

TREADMILL GRADE AS A DETERMINANT OF ROLLER SKIING OXYGEN  
CONSUMPTION AT A CONSTANT EXTERNAL POWER DEMAND

By

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## ABSTRACT

Cross-country (XC) skiing is typically considered an aerobic activity, yet the accumulated oxygen deficit ( $\Sigma O_2$ -deficit), a representation of anaerobic capacity, has shown to be a valuable predictor of XC skiing performance. The  $\Sigma O_2$ -deficit is calculated as the difference between the predicted oxygen consumption ( $VO_2$ ) demand and the measured  $VO_2$  cost during a roller skiing time-trial protocol (RSTT). To determine  $VO_2$  demand, a lactate threshold (LT) protocol is performed with the purpose of plotting external power demand (TEPD) against measured steady-state  $VO_2$  cost. A regression line is fit and used to predict the  $VO_2$  demand of the RSTT. A possible limitation of this methodology is that it is common to use a lower treadmill grade for the LT protocol than that used for the RSTT. In order to validate the use of the LT protocol as a component of calculating the  $\Sigma O_2$ -deficit, this study investigated the influence of different treadmill grades on the linear relationship between  $VO_2$  cost and TEPD in collegiate XC skiers. Fifteen female collegiate XC skiers (Mean $\pm$ SD, Range: 20 $\pm$ 1, 18-24 years) completed three laboratory visits within a 10 day period. During each visit, skiers completed a single LT protocol at one of three treadmill grades (2°, 3°, 4°), for the purpose of measuring  $VO_2$  while roller skiing. The TEPD values of each treadmill stage were computed as the sum of both rolling and gravitational resistances. Steady-state  $VO_2$  values were plotted against corresponding TEPD values and a regression line was fit to the data. The resulting slope and intercept terms for each line were compared across treadmill grades using two-way repeated measures ANOVA and Scheffe's post hoc test ( $\alpha=0.05$ ). Neither the slopes ( $P=0.31$ ) nor the intercepts ( $P=0.63$ ) were significantly different between treadmill grades. This study demonstrated that the slope and the intercept terms of the  $VO_2$  cost - TEPD regression line were not significantly influenced by treadmill grades between 2-4°, in female collegiate XC skiers. Consequently, this study indicates that the treadmill grade of LT roller skiing protocols will not significantly affect a skier's calculated  $\Sigma O_2$ -deficit.

## 1. INTRODUCTION

Elite endurance athletes, such as cyclists, distance runners, and cross-country (XC) skiers, are known to have high capacities for oxygen consumption ( $\text{VO}_2$ ). Subsequently, aerobic measures are commonly used to predict athletic performance within these sports. Notably, maximal  $\text{VO}_2$  ( $\text{VO}_{2\text{MAX}}$ ) has consistently been reported as a strong predictor of distance XC skiing performance within heterogeneous populations (Hoffman & Clifford, 1992; Losnegard, et al., 2012a; Sandbakk et al., 2010). Unfortunately, measures of  $\text{VO}_{2\text{MAX}}$  are limited in their ability to predict XC skiing performance within homogeneous populations. For the purpose of better predicting XC skiing success within homogeneous populations, other physiological variables have been investigated. For example, Alsobrook & Heil (2009) and Staib et al. (2000) found average XC skiing race speed to be highly correlated with measures of upper body power. Vesterinen et al. (2009) and Stöggl et al. (2007) concluded a XC skier's race performance to be significantly related to the treadmill speed at which lactate threshold is reached. Sandbakk et al. (2011) reported high correlations between measures of gross efficiency and XC sprint performance. Finally, Losnegard et al. (2012a) and Reinking et al. (2012) determined the accumulated oxygen deficit ( $\Sigma\text{O}_2$ -deficit) to be a strong predictor of XC skiing performance.

Cross-country skiing is typically considered an aerobic sport, yet the  $\Sigma\text{O}_2$ -deficit, a measure of anaerobic capacity, has been shown to be a valuable predictor of both sprint (Losnegard et al., 2012a) and distance (Reinking et al., 2012) XC skiing events. A skier's  $\Sigma\text{O}_2$ -deficit is determined during a maximal effort roller skiing time-trial (RSTT)

protocol and is calculated as the difference between the predicted  $\text{VO}_2$  demand and measured  $\text{VO}_2$  cost of this test.

To determine a skier's predicted  $\text{VO}_2$  demand during the RSTT, each subject must also perform a separate submaximal lactate threshold (LT) protocol. A treadmill based LT protocol requires a XC skier to complete a series of stages that are distinguished by progressive increases in treadmill speed, and consequently, total external power demand (TEPD). To calculate the  $\Sigma\text{O}_2$ -deficit, a LT protocol is used to measure steady-state  $\text{VO}_2$  cost at several TEPDs. Once the  $\text{VO}_2$  costs are measured, the values are plotted against the corresponding TEPDs on a standard Cartesian plane and a regression line is fit. Finally, the  $\text{VO}_2$  cost – TEPD regression line is extrapolated to the TEPDs of the RSTT, and the corresponding  $\text{VO}_2$  cost values are taken as the predicted  $\text{VO}_2$  demand for each skier. With this information, the  $\Sigma\text{O}_2$ -deficit can be calculated.

A possible limitation of the  $\Sigma\text{O}_2$ -deficit methodology is the use of a lower treadmill grade for the LT protocol than that used for the RSTT (Losnegard et al., 2012a; Reinking et al., 2012). This methodological discrepancy between protocols is due to one protocol being designed as submaximal while the other is maximal. For example, in the study conducted by Losnegard et al. (2012b), elite XC skiers performed submaximal testing at treadmill grades of 4-6°, while the RSTT was completed at a treadmill grade of 7°. Losnegard et al. (2012b) reported the lower treadmill grades of the LT protocol were necessary to keep skiers at a submaximal steady-state without moving too slowly on the treadmill (Losnegard et al., 2012b). In another example, Reinking et al. (2012) had collegiate female XC skiers perform the LT protocol at a treadmill grade of 3°, while the

RSTT was conducted at a treadmill grade of 4°. In this case, the steeper treadmill grade during the RSTT was used to avoid overly high treadmill speeds and accidental falls (Reinking et al., 2012).

Since the calculation of the  $\Sigma O_2$ -deficit utilizes  $VO_2$  cost values from both a submaximal test and a maximal effort RSTT, the differences in treadmill grade between these protocols has the potential to impact the validity of the calculated  $\Sigma O_2$ -deficit. More specifically, the  $\Sigma O_2$ -deficit calculation assumes that the slope and intercept terms of the regression line relating  $VO_2$  cost and TEPD are similar between LT and RSTT protocols. If the slope and intercept terms are not similar between protocols, the validity of the  $\Sigma O_2$ -deficit method for roller skiing may be questioned. Currently, there are no published studies investigating the influence of treadmill grade on the slope and intercept terms of the  $VO_2$  cost – TEPD regression line while roller skiing. More research is necessary within this topic to better support the use of the  $\Sigma O_2$ -deficit method as a predictor of XC skiing performance.

### Purpose

In order to validate the use of the submaximal LT protocol as a component of calculating the  $\Sigma O_2$ -deficit while roller skiing, this study investigated the influence of different treadmill grades on the linear relationship between  $VO_2$  cost and TEPD in collegiate XC skiers.

### Hypotheses

The null hypothesis ( $H_0$ ) stated there were no differences between the slope or intercept terms derived from performing similar submaximal protocols at three separate treadmill grades (2°, 3°, 4°). The alternate hypothesis ( $H_A$ ) stated there was a significant difference between the slope or intercept terms for at least two of the three treadmill grades tested.

$$H_0: \mu_1 = \mu_2 = \mu_3$$

$$H_A: \mu_1 \neq \mu_2 \neq \mu_3$$

where  $\mu_1$ ,  $\mu_2$ , and  $\mu_3$  are population means for either the slope or intercept terms at the three treadmill grades tested (2°, 3°, and 4°, respectively).

### Assumptions

It was assumed that skiers followed all pre-testing diet and exercise guidelines. It was also assumed that all subjects were competent roller skiers using the G3 skating technique and were comfortable roller skiing on the lab's oversized treadmill.

### Limitations

1. Some skiers were more familiar with roller skiing on the lab's oversized treadmill than others.
2. The findings are specific to treadmill grades of 2°, 3°, and 4°.

### Delimitations

1. Daniels & Daniels (1992) found running economy to be different between males and females. As the relationship between TEPD and  $VO_2$  cost is a representation of economy, this study was delimited to female XC skiers with the purpose of removing possible gender influences.
2. This study was delimited to skiers with previous experience using the G3 skating technique while roller skiing on an oversized treadmill.

### Operational Definitions

Accumulated oxygen deficit ( $\Sigma O_2$ -deficit): An indirect measure of anaerobic capacity calculated by summing the differences between  $VO_2$  demand and  $VO_2$  cost during a roller skiing time trial.

Adenosine triphosphate (ATP): A molecule that functions as the universal energy source within the body. It contains high energy chemical bonds that can be hydrolyzed when needed to supply energy to cells for cellular function, including muscle contractions.

Aerobic metabolism: A series of catabolic reactions that take place in the body's cells with the purpose of converting biochemical energy (obtained from nutrients) into ATP. The process is considered aerobic when electrons are able to pass from glycolysis to the citric acid cycle, and ultimately, the electron transport chain, where the final oxidizing agent, or electron acceptor, is oxygen.

**Anaerobic metabolism:** In the absence of sufficient oxygen supplies, the conversion of biochemical energy into ATP is stopped after glycolysis. At this point, pyruvate, the end product of glycolysis, is converted to lactate and other phosphagens for substrate level phosphorylation.

**Blood lactate (BLa):** A chemical compound released into the blood stream as a byproduct of glycolytic metabolism, measured in mmol/L.

**Heart Rate (HR):** The number of contractions the heart completes in one minute, expressed as beats per minute (BPM).

**Lactate Threshold (LT):** The point at which lactate production rate exceeds lactate clearance rate, as determined using a graded exercise protocol and fingertip blood samples.

**Maximal oxygen consumption ( $VO_{2MAX}$ ):** The highest rate that oxygen can be utilized for aerobic ATP production by an individual. Commonly expressed as the volume of oxygen utilized per kg body mass per minute (ml/kg/min).

**Oxygen consumption ( $VO_2$ ):** The rate of oxygen utilized by the tissues in the body to convert fuels into ATP. Commonly expressed as the volume of oxygen utilized per kg body mass per minute (ml/kg/min).

**Oxygen consumption cost ( $VO_2$  cost):** The measured rate of oxygen utilization required to overcome a certain external power demand. Commonly expressed as the volume of oxygen utilized per kg body mass per minute (ml/kg/min).

Oxygen consumption demand ( $\text{VO}_2$  demand): The predicted rate of oxygen utilization to overcome a certain external power demand assuming ATP is primarily produced through aerobic metabolism. Commonly expressed as the volume of oxygen utilized per kg body mass per minute (ml/kg/min).

Roller Ski: A piece of equipment, about 600 mm (24 in) in length, with two wheels and a cross-country ski binding. A roller ski allows an individual to perform a cross country skiing technique on non-snow surfaces, such as asphalt, concrete, and treadmills.

Steady-state: A stable condition where physiological variables remain steady over time while performing at a constant workload.

Submaximal intensity: A workload that does not exceed an individual's lactate threshold. When a steady-state is achieved, ATP is produced exclusively through aerobic metabolism.

Time-trial (TT): A performance test that demands subjects complete a predetermined event as fast as possible (maximal effort).

