiing and were measured every other day during the skiing and then three and seven days after skiing. Maximum isometric extension torque of the right knee was measured at 45 degrees knee extension with a hip angle of 110 degrees. After the maximal isometric contraction was establish, a 0.08 second train of electrical impulses strong enough to contract the quadriceps was administered to completely contract the quadriceps muscle. Following the MVC, the researchers examined the twitch time of the relaxed quadriceps by inducing five twitches of a single supramaximal electrical shock to the femoral nerve.

Strojnik et al. (2001) reported that the isometric torque production decreased significantly after the first day of skiing from 100% to approximately 90% of maximal isometric torque. The researchers noted a down day for all measures on the second day to surpass the initial values and again saw a significant decrease in all measures the fourth day. The maximal voluntary contraction increased by 25% and the electrically stimulated maximal muscle contraction increased to about 10% on Day 6 of skiing. The authors also reported that the twitch parameters had increased by 10% after a week of skiing. These data were interpreted from graphs as the researchers did not provide the numerical data.

From these results, the researchers concluded that there was an overall increase in torque production, as well as an increase in muscle function and twitch time. The subjects skied an average of 20 $\pm$5 km a day (Figure 2); however these were estimated values as the authors did not provide raw data. The average distance skied increased linearly during the first four days from approximately 20 km to 24 km ($p < 0.05$). The researchers also reported a significant decrease to an estimated 21 km ($p < 0.01$) on the fifth day. However, skiing distance increased to 23 km on the sixth day. The results could imply that a week of skiing can make a positive contribution to neural recruitment and physical fitness. The subjects were able to regulate skiing in order to minimize fatigue and seemed to experience a positive physical conditioning to skiing six days. However, it is more likely that the subjects improved neurologically in six days rather than their physical fitness level. With the improvement of MVC and increased activation level it is possible to conclude that both peripheral and central components of the voluntary motor control improved.

Figure 2. Average ski distance a day (Strojnik et al., 2001).



* = Significantly different

It is very important to note that the authors in the two studies stated above did not take into account different skiing characteristics. Skiers could have switched from making short, quick turns down the fall line to taking longer, wider turns across the fall line which would have increased the amount of descent time on the hill and decreased their mean skiing heart rate and number of turns completed, while not significantly impacting fatigue.

Conclusion

Recreational alpine skiing is a winter sport involving technical turns and aerobic metabolism being the primary energy pathway. Previous research has shown that recreational skiers were able to adapt and overcome many of the stresses thought to occur with multiple days of skiing. There are multiple factors that can contribute to fatigue of the skier, such as the elevation and amount of hypoxia, amount of glycogen depletion, skiing intensity, skiing style, and muscle damage.

Chronic stress and fatigue could cause an increase in serum creatine kinase due to microtears in the muscle fiber. Due to the breakdown of the muscle structure, the muscle itself would not be able to produce the amount of force it could before it was stressed and fatigued. Chronic stress and fatigue could also result in the decrease of enjoyment a skier normally experiences while skiing. Chronic stress and fatigue can also be apparent with a decreased heart rate due to a decrease total descent time, and the way the skier adjusts their ski habits. Repeated days of skiing could result in an increase in markers of muscular stress; however the muscular stress and subjective perceptions of fatigue that may occur over repeated days of recreational skiing have not been thoroughly examined.

CHAPTER 3

MANUSCRIPT

Introduction

The National Ski Area Association (2010) reported that there were 58 million skier days in 2009 in the United States, with many of these skiers having only skied while on a ski vacation. While skiers enjoy the vacation and relaxation benefits that many associate with a ski trip, some may forget the important physical aspects that affect the enjoyment, safety, and success that come with skiing (Bridger Bowl Marketing Department, 2010).

Recreational skiing may cause many different physiological changes due to the muscular stress and hypoxic conditions that are normally associated with skiing. Oxygen uptake, glycogen depletion, and muscle stress (assessed by creatine kinase and myoglobin) change based on skiing intensity, slope, and skiing velocity (Scheiber et al., 2009; Seifert et al., 2005, 2009). The majority of skiing in the western United States occurs in the mountains at elevations in excess of 2,000 meters; therefore, hypoxia could also be factor in the development of fatigue. Szmedra et al. (2001) reported that junior alpine ski racers experienced significant oxygen desaturation in both giant slalom (-28.2%) and slalom (-34.3%) during races.

Another potential stress encountered during skiing is muscle glycogen depletion. Nygaard et al. (1987) found that muscle glycogen in the vastus lateralis was reduced to 30% of baseline after a full day of recreational skiing. Interestingly, these authors found no difference in the amount of glycogen depletion after skiing on short slopes versus skiing on long slopes. However, the effect of pacing during skiing was not addressed.

In addition to oxygen desaturation and glycogen depletion during skiing, mechanical stress can also have a large impact. Mechanical stress, such as eccentric muscle contractions, strenuous exercise, or brief repeated hard impact exercise, is thought to be responsible for the loss of intracellular enzymes and increases the activity of various serum enzymes, in particular, creatine kinase (Clarkson et al., 1982; Haralambie et al., 1976; Sirikul et al., 2007). As the intensity of the exercise increases, the amount of force generated by the muscles increases linearly leading to more microtears and, therefore, cause a greater increase of serum creatine kinase (Clarkson et al., 1982).

Hintermeister et al. (1995) reported EMG activity can increase 150% from baseline during skiing. With increased EMG activity, there is greater muscle activity and potentially more muscle damage. Seifert et al. (2005) reported a significant increase in creatine kinase during recreational skiing, the subjects skied approximately 19,000 vertical feet over three hours. These authors reported that the two hour post skiing creatine kinase levels increased 93% following the three hours of self paced skiing. Even with recreational skiers pacing themselves, there is still the potential to have significant physiological changes during one day of skiing.

Research on repeated days of skiing has been limited. Kahn et al. (1993) and Strojnik et al. (2001) concluded that repeated days of self paced skiing did not lead to significant fatigue. Kahn and colleagues were the first to report on the physiological responses during repeated days of skiing; ten healthy males (51.0 ±1.3 years) who participated in light physical activity skied at leisure paces for six days.

Strojnik et al. (2001) reported that a week of self-paced skiing did not lead to significant levels of fatigue in non active male skiers. The subjects skied for one week and chose what type of slope they skied. The researchers used the information gathered from the chairlift rides to estimate ski distance subjects skied each day. Interestingly, the researchers treated all runs as equally demanding, even though the runs ranged from easy to expert. Nonetheless, Strojnik et al. (2001) concluded that there was an overall increase in muscle function. The results could imply that a week of skiing can account for a positive contribution to neural recruitment and/or physical fitness levels. The subjects were able to regulate their intensity level during skiing in order to minimize fatigue and that the subjects seemed to experience a positive physical conditioning by skiing six days. However, it is more likely that the subjects improved neurologically rather than their physical fitness level in six days. It is important to note that the authors in the two studies stated above did not take into account the different skiing characteristics such as changing the intensity of skiing, radii of the turns, difficulty of the runs, and the amount of time skiing on each run.

Skiing characteristics and intensities change throughout a skier's day and therefore the amount of force the skier is subject to also changes. Thus far, there has not been a method of assessing the load while skiing. Banister et al. (1975) proposed a model comprised of a number of factors that contribute to general physical performance. These researchers determined that athletic performance is based on multiple aspects of physical fitness such as the degree of fitness as well as emotion and fatigue. While the fitness aspect can be quantified, Banister and associates were interested in quantifying the fatiguing and emotional components that influence performance. Any form of fatigue or emotional stress could negatively affect the performance, this includes fatigue from the amount of training as well as the fatigue that results from daily routines, should be taken into account. The resulting model was an attempt to quantify any changes in the level of performance in both the physical fitness aspects (such as heart rate and the duration of the activity) as well as the emotional and fatiguing aspects of the activity.

Single bouts of skiing and the physiological changes have been examined; however the muscular stress and subjective perceptions of fatigue that may occur over repeated days of recreational skiing have not been thoroughly examined. Therefore, the purpose of this study was to describe the changes in creatine kinase, heart rate, resting blood pressure, perception scales, ski time, and TRIMP score during five consecutive days of recreational skiing.

Methods

Fourteen intermediate and advanced skiers participated in the study. The qualifications of intermediate versus advanced skiers can be found in Appendix B. Prior to participation, each subject interested in participating in the study was emailed a copy of the IRB approved informed consent and a questionnaire about their ski ability.

Study Protocol

Each subject arrived at the Bridger Bowl Ski Area (elevation: 1,859 meters to 2,652 meters) in Bozeman, Montana and skied for five consecutive days with data collected on Days 1, 3, and 5. Participants filled out a Likert-type scale about their perceived excitement, fatigue, and soreness upon arrival at the mountain each data collection morning. Each subject was then fit with a heart rate monitor and given directions on how to use it while skiing. Blood pressure was then measured and recorded, followed immediately by a fingertip blood sample. Air temperature and snow conditions were recorded each morning from the Bridger Bowl weather station.

Subjects skied as they desired for three hours each morning (9:00am – 12:00pm) and were allowed to take as many breaks during skiing as they felt necessary. However, all subjects were asked to refrain from back country skiing for the duration of the study due to the possible hiking requirements back country skiing.

During the lunch break (12:00pm – 1:00pm), skiers provided their perceived skiing exertion (RPE) from the morning ski session. In addition, participants were asked what, if any, expert level runs they skied. Heart rate data were then downloaded to a laptop computer. Once the information was downloaded, the monitors were given back to the participants for the remainder of the day. Each subject also recorded their self-reported runs. After the lunch break, subjects were again able to ski where they pleased at a self-selected pace, with the exception of back country skiing.

At the end of each subject's self-determined ski day, the afternoon heart rate data were downloaded and rating of perceived exertion was recorded for the afternoon session. Lastly, each subject recorded how many expert runs they skied during the afternoon session. The next day's protocol was then reviewed with the subjects before they left the mountain.

Heart Rate and Ski Descent Time

A Polar RS400 Heart Rate Monitor (Polar Protrainer 5; Kempele, Finland) was used to record heart rate during skiing. The monitor consists of a receiver watch to record the heart rate data and a transmitter strap. The strap was placed at the base of the sternum; the two sensor pads, wet with gel, were placed on top of the ribs and attached around the back. The watch was worn on the subject's wrist. Heart rate data were stored at 5 second intervals to ensure that the heart rate at the start of the descent was recorded as well as the end of the descent. Peak skiing heart rate and the average skiing heart rate during the morning and afternoon sessions were used in the analysis using the Polar software. If for whatever reason the subject forgot to mark their start and or finish the researcher averaged out the time between the marks (the chairlift ride) and estimated when the subject started and stopped skiing. Out of the approximately 980 runs made by the subjects, the researcher had to estimate the run time 20 times. This equates to 2% of the cases.

Ski descent time was measured by the stored lap times. When the subject began the run, they pushed the "Lap" button to mark when they started the run. They pushed the "Lap" button again once they got into the chairlift line at the end of each run.

Blood Pressure

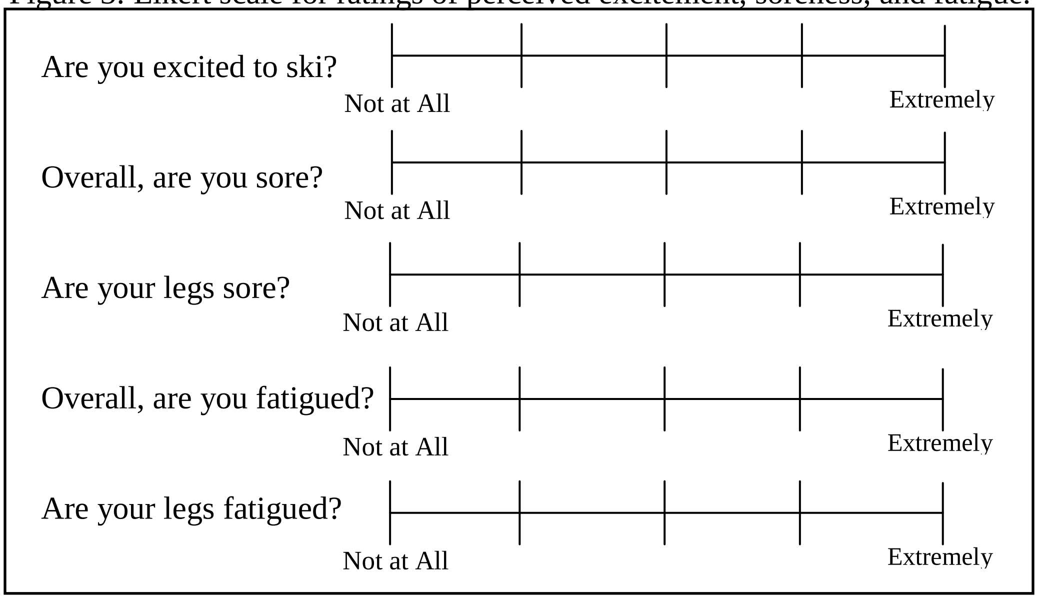
Following the collection of subjective scale data, subjects sat quietly for 10 minutes before having their blood pressure measured. A wrist worn blood pressure cuff (Omron IntelliSence Blood Pressure Monitor # 637; Omron Healthcare, Bannackburn, Illinois) was used to measure systolic and diastolic blood pressure. The blood pressure cuff was placed on the subject's left wrist. The subject then held their arm across their chest and remained still for approximately 30 seconds until the monitor provided a reading of the blood pressure. Blood pressure was measured to establish if the subjects experienced neural adaptations and/or relaxation over the five days of skiing. Mean arterial blood pressure (MAP) was calculated using systolic (BP_S) and diastolic (BP_D) blood pressures according to the formula: $MAP = ((2 * BP_D) + BP_S) / 3$ (Brooks et al., 2005).

Perceptual Scales

Subjects filled out subjective scales each of the three mornings upon arrival at Bridger Bowl Ski Area. An example of this form can be found in Figure 3. There were five questions that each subject answered from "Not at all" to "Extremely" by indicating their perceived intensity on the scale.

In addition to the enjoyment and soreness scales, the subjects filled out a Borg's rating of perceived exertion scale (Borg, 1970). The scale ranged from "6" (No Exertion at All) to "20" (Maximal Exertion). Rating of perceived exertion for skiing exertion was recorded for each subject for the morning and afternoon ski sessions when they returned for their lunch break and when they were done skiing at the end of the day. Borg's RPE scale (Borg, 1970) can be found in Table 11 of Appendix B. Additionally, each subject reported any falls during the morning and afternoon session each day.

Figure 3: Likert scale for ratings of perceived excitement, soreness, and fatigue.



Grading Code: Not at all = 1, Extremely = 5.