Total external power demand (TEPD): The amount of power an individual must generate, for the purposes of forward movement, in order to overcome external resistances, such as gravitational resistance, frictional and rolling resistances, and aerodynamic resistance.

## 2. LITERATURE REVIEW

### Introduction

The accumulated oxygen deficit ( $\Sigma O_2$ -deficit) is an indirect measure of an individual's anaerobic capacity and has recently been shown to be a strong predictor of cross-country (XC) skiing performance (Losnegard et al., 2012a; Reinking et al., 2012). To calculate a skier's  $\Sigma O_2$ -deficit, previous researchers have summated the differences between predicted oxygen consumption ( $VO_2$ ) demand and measured  $VO_2$  cost during a maximal effort roller skiing time-trial (RSTT) protocol. The methodology for the calculation of the  $\Sigma O_2$ -deficit requires each skier to first complete a separate submaximal lactate threshold (LT) protocol for the purpose of developing a regression line relating  $VO_2$  cost to total external power demand (TEPD). This regression line is subsequently extrapolated to the RSTT and determines a skier's predicted  $VO_2$  demand during this test (Losnegard et al., 2012a; Reinking et al., 2012).

Use of the  $\Sigma O_2$ -deficit method requires two primary assumptions. The first assumption is that all energy requirements are met through aerobic processes during steady-state submaximal workloads. The second assumption is that the values of the regression terms (slope and intercept) for the line relating  $VO_2$  cost to TEPD are similar between the LT and RSTT protocols (Losnegard et al., 2012a; Noordhof et al., 2010). Through the evaluation of muscle biopsies taken during exercise, Hultman (1967) supported the first assumption by concluding that at steady-state submaximal intensities, the rate of adenosine triphosphate (ATP) utilization is directly related to measures of

VO<sub>2</sub>. The second assumption, however, has not been substantiated. In XC skiing, skier's rate of energy expenditure, and consequently, the VO<sub>2</sub> cost – TEPD relationship, is impacted by technique choice, skiing conditions (speed and grade), and overall motor unit recruitment patterns.

### XC Skiing Technique

Cross-country (XC) skiing is a technically demanding sport as forward propulsion is dependent on both the upper and the lower body. Power is generated by the upper and lower body and is transmitted through the poles and the skis, respectively, creating arm-to-pole and leg-to-ski interaction forces (Alsobrook & Heil, 2009; Vähäsöyrinki et al., 2008). Since both the upper and the lower body musculature are important to XC skiing performance, metabolic costs of each significantly influence measures of VO<sub>2</sub>. Thus, changing how the poles, the skis, or both, interact with the skiing track will influence both limb movement and motor unit activation patterns, and subsequently, the metabolic costs of XC skiing (Hoffman and Clifford, 1992; Hoffman et al., 1994; Millet et al., 1998b).

There are three general techniques of XC skiing. The diagonal stride (DS) technique, also known as the traditional or classic technique, requires the skis stay parallel to each other and to the direction of travel while the poles are used in a contralateral fashion with the legs. The double pole (DP) technique involves all propulsion forces to be directed through the poles. As the poles are guided straight back to push the body forward, the skis stay together and parallel to the direction of travel.

Finally, the skating technique involves the skis gliding obliquely outward from the direction of travel while the use of the poles varies depending on the sub-technique, or gear, performed. Gear two (G2) is used during steeper uphill conditions and involves asymmetrical poling on every other leg push (also known as the V1 skating technique). Gears three (G3) and four (G4) are used on low to moderate uphill and flat conditions, and involve the poles being used symmetrically on every single or every other leg push, respectively (also known as the V2 and the V2-alternate skating techniques, respectively) (Andersson et al., 2010; Gaskill et al. 1999; Hoffman & Clifford, 1992).

### Technique Choice

When a skier is performing the skating technique, it is common to shift between the different gears as different slopes are encountered. When changing from gear to gear, there is an alteration of how the poles are utilized and this may have a significant impact on the skier's overall energy expenditure. It is well documented that  $\text{VO}_2$  costs vary significantly between the diagonal stride and the skating techniques (Hoffman and Clifford, 1992; Hoffman et al., 1994), however, it is less clear whether or not there are changes in  $\text{VO}_2$  costs between the different skating sub-techniques. For elite XC skiers, Losnegard et al. (2012b) determined that submaximal measures of  $\text{VO}_2$  do not differ between the G2 and the G3 sub-techniques when skiing at treadmill grades of 4-6°. Kvamme et al. (2005), studying national level Nordic combined athletes, and Boulay et al. (1995), studying sub-elite skiers, also found measures of  $\text{VO}_2$  to be the same between the G2 and G3 sub-techniques when skiing on grades  $< 4^\circ$ . However, both Kvamme et

al. (2005) and Boulay et al. (1995) reported that when skiing on slopes  $> 5^\circ$ , the G3 sub-technique resulted in greater  $\text{VO}_2$  costs than the G2 sub-technique.

During competition, the G3 skating sub-technique is regularly used by skiers on flatter terrain, while the G2 technique is applied on steeper slopes (Boulay et al., 1995; Losnegard et al. 2012b). Although  $\text{VO}_2$  demands between the G2 and G3 sub-techniques are relatively similar at lower inclines, the G3 technique is preferred by racers because it is typically faster (Andersson et al., 2010). Supporting this further, Andersson et al. (2010) reported that overall XC skiing success is directly related to the amount of time a skier spends using the G3 sub-technique during competition.

Maintaining the balance between speed and energy expenditure is critical for competitive XC skiers and each skier will have individual preferences regarding gear selection, even under similar racing conditions (Boulay et al., 1995; Kvamme et al., 2005; Losnegard et al., 2012b). Although the utilization of different skating sub-techniques within competitive situations is varied, metabolic demands suggest sub-elite skiers should transition from the G3 to the G2 sub-technique when inclines exceed  $4^\circ$  or  $5^\circ$  (Boulay et al., 1995; Kvamme et al., 2005).

### Effects of Power on Energy Expenditure

The overall metabolic costs of an activity are determined by the amount of energy required to overcome power demands (Lay et al., 2002). For treadmill roller skiing, external power demands are a function of both gravitational and rolling resistances (Losnegard et al., 2012a). As treadmill speed and/or grade increase, external power

demands do so in a linear fashion and the metabolic result is a rise in  $\text{VO}_2$  cost.

However, there is debate within the literature as to whether or not the metabolic response to increased external power demands is linear (Donovan & Brooks, 1977; Gaesser & Brooks, 1975).

To begin, several studies have reported energy expenditure to rise linearly with increasing external power demand. While investigating elite XC skiers performing the G3 sub-technique, Sandbakk et al. (2010) reported relatively constant measures of gross efficiency rates across several treadmill speeds, indicating a linear relationship between  $\text{VO}_2$  and external power demand. In another study, Kvamme et al. (2005) tested national level Nordic combined athletes performing both the G2 and the G3 sub-techniques, also, at a variety of treadmill speeds. Similarly, the findings of this study concluded a linear relationship between  $\text{VO}_2$  costs and external power demands for both the G2 and the G3 sub-techniques (Kvamme et al., 2005). Finally, Hoffman et al. (1994) tested skiers performing the DS technique and also reported a linear  $\text{VO}_2$  response with increases in treadmill speed, and consequently, external power demand.

In contrast, there are several studies that have reported disproportionate increases in energy expenditure with rises in external power demands. Nakai & Ito (2011) investigated the impact of DS skiing speed on rates of energy expenditure and found net energy expenditure to increase exponentially as external power demand increased linearly. In a similar study, Hoffman et al. (1995) determined a significant treadmill speed effect on measures of delta efficiency, while skiers performed the DS technique. Finally, in a study investigating the physiological impact of different travel speeds while

walking, Donovan & Brooks (1977) noted measures of muscular efficiency to be inversely related to treadmill walking speed (3, 4, 5, and 6 km/h). In each of these studies, external power demands were altered by changing treadmill speed. The proposed explanation for the observed exponential rise in energy expenditure is that the increased treadmill speeds resulted in higher limb cadences, and subsequently, higher internal power demands (Donovan & Brooks, 1977; Hill & Vingren, 2012). As overall energy expenditure is a function of both external and internal power demands, the exponential rise in  $\text{VO}_2$  costs observed in the previous studies may be attributed to increased internal power demands (forces required to move limbs) (Donovan & Brooks, 1977; Hill & Vingren, 2012).

In order to determine the influence of cadence on rates of energy expenditure, investigators have used cycle ergometers that enable external workloads to be held constant while pedaling frequency is increased. Specifically, Powers et al. (1984) investigated the influence of different arm ergometer cadences (50, 70, and 90 rpm) on measures of gross, work, and delta efficiencies. In another study, Suzuki (1979) compared mechanical efficiencies at separate cycle ergometer cadences (60 and 100 rpm). In each of these studies, external power demands were held constant across the different cadences, but both authors reported rises in energy expenditure with pedaling frequencies. To explain these observed increases of internal power demands, electromyographic (EMG) analyses were used to understand motor unit firing patterns across different cadences (Neptune et al., 1997). In one study, Neptune et al., (1997) had subjects ride a cycle ergometer and found that motor unit activity of the lower extremity

increased with increasing pedaling cadences. As motor unit recruitment increases at faster cadences, energy expenditure rises in response to the higher muscular contractions rates, even as external power demands are held constant (Lay et al., 2002).

It is clear there is discrepancy regarding the relationship between energy expenditure and external power demands. When calculating the  $\Sigma O_2$ -deficit, linear regression procedures are used to relate submaximal  $VO_2$  costs and TEPD (Losnegard et al., 2012a; Reinking et al., 2012). If energy expenditures increase exponentially with TEPD, use of a linear regression line is inappropriate. This inaccuracy may cause unreliable calculations of the  $\Sigma O_2$ -deficit, and the resulting validity of using the  $\Sigma O_2$ -deficit as a predictor of XC skiing performance is weaker.

#### Influences of Speed and Grade on Motor Unit Recruitment

Given the direct association between motor unit recruitment and energy expenditure, identifying overall muscle utilization during an activity provides a reliable indicator of  $VO_2$  costs (Lay et al., 2002). Subsequently, any alteration in motor unit recruitment patterns will change one's overall energy expenditure. These changes are not only related to XC skiing technique choice, but also travel speed and even grade (LaRoche et al., 2010).

The additional power required to increase XC skiing travel speed can be generated by the upper body, the lower body, or both. During DS skiing, Vähäsöyrinki et al. (2008) determined that the overall contribution of the upper body to propulsion decreased with increased speed. This same inverse relationship was found by Millet et al.

(1998b) while testing skiers at a variety of treadmill speeds performing the G3 sub-technique. In other words, when skiers increase travel speed, they depend more on the musculature of the lower body, rather than the upper body, to supply the increased power demands (Millet et al., 1998b; Vähäsöyrinki et al., 2008).

In addition to the impact of travel speed on muscle utilization, grade significantly affects motor unit recruitment patterns and, consequently, metabolic costs. While performing an activity on a slope, the body's orientation to gravity is altered and leads to changes in how muscles are recruited for the purpose of performing work (Li & Caldwell, 1998). In one study, Lay et al. (2007) found that while walking uphill, there were significant increases in motor unit recruitment activity of several lower extremity muscles when compared to horizontal walking. Electromyographic analysis revealed increases in both the magnitude and the duration of lower extremity muscular contractions while hill walking (Lay et al., 2007). In another study, Li & Caldwell (1998) investigated the influence of slope on motor unit firing patterns while cycling. In agreement with Lay et al., (2007), Li & Caldwell (1998) determined that EMG activity of the lower extremities increased while riding on an incline. The authors reasoned that the change in grade altered the line of action of the forces exerted on the bike pedal, leading to modifications of the motor unit firing patterns (Li & Caldwell, 1998). Currently, there are no published studies investigating motor unit firing patterns while XC skiing on different inclines. However, based on these previous studies, it is reasonable to assume that changing slope while XC skiing will alter motor unit recruitment, and subsequently,

change energy expenditures, even if external power demands are held constant.