Grading of Ski Runs

In order to assess ski load, a formula was devised similar to Banister et al.'s (1975) TRIMP score. Banister et al. (1975) developed a model for training impulse (TRIMP) which is the product of the training intensity (measured by average heart rate), the training volume (number of minutes exercising), and/or the perceived exertion or difficulty of a specific activity (easy = 1, moderate = 2, difficult = 3). This new ski load score would account for skiing intensity (average HR), duration of the run (in seconds), and run difficulty. The beginner and intermediate runs were given 2 points and expert runs received 3 points. At the end of the morning and afternoon skiing sessions, the researcher added the total of points from the runs that each subject skied and computed the average run difficulty for each session. From this information the researcher was able to get a morning and afternoon TRIMP score:

TRIMP = ([am/pm Average Skiing HR] x [am/pm Average Run Difficulty] x [am/pm Average Descent Time in seconds]) / [am/pm Number of Runs]

In addition, there will be another TRIMP score that incorporates Foster et al. (2001) findings that adds subjective RPE scales to the TRIMPs. Foster et al.'s (2001) concluded that the consistency between the objective (heart rate) and subjective methods (RPE scales) of monitoring during different types of exercises show that subjective scales may be useful over a wide range of exercise sessions, even non-steady state, high intensity exercise.

Creatine Kinase

To assess muscle stress, a fingertip blood sample was collected from each subject and analyzed for creatine kinase. Subjects were asked to sit in the chalet and warm up the hand of their choice for about five minutes to ensure that the researcher was able to get enough blood. The chosen finger was cleaned with an alcohol wipe. Once the alcohol was dry, the selected finger was pricked and wiped away the blood with a gauze pad. Two 75 µm long heparinized capillary tubes were filled and plugged one end of the tube with putty and placed it in a cooler for transport to the laboratory. All samples were then centrifuged and plasma separated and frozen until analysis. A Johnson & Johnson Vitros II (Ortho Clinical Diagnostics, Rochester, New York) was used for creatine kinase analysis via reflectance photometry.

Statistical Analysis

The dependant variables measured on Days 1, 3, and 5 were creatine kinase, resting systolic and diastolic blood pressure, ski descent time, peak and average skiing heart rate, TRIMP score, and the subjective assessments of excitement, overall soreness, leg soreness, overall fatigue, and leg fatigue. The independent variable was the ski day. Creatine kinase, resting systolic and diastolic blood pressure, and peak and average skiing heart rate data from the morning and afternoon sessions were analyzed with a 1-factor repeated measures ANOVA. A 1-factor repeated measures ANOVA was also used to analyze ski descent time, number of runs, and TRIMPS data from the morning session and daily totals. Upon a significant ANOVA, a Tukey's Post Hoc test was performed to differentiate ski days. As four subjects did not ski in the afternoon on Day 5, a 1-factor repeated measures ANOVA was performed on the subgroup of the remaining seven subjects. Data analyses were performed with the computer software package Statistica (Tulsa, Oklahoma). Subjective scales were analyzed using Friedman Ranks Nonparametric analysis because subjective scales do not meet the assumption of repeated measures ANOVA of interval level data. Alpha level of significance was established at the 0.05 level.

Results

Fourteen intermediate and advanced skiers participated in this study. Subjects ranged in age from 29 years old to 65 years old (mean $\pm$SD; 45.7 $\pm$11.5); ten males with a mean age of 47.9 $\pm$11.2 years old and four females with a mean age of 41.3 $\pm$6.2 years old. Average morning temperatures along with the range of snow conditions found on

Days 1, 3, and 5, as reported by the Bridger Bowl weather station, are summarized in Table 2. Three subjects were dropped from the data analysis. One subject became ill and missed a day and two subjects failed to follow the instructions of the study, therefore data analysis was performed on 11 subjects (9 men, 2 women). It is important to note that some subjects (four subjects on Day 5) chose not to ski during the afternoon ski session.

The test variables were summarized by day (Day 1, Day 3, and Day 5) for descriptive analysis in Tables 3 – 10 and Figures 4 – 6. Individual subject data can be found in Appendix C, Figures 9 – 29.

Table 2. Range of morning temperatures and snow conditions.

	Day 1	Day 3	Day 5
Temperature (°C)	-21 to -2	-19 to -2	-8 to -2
Snow Conditions	Groomed - 4 inches	Groomed	1 - 3 inches

Table 3 summarizes the total ski descent time over the three measurement days. No significant differences between days were observed. In addition, three subjects fell while skiing, two subjects fell on Day 1 and one subject fell on Day 3. There were no reported injuries and all subjects were able to immediately ski again. The number of runs each subject skied during the morning and the total ski sessions on Days 1, 3, and 5 are depicted in Table 4. There was no significant difference between days for the number of runs skied.

Table 3. Average ski descent time and number of falls each day (Mean $\pm$ SE, n = 11).

	Day 1	Day 3	Day 5
SDT_{AM} (minutes)	71 $\pm$ 3	62 $\pm$ 5	63 $\pm$ 5
SDT_{Total} (minutes)	105 $\pm$ 7	97 $\pm$ 9	98 $\pm$ 16
Falls	2	1	0

SDT_{AM} = Average morning ski descent time; SDT_{Total} = Average total ski descent time; Falls = Total number of falls while skiing over the three testing days during both the morning and afternoon ski session.

Table 4. Average number of morning and total runs (Mean $\pm$ SE, n = 11).

	Day 1	Day 3	Day 5
$Runs_{AM}$	9 $\pm$ 0.7	9 $\pm$ 0.5	8 $\pm$ 0.7
ER_{AM}	3 $\pm$ 0.7	4 $\pm$ 1	3 $\pm$ 0.8
$Runs_{Total}$	13 $\pm$ 1	12 $\pm$ 1	13 $\pm$ 1
ER_{Total}	5 $\pm$ 1	5 $\pm$ 1	6 $\pm$ 1

$Runs_{AM}$ = Average number of morning runs; ER_{AM} = Average number of expert runs in the morning; $Runs_{Total}$ = Average number of total runs; ER_{Total} = Average number of expert runs total.

Figures 4 and 5 illustrate the average percent of expert runs skied on Days 1, 3, and 5. There was a large variation on how many expert runs were skied during the morning and afternoon ski sessions. During the morning ski session on Day 1 the average number of expert runs skied were three out of nine runs. On Day 3 subjects skied four out of nine expert runs, and on Day 5, three of nine runs skied were expert runs. During the afternoon ski session two of four runs skied were expert, one of four runs skied were expert runs on Day 3, and on Day 5 subjects skied two out of five runs were expert runs. In addition, two subjects did not ski any expert runs during the five days of skiing, this, in part, accounts for the large variation. There was no significant change in the number of expert runs skied in the morning or afternoon ski session during Days 1, 3, and 5.

Figure 4. Average percent of expert runs skied during the morning ski session

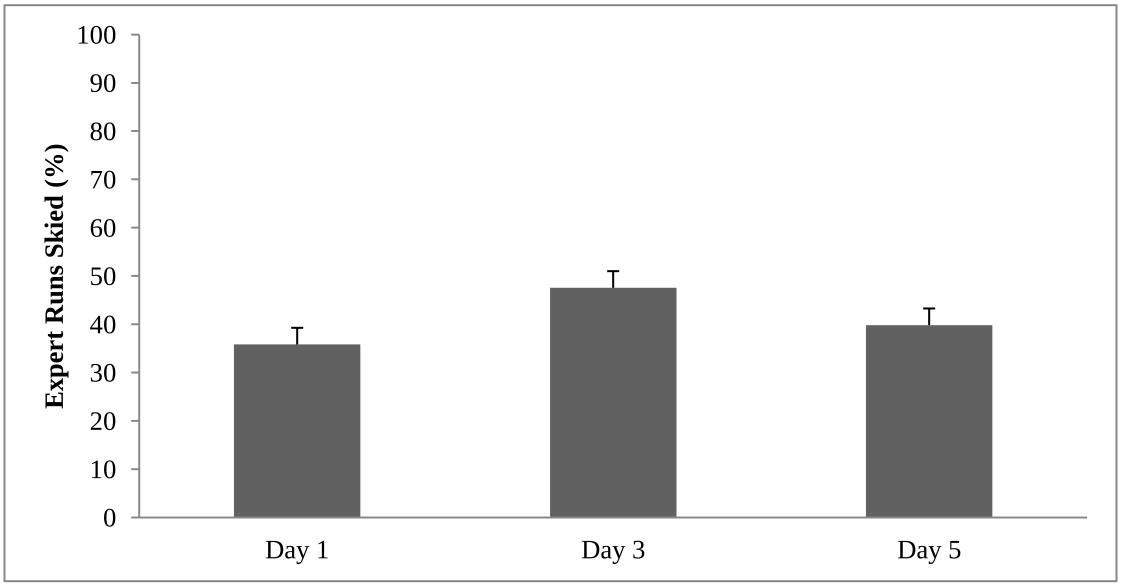
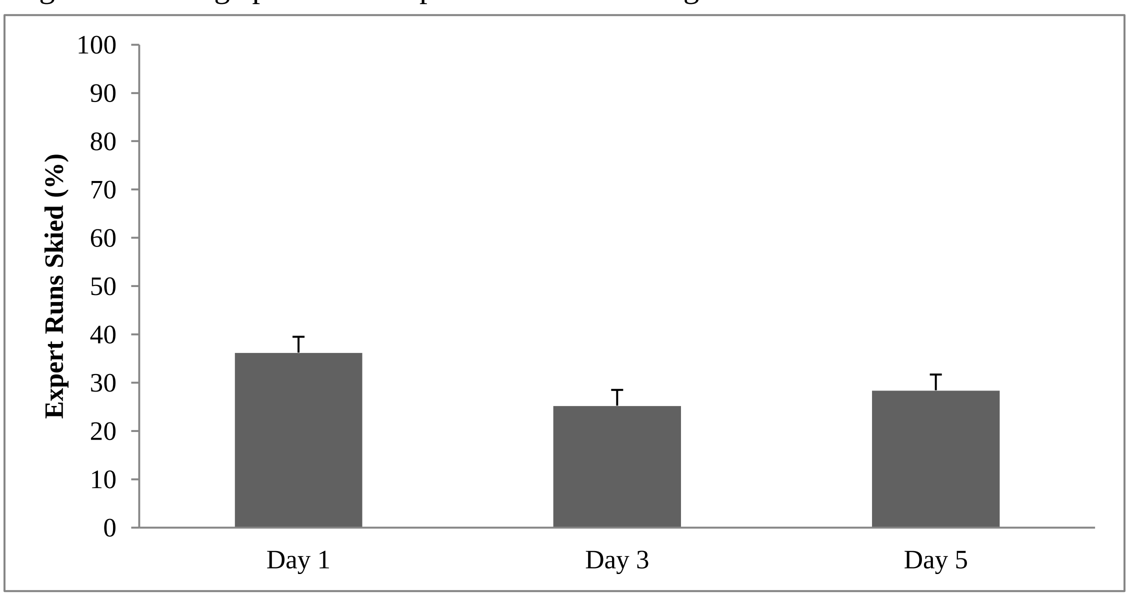


Figure 5. Average percent of expert runs skied during the afternoon ski session.



There was a significant change in the subjects' average rating of perceived exertion during both the morning ($p = 0.001$) and afternoon ($p = 0.001$) ski sessions (Table 5). For the morning ski session on Day 1 the subjects' average rating of perceived exertion was 13.5 ±1.8 and 13.4 ±2.0 for the afternoon ski session. These values increased to 16.7 ±1.7 during the morning ski session and 16.3 ±2.1 during the afternoon ski session from Day 1.

Table 5. Average rating of perceived exertion of skiing intensity during the morning and afternoon ski session (Mean ± SE, n = 11).

	Day 1	Day 3	Day 5
RPE_{AM}	13.5 ± 0.5	14.5 ± 0.4	16.7 ± 0.5* #
RPE_{PM}	13.4 ± 0.6	15.4 ± 0.7*	16.3 ± 0.6*

Significance was determined to be $p < 0.05$. * denotes a significant change from Day 1 (AM: $p = 0.001$; PM: $p = 0.03$ and $p = 0.002$). # denotes a significant change from Day 3 ($p = 0.02$). RPE_{AM} = Average morning ski session RPE; RPE_{PM} = Average afternoon ski session RPE.

Table 6 contains the average morning and afternoon resting heart rate, average heart rate during skiing, peak skiing heart rate, and percent of estimated maximal heart rate during skiing. There were no significant differences between days for any of the heart rate variables. The subject's average skiing heart rate and the percent of maximal heart rate during both the morning and afternoon ski sessions remained remarkably stable throughout the week. However, the average peak heart rate, although not significant, did decrease by about 8 bpm throughout the week during both the morning and afternoon ski sessions.

Table 6. Average resting, morning, afternoon heart rate, peak morning and afternoon heart rate, and percent estimated of maximal heart rate (Mean ± SE, n = 11).

	Day 1	Day 3	Day 5
HR_R (bpm)	83 ± 4	80 ± 4	81 ± 3
HR_1 (bmp)	121 ± 5	118 ± 4	118 ± 4
HR_{1P} (bpm)	144 ± 6	138 ± 5	136 ± 5
HR_{1MAX} (%)	66 ± 3	67 ± 2	67 ± 2
HR_2 (bpm)	120 ± 4	120 ± 5	119 ± 4
HR_{2P} (bpm)	140 ± 5	137 ± 6	136 ± 4
HR_{2MAX} (%)	68 ± 2	68 ± 2	68 ± 2

HR_R = Average resting heart rate; HR_1 = Average morning skiing heart rate; HR_{1P} = Average morning peak skiing heart rate; HR_{1MAX} = Average morning percentage of estimated maximal heart rate; HR_2 = Average afternoon skiing heart rate; HR_{2P} = Average afternoon peak skiing heart rate; HR_{2MAX} = Average afternoon percentage of estimated maximal heart rate.

Table 7 summarizes the subject's average systolic, diastolic, and mean arterial blood pressures taken before skiing each morning. No significant differences were observed over the three testing days. No significant differences between days for the subjective scales were observed (Table 8). Additionally, Table 8 contains the nonparametric ranking where each answer ranged from 1 (Not at all) to 5 (Extremely). The parametric ranking is the relationship between the numerical value and the question being asked.

Table 7. Average resting systolic blood pressure, diastolic blood pressure, and mean arterial blood pressure (Mean ± SE, n = 11).

	Day 1	Day 3	Day 5
BP_S (mmHg)	126 ± 5	125 ± 4	122 ± 4
BP_D (mmHg)	82 ± 4	79 ± 3	78 ± 3
MAP (mmHg)	112 ± 4	109 ± 3	108 ± 3

BP_S = Systolic blood pressure; BP_D = Diastolic blood pressure; MAP = Mean arterial pressure.

Table 8. Average morning subjective scales with the nonparametric rank (Mean $\pm$ SE, n = 11).

	Day 1	Day 3	Day 5	Nonparametric Rank
Are you excited to ski today?	4.5 $\pm$ 0.2	4.1 $\pm$ 0.3	4.0 $\pm$ 0.4	4.8 $\pm$ 0.9
Are you sore today?	1.4 $\pm$ 0.2	1.7 $\pm$ 0.2	2.3 $\pm$ 0.3	2.5 $\pm$ 0.8
Are your legs sore today?	1.2 $\pm$ 0.2	2.0 $\pm$ 0.2	2.1 $\pm$ 0.2	2.4 $\pm$ 0.8
Are you fatigued today?	1.4 $\pm$ 0.2	2.2 $\pm$ 0.2	2.3 $\pm$ 0.2	2.8 $\pm$ 0.8
Are your legs fatigued today?	1.3 $\pm$ 0.2	2.3 $\pm$ 0.2	2.1 $\pm$ 0.2	2.6 $\pm$ 0.8

Ranking: 1 = "Not at all" to 5 = "Extremely"

The average relative and absolute TRIMP scores during the morning ski session and total ski session each day are reported in Table 9. The absolute TRIMP scores were calculated the same as the relative score; however the result was not divided by the number of runs. There were no differences observed between days with either the relative or absolute TRIMP scores. Table 10 incorporates Foster et al.'s (2001) TRIMP scores with subjective RPE scales.

Table 9. Average relative and absolute TRIMP scores during the morning and total ski session (Mean $\pm$ SE, n = 11).

	Day 1	Day 3	Day 5
$TRIMP_{1R}$	149,378 $\pm$ 22,647	133,461 $\pm$ 17,700	140,137 $\pm$ 23,862
$TRIMP_{TR}$	281,817 $\pm$ 49,793	253,371 $\pm$ 49,221	152,535 $\pm$ 68,021
$TRIMP_{1A}$	1,185,016 $\pm$ 122,473	1,108,576 $\pm$ 124,995	1,823,593 $\pm$ 838,473
$TRIMP_{TA}$	1,908,388 $\pm$ 229,271	1,746,695 $\pm$ 214,757	2,635,289 $\pm$ 912,799

$TRIMP_{1R}$ = Average relative morning TRIMP score; $TRIMP_{TR}$ = Average relative total TRIMP score; $TRIMP_{1A}$ = Average absolute morning TRIMP score; $TRIMP_{TA}$ = Average absolute total TRIMP score.

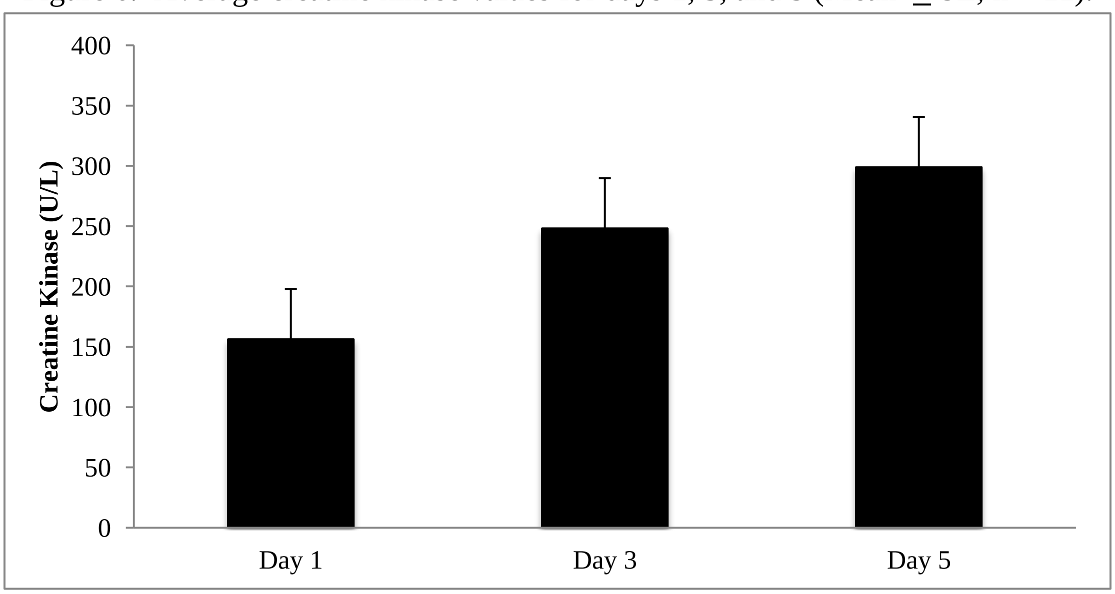
Table 10. Average morning and total TRIMP scores in addition with Borg's RPE scale (Mean ± SE, n = 11).

	Day 1	Day 3	Day 5
$TRIMP_{AM}$	2,057,884 ± 371,549	2,182,573 ± 411,724	2,316,760 ± 458,553
$TRIMP_{Total}$	3,910,648 ± 765,884	4,195,751 ± 1,043,324	3,755,720 ± 835,799

$TRIMP_{AM}$ = Average morning ski session TRIMP with RPE; $TRIMP_{Total}$ = Average total ski session TRIMP with RPE.

Creatine kinase (Figure 6) levels increased linearly throughout the five days of skiing. However, these days were not significantly different from one another. An analysis was run excluding a subject who had an extremely high creatine kinase value (1122 U/L) on Day 5 and it was found that creatine kinase was significantly different from Day 1 to Day 5, which is explained further in the discussion.

Figure 6. Average creatine kinase values for days 1, 3, and 5 (Mean ± SE, n = 11).



When the four subjects who did not ski in the afternoon of Day 5 were removed and analyses performed on the remaining seven skiers, no significant differences were observed between days for the dependent variables. Additionally, there were no objective data that would indicate why these four skiers chose not to ski in the afternoon on Day 5.

Discussion

The purpose of this study was to determine whether repeated days of skiing amplified the physiological changes that have been reported by researchers who have examined single bouts of recreational skiing. While Kahn et al. (1993) and Strojnik et al. (2001) found that there were increases in physiological changes, these changes were not enough to inhibit the subjects skiing ability. The current study only reported data from Days 1, 3, and 5; however, the subjects also skied on Days 2 and 4 and may have changed their skiing habits without the investigator's knowledge.

According to the hypothesis, the variables that were expected to decrease relative to Day 1 were ski time, excitement of skiing, TRIMP score, and resting blood pressure. These variables remained stable throughout the week. The variables that were expected to increase relative to Day 1 were fatigue, soreness, rating of perceived exertion, heart rate, and creatine kinase. With the exception of heart rate, the increased changes in these variables supported the hypothesis relative to Day 1.

Ski Descent Time

There were no significant differences ($p = 0.56$) between days in the average total skiing descent time. The average total descent time was consistent for the three measurement days at 100 minutes (Table 3). The present results differ from Kahn et al.'s (1993) results where those researchers reported significant fluctuations in the descent time. Those authors reported an increase from Day 1 to Day 3 (from 66.9 minutes to 145.5 minutes), followed by a significant decrease on Day 4 to 89.8 minutes, Day 5 again increased to 141.8 minutes, and decreased again on Day 6 to 42.8 minutes. Kahn and associates reported that skiers skied for the longest time on Day 3; while the current study reported the longest ski descent times on Day 1, although it was not significantly different from Days 3 and 5. Strojnik et al. (2001) examined linear ski distance, which is not a normal practice when measuring ski distance; the reason being that the readers do not know if the skiers skied all expert runs, all beginner runs, or a combination of both. In addition, these researchers did not measure ski time, therefore no reasonable comparisons could be made.

Number of Runs and Expert Runs

It was expected that the number of runs, along with the number of expert runs skied would decrease over the three testing days; however, the average number of both variables remained constant during the three testing days. No statistical differences were found between the days perhaps because the subjects may have become accustomed to the mountain and therefore became more comfortable with skiing different expert runs, or skiing faster on the same expert runs. This is supported because the subjects descent time decreased slightly during the week while the number of runs skied remained the same.

Another way to minimize stress, but maintain descent time, is to change ski habits from skiing easy to moderate level runs to more demanding runs; although this was not seen in the current study. While skiing expert runs, the subjects could have started off skiing down the fall line, requiring less muscular force; rather than skiing across the fall line. By skiing closer to the fall line the subjects could have slowed to maintain a given intensity where they were comfortable. This can be accomplished by side slipping through the turn down the hill which would result in a less aggressive body position. In addition to skiing across the fall line, the subjects could have decreased their velocity or changed their body position from a more crouched position to a more upright position to ensure they were skiing within their comfort zone on the more challenging runs.

Interestingly, the average number of runs skied each day was about 13 even though the average descent time decreased slightly from 105 minutes on Day 1 to 98 on Day 5. In addition, the number of expert runs skied remained stable with an average of five a day over the three testing days.

Rating of Perceived Exertion

Rating of perceived exertion increased significantly in both the morning and afternoon ski sessions, as hypothesized. The morning RPE increased significantly from Day 1, (13.5) to Day 5, (16.7). The afternoon RPE also increased significantly from Day 1, (13.4) to Day 5, (16.3). While the subjects' morning and afternoon RPE increased significantly throughout the three data collection days, the subjects' heart rate remained consistent at approximately 119 bpm and at about 68% of their predicted maximal heart rate during the week. Again, this could have occurred because the subjects changed their body position during skiing. Scheiber et al. (2009) reported that skiing at low intensities with parallel ski steering (upright skiing position) resulted in a lower heart rate and lower energy expenditure on both flat and steep slopes as compared to skiing at a high intensity with long radii carving turns (crouched skiing position).

Hence, the current study's heart rate results indicate that skiers paced themselves and maintained their relative exertion level throughout the week. However, the subjects' perceived exertion increased. The increased RPE could have been a result of slight leg and overall fatigue experienced while skiing, perhaps due to glycogen depletion. During exercise, depletion of glycogen and other energy stores, and/or a buildup of metabolites such as lactate, calcium, hydrogen ions, and inorganic phosphate increase fatigue in the muscle (Allen et al., 2002; McLester, 1997; Sirikul et al., 2007). However, as heart rate, the number of runs, and the difficulty of the runs did not change significantly throughout the week it can be concluded that any stress or fatigue subjects experienced was not enough to hinder their skiing output.

Heart Rate

Interestingly, even as RPE increased significantly throughout the week, the subjects skiing heart rate remained stable over the five days of skiing. Responses to repeated days of recreational skiing have not been thoroughly examined. However, single days of recreational skiing have been well documented. Scheiber et al. (2009) and Seifert et al. (2009) reported skiers ski from approximately 60 to 80% of their maximal heart rate during one day of recreational skiing. Kahn et al.'s (1993) subjects skied in a range from 69 to 78% of their maximal heart rate. The subjects in the current study skied at approximately 68% of their maximal heart rate with a range from 54% to 80% during both the morning and afternoon ski sessions. In the current study, subjects' skiing heart rate could have been altered by decreasing the amount of muscular work performed during each run. This can be achieved by changing from a crouched skiing position to a more upright position as well as changing from carving turns to skidding turns which would decrease the amount of force the legs need to produce during each turn causing a decrease in heart rate.

In a crouched position there would be an increased intramuscular pressure due to the intense isometric contraction; this isometric contraction would increase the pressure on the blood vessels within the leg muscles, narrowing them and therefore decreasing the amount of blood able to get to the working muscles. In an attempt to compensate for the decreased blood flow, heart rate will increase, which would result in more blood getting to the working muscles. When a skier moves from a crouched position to a more upright position it relieves some of the intramuscular pressure (ischemia) and therefore reducing the skiers heart rate.

The consistent heart rate that was observed in the current study is contrary to Kahn et al.'s (1993) finding where both mean and maximal heart rate decreased throughout six days of recreational skiing. In addition, Kahn et al. (1993) also found that the maximal skiing heart rate ranged from 141 bpm to 144 bpm. Similarly, the current study's subject's average maximal skiing heart rate ranged from 136 bpm to 144 bpm in the morning and from 136 bpm to 140 bpm during the afternoon ski session. The subjects from the current study could have paced themselves at a lower intensity as to minimize fatigue or changed their ski habits enough throughout the week. With a linear decrease in maximum skiing heart rate of 8% along with a 10% decrease in mean skiing heart rate from Day 1 to Day 6, Kahn et al. (1993) accounted for the drop in heart rate to be a direct result of physical and mental relaxation, as well as a certain degree of acclimatization to altitude.

Scheiber et al. (2009) and Seifert et al. (2009) determined that recreational skiing heart rate varies greatly depending on what time of day the subjects ski, the snow conditions, skill level of skiers, skiing terrain, and duration of the ski runs. However, the subjects in the current study did not experience the variation of heart rate that Scheiber et al. (2009) and Seifert et al. (2009) measured with their skiers. One possible reason for this is because these studies were conducted during a few hours of skiing which could result in the subjects skiing a lot more aggressively than they would if they had to ski for an entire week. In contrast, the current study was conducted over five days; the subjects may have paced themselves in order to make it through the day as well as all five days of skiing. The most logical reasoning would be that they skied at a certain intensity that resulted in minimal change in their heart rate even if there was an increase or decrease in intensity due to different snow conditions or runs. Nevertheless, subjects in the current study did not experience the fluctuation in heart rate between the morning and afternoon ski session. In addition, snow conditions did not appear to affect the subjects' heart rate, as seen in Table 6. The snow conditions ranged from groomed runs up to four inches of new powder and snowing all day; while the temperatures ranged from -21^{o} C and cloudy, to -2^{o} C and sunny. Likewise, the skiing terrain did not seem to interfere with the subjects heart rate either. The subjects in the current study were intermediate to advanced skiers and therefore could adjust their skiing habits or intensity to be able to maintain output within their comfort for the five days.

Blood Pressure

It was hypothesized that blood pressure would decrease as a result of recreational skiing for five days. However, blood pressure remained stable throughout the week. Kahn et al. (1993) reported a 7% decrease in diastolic blood pressure while systolic blood pressure remained stable over the six days. Kahn et al. (1993) reported that one week of recreational skiing positively contributed to improved physical fitness as noted by the decrease in blood pressure. No significant changes in systolic or diastolic blood pressure (Day 1: 126/82 to Day 5: 122/78) were observed in the current study. One possible explanation of why Kahn et al.'s (1993) subjects did not experience a decrease in systolic or diastolic blood pressure is because they may not have skied intensely enough and therefore did not have the stimulus needed for neurological adaptations.

Schobersberger et al. (2003) determined that exposure to moderate to high altitude increases the sympathetic pathways in healthy individuals. Conversely, Palatini et al. (1991) reported that while high altitude, above 3,322 meters, resulted in a significant increase in blood pressure while moderate altitude (elevations above 1,322 meters) did not exert a significant influence in blood pressure. The base of Bridger Bowl (where blood pressure was measured) is located at 1,860 meters and is, therefore, considered moderate altitude. Based on previous research, ascent to moderate altitude should have minimal influence on blood pressure; even though resting blood pressures were not measured before the subjects arrived at Bridger Bowl. The current study supports

Scheiber et al.'s (2009) and Palatini et al.'s (1991) findings where moderate altitude does not seem to affect the subjects' blood pressure. From this information, it can be assumed that the subjects in the current study did not experience any improvement in physical fitness benefits from skiing as the subjects in Kahn et al.'s (1993) study reported.