(LaRoche et al., 2010; Li & Caldwell, 1998).

LaRoche et al. (2010) further investigated the effect of incline on measures of blood lactate (BLa) at a constant TEPD. Through evaluation of XC skiers performing the skating technique, LaRoche et al. (2010) supported Millet et al. (1998a) and found the relative demands on the upper body musculature to increase with an increase of slope. Further, it was determined that BLa increased with greater treadmill grades, which may have been due to the greater reliance on the upper body musculature. The rationale is that BLa is a representation of anaerobic metabolism and the upper body musculature is more anaerobic than the lower body musculature. With the rise in slope, and the subsequent increase in the relative contribution of the upper body for power production, anaerobic metabolism increased. This led to higher levels of BLa even though TEPD was constant (LaRoche et al., 2010). The alterations of blood lactate can also be applied to travel speed because there is greater activity of the lower body musculature as speed increases. This alteration in how ATP is catabolized (anaerobic versus aerobic) across different slopes will undoubtedly affect measures of  $VO_2$  and subsequently influence the  $VO_2$  cost – TEPD regression line.

### Summary

As all of the previously discussed factors are either directly or indirectly related to measures of  $VO_2$ , all have the potential to significantly influence the relationship between TEPD and  $VO_2$  cost during treadmill roller skiing. Considering that the regression terms

(slope and intercept) are critical for the calculation of the  $\Sigma O_2$ -deficit, further understanding of how these terms are impacted by different submaximal LT protocol conditions (technique, speed, grade) is necessary to assess the validity of the  $\Sigma O_2$ -deficit method. This understanding is especially important for XC skiing research as recent studies have supported the use of the  $\Sigma O_2$ -deficit method as a valuable determinant of XC skiing performance (Losnegard et al., 2012a; Reinking et al., 2012).

CHAPTER THREE

TREADMILL GRADE AS A DETERMINANT OF ROLLER SKIING OXYGEN  
CONSUMPTION AT A CONSTANT EXTERNAL POWER DEMAND

Contribution of Authors and Co-Authors

Manuscript in Chapter 3

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Abstract

Cross-country (XC) skiing is typically considered an aerobic activity, yet the accumulated oxygen deficit ( $\Sigma O_2$ -deficit), a representation of anaerobic capacity, has shown to be a valuable predictor of XC skiing performance. The  $\Sigma O_2$ -deficit is calculated as the difference between the predicted oxygen consumption ( $VO_2$ ) demand and the measured  $VO_2$  cost during a roller skiing time-trial protocol (RSTT). To determine  $VO_2$  demand, a lactate threshold (LT) protocol is performed with the purpose of plotting external power demand (TEPD) against measured steady-state  $VO_2$  cost. A regression line is fit and used to predict the  $VO_2$  demand of the RSTT. A possible limitation of this methodology is that it is common to use a lower treadmill grade for the LT protocol than that used for the RSTT. In order to validate the use of the LT protocol as a component of calculating the  $\Sigma O_2$ -deficit, this study investigated the influence of different treadmill grades on the linear relationship between  $VO_2$  cost and TEPD in collegiate XC skiers. Fifteen female collegiate XC skiers (Mean $\pm$ SD, Range: 20 $\pm$ 1, 18-24 years) completed three laboratory visits within a 10 day period. During each visit, skiers completed a single LT protocol at one of three treadmill grades (2°, 3°, 4°), for the purpose of measuring  $VO_2$  while roller skiing. The TEPD values of each treadmill stage were computed as the sum of both rolling and gravitational resistances. Steady-state  $VO_2$  values were plotted against corresponding TEPD values and a regression line was fit to the data. The resulting slope and intercept terms for each line were compared across treadmill grades using two-way repeated measures ANOVA and Scheffe's post hoc test ( $\alpha=0.05$ ). Neither the slopes (P=0.31) nor the intercepts (P=0.63) were significantly

different between treadmill grades. This study demonstrated that the slope and the intercept terms of the  $\text{VO}_2$  cost - TEPD regression line were not significantly influenced by treadmill grades between 2-4°, in female collegiate XC skiers. Consequently, this study indicates that the treadmill grade of LT roller skiing protocols will not significantly affect a skier's calculated  $\Sigma\text{O}_2$ -deficit.

### Introduction

Traditionally, measures of maximal oxygen consumption ( $\text{VO}_{2\text{MAX}}$ ) have been widely used to classify a cross country (XC) skier's capacity for performance (Staib et al., 2000). However, limitations in the predictive ability of  $\text{VO}_{2\text{MAX}}$  within homogeneous populations have led researchers to investigate other physiological variables for the purpose of better projecting XC skiing success (Alsobrook & Heil, 2009; Sandbakk et al., 2011; Staib et al., 2000; Stöggl et al., 2007; Vesterinen et al., 2009). Recently, the accumulated oxygen deficit ( $\Sigma\text{O}_2$ -deficit), a representation of anaerobic capacity, has been shown to be a strong predictor of XC skiing performance (Losnegard et al., 2012a; Reinking et al., 2012). The  $\Sigma\text{O}_2$ -deficit is determined from a maximal effort roller-skiing time trial (RSTT) and is calculated as the difference between a skier's predicted  $\text{VO}_2$  demand and measured  $\text{VO}_2$  cost during this test.

Although the  $\Sigma\text{O}_2$ -deficit method has been shown to correlate well with XC skiing performance, there are methodological concerns that must be considered. In order to calculate the  $\Sigma\text{O}_2$ -deficit, each skier must perform both a submaximal lactate threshold (LT) protocol and a maximal effort RSTT. The purpose of the LT protocol is to establish

a regression line relating  $\text{VO}_2$  cost and total external power demand (TEPD). This line is then extrapolated to the TEPD of the RSTT in order to determine a skier's predicted  $\text{VO}_2$  demand for this test (Losnegard et al., 2012a; Reinking et al., 2012). Methodologically, it is common for the LT protocol and the RSTT to be performed at different treadmill grades (Losnegard et al., 2012a; Reinking et al., 2012). It is possible that physiological responses will be different when roller skiing on different inclines, and if this is true, the  $\text{VO}_2$  cost – TEPD relationship established during the LT protocol may not be appropriate for calculating the predicted  $\text{VO}_2$  demand of the RSTT. As a result, the calculation of a skier's  $\Sigma\text{O}_2$ -deficit may be influenced by this characteristic of the protocol and the appropriateness of using the  $\Sigma\text{O}_2$ -deficit as a predictor of XC skiing performance can be questioned.

When the grade of the XC skiing race course changes, the demands on the upper and the lower body musculature change relative to a racer's orientation to gravity. For example, previous studies have reported that the relative demands on the upper body increase as grade increases while skate skiing. Thus, the increased power required to go uphill is generated more from the upper body than the lower body musculature (LaRoche et al., 2010; Millet et al., 1998b). A concern of the increased reliance on the upper body musculature with increased grade is that in general, the upper body produces more BLa than the lower body (LaRoche et al., 2010). The increased contribution of anaerobic metabolism will cause measures of  $\text{VO}_2$  to provide inaccurate representations of overall energy utilization (Lay et al., 2002). This may ultimately influence the regression line

relating  $\text{VO}_2$  cost and TEPD when computing the  $\Sigma\text{O}_2$ -deficit since the LT and RSTT protocols are performed at different treadmill inclines.

To investigate the potential grade-related changes in energy expenditure, the present study compared several physiological variables while treadmill roller skiing at three separate treadmill grades ( $2^\circ$ ,  $3^\circ$ , and  $4^\circ$ ). Further, this study examined the influence of treadmill grade on the regression terms (slope and intercept) of the line relating  $\text{VO}_2$  cost and TEPD for the purpose of understanding the potential influence of treadmill grade on the calculation of the  $\Sigma\text{O}_2$ -deficit.

## Methods

### Subjects

Female collegiate XC skiers, all of whom were actively training for the upcoming competitive ski season, were recruited from the Bozeman, MT, USA, area to participate in this investigation. Each skier self-reported competency performing the G3 skating technique while roller skiing. After being fully informed of the study's procedures, and prior to participation, each skier was asked to complete a health history questionnaire as well as an informed consent document approved by the Montana State University (MSU) Institutional Review Board.

### Study Design

This study evaluated the impact of three treadmill grades on measures of  $\text{VO}_2$ , heart rate (HR), blood lactate (BLa), energy expenditure (EE), cycle rate (CR), cycle length (CL), and the slope and intercept terms of the  $\text{VO}_2$  cost – TEPD regression line.

The three treadmill grades investigated were 2° (3.5%), 3° (5.2%), and 4° (7.0%), while the respective treadmill speeds were adjusted so that the TEPD was similar between grades (Table 3.1). The treadmill grades chosen were based upon a previous study investigating the  $\Sigma O_2$ -deficit for this same population of skiers (Reinking et al., 2012), as well as studies that support the use of the G3 skating sub-technique at these treadmill grades (Boulay et al., 1995; Kvamme et al., 2005)

### Testing Procedures

All skiers completed three testing sessions. Those skiers that volunteered without previous treadmill roller skiing experience were required to visit the lab on at least one separate occasion prior to testing for the purpose of familiarizing themselves with roller skiing on an oversized treadmill. During each testing visit, and in a randomized counterbalanced order, each skier performed a single submaximal LT protocol at one of the three treadmill grades tested (2°, 3°, and 4°). All three testing visits were completed at least 24 hours apart, but within 10 days of each skier's first visit. Each visit occurred at a similar time of day ( $\pm 2$  hours) and  $\geq 2$  hours postprandial. Skiers were asked to avoid exercise for  $\geq 24$  hours as well as avoid caffeine for  $\geq 3$  hours prior to each testing visit. Two hours prior to each visit, skiers were asked to consume a standard energy bar, provided by the lab, for the purpose of standardizing the caloric content of each skier's last meal prior to testing. Water consumption was allowed before and during the testing sessions *ad libitum*.

Upon arrival to the lab, each skier, while wearing their exercise clothing without ski boots, was measured for both body height (cm) and mass (kg) (Health-O-Meter beam

scale, Continental Scale Corp., Bridgeview, IL, USA) using standard procedures. Each skier's boots were massed separately, along with the provided ski poles, roller skis, safety harness, and portable metabolic system, described below.

Once dressed and fitted with all skiing and testing equipment, subjects began a 10-minute roller skiing warm-up on the oversized treadmill used for testing. For the warm-up, the treadmill grade was fixed at 2° while speed was self-selected by each skier. During the warm-up session of the first visit, each skier's self-selected speed was recorded so that the same warm-up speed was repeated during subsequent testing sessions. Once the warm-up was completed, skiers began a submaximal LT protocol at one of the three treadmill grades tested. Each stage of the LT protocol lasted five minutes, during which subjects roller skied for four minutes, using only the G3 skating technique, followed by one minute of rest before progressing to the next stage. During the one-minute rest, a fingertip blood sample was collected and then measured for blood lactate concentration using a handheld analyzer. All skiers began each LT protocol at the same speed setting for each grade. When skiing at 2°, subjects roller skied at 2.2, 2.8, 3.3, 3.9, and 4.5 m/s. At the 3° and 4° conditions, subjects roller skied at 1.8, 2.2, 2.7, 3.1, and 3.6 m/s and 1.5, 1.9, 2.2, 2.6, and 3.0 m/s, respectively (Table 3.1). The LT protocol was stopped when a blood lactate measure both exceeded 4.0 mmol/L and exceeded the previous blood lactate measure by  $\geq 1.0$  mmol/L. Once this occurred, skiers began five minutes of active recovery while roller skiing at 2° and 1.8 m/s (4 mph).

## Instrumentation

Treadmill Testing Equipment. All roller skiing tests were performed on an oversized treadmill (treadmill belt was 2.44 m wide by 3.05 m long; Fitnexus Fitness Equipment, Inc., Dallas, TX, USA). To standardize rolling resistance, skiers used one of two pairs of identical roller skis (Marwe 610C; Peltonen Ski Oy, Finland) mounted with either the NNN (Rottefella, Klokke, Norway) or the SNS (Salomon, Annecy, France) binding system designed for skate skiing. Each skier used their own skate boots and, subsequently, used the same pair of roller skis for each testing visit. All skiers used the same style of elite racing poles (Swix Star CT1 poles and Star grips; Swix Sport USA, Inc., Haverhill, MA, USA) with trekking pole tips (Flex Tip; Black Diamond Equipment, Salt Lake City, UT USA) sized to within 2.5 cm of the skier's preferred pole length for skate skiing. To increase safety during roller skiing, each skier wore a sized climbing harness (Momentum DH Harness; Black Diamond Equipment, Salt Lake City, UT USA) that attached to an overhead suspension system to catch the skier in the event of a fall.

Indirect Calorimetry. During each submaximal test, oxygen consumption (ml/kg/min) and heart rate (bpm) were measured continuously, and reported as 5-second averages, by a portable metabolic system (Oxycon Mobile, Viasys Healthcare, Yorba Linda, CA USA) using standard indirect calorimetry procedures. In accordance with the manufacturer's guidelines, the system's ventilation meter, oxygen sensor, and carbon dioxide sensor were calibrated prior to each submaximal LT protocol. Heart rate was

measured using a Polar RS400 heart rate monitor (Polar Electro, Inc., Lake Success, NY, USA) that transmitted via telemetry to the portable metabolic system's base station.

Blood Lactate Analyzer. Blood lactate was measured at the end of each stage using the Lactate pro analyzer (Lactate Pro; Arkay, Inc., Kyoto, Japan). To analyze blood lactate, each skier's finger was punctured with a single-use lancet to obtain 5  $\mu$ l of whole blood. This whole blood was sampled via capillary action using the appropriate reagent strips designed for use with the Lactate Pro analyzer. Calibration of the Lactate Pro analyzer was completed prior to each testing session according to the manufacturer's guidelines.

Kinematics. Cycle rate was evaluated at the 3-minute mark during each stage of each LT protocol. For this study, a cycle started and finished with two consecutive left side pole plants. Cycle rate was initially represented as the time to complete 10 consecutive cycles and was determined using a standard handheld stopwatch (Accusplit Pro Survivor, A601X, Accusplit, Inc., Livermore, CA, USA). Three 10-cycle bouts were measured and the average time to complete 10 cycles was extrapolated to determine CR as the number of cycles completed per minute at each stage of each grade. Cycle length was determined from CR, given the known treadmill speed.

### Data Processing

Oxygen consumption and HR were defined as the respective mean values between the 2.5 and the 3.5 minute marks of each stage. Where appropriate, all variables used in the calculation of each skier's EE, as well as the slope and intercept terms, were

also taken as the mean values between the 2.5 and the 3.5 minute marks of each stage. Treadmill speed of each stage for each grade was determined using a digital contact handheld tachometer (Model 461891; EXTECH Instruments Corp., Nashua, NH, USA). Only the stages below LT were used for the calculation of the slope and intercept terms. Comparative analyses for  $\text{VO}_2$ , HR, BLa, EE, CR, and CL were based on the two stages below LT and the single stage above LT for each skier.

Calculating EE. As described by Péronnet & Massicotte (1991), EE (kcal/min) was calculated using the following:

$$(3.1) \quad \text{EE} = \text{VO}_2 \times \text{C}_{\text{RQ}}$$

where  $\text{VO}_2$  is the oxygen consumption in liters per minute and  $\text{C}_{\text{RQ}}$  is a conversion factor representing the caloric equivalent derived from the respiratory quotient. For the purposes of this study, it was assumed that the subject's respiratory exchange ratio (RER) was equivalent to the non-protein respiratory quotient allowing the  $\text{C}_{\text{RQ}}$  to be obtained from the non-protein respiratory quotient table, presented by Péronnet & Massicotte (1991).

Calculating Kinematic Variables. Cycle rate was initially determined as the time elapsed for each skier to complete 10 consecutive cycles. In order to convert this to cycles per minute, the following was used:

$$(3.2) \quad \text{CR} = 60 / (\text{CR}_{10} / 10)$$

where 60 is the number of seconds per minute,  $CR_{10}$  is the time in seconds it took to complete 10 cycles, and dividing  $CR_{10}$  by 10 converts the value into the time in seconds it takes to complete one cycle.

As speed is a function of both cycle length and CR, CL (m/cycle) was subsequently determined by rearranging this equation, so that:

$$(3.3) \quad CL = s / CR$$

where  $s$  is the treadmill speed in meters per minute and CR is the skier's cycle rate in cycles per minute.

Calculating TEPD. Total external power demand (W) is a function of both gravitational resistance ( $R_G$ , N) and frictional rolling resistances ( $R_f$ , N). The  $R_G$  and  $R_f$  were calculated using the procedures outlined by Losnegard et al. (2012a) where TEPD was calculated as:

$$(3.4) \quad TEPD = (R_G + R_f) \times s$$

where  $s$  is the treadmill speed in meters per second. In order to calculate  $R_G$  and  $R_f$ , the following were used:

$$(3.5) \quad R_G = M_T \times g \times \sin(\theta)$$

$$(3.6) \quad R_f = \mu \times M_T \times g \times \cos(\theta)$$

where  $M_T$  is the total mass of the skier and equipment in kilograms,  $g$  is the constant for gravitational acceleration ( $9.81 \text{ m/s}^2$ ),  $\theta$  is the treadmill grade in degrees, and  $\mu$  is the coefficient of rolling friction (0.035 and 0.037 for the roller skis with the NNN and SNS bindings, respectively).

Calculating the Slope and Intercept Terms. Once TEPD and  $\text{VO}_2$  were calculated, a linear regression line was fit to the data for each subject and each grade. The resulting slope and intercept coefficients of this line were used for subsequent analyses.

Pre-Test Treadmill Speed Calculations. The speed settings for each stage of each treadmill grade were calibrated so that TEPD was calculated to be relatively constant between grades (Table 3.1). The speed settings for the 3° condition were the same as those described by Reinking et al. (2012), while the speed settings for each stage of the 2° and the 4° conditions were calculated based on the TEPD of each stage of the 3° treadmill grade. Using equations 3.4-3.6, TEPD was first calculated for each stage of the 3° condition. Next, equation 3.4 was rearranged for  $s$ , while keeping TEPD constant, enabling the calculation of the corresponding speeds of each stage for both the 2° and 4° conditions:

$$(3.7) \quad s = P_T / (R_g + R_f).$$

Table 3.1. Treadmill grades and speeds for each stage of the submaximal lactate threshold protocol.

	2° Treadmill Grade Speeds	3° Treadmill Grade Speeds	4° Treadmill Grade Speeds
Stage 1	2.2 m/s (5.0 mph)	1.8 m/s (4.0 mph)	1.5 m/s (3.3 mph)
Stage 2	2.8 m/s (6.2 mph)	2.2 m/s (5.0 mph)	1.9 m/s (4.2 mph)
Stage 3	3.3 m/s (7.5 mph)	2.7 m/s (6.0 mph)	2.2 m/s (5.0 mph)
Stage 4	3.9 m/s (8.7 mph)	3.1 m/s (7.0 mph)	2.6 m/s (5.9 mph)
Stage 5	4.5 m/s (10.0 mph)	3.6 m/s (8.0 mph)	3.0 m/s (6.7 mph)

### Statistical Analysis

Standard linear regression procedures were used to compute a least-squares fit equation for the  $\text{VO}_2$  cost – TEPD regression line for each subject at each treadmill grade. The resulting slope and intercept terms of these lines, as well as measures of TEPD,  $\text{VO}_2$ , HR, EE, BLa, CR, and CL were evaluated for statistical significance using multivariate two-factor repeated measures ANOVA ( $\alpha = 0.05$ ). Scheffe's post-hoc test was used to evaluate all pairwise comparisons ( $\alpha = 0.05$ ). All statistical analyses were performed using the software Statistix (Version 9.0, Analytical Software, Tallahassee, FL).

### Reliability of the Submaximal LT Test

In order to evaluate the reliability of computing the slope and intercept terms from the LT protocols, seven male collegiate XC skiers (ages 18-24) were recruited to perform two identical submaximal LT protocols. With the exception of only requiring two visits within a seven day period, the same procedures were used as described above. As outlined by Reinking et al. (2012), each subject roller skied at a fixed grade of  $5^\circ$  with successive stages of 1.8, 2.2, 2.7, 3.1, 3.6, and 4.0 m/s (4-9 mph). Standard linear regression procedures ( $\alpha = 0.05$ ) were used to compare measures of  $\text{VO}_2$ , HR, BLa, and EE, as well as the slope and intercept terms of the  $\text{VO}_2$  cost – TEPD regression line. The slope and intercept terms for each visit were calculated and then compared using the intraclass correlation coefficient (ICC) and the standard error of measurement (SEM), both of which were computed for 2-trial and 1-trial reliability.

Results

Subject demographics for the 15 female subjects who completed this study, as well as the seven males who completed the reliability component, are presented in Table 3.2.

Table 3.2. Subject demographics (Mean $\pm$ SD).

	N	Age (years)	Body Height (cm)	Body Mass (KG)	BMI (kg/m <sup>2</sup> )
Females	15	20 $\pm$ 1.0	165.9 $\pm$ 3.5	64.6 $\pm$ 7.3	23.5 $\pm$ 2.6
Males	7	21 $\pm$ 1.0	181.5 $\pm$ 10.5	77.0 $\pm$ 13.2	23.2 $\pm$ 1.5

Physiological Variables

Calculated TEPD was statistically similar ( $P = 0.15-0.45$ ) within the common stages of each treadmill grade tested (Table 3.3). There were significant differences between at least two of the treadmill grades for measures of  $VO_2$  ( $P = 0.01-0.03$ ), HR ( $P = 0.02-0.07$ ), BLa ( $P = 0.01-0.04$ ), and EE ( $P = <0.01-0.03$ ) (Figure 3.1). Specifically, mean  $VO_2$ , HR, BLa, and EE at the 2° condition were significantly lower than values at 3° and/or 4° for all variables and stages.

Table 3.3. Mean ( $\pm$ SE) total external power demand (TEPD) computed in watts for each stage of each grade of the submaximal lactate threshold protocol. The data was compared across treadmill grades and within each stage.