Subjective Scales

It was expected that the subjects' perceived excitement of skiing would decrease over the three testing days, while the subjects' leg and overall soreness and fatigue would increase. However, there were no significant changes in any of the subjective variables. The subjects' rating of perceived excitement decreased, though not significantly, from an average of 4.5 on Day 1 to a 4.0 on Day 5. One subject began the study with a 5 on the excited to ski scale, but had decreased to a 1 on Day 5 even though her ski times and creatine kinase were not any higher than the other subjects. However, the majority of the subjects rating of excitement decreased only slightly during the week of recreational skiing, which in turn can be concluded that skiers were not fatigued to the point where it significantly impacted their excitement to ski.

This was the first time skiing multiple days in a row for the season for many of the subjects. Additionally, many of the subjects engaged in regular exercise throughout the year, therefore fitness level could have minimized the soreness. However, when skiing for the first time a season, muscles are being used in different ways and new muscles may have been stressed more than what the muscle was normally used to, but this did not appear to be a strong factor with the current subjects.

Even though the subjects did not feel as though they, or their legs, were sore and/or fatigued; subjects did make subjective comments throughout the week during their lunch break and again at the end of the day. Towards the end of the week, subjects commented more on how tired and sore their legs felt and that they needed a break because they did not think that their legs could make another run safely. These subjective comments suggest that the subjects started to experience the early stages of fatigue but were partially able to recover before the next ski day, which could explain why the subjects did not feel any significant change in fatigue or soreness at the beginning of the day before skiing.

TRIMPs

A training impulse formula was established in an attempt to quantify ski load. The TRIMP scores in the morning were slightly higher, but not significantly different, from the afternoon TRIMP scores (see Table 9). However, it is important to note that some subjects chose not to ski during the afternoon session. However, it is important to note that while 4 subjects did not ski in the afternoon, the other 6 subjects skied until the mountain closed on Day 5. This resulted in the TRIMP scores to remain stable on Day 5.

Foster et al. (2001) developed a formula much like Banister et al. (1975). Foster et al. (2001) concluded that the consistency between the objective (heart rate) and subjective methods (RPE scales) of monitoring during different types of exercises show that subjective scales may be useful over a wide range of exercise sessions, even non-steady state, high intensity exercise. Therefore, in an attempt to add the subjective measures, morning and afternoon RPE was added to the TRIMP calculation to determine if there was a change in the TRIMP scores. With the RPE added to the TRIMP calculation there were still no significant differences between days in either the morning ski session or the totals for each day even though RPE increased significantly throughout the week during both the morning and afternoon session (Table 10). From these findings, it may be inferred that the subjects were able to maintain their training impulse throughout the morning and afternoon ski sessions, as well as from day to day.

Creatine Kinase

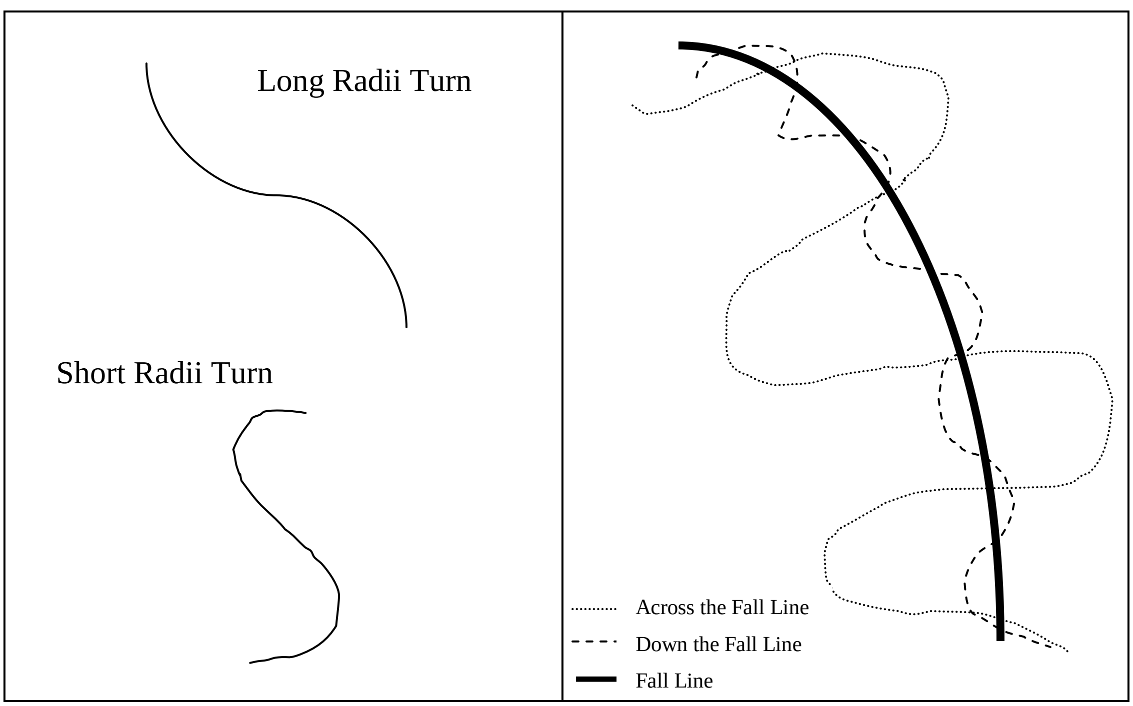
Creatine kinase changes have not been examined over repeated days of skiing. However, Seifert et al. (2005 and 2009) reported that creatine kinase values can increase just from a few hours of recreational skiing at a self selected pace. Those researchers found that after three hours of recreational skiing, serum creatine kinase values significantly increased by 97% and 41%, respectively.

The current study found that in creatine kinase increased Day 1 from 156 U/L, to 299 U/L on Day 5. Although there were no significant differences in creatine kinase between Days 1, 3, and 5, one subject skied abnormally hard on Day 4 which caused the creatine kinase sample to be 1122 U/L on Day 5. This skier's creatine kinase values from Days 1 and 3 were similar to the rest of the group to start the ski week. With this outlier removed from of the analysis, the variability of the sample decreased causing the ANOVA to become significant ($p = 0.001$) and resulting in a significant change increase from Day 1 to 3 ($p = 0.009$) and Day 1 to 5 ($p = 0.004$). From the linear increase of creatine kinase levels throughout the week, it is possible that stress was increasing even though subjects' subjective scales indicate otherwise.

Ski Habits

When the top three skiers and the bottom three skiers of the test subjects were grouped by skill, no physiological differences between the two groups were observed. Ski times, creatine kinase, and heart rate were similar for both groups throughout the week showing that each group was skiing at about the same relative intensity. In addition, while the top three skiers skied all expert runs and the bottom three skiers only skied intermediate and beginner runs, both groups' creatine kinase levels and RPE scores were similar. Figure 7 depicts different ski habits and ways the subjects could have changed their skiing habits to maintain a comfortable intensity.

Figure 7. Different ski habits: long radii turns versus short radii turns and skiing down the fall line versus skiing across the fall line.



The subjects in the current study were experienced skiers who were able to pace themselves for the five days of skiing which limited the affect of the physiological changes. These findings coincide with the findings from Kahn et al. (1993) and Strojnik et al. (2001) where they found that repeated days of skiing under self paced conditions did not induce significant levels of fatigue. While both previous researchers reported limited levels of fatigue, they also reported a significant “down day” from skiing on Day four (Kahn et al., 1993) and Day five (Strojnik et al., 2001) which could result in the limited fatigue. Based on run number, ski descent time, and TRIMPS score, the current study did not observe a “down day” however; data was only collected on Days 1, 3, and 5. It is plausible that there could have been a “down day” on either Day 2 or 4. The current study did not report a “down day” however; data was only collected on Days 1, 3, and 5. It is plausible that there could have been a “down day” on either Day 2 or 4. The subjects were able to limit their fatigue by pacing themselves throughout the week. This could be possible by the subjects changing their skiing habits. In order to achieve this, subjects in the current study could have changed from quick, sharp, short radius turns to slow, wide, long radius turns or from skiing down the fall line to across the fall line. Another way subjects could have minimized fatigue was by increasing the number of times the subjects stopped on a run or changing the type of runs skied. However, the current data does not support these possibilities. While there was no difference in the amount of descent time, the subjects could have changed from skiing steeper, bumpy runs to shallower, groomed runs possibly allowing extra time to stop on the runs.

These changes could account for the subjects maintaining heart rate values, the amount of time spent on the hill, the number of runs, and the number of expert runs they skied from Day 1 to Day 5. However, while pacing and possibly changing their ski habits, the subjects still experienced slight to moderate fatigue because while they were able to maintain the amount of time spent on the hill and the number of runs they skied; their rating of perceived exertion during both the morning and afternoon increased significantly throughout the week of skiing.

Conclusion

The findings of the current study supports those of previous studies conducted on repeated days of skiing where minimal fatigue was observed under self paced skiing conditions. Under the current conditions, five consecutive days does not appear to cause significant fatigue in which skiing ability and enjoyment is hindered as the subjects appeared to have paces themselves during the week. In the current study, heart rate, number of runs, and remained quite consistent throughout the week implying that the subjects were able to pace themselves sufficiently as to minimize fatigue. The subjects' rating of perceived exertion did increase significantly, suggesting that the subjects were fatigued to some point while skiing at the same intensity determined by the physiological stress markers. Creatine kinase did not increase significantly because of one outlier. However, these values changed significantly when that subject was removed from analysis. Significant changes in creatine kinase and RPE does lead the researcher to believe that subjects did experience some fatigue over the five days of skiing, however as previous researchers have stated, it was not enough fatigue to hinder the subjects ability to ski over repeated days of skiing. Therefore, the subjects in the current study were experienced enough skiers to pace themselves throughout the week and could have possibly changed their ski habits throughout the week, which could have decreased their actual skiing intensity, even though the subjects felt as though they were skiing more intensely throughout the week.

CHAPTER 4

CONCLUSION

The findings of the current study supports those of Kahn et al. (1993) and Strojnik et al. (2001) in which repeated days of recreational skiers paced themselves sufficiently as to minimize fatigue and muscle stress. The overall conclusions from these previous researchers were that that subjects' were able to pace themselves and prevent significant amounts of fatigue. While these two authors did not examine stress markers, Kahn et al. (1993) reported a "down day" where the subjects decreased the amount of time spent on the hill; Strojnik et al. (2001) also reported a 'down day' where the distance skied decreased. However, both researchers also reported a significant increase in both the time spent on the hill along (Kahn et al., 1993) with the ski distance (Strojnik et al., 2001) covered the following day. The current study found that the stress markers of creatine kinase and rating of perceived exertion increased throughout the week, indicating that the subjects' were indeed slightly fatigued. However, the current study reported the total ski distance and time to remain stable throughout the week also indicating that the amount of fatigue they experienced did not hinder their skiing.

From the results of the current study, and in support of Kahn et al. (1993) and Strojnik et al. (2001), it can be concluded that repeated days of skiing is not an overly fatiguing event when skiers ski as self-selected paces. Intermediate to advanced skiers over a wide age range (29 to 65 years old) are able to pace themselves to ensure that they are able to ski for the entire vacation. This information may aid ski instructors in maximizing the skiers full potential by allowing them to ski within their comfort zone during the lesson to ensure the skier is able to ski for the full time they are on vacation. In addition, Kahn et al. (1993) and Strojnik et al. (2001) did find some possible health benefits to repeated days of skiing, however the current study did not examine this. Skiing could be considered a positive contribution to physical fitness and therefore could be considered a valid workout for daily skiers. Future studies should examine what health benefits, if any, could result from repeated days of recreational skiing.

REFERENCES

Allen DG, Kabbara AA, Westerblad H. Muscle fatigue: the role of intracellular calcium stores. Can J Appl Physiol 2002; 27:83-96.

Andersen RE, Montgomery DL. Physiology of alpine skiing. Sports Med (Auckland) 1988; 4:210-221.

Armstrong RB. Mechanisms of exercise-induced delayed onset muscular soreness-a brief review. Med Sci Sports Exerc 1984; 22:699-677.

Banister EW, Calvert TW, Savage MV, Banch TM. A systems model of training for athletic performance. Aust J Sports Med 1975; 7:57-61.

Berg HE, Eiken O, Tesch PA. Involvement of eccentric muscle actions in giant slalom racing. Med Sci Sports Exerc 1995; 27:1666-1670.

Borg G. Perceived exertion as an indicator of somatic stress. Scand J Rehabil Med 1970; 2:92-98.

Brooks AB, Fahey TD, Baldwin KM. Cardiovascular dynamics during exercise; Exercise testing and prescription. In: Exercise physiology human bioenergetics and its applications (4^{th} ed.). New York: McGraw-Hill; 2005. p. 341-362.

Clarkson PM, Kroll W, Graves J, Record WA. The relationship of serum creatine kinase, fiber type, and isometric exercise. Int J Sports Med 1982; 3:145-148.

Duffield R, Edge J, Merrells R, Hawke E, Barnes M, Simcock D, Gill N. The effects of compression garments on intermittent exercise performance and recovery on consecutive days. IJSPP 2008; 3:454-468.

Foster C, Florhaug JA, Franklin J, Cottschall L, Hrovatin LA, Parker S, Doleshal P, Dodge C. A new approach to monitoring exercise training. J Strength Cond Res 2001; 15:109-115.

Foster GE, Hanly PJ, Ahmed SB, Beaudin AE, Pialoux V, Poulin MJ. Intermittent hypoxia increases arterial blood pressure in humans through a rennin-angiotensin system-dependent mechanism. Hypertension 2010; 56:369-378.

Green JM, McLester JR, Crews TR, Wickwire PJ, Pritchett RC, Redden A. RPE-lactate dissociation during extended cycling. Eur J Appl Physiol 2005; 94:145-150.

Haralambie G, Cerny FJ, Huber G. Serum enzyme level after bobsled racing. J Sports Med 1976; 16:54-56.

Hintermeister RA, O'Connor DD, Dillman CJ, Suplizio CL, Lange GW, Steadman JR. Muscle activity in slalom and giant slalom racing. Med Sci Sports Exerc 1995; 27:315-322.

Hintermeister RA, O'Connor DD, Lange GW, Steadman JR. Muscle activity in wedge, parallel, and giant slalom skiing. Med Sci Sports Exerc 1997; 29:548-55.

Hubal M, Devaney J, Hoffman E, Zambraski E, Gordish-Dressman H, Kearns A, Larkin J, Adham K, Patel R, Clarkson P. CCL2 and CCR2 polymorphisms are associated with markers of exercise-induced skeletal muscle damage. J Appl Physiol 2010; 108:1651-1658.

Kahn JF, Jouanin JC, Espirito-Santo J, Monod H. Cardiovascular responses to leisure alpine skiing in habitually sedentary middle-aged men. J Sports Sci 1993; 2:31-36.