Treadmill Grade (°)	Stage 1 TEPD (W)	Stage 2 TEPD (W)	Stage 3 TEPD (W)	Stage 4 TEPD (W)
Grade 2	108 $\pm$ 3.7	134 $\pm$ 4.2	163 $\pm$ 5.1	191 $\pm$ 5.8
Grade 3	108 $\pm$ 3.7	135 $\pm$ 4.4	163 $\pm$ 5.1	190 $\pm$ 5.9
Grade 4	107 $\pm$ 3.6	135 $\pm$ 4.5	162 $\pm$ 5.1	190 $\pm$ 5.5

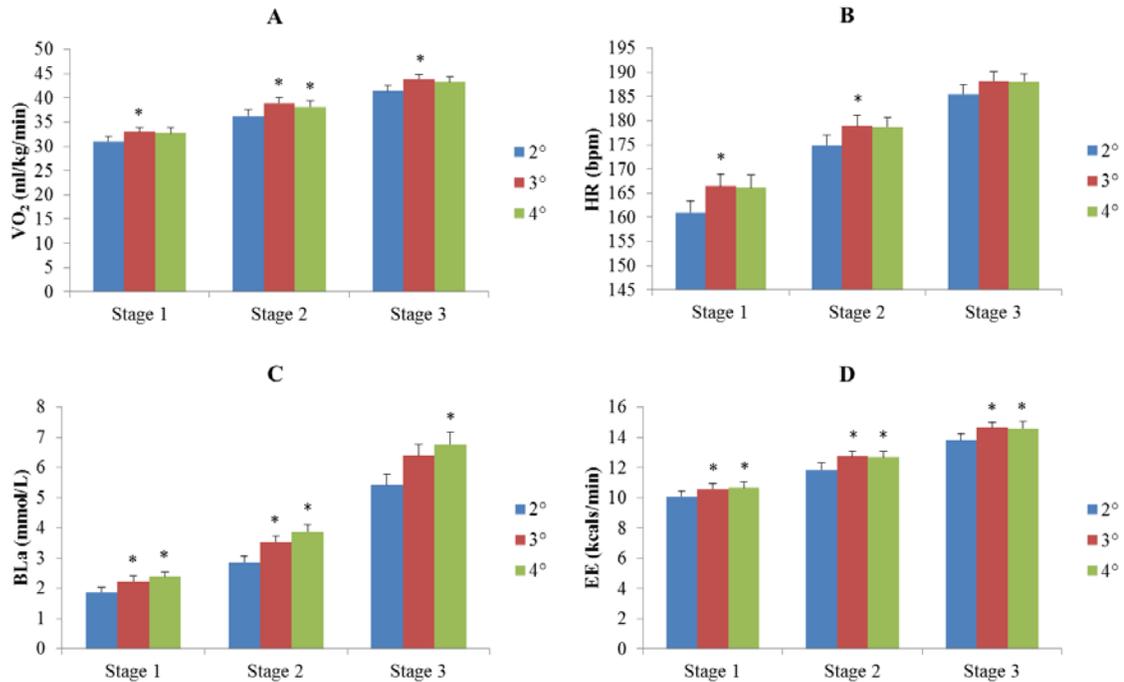


Figure 3.1. Mean values ( $\pm$  SE) for (A) oxygen consumption ( $VO_2$ ), (B) heart rate (HR), (C) blood lactate (BLa), and (D) energy expenditure (EE) plotted for each stage of each grade (2°, 3°, 4°). \* Significantly different ( $P < 0.05$ ) from the 2° condition.

### Kinematic Variables

Cycle rate was statistically similar ( $P = 0.52-0.74$ ) across all three grades while CL decreased significantly ( $P < 0.01$ ) as treadmill grade increased (Figure 3.2).

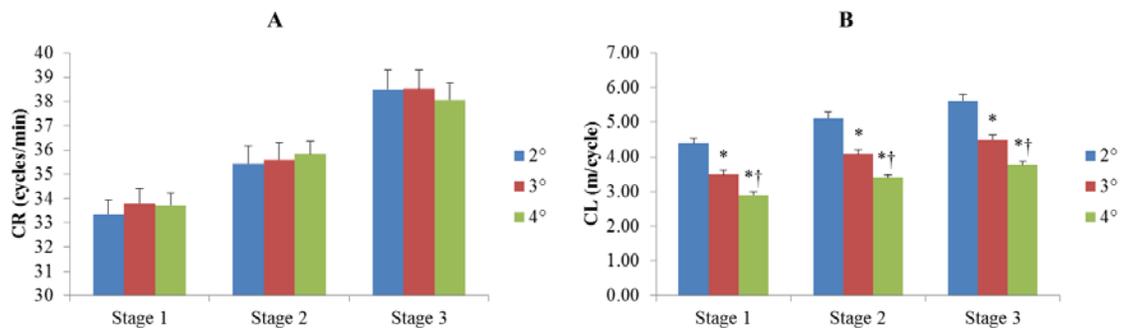


Figure 3.2. Mean values ( $\pm$  SE) for (A) cycle rate (CR) and (B) cycle length (CL) for each stage of each treadmill grade tested (2°, 3°, 4°). \* Significantly different ( $P < 0.05$ ) from the 2° condition. † Significantly different ( $P < 0.05$ ) from the 3° condition.

### Slope and Intercept Terms

Examples of the calculated VO<sub>2</sub> cost–TEPD regression lines for two of the female subjects who completed three stages below LT are presented in Figure 3.3.

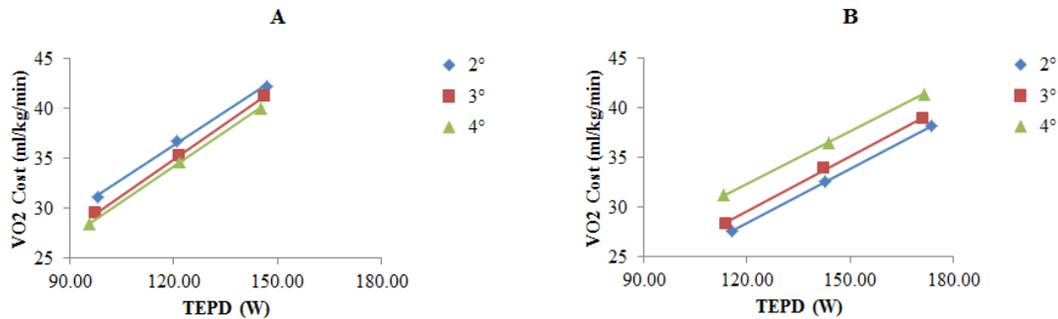


Figure 3.3. Illustration of the calculated oxygen consumption cost (VO<sub>2</sub> cost) – total external power demand (TEPD) regression line at each treadmill grade tested (2°, 3°, 4°) for two female subjects. In graph A, the regression line equations for the 2°, 3°, and 4° conditions are  $y = 0.23x + 9.13$ ,  $y = 0.24x + 6.27$ , and  $y = 0.24x + 5.93$ , respectively. In graph B, the regression line equations for the 2°, 3°, and 4° conditions are  $y = 0.18x + 6.54$ ,  $y = 0.18x + 7.42$ , and  $y = 0.18x + 11.36$ , respectively.

Primary Analysis. There were no significant differences between grades for either the slope ( $P = 0.31$ ) or intercept terms ( $P = 0.63$ ) for the lines relating VO<sub>2</sub> cost and TEPD (Figure 3.4). The slope terms did not have any non-significant trends, but the intercept terms tended to increase with increasing grade.

Sub-Analysis. The subject sample was further divided into sub-groups based on the number of stages each skier completed below LT. Six skiers (40%) completed three stages below LT while nine skiers (60%) completed two stages below LT. A sub-analysis evaluated the slope and intercept terms for the regression lines relating VO<sub>2</sub> cost and TEPD for each sub-group. There were no significant differences between treadmill

grades for either the slope ( $P = 0.38$  and  $0.64$ ) or intercept terms ( $P = 0.89$  and  $0.68$ ) for the regression lines relating  $\text{VO}_2$  cost and TEPD for either group (Figure 3.5).

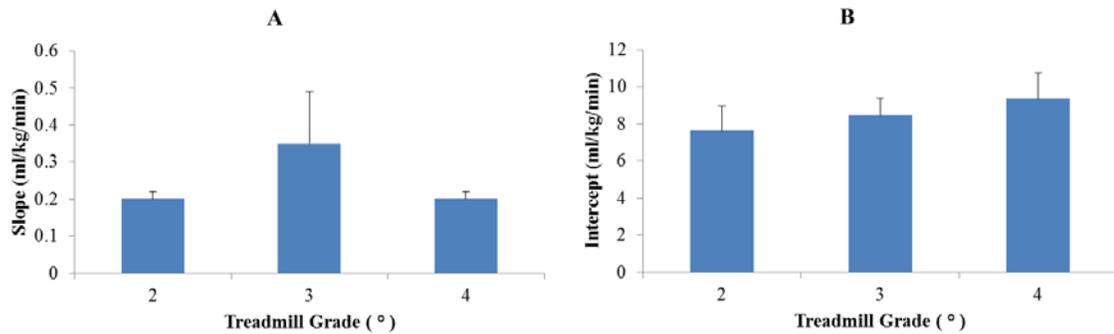


Figure 3.4. Mean values ( $\pm$  SE) for the (A) slope and (B) intercept terms for the lines relating oxygen consumption cost ( $\text{VO}_2$  cost) to total external power demand (TEPD) for each treadmill grade ( $2^\circ$ ,  $3^\circ$ ,  $4^\circ$ ).

### Reliability Evaluation

Subject demographics for the 7 male subjects who completed the reliability testing for this study are presented in Table 3.2. There were no significant differences between visits for any of the physiological variables ( $P = 0.25$ - $0.87$ ), the slope terms ( $P = 0.76$ ), or the intercept terms ( $P = 0.69$ ) evaluated.

The 2-trial and 1-trial ICC values were high for  $\text{VO}_2$ , HR, and EE for both 2-trial ( $0.92 - 0.96$ ) and 1-trial ( $0.84 - 0.91$ ) assessments. The SEM values for the 2-trial assessments were low to moderate for  $\text{VO}_2$  ( $\pm 1.3$ - $1.4$  ml/kg/min), HR ( $\pm 2.1$ - $2.4$  bpm), and EE ( $\pm 0.9$ - $1.5$  kcal/min). The SEM values for the 1-trial assessments were slightly less reliable for  $\text{VO}_2$  ( $\pm 1.8$ - $1.9$  ml/kg/min), HR ( $\pm 2.9$ - $3.2$  bpm), and EE ( $\pm 1.2$ - $2.0$  kcal/min). The ICC values for the slope and intercept terms were moderate to high for both 2-trial ( $0.95$  and  $0.77$  respectively) and 1-trial ( $0.91$  and  $0.62$ , respectively)

assessments. The 2-trial and 1-trial SEM values were low for both the slope term ( $\pm 0.01$  ml/kg/min for both) and the intercept term ( $\pm 1.8$  and  $\pm 2.2$  ml/kg/min, respectively). Collectively, these reliability data indicate that a single treadmill based roller skiing LT visit provides reliable data for further analyses.

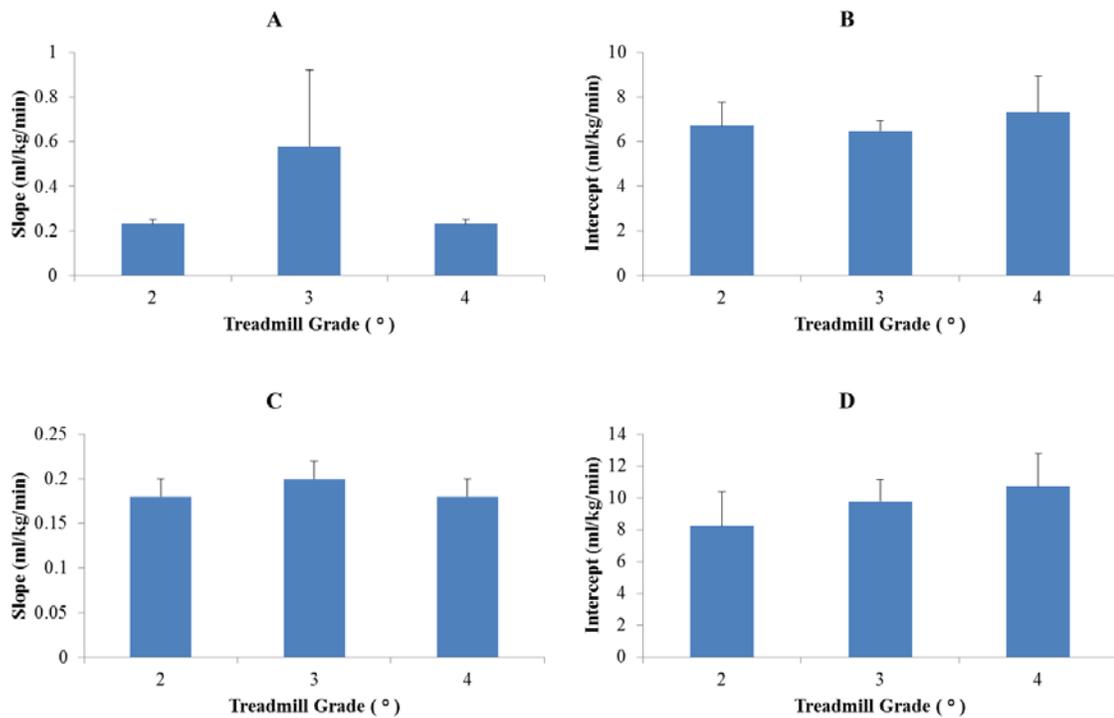


Figure 3.5. Mean values ( $\pm$  SE) for the (A) slope and (B) intercept terms of the oxygen consumption cost ( $\text{VO}_2$  cost) – total external power demand (TEPD) regression line for the sub-group that completed three stages below lactate threshold and the (C) slope and (D) intercept terms of the  $\text{VO}_2$  cost – TEPD regression line for the sub-group that completed two stages below LT for each treadmill grade tested ( $2^\circ$ ,  $3^\circ$ ,  $4^\circ$ ).

### Discussion

The main purpose of the primary investigation was to determine the impact of treadmill grade on the calculated slope and intercept terms of the regression line relating  $\text{VO}_2$  cost and TEPD. In addition, this study investigated the influence of treadmill grade

on various physiological ( $\text{VO}_2$ , HR, BLa, EE) and kinematic (CR, CL) variables while treadmill roller skiing. The principal finding of this study was that there were no significant differences between treadmill grades for the calculated slope and intercept terms of the  $\text{VO}_2$  cost – TEPD regression line, even though significant differences existed between treadmill grades for  $\text{VO}_2$ , HR, BLa, and EE.

### Reliability

Currently, there is no published research identifying the reliability of calculating the slope and intercept terms of the  $\text{VO}_2$  cost - TEPD regression line from submaximal LT tests performed while treadmill roller skiing. An assumption of the primary investigation was that the reliability of repeat submaximal LT tests was high. To address this assumption, male XC skiers completed repeat submaximal LT tests while roller skiing for the purpose of identifying the reliability of using this LT protocol to calculate the slope and intercept terms of the  $\text{VO}_2$  cost – TEPD regression line. The principal findings of this secondary study were that no significant differences existed across days. These reliability data support the assumption of the primary investigation that any differences observed between LT tests could be attributed to changes of treadmill grade.

### Physiological Variables

Since the TEPD within treadmill stages was computed to be the same for each skier (Table 3.3), the physiological differences observed within stages (Figure 3.1) must have been related to some other factor related to changes in treadmill grade. All four physiological variables examined ( $\text{VO}_2$ , HR, BLa, and EE) were significantly lower at

the 2° treadmill grade for all stages. Interestingly, the values for these same variables were similar between the 3° and 4° treadmill grades, indicating that the physiological response at the 2° condition was significantly different than at the 3° and 4° conditions.

One hypothesis for the observed differences in physiological parameters across treadmill grades is that changing a skier's orientation to gravity may have led to changes in motor unit recruitment patterns. For example, Lay et al. (2007) and Li & Caldwell (1998), evaluated walkers and cyclists, respectively, and reported that the magnitude and the frequency of motor unit recruitment increased as incline increased. Although neither of these studies investigated XC skiers, it is likely that motor unit recruitment increases while treadmill roller skiing at increasing inclines as well. The importance of the increased motor unit activity is that overall metabolic costs are directly related to motor unit activity. If the magnitude and frequency of motor unit recruitment is increased at greater inclines, measures of  $\text{VO}_2$  and HR will rise as well (Lay et al., 2002). In agreement with these authors,  $\text{VO}_2$ , HR, and BLA in the present study were lowest at the 2° grade, possibly in relation to lower motor unit recruitment. However, this hypothesis is not consistent for the 3° and 4° treadmill grades because measures of  $\text{VO}_2$ , HR, and BLA do not continue to rise significantly. In fact, measures of  $\text{VO}_2$  and HR decreased slightly, though non-significantly, as skiers progressed from the 3° to the 4° treadmill grade. Further analysis of motor unit recruitment patterns while treadmill roller skiing at different inclines is warranted to better understand the influence of incline on metabolic costs.

In the present study, BLa concentration was the only physiological variable to systematically rise as treadmill grade increased. LaRoche et al. (2010) and Millet et al. (1998a) determined that the demands on the upper body musculature disproportionately rise, compared to the lower body, when incline rises. The elevated contribution of the upper body at higher inclines is noteworthy because the upper body musculature is more anaerobic than the lower body. It was proposed that because the upper body musculature is more anaerobic, BLa concentrations will rise with increased inclines, reflecting the greater demand of the upper body at these inclines (LaRoche et al., 2000). LaRoche et al. (2010) measured BLa concentrations of XC skiers and found BLa measures to increase as incline rose, even when TEPD was held constant. Supporting the findings of LaRoche et al., BLa concentrations of the present study were always highest when skiers performed the G3 skating technique at the 4° condition and lowest at the 2° condition. Even though TEPD did not change across treadmill grades, there was a regular increase in BLa concentrations as incline increased.

### Kinematic Variables

In order to increase travel speed while XC skiing, CL, CR, or both, may be increased. Previous investigations have reported that XC skiers increase travel speed more by increasing CL, rather than CR (Boulay et al., 1995; Lindinger et al., 2009; Millet et al., 1998a; Sandbakk et al., 2010). The present study was in agreement with these previous studies as CL was always higher at the faster treadmill speeds while CR, held constant as travel speed changed within a stage. Unfortunately, these kinematic trends

cannot completely explain the observed metabolic discrepancy between the 2° condition and the 3° and 4° conditions for the present study.

Previous research has focused exclusively on how CL and CR change with travel speed (Boulay et al., 1995; Lindinger et al., 2009; Millet et al., 1998a; Sandbakk et al., 2010). Interestingly, no information has been published addressing the impact of TEPD on CR. In the present study CR held constant within a stage but increased within a grade. As speeds changed to maintain a common TEPD within a stage, CR remained unchanged. In contrast, as speeds increased to elevate TEPD, CR increased. As a result, it is possible that CR for female collegiate XC skiers is determined more by TEPD than travel speed. Further investigation of the CR – TEPD relationship is necessary.

### Regression Terms

Primary Analysis. The calculated slope and intercept terms of the regression line relating  $\text{VO}_2$  cost and TEPD were not significantly influenced by treadmill grade (Figure 3.4). This was an interesting finding given that measures of  $\text{VO}_2$ , HR, and BLA, and the subsequent calculation of EE, were significantly different across the three treadmill grades tested. The lack of significant change for either the slope or intercept terms provides the possibility that the calculation of these regression coefficients is relatively robust (Hill & Vingren, 2012). Unfortunately, it is also possible that the calculated slope and intercept terms are similar because they have relatively higher standard errors (Russell et al., 2000). Addressing the accuracy of the  $\text{VO}_2$  cost – TEPD regression line was beyond the scope of this study, but something to consider in future research.

Evaluation of the slope and intercept terms themselves revealed a couple of interesting trends. The value of the slope term between the 2° and the 4° condition was almost identical, while the slope at 3° was noticeably steeper, though non-significantly, than the other two conditions. Investigation of each skier's data showed that the slope of the 3° condition was either the steepest or the second steepest slope for 14 of 15 skiers. In contrast, the 2° and 4° slopes were equally distributed amongst the 15 skiers as either the least, the middle, or the steepest. There does not appear to be any explanation for this observation, except that the 3° condition, itself, may have been more "uncomfortable" than the other two conditions for performing the G3 skating gear. The intercept term, on the other hand, was more regular across treadmill grades. The only noteworthy trend was that the value increased slightly from the 2° through the 4° condition.

Unfortunately, there are no published studies addressing the impact of treadmill grade on either the calculation of the slope and intercept terms of the  $\text{VO}_2$  cost – TEPPD regression line or on the overall calculation of a subject's  $\Sigma\text{O}_2$  – deficit, for which to compare the present study's results. However, two studies have been conducted that have investigated the impact of cycling cadence on the calculation of a subject's  $\Sigma\text{O}_2$  – deficit. (Hill & Vingren, 2012; Russell et al., 2002a). Hill & Vingren (2012) calculated a cyclist's  $\Sigma\text{O}_2$ -deficit based upon LT protocols performed at 60, 80, and 100 RPM and reported that the calculation of the  $\Sigma\text{O}_2$ -deficit was not changed by cadence. Russell et al. (2002a) similarly investigated the effect of calculating the  $\Sigma\text{O}_2$ -deficit based on a LT protocol performed at 80 RPM and at 120 RPM. In contrast to Hill & Vingren (2012), Russell et al. (2002a) reported that the slope term calculated from the LT performed at

120 RPM was steeper than at 80 RPM. The findings of these two studies are important to the present study because they indicate that the methodology of the submaximal LT protocol may affect the subsequent calculation of the  $\Sigma O_2$ -deficit.

Sub-Analysis. One concern of the present study was that six of the subjects completed three stages below LT while nine of the subjects completed just two stages below LT. This is important because the  $VO_2$  cost – TEPD regression line was calculated using only a skier's  $VO_2$  cost values below LT. As a result, 60% of the regression lines were developed using only two data points.

For the purpose of better understanding the consequence of using two data points below LT, a sub-analysis of the data was completed. The subject sample was divided into two sub-groups: those that completed three stages below LT (LT<sub>3</sub>) and those that only completed two stages below LT (LT<sub>2</sub>). The same statistical analyses that were run on the complete sample were run on each sub-group. The analyses revealed that within both sub-groups, the slope and intercept terms of the  $VO_2$  cost – TEPD regression line were similar across treadmill grades (Figure 3.5).

Further evaluation of the graphs of the two sub-groups did reveal some points of interest. In both sub-groups, and similar to the results of the entire sample, the steepest slope was at the 3° treadmill grade. Interestingly, the elevated 3° slope was much more pronounced in the LT<sub>3</sub> sub-group and the standard error for the 3° grade was much higher. Another interesting trend was that the slope terms for the LT<sub>3</sub> sub-group were steeper than the LT<sub>2</sub> sub-group. The authors of this study do not have any explanation for either of these trends. It is noted, however, that there were only six skiers in the LT<sub>3</sub>

sub-group, so it is possible that simply increasing the size of the group would cause the differences between the two sub-groups to be reduced.

Evaluation of the intercepts was also conducted for each sub-group. The intercepts for the LT<sub>3</sub> sub-group were noticeably lower than the intercepts for the LT<sub>2</sub> sub-group. This is likely a consequence of the LT<sub>3</sub> sub-population having steeper slopes, causing the VO<sub>2</sub> cost – TEPD regression line to intersect the y-axis at a lower coordinate.