Karlsson J. Profiles of cross-country and alpine skiers. Clin Sports Med 1984; 3:245-271.

Karlsson J, Eriksson A, Forsberg A, Kallberg L, Tesh P. The Physiology of Alpine Skiing. Park City: The United State Ski Coaches Association; 1978.

Katayama K, Yoshitake Y, Watanabe K, Akima H, Ishida K. Muscle deoxygenation during sustained and intermittent isometric exercise in hypoxia. Med Sci Sports Exerc 2010; 42:1269-1275.

Kröll J, Müller E, Seifert J, Wakeling J. Changes in Quadriceps muscle during sustained recreational alpine skiing. In publication process; Manuscript: 1-20.

Mackey A, Bojsen-Moller J, Qvotrup K, Langberg H, Suetta C, Kalliokoski K, Kjaer M, Magnusson S. Evidence of skeletal damage following electrically stimulated isometric muscle contractions in humans. J Appl Physiol 2008; 105:1620-1627.

Maskowski K, Aschenbrenner P, Szymczak R, Grzywacz T. Physiological cost of skiing in hypoxic or normoxic environments. Research Yearbook 2006; 12:222-226.

McLester JR. Muscle contraction and fatigue: the role of adenosine 5'-diphosphate and inorganic phosphate. Sports Med 1997; 23:287-305.

Millet GY, Aubert D, Favier FB, Busso T, Benoît H. Effect of acute hypoxia on central fatigue during repeated isometric leg contractions. Scand J Med Sci Sports 2009; 19:695-702.

Müller E, Schwameder H. Biomechanical aspects of new techniques in alpine skiing and ski-jumping. J Sports Sci 2003; 21:679-692.

National Ski Area Association [Internet]. New York: National Ski Area Association; ©1962-2010 [cited 2010 Sep 15]. Available from: http://www.nsaa.org/nsaa/home/.

Nyaard E, Anderson P, Nilsson P, Eriksson E, Kjessel T, Saltin B. Glycogen depletion pattern and lactate accumulation in leg muscles during recreational downhill skiing. Eur J Appl Physiol 1978; 38:261-269.

Palatini P, Guzzardi G, Penzo M, Dorigatti F, Anaclerio M, Pessina AC. Effect of high and low altitude exposure on the blood pressure response to physical exercise. Cardiologia 1991; 36:853-859.

Richardson R, White A, Seifert J, Porretta J, Johnson S. Blood lactate concentrations in elite skiers during a series of on-snow downhill ski runs. J Strength Cond Res 1993; 7:168-171.

Saibene F, Cortili G, Gavazzi P, Magistri P. Energy sources in alpine skiing (giant slalom). Eur J Appl Physiol 1985; 53:312-316.

Scheiber P, Krautgasser S, Duvillard SP, Müller E. Physiologic responses of older recreational alpine skiers to different skiing modes. Eur J Appl Physiol 2009; 105:551-558.

Schobersberger W, Schmid P, Lechleitner M, Duvillard SP, Hortnagl H, Gunga HC, Klingler A, Fries D, Kirsch K, Spiesberger R, Pokan R, Hofmann P, Hoppichler F, Riedmann G, Baumgartner H, Humpeler E. The effects of moderate altitude (1,700 m) on cardiovascular and metabolic variables in patients with metabolic syndrome. Eur J Appl Physiol 2003; 88:506-514.

Seifert J, Kipp R, Amann M, Gazal O. Muscle damage, fluid ingestion, and energy supplementation during recreational alpine skiing. Int J Sports Nutr Exerc Met 2005; 15:528-536.

Seifert J, Kröll J, Müller E. The relationship of heart rate and lactate to cumulative muscle fatigue during recreational alpine skiing. J Strength Cond Res 2009; 25:698-704.

Sirikul B, Hunter GR, Larson-Meyer DE, Desmond R, Newcomer BR. Relationship between metabolic function and skeletal muscle fatigue during a 90 second maximal isometric contraction. Appl Physiol Nutr Met 2007; 32:394-399.

Stewart R, Duhamel T, Rich S, Tupling A, Green H. Effects of consecutive days of exercise and recovery on muscle mechanical function. Med Sci Sports Exerc 2008; 40:316-325.

Strojnik V, Nicol C, Komi PV. Fatigue during one-week tourist alpine skiing. Proceedings of the 2nd International Congress in Science and Skiing; 2001 Dec 18-23; Hamburg, Kovač.

Szmedra L, Im J, Nioka S, Chance B, Rundell KW. Hemoglobin/myoglobin oxygen desturation during alpine skiing. Med Sci Sports Exerc 2001; 33:232-236.

Tesch P. Aspects on muscle properties and use in competitive alpine skiing. Med Sci Sports Exerc 1995; 27:310-314.

Tesch P, Larsson A, Eriksson A, Karlsson J. Muscle glycogen depletion and lactate concentration during downhill skiing. Med Sci Sports Exerc 1987; 10:85-90.

Turnbull JR, Kilding AE, Keogh JWL. Review: Physiology of alpine skiing. Scand J Med Sci Sports 2009; 19:146-155.

Veicsteinas A, Ferretti G, Margonato V, Rosa G, Tagliabue D. Energy costs of and energy sources of alpine skiing. J Appl Physiol 1984; 56:1187-1190.

Völkl Ski's [Internet]. Straubing: Völkl Ski Corporation; © 1923-2010 [cited 2010 Oct 12]. Available from: http://www.volkl.com/ski/.

Zeglinksi CM, Swanson SC, Self BP, Greenwald RM. Muscle activity in the slalom turn of alpine skiing and in-line skating. Int J Sports Med 1998; 19:447-454.

APPENDICES

APPENDIX A

ELIGIBILITY INFORMATION

Subject Consent Form for Participation in Human Research at Montana State University

Title: Physiological stress during five days of vacation skiing

You have been invited to participate in a five-day ski vacation study investigating different physiological markers of muscle stress. You will be skiing for five consecutive days, three hours in the morning and finishing up in the afternoon. You will be skiing at a self pace and will be able to ski within your comfort zone, it is only asked that you record what lifts and runs you ski for the duration of the study.

Funding Agency: Bridger Bowl Ski Area, Bozeman, MT and Osprey Packs Inc., Cortez, CO

Procedures: For this study there will be five consecutive days on the mountain. On day one you will be asked to arrive at Bridger Bowl Ski Area at 8:00am to get instructions on the week ahead and to be informed on the "Food and Sleep Record" log and the "Ski Record" log.

Days two through five we will be at Bridger Bowl doing the ski portion of the study. Each day you will be asked to arrive in the lodge by 8:30am in order for the researchers to attach heart rate and give you a global positioning system (GPS). When the mountain opens as 9:00am you will be asked to ski two runs on each chairlift, starting with Alpine Lift, moving over to Bridger Lift, and lastly going to Pierres Knob. After three hours you are free to ski the mountain, however, the researchers ask that you stay off of Schlassmann's and the ridge for the duration of this study. During the skiing portion of this study you are skiing at a self paced and self selected runs. The researchers are not controlling the ski speed or the terrain required. During or at the end of each day the researchers ask that you fill out your food and ski logs as accurately as possible to ensure more accurate results.

Time Commitment: The total time for your participants in this study will be five days of skiing 8:00am - 4:30pm. You are free to discontinue the testing at any time. In total the time commitment will be about five days.

Confidentiality: Personal information as well as any data collected during the duration of this study will be kept in a secure place and your data will be coded as another precaution to ensure your confidentiality.

Benefits: The results of this study will further ski research and aid in the development of a possible pre-ski vacation workout that would decrease the affects of fatigue and soreness during a week ski vacation, which would in turn decrease the number of ski vacation accidents on the mountain.

Compensation: Compensation will consist of five ski passes for Bridger Bowl Ski Area as well as five lunch coupons to be used in the Bridger Bowl Chalets during the study. Each subject will also receive an Osprey cold weather hydration pack at the completion of the study.

Risks: If you choose to participate in this study the risks you may encounter will be sore and/or fatigued muscles from the repeated days of skiing. An injury may occur due to a fall from fatigue or the ski terrain. The researchers to ask that you ski in control and are aware of your surroundings while participating in the study to help eliminate the chance of any fall that may result in an injury. Other possible risks from this study include discomfort and infection from the fingerstick blood sampling. If complications do arise during this study, the researchers can refer you to an appropriate medical provider. Ski patrol will also be available on the mountain as first responders to an accident. However, there is no compensation available from MSU for injury.

Questions: Please be assured that your decision to participate or not will not affect your relationship with the Movement Science Lab. If you choose to discontinue participating in the study at any time, there will not be any negative effects on your relationship with MSU or the researchers involved.

If you have any additional questions, John Seifert (406-994-7154) or Jennifer Portmann (612-810-2676) would be happy to answer them. Additional questions about the rights of human subjects can be answered by the Chairman of the Institutional Review Board, Mark Quinn, (406) 994-4707.

Health History Form for Participating in the Ski Study
Montana State University—Bozeman

Personal Information

Name: ____________________________ Sex: [ ] Male [ ] Female
Date of Birth: _____ / _____ / _____ Age: _______

Address: ____
City:_________________________ State: _____ Zip: _______

Day Phone: (_____) _____ - ________ Night Phone: (_____) _____ - ________
Email: ______________________________

Height: __________ Weight: __________

Emergency Contact

Name: ________________________________ Relationship: ______________________

Day Phone: (_____) _____ - ________ Night Phone: (_____) _____ - ________

Insurance Provider: __________________________________

Medications

List any prescribed medications you are currently taking: Reason

____
____
____
____

List any self-prescribed medications you are currently taking (including herbal and NSAIDS such as Advil, Motrin, Tylenol, etc.):

____
____
____
____

ACSM Coronary Artery Disease Risk Factors
To the best of your ability, please check the appropriate yes/no box for each of the following questions:

Family history

□□Has your father or brother had a heart attack, stroke, or died suddenly of heart disease before the age of 55?
□□Has your mother or sister had a heart attack, stroke, or died suddenly of heart disease before the age of 65?

Cigarette Smoking
□Are you currently a cigarette smoker or have you quit within the past 6 months?

Hypertension (high blood pressure)
□□Is your blood pressure over 140/90 mm Hg?
□□Are you on medication to control your blood pressure?

Hypercholesterolemia (high cholesterol)
□□Is your total serum cholesterol > 200 mg/dl, low-density lipoproteins (LDL) > 130 mg/dl, or high-density lipoproteins (HDL) < 35 mg/dl?
□□Are you on medication to control your cholesterol?

Please list your cholesterol numbers if you know them:
Total:_______ LDL:_______ HDL:_______

Impaired fasting glucose
□□Do you have diabetes mellitus?
□□Have you had fasting blood glucose measurements of ≥110 mg/dL confirmed on at least 2 separate occasions?

Sedentary lifestyle
□□Are you physically inactive and/or sedentary (little physical exercise on the job or after work)?

Do you have any of the following known diseases? Please elaborate on any checked boxes below.
Cardiovascular
□□Cardiac, peripheral vascular, or cerebrovascular disease

Pulmonary
□□Chronic obstructive pulmonary disease, asthma, interstitial lung disease, cystic fibrosis

Metabolic
□□Diabetes mellitus (type I or II), thyroid disorders, renal or liver disease

Comments:
____
____

Signs and Symptoms
Please elaborate on any checked boxes below.

□□Have you experienced unusual pain or discomfort in your chest (pain due to blockage in coronary arteries of the heart)?
□□Have you experienced unusual shortness of breath during moderate exercise (such as climbing stairs)?
□□Have you had any problems with dizziness or fainting?
□□When you stand up, or sometimes during the night, do you have difficulty breathing?
□□Do you suffer from swelling of the ankles (ankle edema)?
□□Have you experienced a rapid throbbing or fluttering of the heart?
□□Have you experienced severe pain in your leg muscles during walking?
□□Has your doctor told you that you have a heart murmur?
□□Have you felt unusual fatigue or shortness of breath with usual activities?

Comments:

Musculoskeletal

□□Do you have any current musculoskeletal limitations that would impair your ability to perform maximalexercise (back pain; swollen, stiff, or painful joints; arthritis; etc.)? If yes, please explain below.

Comments:

Other

Please list and explain any other significant medical problems that you consider important for us to know:

Ski Habit Questionnaire for Five Day Ski Vacation Study
Montana State University

Name:____

1) What dates are you available to ski/snowboard?

2) Please circle the activity you would be performing during the study.

Downhill skiing Telemark skiing Snowboarding

3) How many years have you been skiing/snowboarding? _____________________

4) Normally how many days per season do you ski/snowboard? ________________

5) Do you go on a yearly ski vacation? If so, where and for how many days do you ski/snowboard?

____

____

6) When skiing, what type of runs do you <u>typically</u> ski/snowboard?

Green Circles Blue Square Black Diamonds

Double Black Diamonds Back Country

7) In your opinion, how aggressively do you ski/snowboard?____________________

8) What level skier/snowboarder are you?

Beginner Intermediate Advanced Expert

9) Do you have any previous or current injury that could hinder your ability to ski all five days? If so, please explain.

____

____

10) Do you consider yourself fit enough to ski five consecutive days? Yes No

APPENDIX B

DATA COLLECTION

Table 11: Borg's Rating of Perceived Exertion (RPE) Scale

RPE	Interpretation
6	No Exertion at All
7	Extremely Light
8	
9	Very Light
10	
11	Light
12	
13	Somewhat Hard
14	
15	Hard (Heavy)
16	
17	Very Hard
18	
19	Extremely Hard
20	Maximal Exertion

Borg's Rating of Perceived Exertion (RPE) Scale was used to help the researcher's measure how intense the subjects thought they were skiing throughout the five day trial. The subjects were asked to pick a number on the RPE side that represented their interpretation of how hard they were working, on average, throughout the ski day. While this scale is subjective and individualized to each participant, a general rule says that the RPE should be relatively close to the participant's heart rate if a zero was added to the number.

Figure 8: Ski Ability Chart

Type I "Cautious skiing at lighter release/retention settings"	**Type II** "Moderate skiing at average release/retention settings"	**Type III** "Aggressive skiing at higher release/retention settings"
• Ski conservatively • Prefer slower speeds • Prefer easy, moderate slopes • Favor lower than average release/retention settings. This corresponds to an increased risk of inadvertent binding release in order to gain increased releasability in a fall • Type I settings apply to "entry level skiers uncertain of their classification"	• Ski moderately • Prefer a variety of speeds • Ski on varied terrain, including most difficult trails • Are all skiers who do not meet all the descriptions of either Type I or Type III	• Ski aggressively • Normally ski at high speeds • Prefer steeper and more challenging terrain • Favor higher than average release/retention settings. This corresponds to decreased releasability in a fall in order to gain a decreased risk of inadvertent binding release

Subject Data Sheet

Subject #:	Date:	Ski Day: 1 3 5
Activity:	Temperature:	Snow Conditions:
HR monitor number:		GPS monitor number:

MORNING

Blood | Blood pressure

Subjective scales | Heart Rate

RPE:

Excited to Ski:

Overall Sore:

Legs Sore:

Overall Fatigued:

Legs Fatigued:

NOON HOUR

Expert Runs Skied:

Subjective scales

RPE:

Download HR monitors

AFTER SKIING

Expert Runs Skied:

Subjective scales

RPE:

Download HR and GPS monitors

OTHER NOTES

APPENDIX C

TEST VARIABLES SUMMARIZED BY DAY

FOR INDIVIDUAL SUBJECTS

Variables Summarized by Day for Individual Subjects

Pre Ski Values

Figure 9: Individual resting systolic blood pressure.

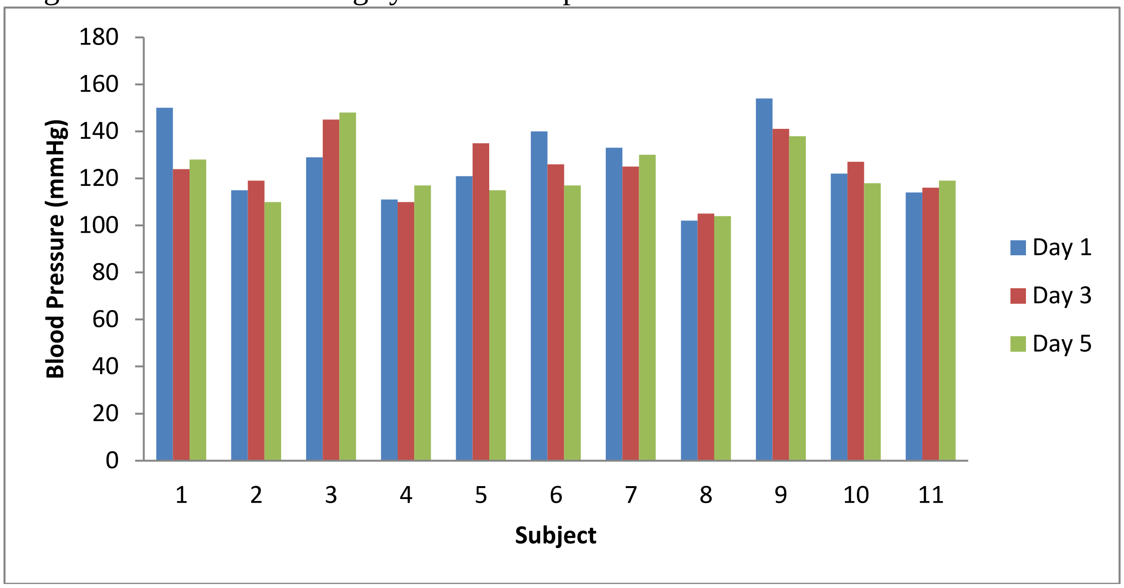


Figure 10. Individual resting diastolic blood pressure.

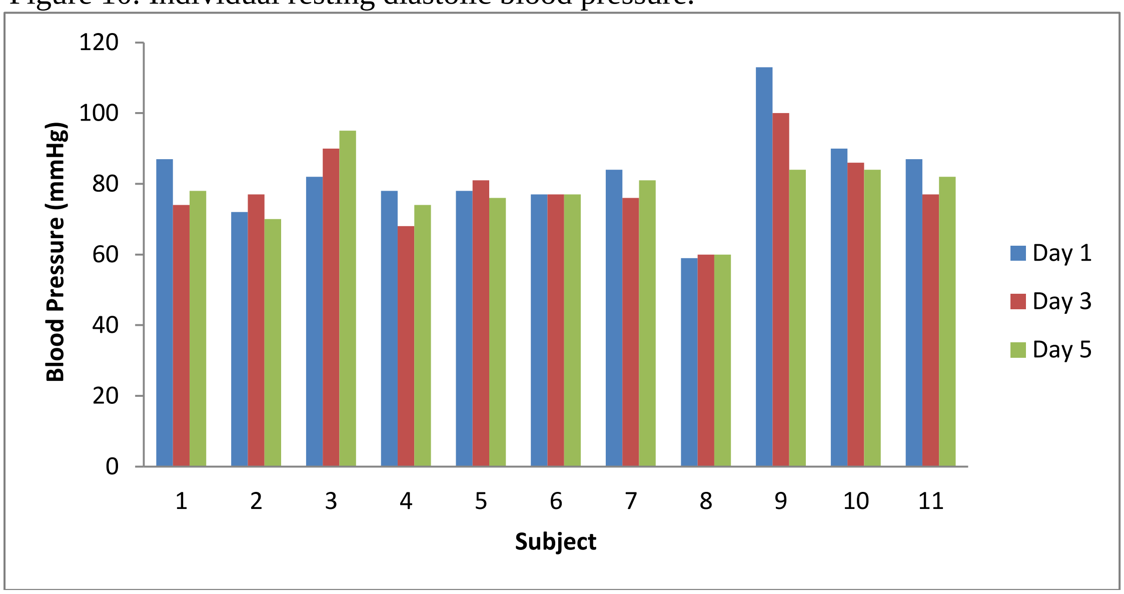


Figure 11. Individual resting mean arterial pressure (MAP).

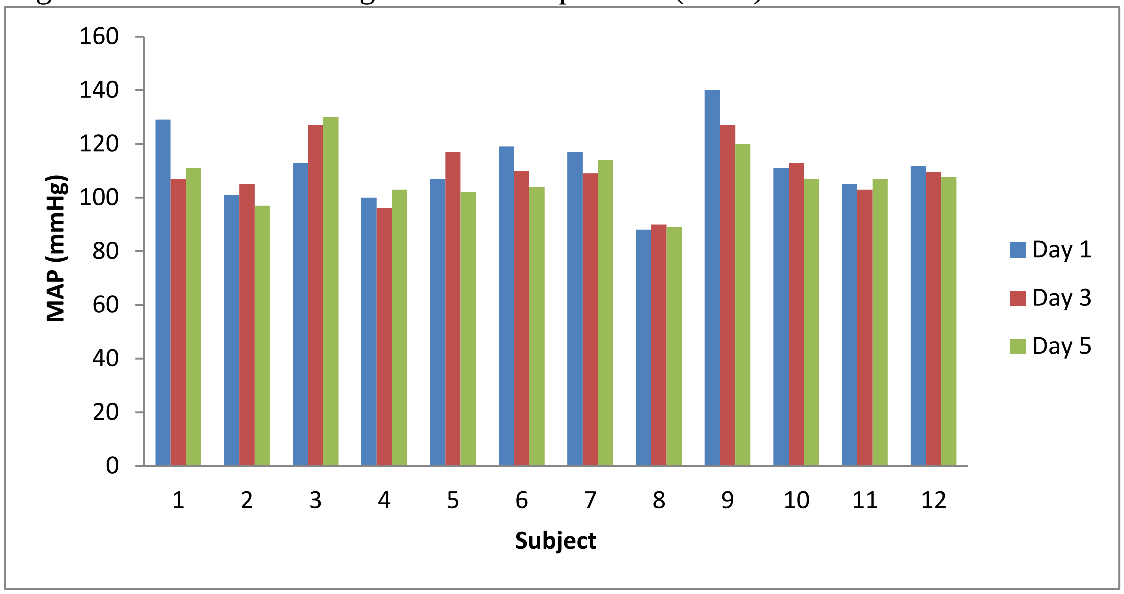


Figure 12. Individual resting heart rate.

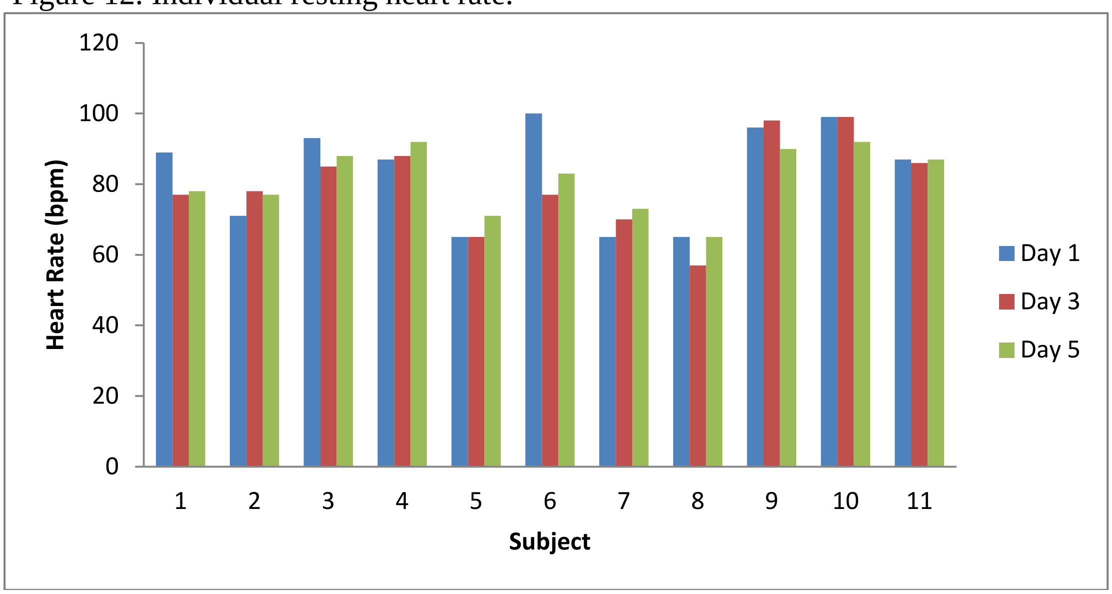
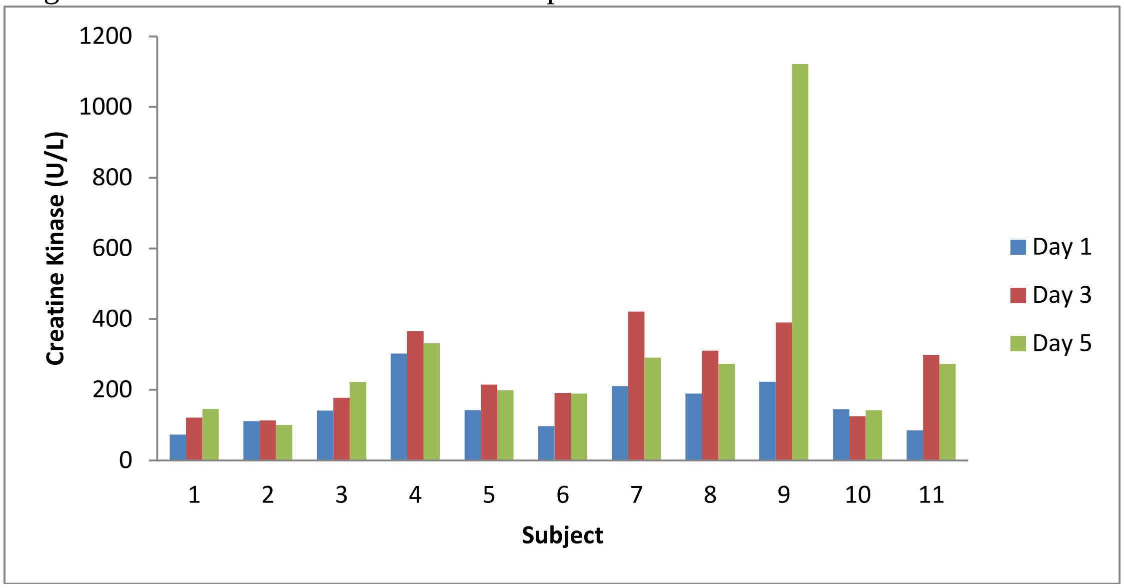


Figure 13. Individual creatine kinase samples.



Morning Ski Values

Figure 14. Individual average skiing heart rate during the morning ski session.

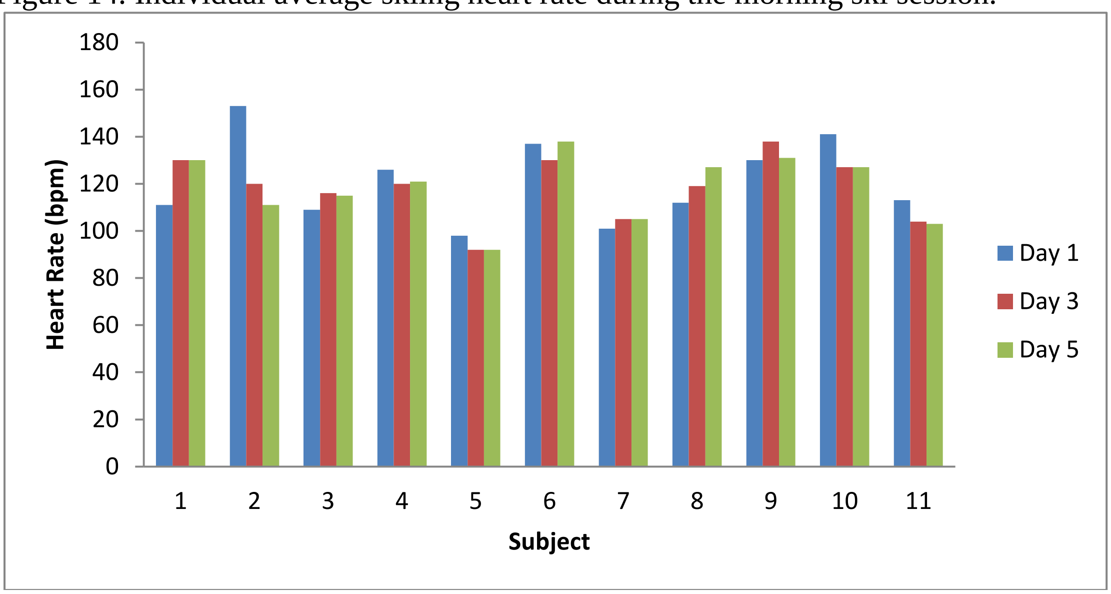


Figure 15. Individual percent of maximal heart rate during the morning ski session.

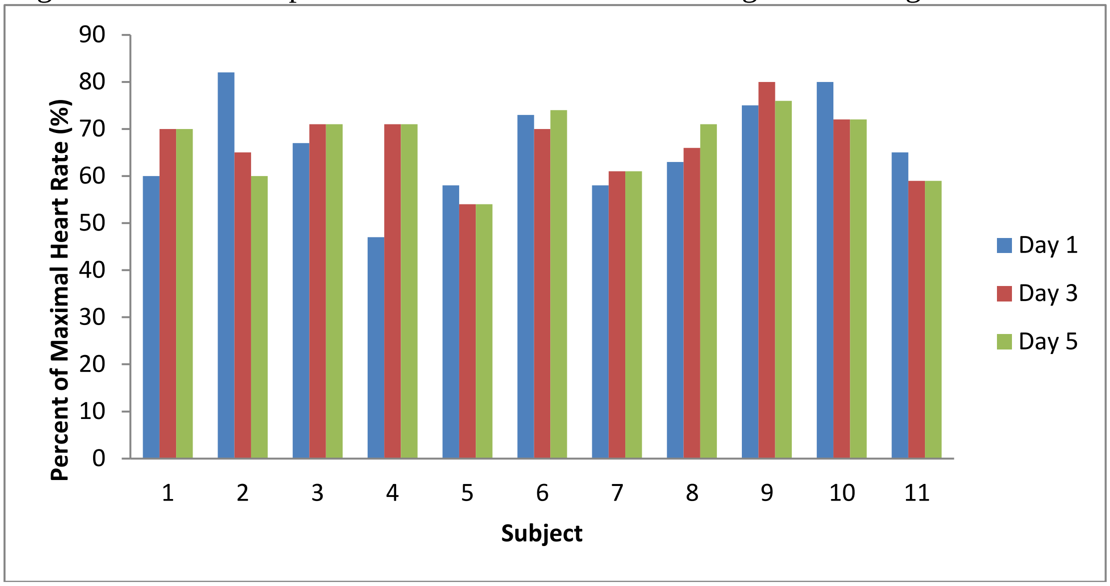


Figure 16. Individual rating of perceived skiing exertion during the morning ski session.

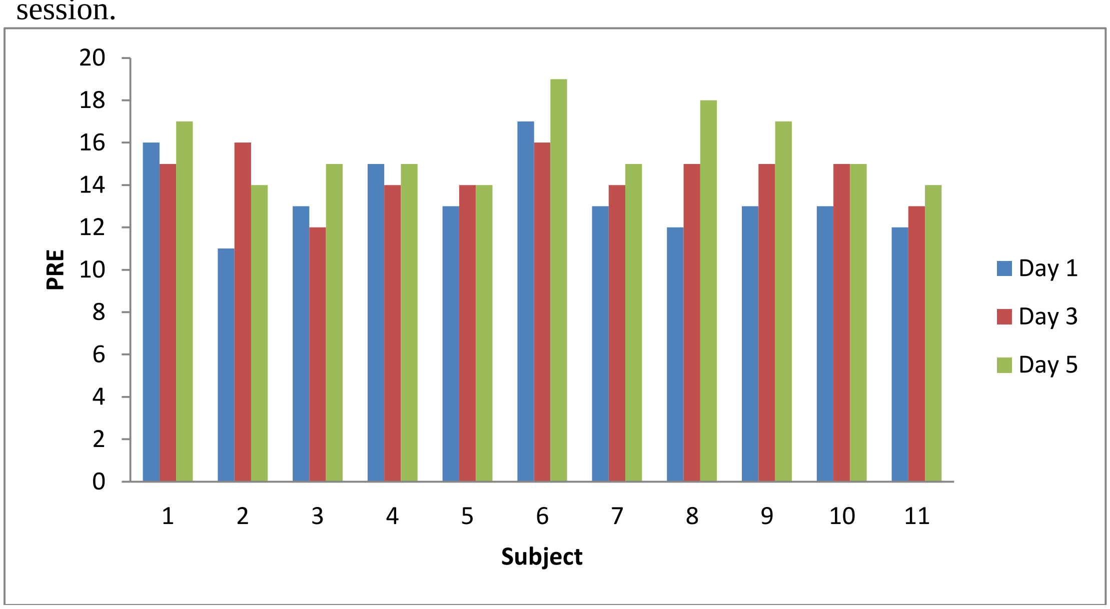


Figure 17. Individual number of runs skied during the morning ski session.

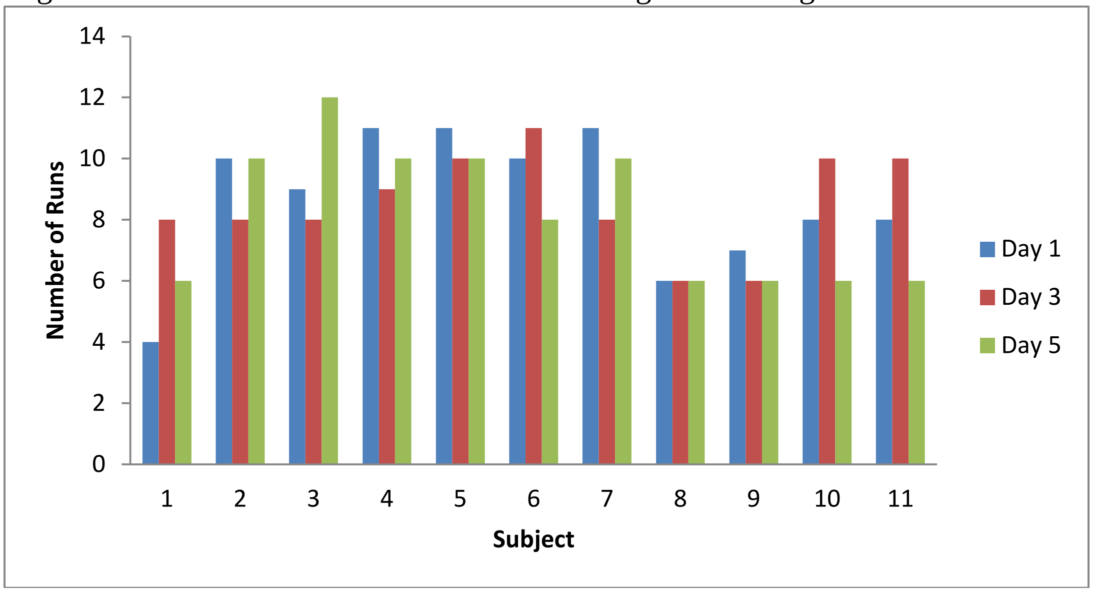


Figure 18. Individual number of expert runs skied during the morning ski session.

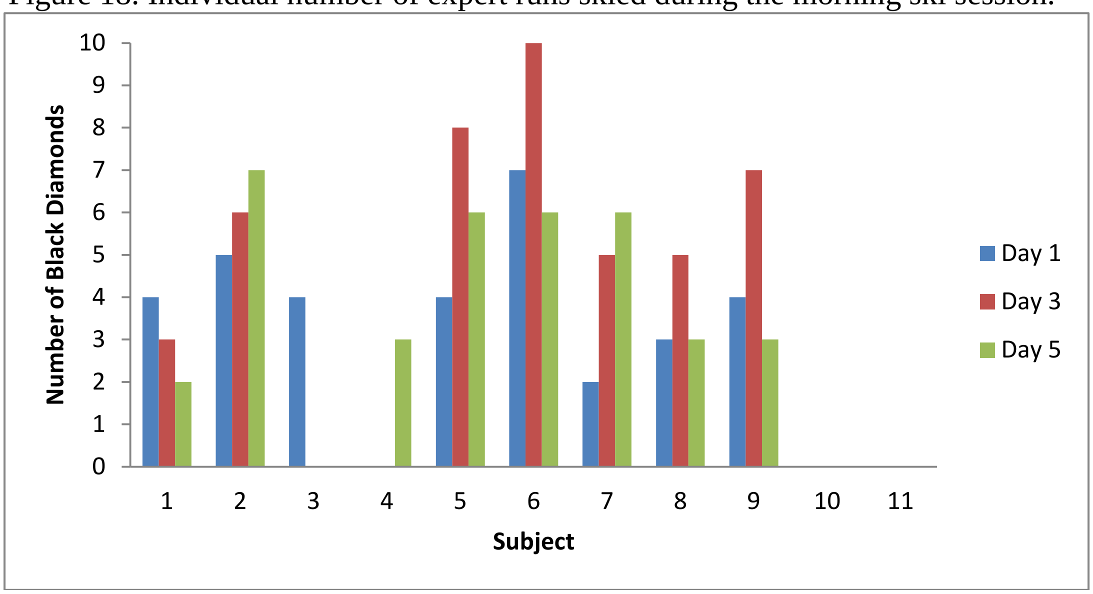


Figure 19. Individual percent of expert runs skied during the morning ski session.

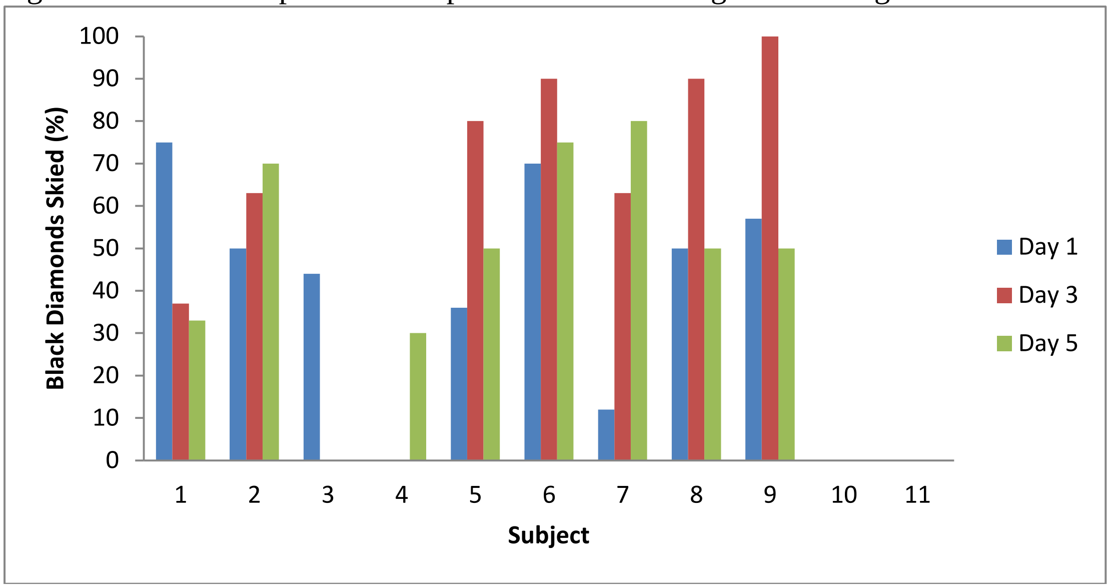
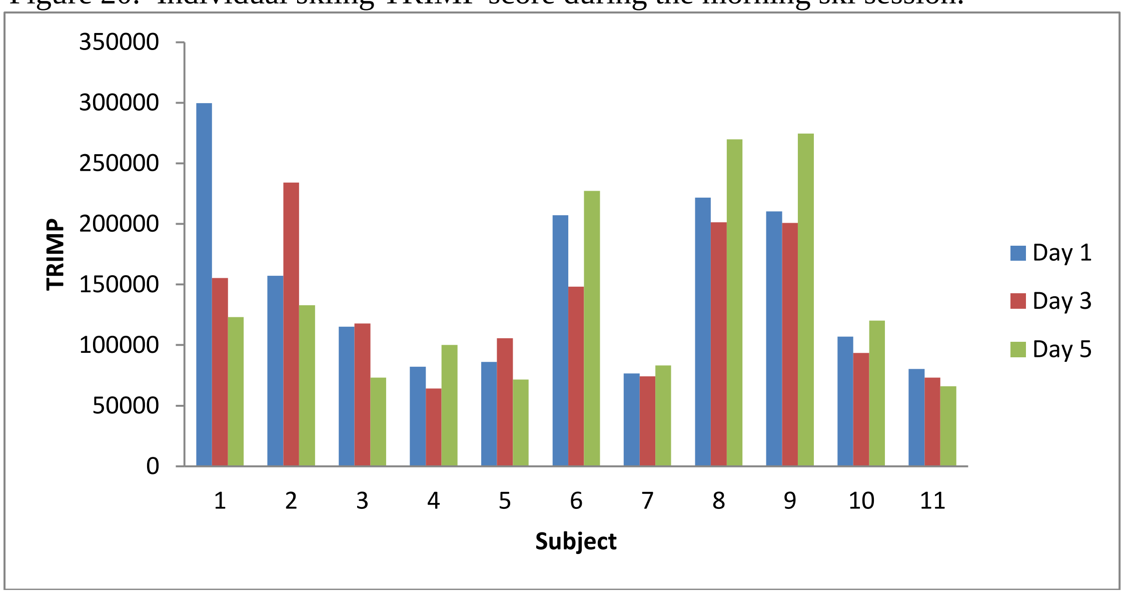


Figure 20. Individual skiing TRIMP score during the morning ski session.



Afternoon Ski Values

Figure 21. Individual average skiing heart rate during the afternoon ski session.

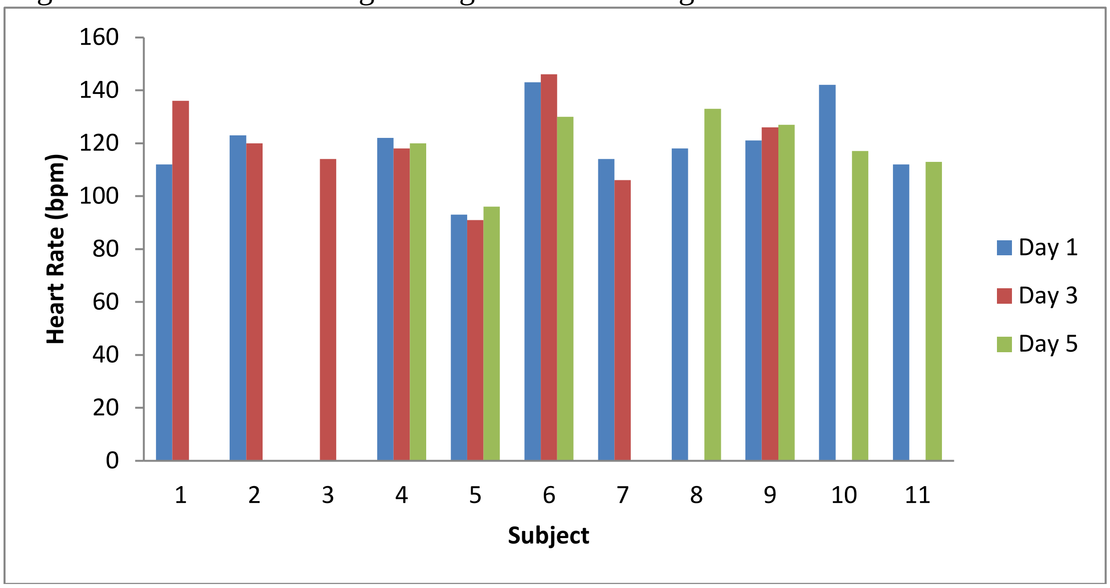


Figure 22: Individual percent of maximal heart rate while skiing during the afternoon ski session.

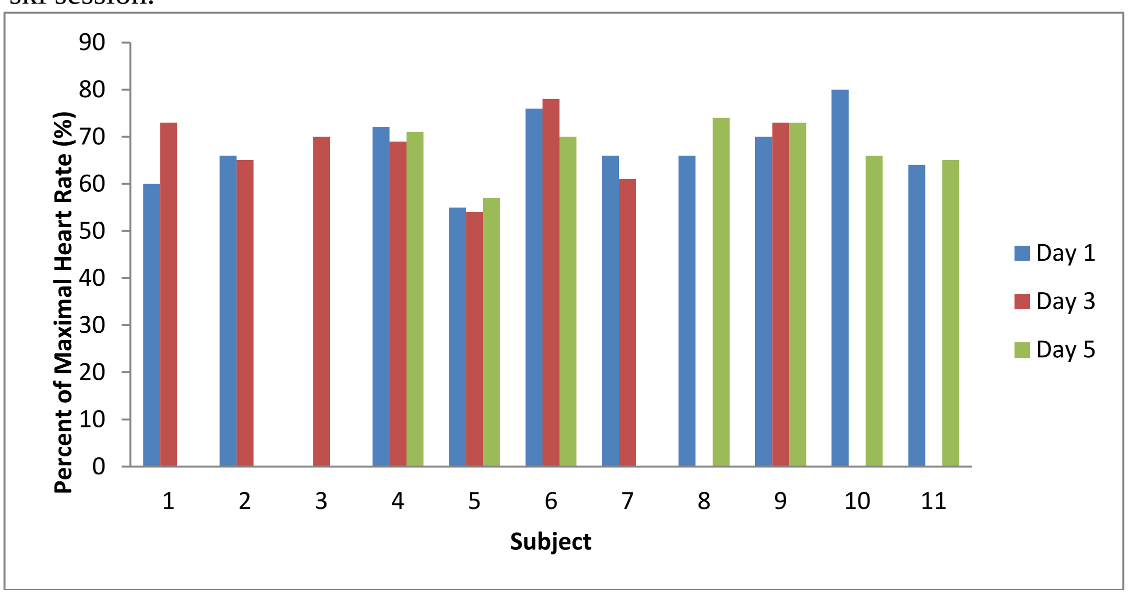


Figure 23. Individual rating of perceived exertion during the afternoon ski session.

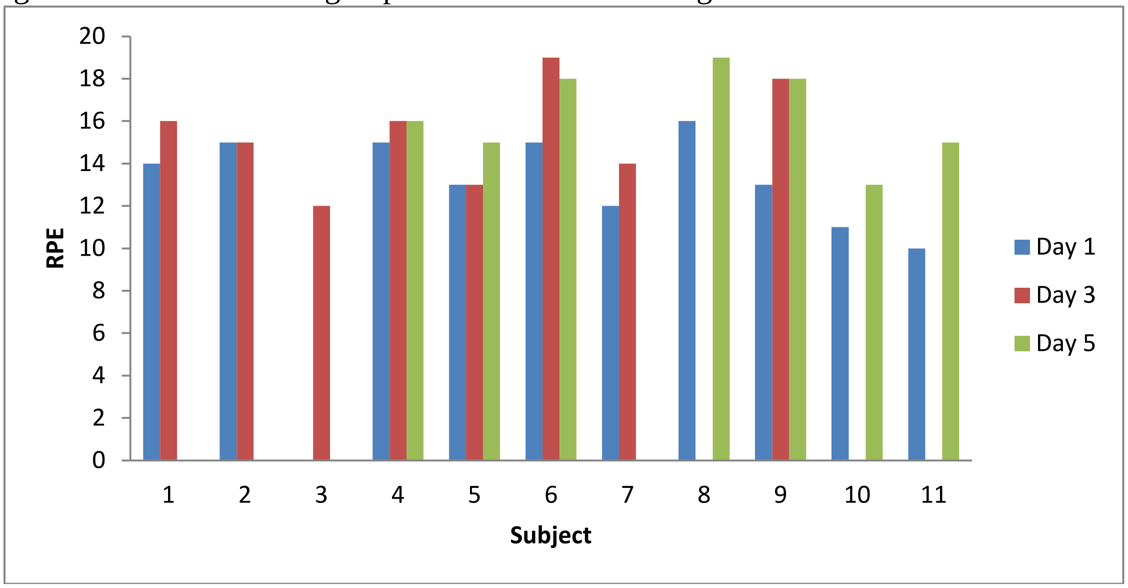


Figure 24. Individual number of runs skied during the afternoon ski session.

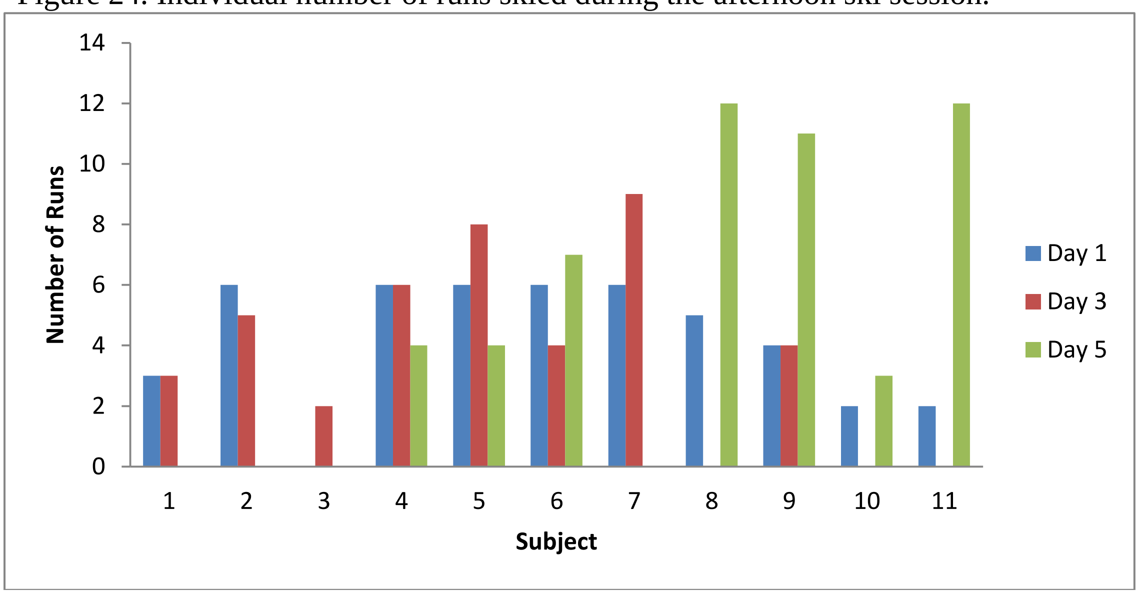


Figure 25. Individual number of expert runs skied during the afternoon ski session.

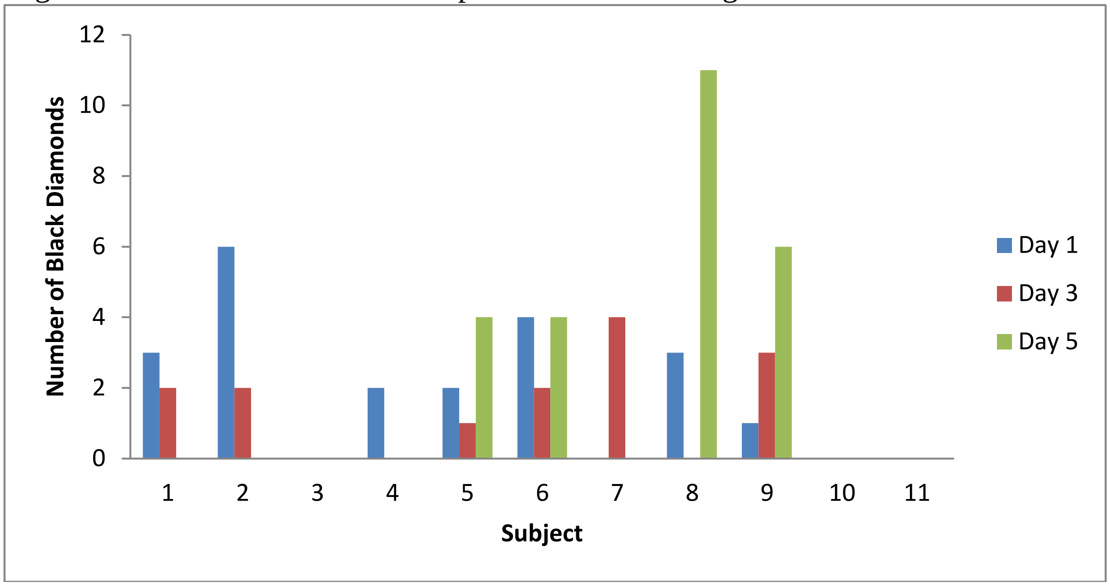


Figure 26. Individual percent of expert runs skied during the afternoon ski session.

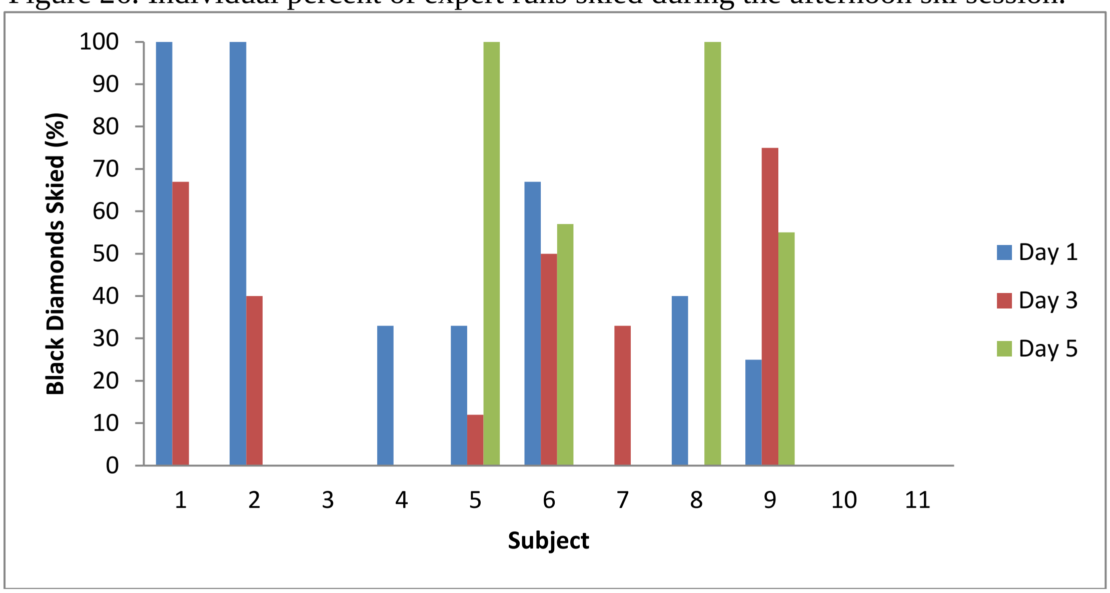
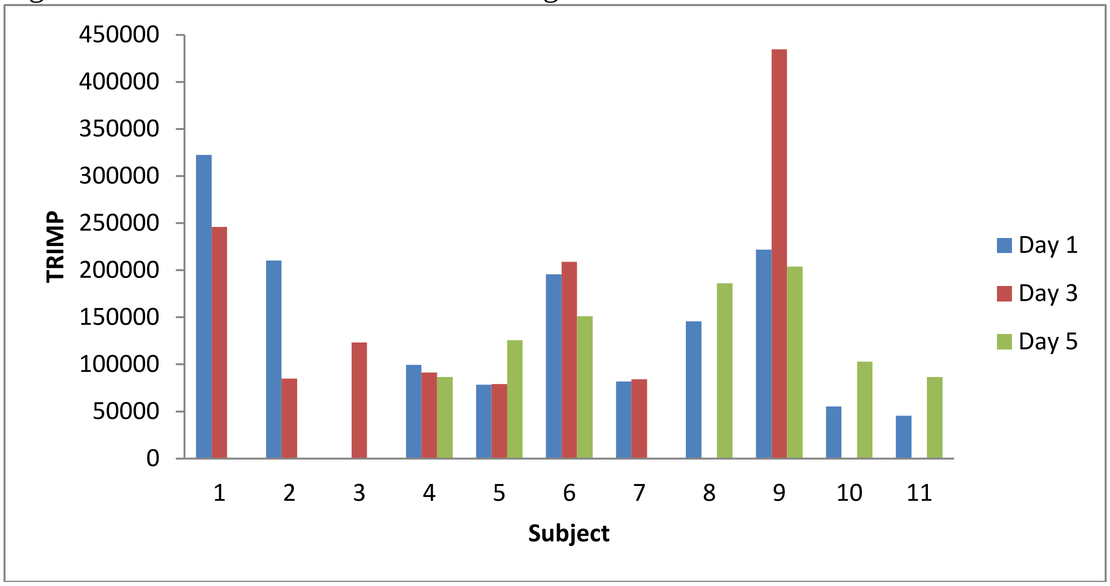


Figure 27. Individual TRIMP scores during the afternoon ski session.



Post Ski Values

Figure 28. Individual total decent time during the morning and afternoon ski session.

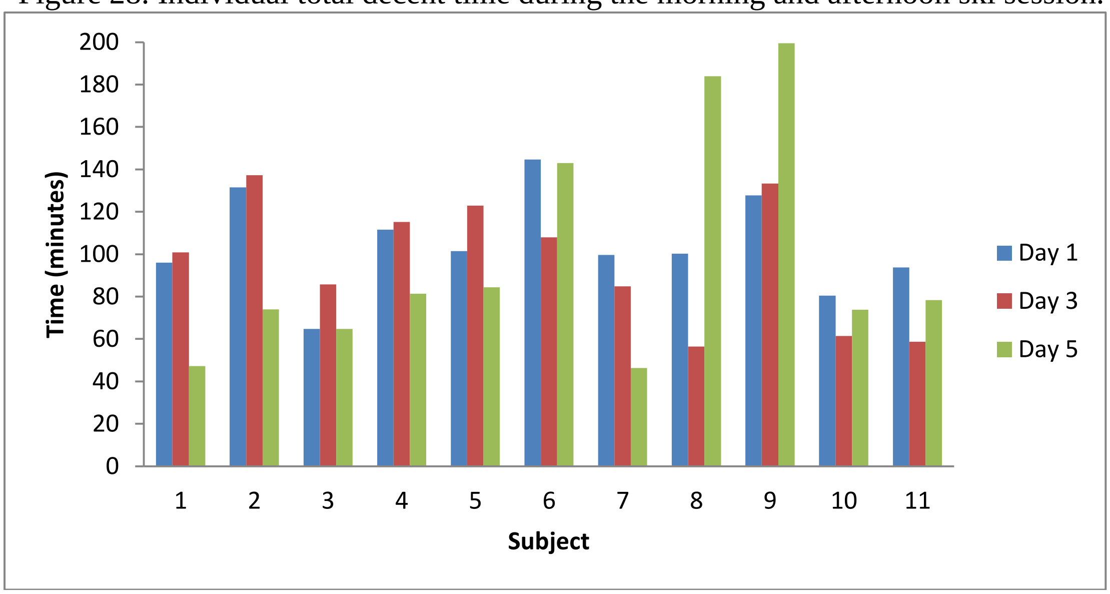


Figure 29. Individual percent of expert runs skied during the morning and afternoon ski session.