Methodology. The methodology for calculating the slope and intercept terms of the VO<sub>2</sub> cost – TEPD regression line were identical to the procedures outlined by both Losnegard et al. (2012) and Reinking et al. (2012). The purpose of the present study was to validate the methodology used by these authors, and thus, it was necessary to repeat their procedures. Currently, no published studies have investigated the influence of treadmill grade on the calculation of the slope and intercept terms of the VO<sub>2</sub> cost – TEPD regression line. However, there are several studies that address other methodological considerations for the calculation of the  $\Sigma$ O<sub>2</sub>-deficit.

A primary methodological consideration is the number of stages to include in the submaximal LT protocol (Russell et al., 2000; Russell et al., 2002b). In order to calculate the VO<sub>2</sub> cost – TEPD regression line with the least amount of error, it has been previously reported that at least 10 stages be used. Of these 10 stages, five stages are below LT and five stages are above LT (Russell et al., 2002b). To further reduce the error, the inclusion of a forced y-intercept has been recommended (Russell et al., 2000; Russell et al., 2002b). However, it was noted that the precision of using five stages and a forced y-intercept to calculate the VO<sub>2</sub> cost – TEPD regression line is the same as using

10 stages (Russell et al., 2002b). In addition Russell et al. (2000) investigated the influence of three different LT protocols for calculating the  $\Sigma O_2$ -deficit. These authors looked at a 5-stage protocol with a forced y-intercept, a 5-stage protocol without a forced y-intercept, and the “procedure 3” method proposed by Medbø et al. (1988). In these three protocols, points from below LT and above LT were combined to calculate the  $VO_2$  cost –TEPD regression line. Russell et al. (2000) reported that the calculated slope term was similar between all three protocols. The only significant difference observed between protocols was the level of precision, as evidenced by tighter confidence intervals (Russell et al., 2000).

In the present study, only the stages below LT were used to calculate the  $VO_2$  cost – TEPD regression line and a forced y-intercept was not used. This meant that 40% of the regression lines were calculated with three points and 60% of the regression lines were calculated with only two points. Following the recommendations of Russell et al. (2002b) and Russell et al. (2000), the present study would have been more precise if more stages were used to calculate the  $VO_2$  cost – TEPD regression line. The methodology of the present study intended for all skiers to have at least three sub-LT stages. Unfortunately, the pilot work that indicated the chosen workloads would allow each skier to complete three stages below LT did not hold true for 60% of the skiers in the present study. The calculated workloads were based upon the 3° treadmill condition, with each stage increasing in speed by 0.45 m/s (1 mph). If this study is repeated in this same population of XC skiers, it may be prudent to increase travel speed by only 0.22 m/s (0.5 mph) at the 3° treadmill grade, which will allow more stages to be completed below

LT. It would not be appropriate to add stages to the front end of the protocol because the treadmill speeds would be too slow for skiers to comfortably perform the G3 skating technique.

One point of interest is that Russell et al. (2002b) and Russell et al. (2000) calculated the  $\text{VO}_2$  cost – TEPD regression line using points that were both below LT and above LT. For the present study, in contrast, the same regression line was based upon only points below LT. A supplemental analysis was conducted to compare the slope and intercept terms calculated from only points below LT with the terms calculated using stages both below LT and above LT. Interestingly, there were no differences between the slope ( $P = 0.32$ ) and intercept ( $P = 0.77$ ) terms calculated from only the stages below LT and from the combined use of stages below and above LT. The concern for using stages above LT is that they may not be at steady-state conditions, which is a primary assumption of the  $\Sigma\text{O}_2$ -deficit method (Losnegard et al., 2012a; Noordhof et al., 2010). Although treadmill grade did not influence the calculation of the slope and intercept terms of the  $\text{VO}_2$  cost – TEPD regression line in the present study, future analyses of the impact of treadmill grade on these regression terms should be performed with more data points.

### Conclusions

The  $\Sigma\text{O}_2$ -deficit has been shown to be a valuable predictor of XC skiing performance across multiple events (sprint and distance) and across multiple ability levels (elite and sub-elite) (Losnegard et al., 2012; Reinking et al., 2012). The present

study found that treadmill grades of 2°, 3°, and 4° produced similar regression lines for female collegiate XC skiers supporting the methodology used by both Losnegard et al. (2012a) and Reinking et al. (2012) for calculating the  $\Sigma O_2$ -deficit.

There are further concerns regarding the methodology of the present study that need to be addressed. Most notably, this includes the number of stages used to calculate the  $VO_2$  cost – TEPD regression line. Including more stages may also help explain why differences were observed across the different stages for the physiological variables tested, but not the regression terms. Regardless, this study substantiates the methodology of the  $\Sigma O_2$ -deficit method and supports its use as a predictor of XC skiing performance.

#### 4. CONCLUSIONS

Distinguishing the characteristics required to become an elite cross country (XC) skier is important for athlete development within the sport. It is well known that XC skiers must have high measures of maximal oxygen consumption ( $VO_{2MAX}$ ) to be successful (Hoffman & Clifford, 1992; Losnegard, et al., 2012a; Sandbakk et al., 2010). However, elite XC skiers must also have high measures of upper body power (Alsobrook & Heil, 2009; Staib et al., 2000), a high  $VO_2$  at lactate threshold (LT) (Stöggl et al., 2007; Vesterinen et al., 2009), and even a high anaerobic capacity (Losnegard et al., 2012; Reinking et al., 2012) to be successful. As each of these variables have proven effective at predicting XC skiing performance, it is important that the methodology for determining each is appropriate. Most notably, there are concerns regarding the complicated procedures required to calculate a XC skiers accumulated oxygen deficit ( $\Sigma O_2$ -deficit), a representation of anaerobic capacity.

The present study investigated the impact of using different treadmill grades to calculate the slope and intercept terms of the regression line relating  $VO_2$  cost and total external power demand (TEPD) used in the  $\Sigma O_2$ -deficit method. It was found that for female collegiate XC skiers, the slope and intercept terms of the  $VO_2$  cost – TEPD regression line are similar when submaximal LT protocols are performed at 2° (3.5%), 3° (5.2%), and 4° (7.0%). Interestingly, measures of  $VO_2$ , heart rate (HR), and blood lactate (BLa) were significantly different across these same three treadmill grades.

The primary concern of the present study is that for some skiers, only two  $VO_2$  cost values were used to calculate the  $VO_2$  cost – TEPD regression line. In order to more

accurately assess the influence of treadmill grade on this regression line, future studies need to design LT protocols that allow for collecting more  $\text{VO}_2$  cost data points below LT. Future studies may also benefit by conducting this same experiment in other XC skiing populations (e.g., male and elite XC skiers) for the purpose of extending the conclusions of the present study to a wider population group. Regardless, the similarity of the slope and intercept terms of the  $\text{VO}_2$  cost – TEPD regression line across treadmill grades supports the use of the current  $\Sigma\text{O}_2$ -deficit method used for XC skiers.

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APPENDICES

APPENDIX A

SUBJECT CONSENT FORM

SUBJECT CONSENT FORM FOR PARTICIPATION IN HUMAN RESEARCH AT  
MONTANA STATE UNIVERSITY – BOZEMAN

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**PROJECT TITLE:** Treadmill grade as a determinant of roller skiing oxygen consumption at a constant external power demand

**FUNDING:** This study is NOT a funded project

**PROJECT DIRECTOR:** Bryant Reinking, ATC/LAT, Masters Student  
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**PURPOSE:** You are being asked to participate in a research project on treadmill roller skiing. The purpose of this project is to determine the influence of treadmill grade on the relationship between power demand and oxygen consumption (VO<sub>2</sub>) cost. You have been identified as a potential subject for this research project because of your skills in Nordic skiing.

Each participant is presented with this Informed Consent Document which explains the purpose of the testing, as well as risks and benefits associated with participation. Also, each participant is asked to complete a health history questionnaire for the purpose of identifying any health conditions that increase the risks associated with participation in this research project. If a concern is identified in your health history questionnaire, it is YOUR responsibility to acquire written medical clearance from your physician, and provide a copy of this written clearance to the Project Director, prior to participation. This procedure is in compliance with policies formulated by the American College of Sports Medicine.<sup>1</sup>

**PROJECT OUTLINE:** There is no cost to you (the participant) and participation in this research project is voluntary. If you agree to participate you will be asked to make three separate visits to the Movement Science / Human Performance Lab at Montana State University – Bozeman. All 3 visits, lasting about 1 hour each, will occur at a similar time of day ( $\pm$  2 hours) and within 10 days of your first visit ( $\geq$  24 hours between visits). Before arriving to the lab you should refrain from all forms of exercise for at least 24 hours. Also, you should refrain from ingesting any foods, drinks (with the exception of

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<sup>1</sup> American College of Sports Medicine (2010). *ACSM's Guidelines for Exercise Testing and Prescription* (8<sup>th</sup> Edition). Williams & Wilkins, Philadelphia, PA.

plain water), or medications, both prescription and over the counter medications, for at least 2 hours. With the purpose of increasing the project's reliability, it is asked that the last item you eat or drink prior to coming to the lab will be a standard food substance (for example, an energy bar), provided by the Project Director. You are asked to consume this food substance at least 2 hours before your lab visit. Water will be allowed prior to and during the testing visits as desired. If any food, drink (other than water), or medication (including cold or allergy medication) is taken within the 2 hours prior to your test visit, please inform the Project Director BEFORE any testing begins and we will gladly reschedule your visit. If you use a rescue inhaler to treat asthma, make certain to bring the inhaler with you to the lab. You should arrive at the lab ready to engage in high intensity exercise. Therefore, you should dress (lightweight exercise clothing suitable for roller skiing), eat, and drink fluids appropriately for the occasion.

Each visit to the lab will involve the completion of a roller skiing submaximal lactate threshold (LT) protocol at one of three treadmill grades ( $2^\circ = 3.5\%$ ,  $3^\circ = 5.2\%$ , and  $4^\circ = 7.0\%$ ). The primary purpose of the roller skiing protocol is to measure your  $\text{VO}_2$  at different treadmill speeds for each treadmill grade. This will allow the calculation of a line relating power demand to  $\text{VO}_2$  cost.

After measuring body height and weight, you will be allowed to warm-up roller skiing on the treadmill at  $2^\circ$  (3.5%) and at a self-selected speed for 10 minutes before starting the submaximal LT protocol. The test itself will start out easy and will gradually increase in difficulty with each stage as the treadmill speed is increased. Each stage will involve four minutes of roller skiing using the V2 technique followed by one minute of rest. During each one-minute rest, a fingertip blood sample will be collected from the left hand with the purpose of analyzing your blood lactate concentration. This procedure involves a prick at the end of the finger with a sterile lancet to produce a small droplet of blood that is then absorbed onto a blood lactate test strip. The finger is then wrapped with a bandage and the next stage begins. You will continue to progress to each additional stage until the Project Director observes a significant spike in blood lactate, which means that you have crossed lactate threshold. Once this happens, the submaximal LT protocol will be terminated and you will begin a 5-10 minute active recovery by roller skiing on the treadmill at  $2^\circ$  and 1.8 m/s (4 mph). These protocols typically last 3-5 stages for a total of 15-25 minutes.

For the duration of the submaximal LT protocol you will be breathing through a facemask and wearing a small backpack holding a portable metabolic system (< 5 kg) so that the amount of oxygen you are using can be measured. At the same time, you will be wearing a heart rate monitor strap around your chest to measure heart rate via telemetry. Finally, to increase safety you will be wearing a climbing harness that attaches to an overhead suspension system to catch you in the event of a fall while roller skiing.

During the submaximal LT protocol, video recordings of you will be taken for analytical purposes. These videos will not be shared in any form. Also, you will have the option of

allowing photographs to be taken of you during testing. If photographs are allowed, they may be shared during professional presentations of the research project.

**POTENTIAL RISKS:** You should be aware that submaximal LT tests may cause fatigue immediately after the tests and possibly during the next day. Treadmill testing protocols also involve a chance of precipitating a cardiac event (such as abnormal heart rhythms) or even death. However, the possibility of such an occurrence is very slight (less than 1 in 10,000). These statistics are for maximal treadmill tests and since you are participating in a submaximal test, these risks are even lower. Also, the risks are low since 1) you are in good physical condition with no known symptoms of heart disease and 2) the test will be administered by trained personnel (licensed health care professional) familiar with the lab's emergency action plan. These risks are certainly no greater than those experienced by trained athletes in actual race competition. The measuring and safety devices (facemask, heart rate monitor, and climbing harness) may feel somewhat restricting and/or uncomfortable during testing, but all possible adjustments will be made to achieve the greatest comfort for you.

Approximately 3-5 drops of blood will be removed by fingertip sampling. This is a standard method used to obtain blood for routine hospital laboratory tests. You will experience pain when a sterile lancet goes into your finger. Other than momentary pain, the discomfort of the finger prick should be minimal. However, in about 10% of cases a small amount of bleeding under the skin will produce a bruise (hematoma). A small scar may persist for several weeks. The risk of local infection is less than 1 in 1,000.

All possible precautions will be taken to ensure your safety and make you feel comfortable before any testing takes place.

**SUBJECT COMPENSATION:** You will receive a copy of your LT test results directly. There are no other forms of compensation available for participating in this project.

**BENEFITS:** There are no direct benefits to you as a volunteer for this project. However, the Project Director, Bryant Reinking, is willing to discuss the interpretation of your own test results. You may contact Bryant Reinking by phone (970-389-6171) or E-mail ([bryantreinking@gmail.com](mailto:bryantreinking@gmail.com)) at any time to discuss this option further.

In regards to overall project benefits, the conclusions of this study will be used to investigate the reliability of the methodology used in previous studies to calculate the anaerobic capacity of Nordic skiers. This information will help determine if this technique is appropriate and reliable and can subsequently be used as a predictor of cross-country skiing performance, as was done by the previous studies.

**CONFIDENTIALITY:** The data and personal information obtained from this project will be regarded as privileged and confidential. Your test results will not be released to

anyone else except upon your written request/consent. Your right to privacy will be maintained in any ensuing analysis and/or presentation of the data by using coded identifications of each person's data.

**FREEDOM OF CONSENT:** You may withdraw consent for participation in writing, by telephone, or in person without prejudice or loss of benefits (as described above). Participation in this project is completely voluntary.

In the UNLIKELY event that your participation in the project results in physical injury to you, the Project Director will advise and assist you in receiving medical treatment. No compensation is available from Montana State University for injury, accidents, or expenses that may occur as a result of your participation in the project. Additionally, no compensation is available from Montana State University for injury, accidents, or expenses that may occur as a result of traveling to and from you appointments at the Movement Science / Human Performance Laboratory. Further information regarding medical treatment may be obtained by calling the Project Director, Bryant Reinking, at 970-389-6171 or the Lab Director, Dan Heil, at 406-994-6324. You are encouraged to express any questions, doubts, or concerns regarding this project. The Project Director will attempt to answer all questions to the best of his ability prior to any testing. The Project Director fully intends to conduct the study with your best interest, safety, and comfort in mind. If you have additional questions about the rights of human subjects you can contact the Chair of the Institutional Review Board, Mark Quinn, at 406-994-4707 or [mquinn@montana.edu](mailto:mquinn@montana.edu).

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PROJECT TITLE: Treadmill grade as a determinant of roller skiing oxygen consumption at a constant external power demand

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STATEMENT OF AUTHORIZATION

I have read the above and understand the discomforts, inconvenience, and risk of this study. I, \_\_\_\_\_ (*print your name*), agree to participate in this research. I understand that I may later refuse to participate, and that I may withdraw from the study at any time. I have received a copy of this consent form for my own records.

\_\_\_\_\_  
Signature of Participant

\_\_\_\_\_  
Date

\_\_\_\_\_  
Investigator

\_\_\_\_\_  
Date

Please initial one of the following:

I give permission for photographs to be taken of me during this project with the understanding that these photographs may be used in professional presentations.

I DO NOT give permission for photographs to be taken of me during this project.

APPENDIX B

HEALTH STATUS QUESTIONNAIRE

## Health History Questionnaire (HHQ) - Montana State University Movement Science / Human Performance Laboratory

### INSTRUCTIONS

Complete each of the following questions as accurately as possible by filling in the blanks or checking the most appropriate box. All information provided is confidential and no information will be released without your written consent.

Today's Date \_\_\_\_\_

### GENERAL INFORMATION

Mr.       Ms.       Miss  Mrs.       Dr.

Last Name \_\_\_\_\_ First Name \_\_\_\_\_

Mailing Address \_\_\_\_\_  
\_\_\_\_\_

Home Phone \_\_\_\_\_ Office Phone \_\_\_\_\_

Occupation \_\_\_\_\_

Employer \_\_\_\_\_

Person to Contact in Emergency:      Name \_\_\_\_\_

Relationship \_\_\_\_\_

Phone \_\_\_\_\_

▪ *Descriptive information:*

Gender:      Male       Female       Body Weight \_\_\_\_\_

Age \_\_\_\_\_ Date of Birth \_\_\_\_\_ Body Height \_\_\_\_\_

▪ *Why are you filling out this questionnaire?*

- You have volunteered for a research study or project.
- You are being screened for fitness testing in the Movement Science Lab.
- Other reason... \_\_\_\_\_

**MEDICAL HISTORY**

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Name of your physician \_\_\_\_\_

(Address/phone?) \_\_\_\_\_

▪ *Family History:*

*Did your father, or other first degree male relative (like a brother) die before the age of 55?*

No  Yes  If Yes, cause? \_\_\_\_\_

Age at death? \_\_\_\_\_

Which relative? \_\_\_\_\_

*Did your mother, or other first degree female relative (like a sister) die before the age of 65?*

No  Yes  If Yes, cause? \_\_\_\_\_

Age at death? \_\_\_\_\_

Which relative? \_\_\_\_\_

▪ *List any food or drug allergies:*

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

▪ *List any medication you are currently taking (non-prescription and prescription, including oral contraceptives). Please comment on the reason for each medication.*

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

▪ *Please describe any recent illnesses, hospitalizations, or surgical procedures:*

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

▪ Any of these health symptoms that occurs frequently (ranked as either a 4 or 5 below), either at rest or during physical exertion, is the basis for a prompt medical evaluation. Circle the number indicating how often you have each of the following:

	<b>0 = Never</b>	<b>1 = Practically never</b>	<b>2 = Infrequently</b>	<b>3 = Sometimes</b>	<b>4 = Fairly often</b>	<b>5 = Very often</b>
a. Coughing up blood.	0	1	2	3	4	5
b. Abdominal pain.	0	1	2	3	4	5
c. Low-back pain.	0	1	2	3	4	5
d. Chest pain.	0	1	2	3	4	5
e. Neck, jaw, arm, or shoulder pain.	0	1	2	3	4	5
f. Leg pain.	0	1	2	3	4	5
g. Swollen joints, especially the ankles.	0	1	2	3	4	5
h. Feel faint.	0	1	2	3	4	5
i. Feeling of dizziness.	0	1	2	3	4	5
j. Breathless with slight exertion.	0	1	2	3	4	5
k. Palpitation or fast heart rate.	0	1	2	3	4	5
l. Unusual fatigue with normal activity.	0	1	2	3	4	5
m. Abnormal/labored breathing at night.	0	1	2	3	4	5

For any score of "4" or higher, use the space below to explain the frequency and the conditions under which you experience that particular symptom:

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· Please indicate which of the following for which **you have been diagnosed or treated** by a physician or health professional. Please be as complete as possible.

Check if "Yes"                      If "Yes", please comment further...

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- Alcoholism \_\_\_\_\_
- Anemia, sickle cell \_\_\_\_\_
- Anemia, other \_\_\_\_\_
- Asthma \_\_\_\_\_
- Back strain \_\_\_\_\_
- Blood pressure - High? \_\_\_\_\_  
Low? \_\_\_\_\_
- Bronchitis \_\_\_\_\_
- Cancer \_\_\_\_\_
- Cirrhosis, liver \_\_\_\_\_
- Cholesterol - High? \_\_\_\_\_
- Concussion \_\_\_\_\_
- Congenital defect \_\_\_\_\_
- Diabetes Type? \_\_\_\_\_
- Emphysema \_\_\_\_\_
- Epilepsy \_\_\_\_\_
- Eye problems \_\_\_\_\_
- Gout \_\_\_\_\_
- Hearing loss \_\_\_\_\_
- Heart problems \_\_\_\_\_
- Hypoglycemia \_\_\_\_\_
- Hyperlipidemia \_\_\_\_\_
- Infectious mononucleosis \_\_\_\_\_
- Kidney problems \_\_\_\_\_
- Menstrual irregularities \_\_\_\_\_
- Mental illness \_\_\_\_\_
- Neck strain \_\_\_\_\_
- Obesity \_\_\_\_\_
- Phlebitis \_\_\_\_\_
- Rheumatoid arthritis \_\_\_\_\_
- Stroke \_\_\_\_\_
- Thyroid problems \_\_\_\_\_
- Ulcer \_\_\_\_\_
- Other \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

### BLOOD CHEMISTRY PROFILE

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- Have you ever had a fasting blood sample analyzed for cholesterol?  Yes  No

If "Yes", when was last time your blood was analyzed? \_\_\_\_\_

If "Yes", please provide as much detail as possible with regard to the specific blood components requested below (most recent test results only). Ideally, we would like both the numerical value of the test result AND the units of the measurement (the units are typically reported along with the numerical value of the test result).

· Total serum cholesterol	_____	units? _____
· HDL (high density lipoprotein)	_____	units? _____
· LDL (low density lipoprotein)	_____	units? _____
· VLDL (very low density lipoprotein)	_____	units? _____
· Triglycerides	_____	units? _____
· Blood glucose	_____	units? _____
· Hemoglobin	_____	units? _____
· Hematocrit	_____	units? _____
· Iron	_____	units? _____

### HEALTH-RELATED BEHAVIORS

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- Do you now smoke?  Yes  Infrequently  No

If "Yes" or "Infrequently", indicate the number smoked per day (on average):

Cigarettes:      40 or more                      20-39                      10-19                      1-9

Cigars/pipes - describe: \_\_\_\_\_

- Have you recently quit smoking?  Yes  No

If “Yes”, how long ago did you quit? \_\_\_\_\_ years \_\_\_\_\_ months

- Do you currently work in an environment where smoking is allowed?

Yes  No

If “Yes”, where do you work AND how frequently do you work in this environment?

- Do you drink alcoholic beverages on a regular basis?  Yes  No  
(ie. at least once/week)

If “Yes”, please answer the following:

1) How frequently do you drink?

2) What alcoholic beverages do you typically consume?

- Have you **exercised** regularly in the past 4 weeks?  Yes  No

If “Yes”, describe in terms of frequency, duration, intensity, and type of exercise:

- Do you consider yourself **physically active** due to work-related demands, home or farm chores, etc.?

Yes  No

If “Yes”, describe in terms of frequency, duration, intensity, and type of exercise:

- Please describe anything not already described on this questionnaire that might cause you problems during exercise (use the space below).

- Are there any other health-related problems or concerns NOT addressed on this questionnaire that we should know about?

Yes  No

If “Yes”, please describe: