

DETERMINANTS OF SKATE SPRINT CROSS-COUNTRY SKIING
PERFORMANCE FOR JUNIOR AND COLLEGIATE SKIERS

by

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ABSTRACT

Although previous research has established some correlates of sprint cross-country ski performance, it has not been determined which tests are the best determinants of sprint performance. There may be other tests or combinations of both lab- and field-based tests that are better able to determine sprint performance. **PURPOSE:** To investigate correlational relationships between a battery of test variables as predictors of skate roller skiing sprint performance in male and female junior and collegiate Nordic skiers. **METHODS:** Eleven female (Mean $\pm$ SD; Age (yrs): 19 $\pm$ 2; Height (cm): 167.6 $\pm$ 5.5; Body Mass (kg): 64.9 $\pm$ 7.0; Relative VO_{2MAX} (ml/kg/min): 56.9 $\pm$ 3.3) and nine male (Age (yrs): 18 $\pm$ 1; Height (cm): 180.1 $\pm$ 6.6; Body Mass (kg): 69.9 $\pm$ 2.2; Relative VO_{2MAX} (ml/kg/min): 70.6 $\pm$ 4.8) competitive junior and collegiate skiers performed several lab tests including a maximal ski-striding treadmill test to exhaustion (VO_{2MAX}, lactate threshold, TTE). Additional lab tests included upper body power (UBP) tests of 10 and 60 seconds, and lower body power (LBP) tests using a timing pad (1-jump, 4-jump, 60-jump vertical jump tests). Field-based roller skiing tests (40 m flying sprint, and 400 m sprint on a 200 m indoor track) were also completed. Skiers then performed a 1200 m skate roller ski sprint time trial on the indoor track. Pearson-Product Moment correlations assessed the linear relationship between all lab- and field-based variables and average race speed (m/sec) for time trial variables. Correlations were evaluated for both statistical significance ($\alpha = 0.01$) and practical meaningfulness ($r \geq 0.60$). **RESULTS:** Treadmill variables correlated moderate to high with skate roller skiing sprint speed ($r = 0.78 - 0.80$) as did the indoor skate roller ski testing ($r = 0.74 - 0.78$). Recovery parameters of blood lactate measured 3 minutes post trials correlated moderately ($r = 0.59 - 0.78$) as well as both the UBP 10- and 60- second tests and the jump height variables of the vertical jump testing ($r = 0.63 - 0.68$ and $r = 0.59 - 0.71$). **CONCLUSION:** The correlations between the lab- and field-based tests and skate roller skiing sprint speed indicated that it is important to assess multiple testing methods with a variety of test durations to best determine skate sprint skiing performance.

CHAPTER ONE

INTRODUCTION

Introduction

Bjorn Daehlie, generally considered one of the best cross-country skiers of all time, is noted for his success at the Winter Olympics (earning eight Olympic gold medals and four silver), World Championships (17 medals, 9 being gold), and World Cups (46 victories), as well as having one of the highest maximal oxygen uptake ($\text{VO}_{2\text{MAX}}$) values ever recorded ($96.0 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$). Daehlie's remarkable accomplishments have inspired athletes to dream of racing fast and winning. This elite level of endurance performance also stimulates curiosity in researchers of the physiological characteristics that elite athletes possess which allow them to race fast and become world class athletes.

The interest in understanding top endurance performances has led researchers to create models for endurance performance based on understanding the determinants of physiological power supply (use of aerobic and anaerobic energy systems) and external power demands (external resistances). Physiologists have primarily focused on understanding the physiological power supply side of the model which commonly includes three main components: 1) maximum oxygen uptake ($\text{VO}_{2\text{MAX}}$), 2) VO_2 at lactate threshold, and 3) economy of movement (the rate of energy expenditure to perform a certain task). Additional contributing factors related to performance (such as cardiac output, motor-unit recruitment, muscle fiber type, joint flexibility, muscular

strength and power, etc.) are incorporated into the model through an association with one or more of these three components (Olds, Norton, Craig, Olive, & Lowe, 1995; Pate & Branch, 1992). To produce top performances, it is important for athletes and coaches to understand these variables as well as how improvements in performance develop.

The question of which physiological parameters predict endurance performance is different for each sport, although the foundations of $\text{VO}_{2\text{MAX}}$, VO_2 at lactate threshold, and economy of movement remain similar. Determining predictors of endurance performance within sports such as running and cycling have been possible due to the feasibility of laboratory testing. However, cross-country skiing has provided a greater challenge than other endurance sports because of the difficulty in replicating the sport in a laboratory setting.

Determinants of Endurance Performance in Cross-Country Skiers

Traditional or “classic” cross-country skiing includes four techniques: diagonal stride, double pole, kick double pole, and herring bone. These techniques use a combination of poling and striding with the skis parallel in tracks set within the snow. In the 1980s, “skate” skiing was introduced where the skis are pointed outward in the shape of a V, and the skier transfers weight laterally to each ski, one at a time, while planting both poles simultaneously. Modern skate skiing commonly includes three techniques: V1, V2, and V2-alternate, all of which incorporate different timing of leg pushes and pole plants (Saltin, 1997).

With both styles of skiing (skate and classic), different techniques are used to suit the terrain which allows for higher speeds through improved economy and better use of upper body strength and endurance (Saltin, 1997). Historically, it has been challenging to develop a single test that can predict endurance performance for all styles of skiing. However, with the introduction of over-size roller ski treadmills and upper body ergometry, researchers have been able to successfully predict both skate and classic on-snow skiing performance through treadmill running, treadmill roller skiing, and ski-specific laboratory testing (Alsobrook & Heil, 2009; Gaskill, Serfass, & Rundell, 1999; Heil, Engen, & Higginson, 2004; Larsson, Olofsson, Jakobsson, Burlin, & Henriksson-Larsén, 2002; Mahood, Kenefick, Kertzer, & Quinn, 2001; Staib, Im, Caldwell, & Rundell, 2000; Vergés, Flore, Laplaud, Guinot, & Favre-Juvin, 2006; Wisløff & Helgerud, 1998). Moreover, Larsson, Olofsson, Jakobsson, Burlin, and Henriksson-Larsén (2002) suggested that the most valuable data for predicting endurance performance is in the parameters of power from an upper-body exercise as well as both the ventilatory and lactate thresholds. For example, several studies have suggested that upper body power is the best predictor of both skate and classic roller skiing performance (Mahood et al., 2001; Stöggl, Lindinger, & Müller, 2006; Stöggl, Lindinger, & Müller, 2007a, b). Field-based tests of aerobic and anaerobic upper body power have also been shown to predict both skate and classic roller skiing and on-snow ski performances (Alsobrook & Heil, 2009; Gaskill et al., 1999; Heil et al., 2004; Mahood et al., 2001; Rundell & Bacharach, 1995; Staib et al., 2000; Stöggl et al., 2006; Stöggl et al., 2007a,

b). Therefore, upper body power is crucial to success within the sport of cross-country skiing.

Determinants of Sprint Performance in Cross-Country Skiers

Although sprint racing was introduced to the cross-country ski world in the 1990s, it was not included in racing events until the World Championships in 2001. Sprint racing entails a qualification race that is preceded by heats of races, each of which are typically between 1000 – 1800 m for men and 800 – 1400 m for women (Nordic Competition Guide, 2010). Qualification is performed similar to a time trial where the top 16 to 30 of the fastest skiers qualify for heats that are held one to three hours after qualification with four to six skiers in each heat. The fastest two skiers from each heat advance to the next heat with breaks of 20-25 minutes. The heats begin with quarterfinals, then semifinals, followed by two finals (B Final, places 6-12; and A Final, places 1-6) (Stöggl et al., 2007b).

Sprinting in cross-country skiing is very different than sprinting 100 m or 200 m on a running track because it requires use of energy systems similar to that of the 800 m to 1500 m track running events. The predominant energy system used in events lasting 3 to 15 seconds is the ATP-phosphocreatine (PCr) system, where energy is primarily being supplied by the PCr system. For running events lasting 10 – 75 seconds, the body's utilization of the PCr system decreases and the glycolytic system is relied on more heavily. When performance lasts longer than 2 minutes, the oxidative system is providing most of the energy through ATP generated from the combustion of

carbohydrates, fats and amino acids. Thus, while 100 and 200 m running sprint race performances primarily depend upon the PCr and glycolytic systems, a cross-country sprint race of $\geq 2:50$ minutes requires contributions from each energy system (PCr, glycolysis, and oxidative) (Wilmore, Costill, & Kennedy, 2008).

There is a growing amount of research that focuses specifically on predictors of sprint performance in cross-country skiing. Stöggl et al. (2006) have demonstrated that maximal double pole speed and 1000 m double pole tests can predict double poling sprint performance on roller skis. In a follow up study by Stöggl et al. (2007b), short-duration maximal speed testing was able to predict classic cross-country ski sprint performance and suggested that an increased cycle length and poling frequency led to faster performances. Sprint-like double poling technique that involves higher peak pole forces and a greater impulse of pole force has also been shown to be characteristic of faster skiers (Holmberg, Lindinger, Stöggl, Eitzlmair & Müller, 2005).

Although previous research has established some correlates of sprint cross-country ski performance, it has not been determined which tests are the best predictors of sprint performance. There may be other tests or combinations of both laboratory- and field- based tests that are better able to predict sprint performance. In addition, earlier studies have primarily focused on elite male athletes and classic skiing, while other ages, skiing abilities, skate skiing, and women have not been studied well. Therefore, there is a need to evaluate the relationship between laboratory- and field-based tests with skate cross-country skiing sprint performance in both junior and collegiate skiers of both genders. The study would be exploratory in nature to determine which variables correlate

significantly with cross-country sprint performance. This information could be helpful to coaches and athletes developing training programs for athletes specializing in sprint racing.

Statement of the Problem

The purpose of this study was to investigate correlational relationships between a battery of test variables as predictors of skate roller skiing sprint performance in male and female junior and collegiate Nordic skiers.

Hypothesis

All laboratory- and field-based independent variables will correlate significantly with sprint speed during skate roller skiing:

$$H_0: \rho_r = 0$$

$$H_A: |\rho_r| > 0$$

where ρ_r is the population average correlation between skate roller ski sprint speed (dependent variable) with the laboratory- and field- based independent variables.

Delimitations

1. The scope of this study was delimited to the population of experienced Nordic ski racers in Bozeman, MT.
2. The scope of this study was delimited to skate roller ski sprint performance.

3. The scope of this study was also delimited to the location and terrain of the course for the time trial speed.

Limitations

1. Poles used for the ski-striding protocol of VO_{2MAX} test were in increments of 5 cm from 125 to 160 cm in length. Therefore, some skiers may not have had the preferred length of ski pole to perform the test.
2. Many external factors such as road condition, individual roller-ski type/brand/speed of wheels, and sharpness of pole tips may affect sprint race performance. The current study lacked the methods to control such factors.

Assumptions

1. It was assumed that the roller-ski tests (flying sprint speed, 400 m sprint speed, and time trial speed) will be representative of sprint performance during on-snow skiing.
2. It was assumed that the measurements from each of the tests were representative of the subject's true speed, power output, and maximal effort during a sprint ski performance.
3. It was assumed that the subjects followed instructions, performed a maximal effort, and had no intent of using the test or performance as a training session for future trials of these performances.

Operational Definitions

Classic Skiing	The traditional style of cross-country skiing that incorporates striding while using poles (opposite hand, opposite leg). Skis are parallel to one another usually gliding in set tracks within the snow.
Cycle Length	A measurement of the time of each repetition of the skiing technique which is determined by dividing the speed of the skier by the poling frequency.
Double Poling	A poling technique used during both classic and skate cross-country skiing. During classic, it involves the use of the arms, shoulders, trunk and some leg muscles. While with skate, the poling phase is coordinated with leg pushes. Within both styles, both poles are planted simultaneously while the body compresses and places force on them.
Economy	The rate of energy expenditure (a measure of oxygen uptake) required to perform a given task.

Lactate Threshold (LT)	The point during exercise where blood lactate accumulates heavily with increased intensity. LT is commonly expressed in $\text{mmol}\cdot\text{L}^{-1}$ as a percentage of HR_{MAX} .
Maximal Oxygen Uptake ($\text{VO}_{2\text{MAX}}$)	The maximal rate of oxygen utilization by the working muscles of the body during exercise. It is usually expressed relative to body weight ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), but can also be represented as an absolute value ($\text{L}\cdot\text{min}^{-1}$).
Poling Frequency	The tempo or cadence of the cycle rate during the poling phase in all skiing techniques. Poling frequency is commonly reported as $\text{strokes}\cdot\text{min}^{-1}$.
Pole Forces	The force placed on the poles during the poling phase to move the body forward. This can be measured in the amount of force applied (peak force) or in the time it takes to apply the force (impulse of pole force).

Respiratory Exchange Ratio	The ratio of the volume of CO ₂ expired to the volume of O ₂ inhaled ($V\text{CO}_2 \cdot V\text{O}_2^{-1}$).
Roller Skiing	A type of dryland training for cross-country skiing. This method involves roller-skis which imitate the on-snow techniques of skiing. Skiers use similar poles, boots, and bindings as on-snow for this equipment.
Skate Skiing	A style of cross-country skiing in which the skis point outward in the shape of a V. The skier transfers weight laterally in a skate motion while utilizing poles that are planted in unison.
Upper Body Power (UBP)	A measurement of the amount of power by the upper body during a simulated double poling motion on an ergometer. This variable utilizes arms, shoulders, trunk, and some leg muscles for stabilization. It is represented as an absolute (Watts), or relative ($\text{Watts} \cdot \text{kg}^{-1}$) value.

Ventilatory Threshold (VT)	The point during intense exercise in which the ventilation rate increases disproportionately to the oxygen consumption ($\dot{V}CO_2$ exceeds $\dot{V}O_2$). VT is typically reported as a percentage of HR_{MAX} .
$\dot{V}O_2$ at Lactate Threshold	The volume of oxygen being consumed at the point of lactate threshold. It is measured to determine what percent of $\dot{V}O_2$ is being utilized at the lactate threshold which is related to race pace.
$\dot{V}O_2$ at Ventilatory Threshold	The volume of oxygen uptake at the point of the ventilatory threshold. This variable is used when discussing the percent of $\dot{V}O_2$ at the ventilatory threshold that is associated with race pace.

CHAPTER TWO

REVIEW OF THE LITERATURE

Introduction

Previous research on cross-country ski sprint performance has established various parameters that contribute to determining sprint performance. What has not been evaluated, however, are which tests are the best correlates of performance or what additional tests may also influence performance. Available literature regarding men and women is limited and does not consider athletes of varying ability.

Generalized Model of Endurance Performance

Previous researchers have developed models for endurance performance that are based primarily on understanding the contributions of two components: metabolic power supply and external power demands. Olds, Norton, Craig, Olive, and Lowe (1995), for example, described endurance performance as the power supply (use of aerobic and anaerobic energy systems) divided by the power demand (to overcome resistance). These researchers suggested that “optimal performance occurs when speed increases to the point where power demand exactly matches the power supply from both aerobic and anaerobic sources” (Olds et al. 1995, p. 29). Models for endurance performance have primarily focused on physiological power supply which includes three major components: 1) maximal oxygen uptake (VO_{2MAX}), 2) percent of VO_{2MAX} at lactate

threshold (LT), and 3) economy of movement. Other factors that contribute to performance (such as cardiac output, motor-unit recruitment, muscle fiber type, etc.) are part of the model through an association with one or more of these three major components (Coyle, 1995; Olds et al., 1995; Pate & Branch, 1992). Therefore, researchers have suggested this model for physiologists to understand the components of endurance performance.

Determinants of Endurance Performance

Historically, Hill, Long and Lupton (1923, 1924) were the first to describe the relationship between physiological markers (specifically $\text{VO}_{2\text{MAX}}$) and endurance performance. Although, maximal oxygen uptake had been considered the most important predictor of performance, Ferrell, Wilmore, Coyle, Billing and Costill (1979) addressed the impact of accumulation of lactic acid within the blood on distance running performance. Ferrell et al. (1979) studied the percent of slow twitch muscle fibers from the lateral head of the gastrocnemius, $\text{VO}_{2\text{MAX}}$, running economy, and the VO_2 and treadmill velocity that corresponded with the onset of plasma lactate accumulation (OPLA) in male distance runners. There were significant correlations between the VO_2 that corresponds to OPLA ($r = 0.91$) and of the treadmill velocity associated with OPLA ($r = 0.91$) with all distances of race performance (3.2, 9.7, 15, and 19.3 km). The authors concluded that runners set a race pace which allows the highest utilization of VO_2 that avoids the exponential rise in OPLA. Similarly, Hagberg and Coyle (1983) analyzed the influence of race walking velocity at lactate threshold and submaximal economy in

trained race walkers. The strong relationship between race walking velocity at LT during steady-state performance and race pace during performance ($r = 0.94$) predicted performance times within 0.6%. The researchers concluded that VO_2 at LT was significantly correlated with performance over 20 km ($r = 0.89$), which was similar to the findings by Ferrell et al. (1979). Researchers also concluded that submaximal economy correlated strongly with performance in race walkers ($r = 0.82$). Furthermore, Powers, Dodd, Deason, Byrd, and McKnight (1983) investigated the relationship between ventilatory threshold, running economy and distance running performance in male runners. The authors found that the combination of $\text{VO}_{2\text{MAX}}$ ($r = 0.38$), running economy ($r = 0.51$), and ventilatory threshold ($r = 0.94$) explained 89% of the variance in 10 km running performance. Contrary to Ferrell et al. (1979), Powers et al. (1983) postulated that the accumulation of blood lactate does not control ventilation rates and therefore, ventilatory threshold may not be considered the same as onset of blood lactate accumulation (OBLA). For these reasons, researchers should include variables of running economy and VO_2 at lactate threshold to determine performance from variables other than $\text{VO}_{2\text{MAX}}$.

Both OPLA and OBLA represent the accumulation of lactic acid in the blood which has been diffused by the hypoxic tissue. The difference in these variables is related to the content of the blood. In order to analyze plasma, the blood must be centrifuged to separate the plasma from the erythrocytes (red blood cells). Plasma lactate levels are generally higher than erythrocytes because of how the blood is diffused between compartments (i.e., tissue diffuses lactic acid to the plasma and then to

erythrocytes). For this reason, erythrocytes generally have lower levels of lactate present. In addition, blood lactate levels are generally lower than plasma levels due to the sampling of the blood. When analyzing “total” whole blood, the plasma lactate present is diluted from the erythrocyte lactate levels, which lowers the blood lactate value (Kruse & Carlson, 1990). There is a distinct difference between OPLA and OBLA, however, it is common that OBLA is used for feasibility of testing and a quick analysis.

Research by Coyle (1995) proposed that submaximal VO_2 at LT is the most important determinant of energy expenditure during endurance performance. In a study of a group of cyclists with homogeneous $\text{VO}_{2\text{MAX}}$ values, Coyle (1995) determined that the performance time associated with a VO_2 value was due to LT at VO_2 instead of $\text{VO}_{2\text{MAX}}$. The authors suggested further research to determine which factors can increase LT at VO_2 and therefore performance. This was an important concept considering that after 2-3 years of intense training, VO_2 at LT can be increased, whereas $\text{VO}_{2\text{MAX}}$ generally shows little or no change after several years of training (Coyle, 1995). The variable of VO_2 at LT is crucial to determining performance.

To help support research by Hill et al. (1923, 1924), and develop a deeper understanding of $\text{VO}_{2\text{MAX}}$, Bassett and Howley (2000) discussed the limitations of $\text{VO}_{2\text{MAX}}$ as a determinant of endurance performance. These researchers suggest that the body is limited by the ability to deliver oxygen to the exercising muscles. Additional physiological factors that may limit $\text{VO}_{2\text{MAX}}$ include pulmonary diffusing capacity, maximal cardiac output, and characteristics of the skeletal muscle. Furthermore, the upper limit of energy production is determined by $\text{VO}_{2\text{MAX}}$, though it does not ultimately

determine endurance performance. In accordance with previous research, Bassett and Howley (2000) suggested that running speed at LT integrates all three variables (running economy, fractional utilization of $\text{VO}_{2\text{MAX}}$ and oxygen delivery) and is the best predictor of distance running performance. Similarly, Holmberg, Rosdahl and Svedenhag (2007) analyzed data from elite cross country skiers that further supports the notion that systemic oxygen delivery distinguishes an upper limit of VO_2 . Researchers determined that maximal ventilation was linearly related to $\text{VO}_{2\text{MAX}}$; however, vital capacity “levels off” when compared to less aerobically trained individuals. The authors also reported that elite cross-country skiers reach a higher $\text{VO}_{2\text{MAX}}$ when using both arm and leg exercise in comparison to running. This suggests that to reach a ski-specific $\text{VO}_{2\text{MAX}}$, it is important to use a testing modality that involves the upper and lower body when testing cross-country skiers. Based on the results from the $\text{VO}_{2\text{MAX}}$ test, researchers concluded that there is an upper limit of VO_2 that is controlled by the ability to deliver oxygen to the muscles.

In summary, researchers have suggested that metabolic power supply can be determined by three variables which include $\text{VO}_{2\text{MAX}}$, percent of $\text{VO}_{2\text{MAX}}$ at lactate threshold, and economy of movement. Of these three determinants, it has been proposed that VO_2 at lactate threshold may be the best predictor of endurance performance.

Determinants of Cross-Country Ski Performance

Determining endurance performance has been possible for the sports of running and cycling due to the feasibility of laboratory testing. However, replicating cross-

country skiing in a laboratory setting has been a greater challenge. With the introduction of over-size roller skiing treadmills and upper body ergometry, however, researchers are now able to study cross-country skiers using ski-specific tests. Mygind, Larsson and Klausen (1991), for example, reported a strong correlation ($r = -0.80$) between cross-country ski race results of elite skiers with double pole VO_{2peak} , while being unable to show a significant relationship between running performance and running VO_{2peak} . As seen in earlier studies of endurance performance, the ventilatory and lactate thresholds were important variables for predicting performance. Subsequently, to understand the true relationship between a treadmill running test and cross-country ski performance, measuring ventilatory and lactate thresholds during treadmill testing (running or roller skiing) is crucial (Larsson, Olofsson, Jakobsson, Burlin, & Henriksson-Larsén, 2002). Moreover, in order to understand the relationship between an upper body test and performance, these researchers suggested that it is ideal to measure muscular power and endurance of the upper body. The researchers concluded that measures of these variables are important and unique to the determination of performance within cross-country skiing and should be collected as part of laboratory testing for skiers (Larsson et al., 2002).

To establish accurate determinants of cross-country ski performance through both treadmill and upper body power testing, Rundell and Bacharach (1995) assessed the relationship between laboratory test results and biathlon (cross-country skiing and rifle marksmanship) race performance. With a subject pool of 21 biathletes, researchers measured blood lactate profiles, VO_{2peak} on a running treadmill, as well as lactate profiles and VO_{2peak} using a standing flywheel upper body arm ergometer to simulate the double

poling motion. A subgroup of male subjects also performed an on-snow 1 km uphill double pole time trial. The researchers concluded that there were potential gender differences in the sport of biathlon. Specifically, it was reported that males had strong correlations when comparing run time to exhaustion with race performance ($r = -0.84$). However, strong correlations for females were established between the variables of shooting performance and upper and lower body VO_{2peak} ($r = 0.95$ and $r = 0.81$, respectively). These conflicting results suggest that upper body training should be introduced specifically within the training plans of female biathletes. In addition, there is evidence that both upper and lower body aerobic and anaerobic power are vital for success within cross-country skiing.

Research by Gaskill, Serfass and Rundell (1999) showed that it is important for females, as well as a wide range of subgroups, to train the upper body for improved skiing performance. These researchers analyzed upper body power testing in both high school age and adult cross-country ski racers. The upper body ergometer was designed such that subjects pulled on hand cables to simulate the double poling motion. Upper body power tests lasted 3 to 6 minutes and correlated highly with skate cross-country ski race performances throughout the season ($r = 0.89$). Skiers should use upper body power tests as a testing and training tool of the musculature of the upper body in order to improve performance.

In order to extend the laboratory-based research to a field setting and identify correlates of performance through ski-specific testing, Mahood, Kenefick, Kertzer and Quinn (2001) studied 13 male collegiate skiers. Roller skiing tests of lactate threshold,

ski economy, skate $\text{VO}_{2\text{MAX}}$, and 1 km double pole time trial were performed and compared to on-snow competitive season performances as well as an on-snow 10 km skate time trial. Results indicated that the 1 km double pole time trial was the best indicator for both season performances and 10 km time trial time ($r = 0.77$ and $r = 0.79$, respectively). In accordance with previous studies, the researchers speculated that upper body power influences cross-country ski performance and suggested that an increased amount of upper body training could lead to improved performance. Including field-based testing along with laboratory-based testing would define more determinants of performance in cross-country skiers.

Consistent with the previous studies mentioned (Gaskill et al., 1999; Mahood et al., 2001; Rundell & Bacharach, 1995), Staib, Im, Caldwell and Rundell (2000) concluded that upper body power (UBP) is an essential component of cross-country ski performance. These researchers studied 20 top United States cross-country ski racers in order to determine the importance of double pole aerobic and double pole anaerobic power. For testing aerobic power, measurements of double pole roller ski $\text{VO}_{2\text{peak}}$ and double pole treadmill time to exhaustion were collected. In order to analyze anaerobic power, variables were recorded on an arm ergometer similar to Gaskill et al. (1999). The test of double pole $\text{VO}_{2\text{peak}}$ was considered the best predictor of cross-country ski performance with a correlation of -0.74 with International Ski Federation System (FIS) points for season performances. Furthermore, when correlating aerobic power tests and anaerobic power tests with FIS points, aerobic tests had a stronger correlation of -0.68.

This data implies that longer duration upper body testing is a better predictor of performance than short duration testing.

Contrary to Staib et al. (2000), Heil, Engen and Higginson (2004) analyzed short duration relative peak power output in junior skiers. Using a similar arm ergometer to Gaskill et al. (1999), Heil et al. (2004) modified the ergometer such that subjects pushed on actual ski poles rather than pulling on cables. Results indicated that a 5-second upper body power variable had a strong correlation ($r = 0.88$) with 5 km skate race performance. Heil et al. (2004) concluded that the amount of power produced in a short period of time can be influential to performance even if the skier cannot sustain the power output for several minutes.

Similarly, Rundell (1995) examined the physiological parameters required to roller ski on a treadmill at a speed similar to race pace and the contributions of these variables to race performance. Variables of peak upper body power were collected using a progressive double pole power test with a standing flywheel arm ergometer. These variables of peak upper body power strongly correlated ($r = -0.85$) with the time to complete a 15 km biathlon roller ski race (without shooting time). It was also concluded that variables of mechanical and muscular efficiency play a role in time to exhaustion as well as energy cost of roller skiing at race pace on a treadmill in biathletes, however, roller skiing treadmill testing can define determinants of performance.

Although several studies have shown the physiological determinants of upper body power to predict race performance, Holmberg, Lindinger, Stöggl, Eitzlmair and Müller (2005) developed a biomechanical analysis of the upper and lower body

movements during the double pole technique of cross-country skiing. Pole and ground reaction forces, joint angles, cycle characteristics and electromyography (EMG) of the upper and lower body muscles were analyzed during the double poling motion. Faster skiers were distinguished through higher angular elbow- and hip-flexion velocities, smaller minimum elbow and hip angles and higher peak pole forces. The top skiers also produced varying levels of EMG activity between the trunk, hip flexors, shoulders, elbow extensors and several lower body muscles. The differences in EMG activity throughout the body indicated that the double poling technique was found to recruit both the upper and lower body muscles to perform work. Thus, the use of upper body power during skiing requires the use of both upper and lower body musculature.

Much of the earlier upper body power testing studies used an arm ergometer that simulated the double pole motion of cross-country skiing. Holmberg and Nilsson (2008) addressed the reliability and validity of a new double poling ergometer. Researchers reported a correlation of 0.99 between the power at the flywheel and the power applied to the base of the poles, where power at the base of the poles was 50-70% higher than at the flywheel. High reliability was shown in a test-retest of two 60-second power output tests (coefficient of variation = 3.0%), and no significant difference in peak oxygen uptake in two 6-minute maximal tests (coefficient of variation = 2.4%). These researchers also suggested that there is a strong correlation with absolute and relative power output with on-snow ski performance ($r = 0.86$ and $r = 0.89$, respectively). Therefore, this type of double poling ergometer has high reliability and validity for measuring power output in cross-country skiers.

Even though upper body testing of both long and short durations have been studied, the relationship between an UBP test and longer classic ski race performance (involving many classic techniques) had not been assessed. Alsobrook and Heil (2009) measured short (≤ 60 s) and long (4-12 min) duration UBP tests on experienced skiers using a modified upper body ergometer with actual ski poles attached. Testing included highest average power output during both 10-second (UBP_{10}) and 60-second tests (UBP_{60}), as well as an incremental test to exhaustion for measurement of VO_{2peak} (UBP_{peak}). For the 10-second test, subjects were instructed to gradually increase the power output for 20 seconds before performing the last 10 seconds at maximal effort. The 60-second test started from a dead stop, where subjects poled maximally for 60 seconds. The VO_{2peak} test was an incremental test to exhaustion, where the test started at 30 Watts for women and 40 Watts for men and increased 15 and 20 Watts, respectively. The test continued until the subject could no longer remain at the required work rate for 5 seconds or more. Significant correlations of these UBP power output variables with a 10 km mass start classical race were all high (UBP_{10} , $r = 0.93$; UBP_{60} , $r = 0.92$; and UBP_{peak} , $r = 0.94$). The researchers speculated that both long and short duration UBP variables were important in prediction of mass start classic ski race performance.

In summary, cross-country ski performance can be predicted through tests of treadmill running, ski-specific tests of roller skiing, and upper body power.

Determinants of Sprint Cross-Country Ski Performance

There are a growing number of studies focusing on sprint performance within cross-country skiing. There has been an interest in developing a standardized test or series of tests to predict sprint performance. Therefore, Stöggl, Lindinger and Müller (2006) developed reliable and valid sprint-specific testing concepts with roller skis on a treadmill and in the field. The researchers tested the hypothesis that short duration maximal speed in double poling predicts double pole sprint performance in cross-country skiing. Testing variables of 50 m double pole sprint on an indoor track, double poling maximal speed on the treadmill, 1000 m double pole on the treadmill, and 1000 m double pole test on the road were collected using roller skis in a test and retest method. A total of 31 elite skiers from the Austrian, Slovakian and Swiss teams were included in the study. There were 17 skiers selected to perform all three tests to address validity, while another six performed an additional 1000 m double pole field test. The 50 m double pole sprint, maximal double pole speed, and 1000 m double pole tests were concluded to be reliable ($r = 0.78 - 0.99$). The 50 m double pole sprint was correlated with the maximal velocity of double poling ($r = 0.86$), and the 1000 m double pole field test correlated strongly with the 1000 m double pole treadmill test ($r = 0.96$). These correlations show that there was validity within all of the treadmill tests. The researchers noted that the physiological parameters such as peak blood lactate concentration and heart rate were unable to predict cross country skiing sprint performance. The authors concluded that the relationship between maximal double pole speed and double pole sprint race performance

suggested the use of short-duration sprint tests as a standardized test or series of tests to determine cross-country sprint performance. Therefore, the researchers recommended considering cross-country skiing specific speed training as a way to improve sprint ski performance.

Two follow up studies by Stöggl, Lindinger and Müller (2007a, 2007b) were performed to further analyze the physiological contributions of the cross-country ski sprint. These researchers were particularly interested in the influence of the upper body during sprint race performance. The first study (Stöggl et al., 2007a) was conducted in order to develop a reliable and valid upper body power and strength diagnostic test concept. A two phase test (2PT) was conducted on a roller board to simulate double poling technique. This test consisted of a 4-repetition trial and a 40-repetition trial to determine specific upper body power and explosive strength. Reliability was assessed through repeat testing as well as a 50 m double pole test, double pole maximal speed test and 1000 m double pole test on the treadmill. The authors found that peak values measured in the 4-repetition test contributed to 84% of variation in 50 m double pole sprint time and up to 61% of variation in 1000 m performance. The researchers concluded that the short lasting 2PT was reliable and valid. It was also suggested that the relationship between maximal power output and the sprint performances of 50 and 1000 m indicated a recommendation for increasing the proportion of upper body training for specific explosive strength and max power training (Stöggl et al., 2007a). Similar to endurance race performance, the upper body is an essential physiological component of sprint race performance.

The subsequent study by Stöggl et al. (2007b) was designed to analyze the physiological responses during a cross-country sprint competition simulated on a treadmill using classic roller skis. Once again, the study followed up on testing the hypothesis that short duration maximal speed in double poling and diagonal stride predicts sprint performance over a race distance using classical techniques. The 12 elite male skiers conducted a series of treadmill-based simulations of a sprint competition that included two maximal speed tests (double pole, and diagonal stride), a VO_{2MAX} test and three sprint heats during a 3.5 hour period. The maximal speed tests of double pole and diagonal stride techniques were to assess the short-duration maximal speed abilities of each skier. These tests involved a 30 second medium intensity stage followed by an increase in speed every five seconds until the skier was unable to maintain the front wheel of the roller ski at the front of the treadmill. The purpose was also to allow the athlete to simulate a couple warm-up sprints which were typically performed before race day sprints. Next, the sprint competition started with a VO_{2MAX} test (similar to the qualification heat). This heat was followed by three sprint heats taking place one hour after qualification. During each of the heats, the skiers raced on the treadmill for 1100 m. Researchers had designed a treadmill protocol that was set based on the classic World Cup sprint course in Stockholm, Sweden, including the uphill and downhill sections. Skiers were able to control the treadmill's speed based on their position on the treadmill which was monitored by sensors. Measurements of mean roller skiing velocity for each heat as well as heat times were recorded. The peak blood lactate, time to peak blood lactate, and end lactate (20 minutes post race) were recorded for each heat. Heart rate

and VO_2 variables were collected for each heat and during the $\text{VO}_{2\text{MAX}}$ test. Subjects were also video recorded during all tests for technique analysis. Researchers concluded that faster skiers had a long cycle length of the poling phase in all techniques where poling frequency remained similar. These results indicate a need to increase the focus of training on a quick impulse of force in the propulsion phase of each stride in order to maximize the cycle length of the poling phase. It was also concluded that faster skiers had greater muscular strength and power, consequently, allowing a more effective leg and pole motion in comparison to slower skiers. In order to predict performance in cross-country sprint race performance, “The combination of a high $\text{VO}_{2\text{MAX}}$ with the ability to produce high maximal skiing velocities should be the basis for success in the XC skiing sprint” (Stöggl et al., 2007b, p. 369). Skiers need a combination of aerobic capacity and the ability to recruit muscles for power and force production in order to succeed within sprint cross-country ski performance.

Summary

The ability to predict cross-country ski sprint race performance with a test, or a series of tests, has yet to be fully developed. Researchers agree that upper body power and short duration maximal tests are reliable and valid predictors of sprint performance. Additionally, $\text{VO}_{2\text{peak}}$ of ski specific testing has also been a significant contributor to performance. In order to further investigate various testing methods, the current study has been developed to investigate the relationship between a battery of test variables and

skate roller skiing sprint performance in male and female junior and collegiate Nordic skiers.

CHAPTER THREE

METHODOLOGY

Subjects

Twenty cross-country ski racers (men and women), ages 16 to 24 from Bozeman, MT, volunteered to participate in this study. Subjects were members of a Division I College Ski Team (Montana State University) and a local Nordic ski club (Bridger Ski Foundation). For participation, subjects had approval from their coach and were actively training to compete in the upcoming season. Participants read and signed an informed consent document approved by Montana State University's International Review Board (Appendix A) and completed a health screening protocol prior to the study. Subjects were also required to complete a questionnaire (Appendix B) to assess racing experience and hours of training for the current year. Variables analyzed from the training questionnaire include training hours and training years.

Procedures

Subjects were required to participate in four testing sessions. During the first session, subject demographics (age, height, weight), maximal oxygen uptake (VO_{2MAX}), and heart rate at lactate threshold (HR_{LT}) were determined. The second session consisted of two upper body power tests and three vertical jump tests. The upper body power tests measured double poling power output for 10 and 60 seconds, both of which have been

found to correlate highly with on-snow ski performance (Alsobrook & Heil, 2009).

Vertical jump tests were included to analyze the power contributions of the lower-body to ski sprinting performance. Session three included roller ski tests of flying sprint speed and a 400 m sprint speed, both of which were based on research by Stöggl, Lindinger, and Müller (2006, 2007a). Lastly, the fourth session was a sprint time trial performed on skate roller skis in the indoor track to mimic performance on snow. Time trial speed, the primary independent variable, was compared to all dependent variables from each of the previous testing sessions. Subjects were asked to train as usual following the training plan from their coach during the entire study. Subjects were asked to avoid strenuous training, as well as alcohol consumption within 24 hours prior to any lab visit. It was also asked that the subjects avoid caffeine consumption within 2-3 hours prior to each visit. All testing sessions were completed within a 4-6 week time period.

Session 1:

VO_{2MAX} Test: Variables of VO_{2MAX} were determined with a ski-striding treadmill protocol at the Movement Science Lab of Montana State University, Bozeman, MT.

Tests were performed on an oversized treadmill while measuring oxygen uptake (VO₂), heart rate (HR), and blood lactate (LA). After being fitted with a telemetry-based heart rate monitor, subjects were given five to ten minutes to warm-up at a self-selected pace on the treadmill. Subjects used ski poles with rubber tips to simulate the diagonal striding motion. This protocol emphasized the use of the upper body as well as the lower body by walking with long strides until the pace dictated hill-bounding. The test began

with a 6% grade at $99.24 \text{ m}\cdot\text{min}^{-1}$ (3.7 mph) and then increased by 2% and $8.05 \text{ m}\cdot\text{min}^{-1}$ (0.3 mph) each stage thereafter. The initial three to five stages were three minutes in duration with one minute of standing rest for blood sampling. During the one minute of standing rest, a technician collected a finger tip blood sample from which the blood lactate threshold was determined from an increase of $1.0 - 1.5 \text{ mmol}\cdot\text{L}^{-1}$ from the previous stage (Hagberg & Coyle, 1983; Hoffmann, Pokan, von Duvillard, Seibert, Zweiker, & Schmid, 1997; Mueller, Pokan, Primus, Hofmann, von Duvillard, Wonisch, Smekal, Bachl, & Schmid, 2008). After determination of the lactate threshold, stages were changed to 1-min each with the test ending at volitional exhaustion. A true maximal test was determined when subjects meet two out of the following three $\text{VO}_{2\text{MAX}}$ criteria: 1) Respiratory exchange ratio (RER) ≥ 1.10 ; 2) An increase in workload without an increase in oxygen consumption (VO_2 plateau) (change $< 2.5 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$); 3) A maximal heart rate (HR_{MAX}) ± 10 bpm of the subject's age predicted HR_{MAX} .

Session 2:

Upper Body Power Tests: After reporting to the Movement Science Lab, subjects were allowed five minutes to warm-up on the upper body double poling ergometer at a self-selected power output. The warm up was followed by about three minutes of rest prior to conducting three consecutive trials of the 10-second test. The flywheel resistance of the ergometer was set to 8 for males and 1 for females. Subjects were increased power output and poling cadence for the first 20 seconds before performing at maximal effort for the final 10 seconds. Subjects used the first trial as a warm-up (about 80% of maximal

effort) before giving maximal effort for the final two trials. A rest period of three minutes was allowed between each trial. The highest average power output achieved during the final 10 seconds of the last two trials was used as a variable of 10-second power output (UBP10, W). The poling frequency or cadence of the 10-second UBP test was recorded as well (UBP10-C, strokes·min⁻¹). Subjects were then allowed five minutes to recover before performing a single 60-second test (UBP60, W), where they gave maximal effort to produce the highest average power output over 60 seconds when starting from a dead stop (identical to Alsobrook & Heil, 2009).

Vertical Jump Tests: The vertical jump tests were performed 15 minutes after finishing the upper body power testing. Subjects warmed up through cycling or running at a very light intensity immediately prior to testing. Subjects performed a maximal 1-jump test, in which the subject jumped vertically one time starting in a standing position with thighs parallel with the floor and hands on hips. Subjects held this position for one to two seconds until the position had been reached and the researcher cued the subject to jump. Three trials of the 1-jump test were performed (the first was for practice at about 80% of maximal effort, second and third trials were maximal effort) with each jump recorded (1J-S, inches) and using the highest value for further analysis. The subject also performed three trials of the 1-jump test with a counter-movement protocol, recording each jump (1J-CM, inches) and using the highest value for further analysis. For the counter-movement, the subject started in a standing position with knees and hips extended and hands on hips (squatting down first with no pause at the bottom and then

jumping up), which allowed for greater muscle recruitment of the legs when compared with performing the standing one jump. Next, subjects performed a four consecutive jump test, during which the subject jumped as high and as quickly as possible four successive times. Subjects started by standing with knees and hips extended and were allowed to use an arm swing for the test. Two trials were held two minutes apart with the first being a practice and the last a maximal effort with variables of average jump height (4J-JH, inches), and explosive leg power factor (ELPF) (average air time $\cdot$ average ground contact time⁻¹; 4J-ELPF, dimensionless ratio). The third and final vertical jump test included one trial of 60 consecutive jumps with the same variables as the 4-jump test recorded with 2 measures of each variable (60J-JH, inches; 60J-ELPF, dimensionless ratio) as well as a ratio of the two ELPF measures (60J-Ratio, dimensionless ratio). For this last test, subjects started from a standing position with knees and hips extended and were allowed to swing their arms to maintain stability while jumping. During each vertical jump test, subjects were required to land on the timing pad following each jump, as well as remain standing on the pad after completion of the test, for the data to be recorded as valid. The purpose for each of these types of jump tests (1-jump, 4-jump and 60-jump) was to explore the contributions of lower-body power and endurance as the duration of jumps increased.

Session 3:

Flying Sprint Speed: The indoor track of the Field House at Montana State University, Bozeman, MT was used for session three. Subjects performed a warm-up on

the track for 20 minutes at a self-selected speed while skate roller skiing, followed immediately by 2-3 intervals of 10-15 seconds at about 90% of maximal effort. The purpose of these intervals was to familiarize the athlete with the track's surface at fast roller skiing speeds. The flying sprint speed test involved a "flying start" that allowed the athlete to build up speed around a corner on the track and then sprint maximally, using either the V2 alternate or V2 technique, along a 32 m straight away. Subjects completed three trials allowing adequate recovery between trials lasting no more than three minutes. Total time was recorded to roller ski 32 m and later converted to speed (Flying Sprint Speed, $\text{m}\cdot\text{s}^{-1}$). Sprinting cadence was also determined from the test of flying sprint speed (Spr-Cad, $\text{cycles}\cdot\text{min}^{-1}$).

400 m Sprint Speed: Following the flying sprint speed test, the subject roller skied easily around the indoor track for 10 minutes to recover and prepare for two trials of the 400 m, two-lap sprint, around the 200 m track. The subjects used a standing start and were given a 5-second count down, the standard protocol for starting a race, and then sprinted two laps around the track at maximal effort. Subjects performed this test while using combinations of V2 and V2 alternate skating technique. Recovery parameters of heart rate (HR) and blood lactate (LA) were collected at 3 and 5 minutes (HR-3, HR-5, LA-3, LA-5, respectively) post sprint finish and the total time of the 400 m sprint was recorded and converted to speed (400 m Trial 1 Speed and 400 m Trial 2 Speed, $\text{m}\cdot\text{s}^{-1}$). The subject was given 10 minutes between trials and performed each trial at maximal effort, where the fastest performance was used for subsequent analysis. During the

recovery phases of each trial, subjects were required to keep the body moving at minimal intensity to facilitate recovery.

Session 4:

Skate Sprint Speed: Subjects reported to the indoor track at Montana State University in Bozeman. The subject performed a 30-minute warm-up on the track that was followed immediately by race preparation (i.e., clothes, drink, and 10-15 second intervals at about 90% of maximal effort). Each subject raced six laps around the 200 m track for a total of 1200 m that lasted 2:30 to 3:30 minutes in duration using combinations of V2 and V2 alternate techniques. The format of this time trial allowed two skiers on the course simultaneously, staggered at the start, in order to use the two pair of testing roller skis. One trial was performed with the total time recorded and later converted to speed (Skate Sprint Speed, $\text{m}\cdot\text{s}^{-1}$).

Instrumentation

A JAS Trackmaster treadmill (Full Vision, Newton, KS, USA) was used for the $\text{VO}_{2\text{MAX}}$ tests. Oxygen uptake during the $\text{VO}_{2\text{MAX}}$ test was measured using a TrueMax 2400 Analyzer Module (Parvo Medics, Sandy, UT, USA). Subjects inhaled room air through a mouthpiece containing one-way valves while wearing a nose-clip where the breath was expired into the analyzer through a plastic hose. Certified gas mixtures were used to calibrate both the oxygen and carbon dioxide analyzers. Ventilation measurements were calibrated using a 3-liter syringe (Series 5530, Hans Rudolph, Inc.,

Kansas City, MO, USA). Variables of oxygen consumption were computed every 20-seconds. Heart rate was constantly monitored and every five seconds an average was recorded by a telemetry based heart rate monitor (Polar Electro, Inc., Lake Success, NY, USA). Blood lactate variables were analyzed by the use of a Lactate Pro analyzer and Lactate Pro test strips (Arkay Factory, Inc., Shiga, Japan).

A modified Concept 2 Model D rowing ergometer (Concept 2, Morrisville, VT, USA) was used for the tests of upper body power, the same as that described by Alsobrook and Heil (2009). The air-resisted flywheel was connected to an 8-foot-long square beam for the base of the ergometer. The ergometer had a platform for subjects to stand, which was attached where the flywheel met the front beam. A trolley ran along the beam and was mounted to the flywheel with a static cord to provide the resistance. Skiers pushed the trolley down the beam by using cross-country ski poles which were attached to the trolley to slide backward giving a power output in Watts. Poles were interchangeable, giving each athlete the preferred length. Poles were available within 5 cm increments, from 135 cm to 170 cm (Toko P232; Mammot Sports Group AG, Seon, Switzerland), with Infinity synthetic cork grips and Infinity Vise Straps (Zaverall Racing Equipment, Mt. Upton, NY, USA). A Just Jump timing pad (Probotics, Inc., Huntsville, AL) with dimensions 0.724 m^2 was used for evaluating all vertical jump tests including measurements of explosive leg power factor (ELPF, $\text{average air time} \cdot \text{average ground contact time}^{-1}$, dimensionless) and jump height (JH, inches).

A stopwatch and video camera were used to determine speed during the peak skate speed test. Time from the stopwatch was later converted to speed based on an

average of three trials when analyzing the video tape. During lab visits three and four, the same roller skiing equipment was used for each skier in order to control for variations in roller ski wheel resistance. Marwe roller skis (Hyvinkään Kumi Oy, Finland) were equipped with either a pilot (Salomon, France) or a Rotefella NNN (Garmont USA, Inc.) binding system for ski boot compatibility. The same poles were also used either from the lab (Swix Star CT1 100% UHM/HM carbon fiber shafts, Swix Sport AS, Lilehammer, Norway) or the athlete's own poles. A Rolatape® Professional Series (Spokane, WA, USA) measuring wheel was used for a measurement of track length of the indoor track surface. Stopwatches were used for the 400 m sprint speed test. All variables were gathered with the same instrumentation as the flying sprint speed test.

Statistical Analysis

All dependent variables (VO_{2MAX} , HR_{LT} , UBP10 W, UBP60 W, UBP60, 1J-S, 1J-CM, 4J-ELPF, 4J-JH, 60J-ELPF, 60J-JH, Flying Sprint Speed, 400 m Trial 1 Speed, 400 m Trial 2 Speed, LAT1-3, HRT1-3, LAT1-5, HRT1-5, LAT2-3, HRT2-3, LAT2-5, HRT2-5) were compared with speed from 1200 m time trial (Skate Sprint Speed) using Pearson product-moment correlations at an alpha level of 0.01 and Fischers Z-Transformations were used to calculate 95% confidence intervals (Statisticx 8.0; Analytical Software, Tallahassee, FL). Both gender and class (junior versus non-junior) were analyzed separately as well as all together to examine associations between the dependent variables and 1200 m time trial speed for different ages and skiing abilities of junior vs. collegiate skiers. Previous studies using cross-country skiers have determined

no significant relationships when analyzing different populations of skiers based on age and skiing ability (Alsobrook & Heil, 2009). Therefore, this study required at least 12 – 15 subjects total from all classes together (i.e., junior women, junior men, collegiate women, collegiate men). Following the procedures outlined by Cohen (1988), a sample size of at least 12 skiers was required to identify a correlation of 0.75 or more at a power of 0.80 and alpha of 0.01.

CHAPTER FOUR

RESULTS

The purpose of this study was to investigate correlational relationships between a battery of test variables and skate roller skiing sprint performance in male and female junior and collegiate Nordic skiers. Both laboratory-and field-based tests were performed, where laboratory tests included a maximal treadmill test, upper body power (UBP) tests, as well as several vertical jumping tests. A ski-striding maximal treadmill test was used to measure maximal oxygen uptake (VO_{2MAX}), time to exhaustion (TTE), HR at lactate threshold (HR_{LT}), and LT percentage (LT %). The 10- and 60-second UBP tests included measurements of average power output, as well as poling cadence during the 10-second test (UBP10, UBP60, UBP10-C, respectively). The last of the laboratory-based tests included four vertical jump tests: 1) 1-Jump-Squat (1J-S) and 2) 1-Jump-Counter-Movement (1J-CM) test, where jump height (JH) was measured; 3) 4-Jump test, including variables of JH and explosive leg power factor (ELPF); 4) 60-Jump test, which included 2 measures of JH and ELPF each as well as a ratio of the two ELPF variables. Field-based testing included measures of average speed for a flying sprint, a 400 m sprint, sprint poling cadence during the flying sprint, and average speed from a 1200 m skate time trial using roller skis on an indoor track. The two trials of the 400 m test also included measures of recovery heart rate and blood lactate at 3 and 5 minutes post sprint effort (HR3, LA3, HR5, LA5, respectively).

Twenty subjects (11 women and 9 men) volunteered for all the laboratory- and field-based tests. Summarized in Tables 1 and 2 are the subjects' body height, body mass, relative $\text{VO}_{2\text{MAX}}$, as well as self-reported training hours and training years.

Table 1. Subject demographics (Mean $\pm$ SD).

	N	Age (years)	Body Height (cm)	Body Mass (kg)	$\text{VO}_{2\text{MAX}}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)
Junior Women	2	18.0 ± 0.0	64.9 ± 3.5	57.2 ± 4.7	54.6 ± 2.0
Junior Men	3	17.0 ± 0.0	71.6 ± 3.6	68.9 ± 5.0	66.4 ± 3.6
Collegiate Women	9	19.8 ± 1.6	66.2 ± 2.0	66.6 ± 6.4	57.4 ± 3.4
Collegiate Men	6	18.8 ± 0.8	70.7 ± 2.3	70.4 ± 6.5	72.7 ± 3.9

$\text{VO}_{2\text{MAX}}$ = maximal rate of oxygen used relative to body mass from $\text{VO}_{2\text{MAX}}$ test.

Table 2. Subject demographics for self-reported training history (Mean $\pm$ SD).

	N	Training Hours (hours/year)	Training Years (years)
Junior Women	2	400.0 ± 141.4	5.5 ± 0.7
Junior Men	3	481.7 ± 71.1	6.3 ± 3.1
Collegiate Women	9	509.4 ± 77.8	6.0 ± 1.8
Collegiate Men	5	473.0 ± 123.1	7.0 ± 2.4

Note: Results include 19 of 20 subjects for training history due to a failure to complete the training background questionnaire. Training Hours = the number of self-reported hours the subject trained throughout the 2008-2009 season. Training Years = the number of self-reported years the subject trained for competition.

For descriptive purposes, the test variables were summarized by gender and age group (i.e., junior versus collegiate) for each type of laboratory testing in Tables 3 – 8.

Table 3. Results for ski-striding maximal treadmill test (Mean $\pm$ SD; n = 20).

Test Variable	VO _{2MAX} (ml·kg ⁻¹ ·min ⁻¹)	TTE (minutes)	HR _{LT} (bpm)	LT % (%)
Junior Women	54.6 $\pm$ 2.0	10.8 $\pm$ 0.2	189.0 $\pm$ 2.8	81.4 $\pm$ 0.0
Junior Men	66.4 $\pm$ 3.6	12.7 $\pm$ 0.6	188.7 $\pm$ 14.3	85.6 $\pm$ 5.4
Collegiate Women	57.4 $\pm$ 3.4	11.0 $\pm$ 0.8	179.9 $\pm$ 6.2	82.5 $\pm$ 5.6
Collegiate Men	72.7 $\pm$ 3.9	12.9 $\pm$ 0.6	175.7 $\pm$ 6.7	82.4 $\pm$ 4.3

Note: Results include 18 of 20 subjects for LT % due to telemetry heart rate malfunctions. VO_{2MAX} = maximal rate of oxygen used relative to body mass; TTE = time to exhaustion; HR_{LT} = heart rate at lactate threshold determined from VO_{2MAX} test; LT % = percentage of blood lactate threshold from VO_{2MAX} test (i.e., HR_{LT}/HR_{MAX}).

Table 4. Results for upper body power (UBP) testing (Mean $\pm$ SD; n = 20).

Test Variable	UBP10 (Watts)	UBP60 (Watts)	UBP10-C (strokes·min ⁻¹)
Junior Women	137.0 $\pm$ 24.0	109.0 $\pm$ 11.3	93.0 $\pm$ 4.2
Junior Men	324.0 $\pm$ 41.8	241.7 $\pm$ 30.6	88.0 $\pm$ 18.3
Collegiate Women	191.4 $\pm$ 32.9	146.4 $\pm$ 25.1	84.0 $\pm$ 14.4
Collegiate Men	305.8 $\pm$ 52.9	242.3 $\pm$ 30.1	76.0 $\pm$ 10.5

UBP10 = average power output from 10-second test; UB60 = average power output from 60-second test; UB10-C = poling cadence from 10-second test.

Table 5. Jump height results from vertical jump testing (Mean $\pm$ SD; n = 20).

Test Variable	1J-S JH (m)	1J-CM JH (m)	4J JH (m)	60J JH (m)	
Junior Women	0.39 $\pm$ 0.01	0.40 $\pm$ 0.02	0.40 $\pm$ 0.00	F15	0.32 $\pm$ 0.01
				L15	0.36 $\pm$ 0.02
Junior Men	0.58 $\pm$ 0.07	0.59 $\pm$ 0.08	0.54 $\pm$ 0.07	F15	0.40 $\pm$ 0.04
				L15	0.44 $\pm$ 0.05
Collegiate Women	0.43 $\pm$ 0.06	0.44 $\pm$ 0.06	0.44 $\pm$ 0.04	F15	0.32 $\pm$ 0.02
				L15	0.37 $\pm$ 0.03
Collegiate Men	0.53 $\pm$ 0.04	0.55 $\pm$ 0.05	0.52 $\pm$ 0.08	F15	0.41 $\pm$ 0.08
				L15	0.44 $\pm$ 0.07

1J-S = 1-Jump Squat Jump Height (or non counter-movement); 1J-CM = 1-Jump Counter-Movement Jump Height; 4J-JH = 4-Jump Jump Height; 60J-JH = 60-Jump Jump Height (includes 2 measures- measure 1 is the average JH from the first 15 jumps (F15); measure 2 is the average JH from the last 15 jumps (L15)).

Table 6. Explosive leg power factor (ELPF) results from vertical jump testing (Mean $\pm$ SD; n = 20).

Test Variable	4J ELPF (dimensionless)	60J ELPF-Ratio (dimensionless)	60J ELPF (dimensionless)	
Junior Women	1.6 $\pm$ 0.1	1.1 $\pm$ 0.1	F15	1.7 $\pm$ 0.0
			L15	1.6 $\pm$ 0.1
Junior Men	1.7 $\pm$ 0.6	1.1 $\pm$ 0.1	F15	2.1 $\pm$ 0.1
			L15	2.0 $\pm$ 0.1
Collegiate Women	1.7 $\pm$ 0.4	1.0 $\pm$ 0.1	F15	1.8 $\pm$ 0.3
			L15	1.9 $\pm$ 0.3
Collegiate Men	1.9 $\pm$ 0.4	1.0 $\pm$ 0.1	F15	2.0 $\pm$ 0.3
			L15	1.9 $\pm$ 0.3

60J-ELPF Ratio = ratio of ELPF measures 1 and 2 from the 60J test. 60J-ELPF = includes 2 measures- measure 1 is the ELPF from the first 15 jumps (F15); measure 2 is the ELPF from the last 15 jumps (L15).

Table 7. Roller skiing sprint speed results (Mean $\pm$ SD; n = 20).

Test Variable	Flying Sprint Speed (m·s ⁻¹)	Flying Sprint Poling Cadence (cycles·min ⁻¹)	400 m T1 Speed (m·s ⁻¹)	400 m T2 Speed (m·s ⁻¹)	1200 m TT Speed (m·s ⁻¹)
Junior Women	7.1 $\pm$ 0.3	206 $\pm$ 8	6.2 $\pm$ 0.0	6.2 $\pm$ 0.0	6.1 $\pm$ 0.1
Junior Men	8.9 $\pm$ 0.4	199 $\pm$ 30	7.5 $\pm$ 0.4	7.4 $\pm$ 0.5	6.9 $\pm$ 0.1
Collegiate Women	7.8 $\pm$ 0.4	186 $\pm$ 27	6.5 $\pm$ 0.4	6.4 $\pm$ 0.3	6.2 $\pm$ 0.2
Collegiate Men	9.2 $\pm$ 0.6	164 $\pm$ 20	7.7 $\pm$ 0.4	7.7 $\pm$ 0.5	7.6 $\pm$ 0.9

Flying Sprint = average speed of flying sprint; Flying Sprint Poling Cadence = sprint poling cadence from flying sprint; 400 m Trial 1 and 400 m Trial 2 = average speeds from 400 m testing; 1200 m TT = average speed from 1200 m Time Trial.

Table 8. Recovery variables from 400 m roller ski sprint (Mean $\pm$ SD; n = 20).

Test Variable	Trial	LA-3 (mmol·L ⁻¹)	HR-3 (bpm)	LA-5 (mmol·L ⁻¹)	HR-5 (bpm)
Junior Women	1	6.3 $\pm$ 0.9	129 $\pm$ 16	6.0 $\pm$ 0.9	106 $\pm$ 6
	2	6.6 $\pm$ 0.6	129 $\pm$ 9	6.5 $\pm$ 2.0	104 $\pm$ 8
Junior Men	1	10.8 $\pm$ 1.4	126 $\pm$ 5	10.3 $\pm$ 2.5	108 $\pm$ 3
	2	12.0 $\pm$ 2.1	129 $\pm$ 10	13.7 $\pm$ 4.1	112 $\pm$ 3
Collegiate Women	1	8.1 $\pm$ 1.4	120 $\pm$ 8	7.5 $\pm$ 1.8	98 $\pm$ 9
	2	8.4 $\pm$ 1.6	119 $\pm$ 12	8.0 $\pm$ 1.7	101 $\pm$ 6
Collegiate Men	1	11.4 $\pm$ 1.3	119 $\pm$ 15	9.8 $\pm$ 1.2	101 $\pm$ 15
	2	12.9 $\pm$ 1.7	124 $\pm$ 12	12.9 $\pm$ 2.6	103 $\pm$ 11

LA-3 = blood lactate at 3 minutes post; HR-3 = heart rate at 3 minutes post; LA-5 = blood lactate at 5 minutes post; HR-5 = heart rate at 5 minutes post.

Pearson correlation coefficients for the relationships between laboratory-based variables and 1200 m skate sprint speed are listed in Tables 9 – 11 followed by a summary of UBP, training history and sprint cadence correlations. Preceding these analyses, however, were two different subgroup analyses: subgroups by gender and class (i.e., juniors versus collegiate skiers), and a subgroup analysis based upon a clustering of data. For the first subgroup analysis, dummy variables were used to determine if gender

and/or class contributed significantly to the correlations between variables and skate sprint speed. Neither gender nor class contributed significantly, which suggests that neither variable was significantly related to 1200 m skate sprint speed. Since each demographic group was relatively small (i.e., men versus women, or junior versus collegiate skiers) further analyses by gender or class were not performed.

The second subgroup analysis was based on the observation that the five fastest 1200 m sprinters (four male collegiate, one male junior) formed a cluster when viewing scatter plots of the correlations. For example, Figure 1 shows a cluster of five skiers as outliers to the upper right of the graph. Therefore, the correlations were re-evaluated with these subjects excluded. Tables 9 – 11 show correlation coefficients for the relationships between each laboratory-based variable and average 1200 m time trial speed for the resulting cluster (five outliers excluded). Given the exploratory nature of these analyses, the sub-group correlations were evaluated the 0.05 α -level rather than the 0.01 α -level.

Table 9. Correlation coefficients between ski-striding maximal treadmill test variables and 1200 m skate sprint speed with 95% confidence intervals (in parentheses) and P-values. Analyses provided for all subjects (n = 20), as well as sub-group (n = 15).

Test Variable	VO _{2MAX} (ml·kg ⁻¹ ·min ⁻¹)	TTE (minutes)	HR _{LT} (bpm)	LT % (%)
Skate TT				
All Subjects	0.80 * (0.56 – 0.92) P < 0.001	0.78 * (0.51 – 0.91) P < 0.001	-0.56 * (-0.81 - -0.16) P = 0.010	0.17 (-0.29 – 0.57) P = 0.491
Sub-Group	0.66 * (0.30 – 0.85) P = 0.008	0.63 * (0.26 – 0.84) P = 0.012	-0.07 (-0.49 – 0.39) P = 0.819	0.10 (-0.36 – 0.52) P = 0.751

* Indicates significant correlations.

VO_{2MAX} = maximal rate of oxygen used relative to body mass; TTE = time to exhaustion; HR_{LT} = heart rate at lactate threshold determined from VO_{2MAX} test; LT % = percentage of blood lactate threshold from VO_{2MAX} test (i.e., HR_{LT}/HR_{MAX}).

Table 10. Correlation coefficients between vertical jump height variables and 1200 m skate sprint speed with 95% confidence intervals (in parentheses) and P-values. Analyses provided for all subjects (n = 20), as well as sub-group (n = 15).

Test Variable	1J-S JH (m)	1J-CM JH (m)	4J JH (m)		60J JH (m)
Skate TT					
All Subjects	0.59 *	0.62 *	0.62 *	F15	0.63 *
	(0.19 – 0.82) P = 0.007	(0.24 – 0.83) P = 0.004	(0.24 – 0.83) P = 0.004		(0.26 – 0.84) P = 0.003
				L15	0.71 * (0.40 – 0.88) P < 0.001
Sub-Group	0.12 (-0.34 – 0.53) P = 0.672	0.05 (-0.40 – 0.48) P = 0.860	-0.02 (-0.45 – 0.43) P = 0.959	F15	0.06 (-0.39 – 0.49) P = 0.828
				L15	-0.09 (-0.51 – 0.37) P = 0.746

* Indicates significant correlations.

1J-S = 1-Jump Squat Jump Height (or non counter-movement); 1J-CM = 1-Jump Counter-Movement Jump Height; 4J-JH = 4-Jump Jump Height; 60J-JH = 60-Jump Jump Height (includes 2 measures- measure 1 is the average JH from the first 15 jumps (F15); measure 2 is the average JH from the last 15 jumps (L15)).

Table 11. Correlation coefficients between vertical jump explosive leg power factor variables and 1200 m skate sprint speed with 95% confidence intervals (in parentheses) and P-values. Analyses provided for all subjects (n = 20), as well as sub-group (n = 15).

Test Variable	4J ELPF	60J ELPF-F15	60J ELPF-L15	60J ELPF Ratio
Skate TT				
All Subjects	0.42 (-0.03 – 0.73) P = 0.064	0.36 (-0.10 – 0.69) P = 0.122	0.39 (-0.07 – 0.71) P = 0.093	-0.10 (-0.52 – 0.36) P = 0.687
Sub-Group	-0.20 (-0.59 – 0.27) P = 0.474	0.21 (-0.26 – 0.60) P = 0.461	0.13 (-0.33 – 0.54) P = 0.641	0.06 (-0.39 – 0.49) P = 0.827

60J-ELPF = includes 2 measures- measure 1 is the ELPF from the first 15 jumps (F15); measure 2 is the ELPF from the last 15 jumps (L15); 60J-ELPF Ratio = ratio of ELPF measures 1 and 2 from the 60J test. All measures are dimensionless.

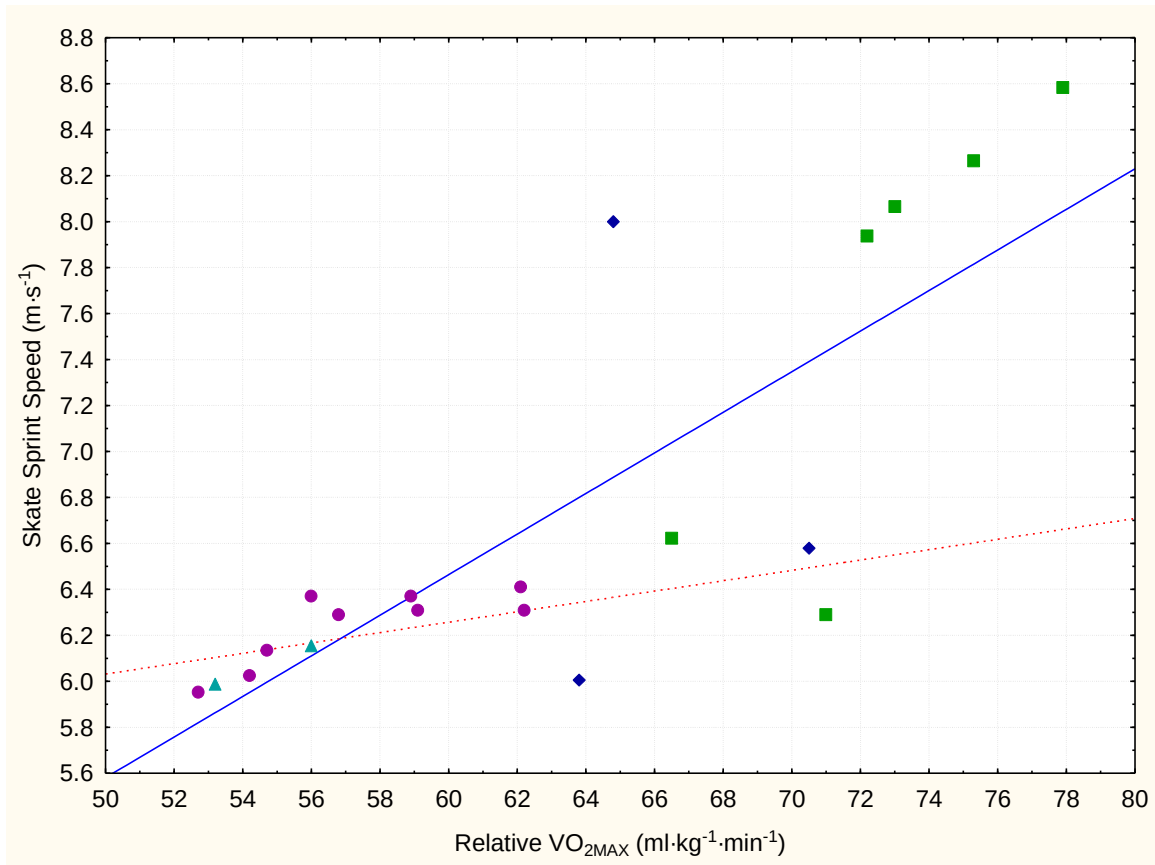


Figure 1. Scatter plot of relationship between relative $\text{VO}_{2\text{MAX}}$ (relative $\text{VO}_{2\text{MAX}}$) and skate sprint speed. Circles represent collegiate women ($n = 9$), squares represent collegiate men ($n = 6$), triangles represent junior women ($n = 2$), and diamonds represent junior men ($n = 3$). Solid line is a regression for relative $\text{VO}_{2\text{MAX}}$ with all subjects included (Skate Sprint Speed = $1.17 + 0.0883x$ relative $\text{VO}_{2\text{MAX}}$; $r = 0.80$; $P < 0.001$; $\text{SEE} = \pm 0.29$ m/sec). Dashed line is a regression for relative $\text{VO}_{2\text{MAX}}$ with all subjects excluding the cluster of the five fastest skiers (Skate Sprint Speed = $4.89 + 0.0227x$ relative $\text{VO}_{2\text{MAX}}$; $r = 0.66$; $P = 0.008$; $\text{SEE} = \pm 0.03$ m/sec).

When analyzing the entire sample, correlations between 10- and 60-second upper body power and 1200 m time trial speed were significant: $r = 0.68$ (95% C.I. = $0.34 - 0.86$; $P = 0.001$) and $r = 0.63$ ($0.26 - 0.84$; $P = 0.003$), respectively. The correlation between poling cadence for the 10-second UBP test was non-significant with an $r = -0.10$ ($-0.37 - 0.51$; $P = 0.675$). The relationship between training hours and 1200 m time trial

speed was non-significant ($r = 0.21$ ($-0.26 - 0.60$), $P = 0.387$). However, training years was borderline significant at the 0.05 alpha level ($r = 0.42$ ($-0.03 - 0.72$), $P = 0.077$).

With the same five skiers excluded as described previously, 10- and 60-second UBP measures were non-significantly correlated with 1200 m time trial speed: $r = 0.26$ ($-0.21 - 0.63$; $P = 0.352$) for UBP10; $r = 0.27$ ($-0.20 - 0.63$; $P = 0.339$) for UBP60; $r = 0.27$ ($-0.64 - 0.20$; $P = 0.330$) for UBP10-C. Training hours and years were also non-significantly correlated with 1200 m time trial speed: $r = 0.35$ ($-0.11 - 0.65$), $P = 0.2237$; and $r = -0.45$ ($-0.74 - 0.00$), $P = 0.1105$, respectively.

Pearson correlations for the field-based testing variables are shown in Tables 12 – 13. The same subgroup correlation analyses were performed as previously described in order to understand the influence of the five fastest skiers on the data.

Table 12. Correlation coefficients between roller ski sprint variables and 1200 m skate sprint speed with 95% confidence intervals (in parentheses) and P-values. Analyses provided for all subjects ($n = 20$), as well as sub-group ($n = 15$).

Test Variable	Flying Sprint Speed ($\text{m}\cdot\text{s}^{-1}$)	Flying Sprint Poling Cadence ($\text{cycles}\cdot\text{min}^{-1}$)	400 m T1 Speed ($\text{m}\cdot\text{s}^{-1}$)	400 m T2 Speed ($\text{m}\cdot\text{s}^{-1}$)
Skate TT				
All Subjects	0.74 * (0.44 – 0.89) $P < 0.001$	-0.10 (-0.51 – 0.37) $P = 0.675$	0.78 * (0.52 – 0.91) $P < 0.001$	0.83* (0.62 – 0.93) $P < 0.001$
Sub-Group	0.56 * (0.15 – 0.80) $P = 0.031$	-0.17 (-0.57 – 0.30) $P = 0.545$	0.51 (0.09 – 0.78) $P = 0.050$	0.56 * (0.16 – 0.80) $P = 0.029$

* Indicates significant correlations.

Flying Sprint = average speed of flying sprint; Flying Sprint Poling Cadence = sprint poling cadence from flying sprint; 400 m Trial 1 and 400 m Trial 2 = average speeds from 400 m testing.

Table 13. Correlation coefficients between 400 m roller ski sprint recovery variables and 1200 m skate sprint speed with 95% confidence intervals (in parentheses) and P-values. Analyses provided for all subjects (n = 20), as well as sub-group (n = 15).

Test Variable	Trial	LA-3 (mmol·L ⁻¹)	HR-3 (bpm)	LA-5 (mmol·L ⁻¹)	HR-5 (bpm)
Skate TT All Subjects	1	0.59 *	-0.42	0.43	-0.26
		(0.20 – 0.82)	(-0.73 – 0.03)	(-0.01 – 0.73)	(-0.63 – 0.21)
		P = 0.006	P = 0.065	P = 0.058	P = 0.271
	2	0.78 *	-0.18	0.50	-0.22
		(0.51 – 0.91)	(-0.58 – 0.28)	(0.07 – 0.77)	(-0.61 – 0.25)
		P < 0.001	P = 0.439	P = 0.027	P = 0.348
Sub-Group	1	0.54 *	0.13	0.59 *	0.05
		(0.13 – 0.79)	(-0.33 – 0.54)	(0.20 – 0.82)	(-0.40 – 0.49)
		P = 0.038	P = 0.638	P = 0.021	P = 0.849
	2	0.65 *	0.33	0.54 *	0.41
		(0.29 – 0.85)	(-0.13 – 0.68)	(0.12 – 0.79)	(-0.04 – 0.72)
		P = 0.009	P = 0.223	P = 0.040	P = 0.127

* Indicates significant correlations.

LA-3 = blood lactate at 3 minutes post; HR-3 = heart rate at 3 minutes post; LA-5 = blood lactate at 5 minutes post; HR-5 = heart rate at 5 minutes post.

When all subjects were included in the analyses, measures of 400 m Trial 1 Speed, 400 m Trial 2 Speed, Flying Sprint Speed, LAT1-3, LAT2-3, HR_{LT}, relative VO_{2MAX}, TTE, HR_{MAX}, UBP10, UBP60, 1J-CM, 1J-S, 4J-JH, 60J-JH-1, and 60J-JH-2 correlated moderate to high (r = 0.56 – 0.83). Average speed for Trial 2 of the 400 m sprint had the highest correlation of all variables with skate sprint speed (r = 0.83). However, it is important to note that at least one variable from each testing method (treadmill, upper body power, vertical jump, and roller skiing) correlated moderate to

high with skate sprint speed ($r = 0.80$ for relative $\text{VO}_{2\text{MAX}}$; $r = 0.68$ for UBP10; $r = 0.72$ for 60J-JH-2; $r = 0.78$ for LAT2-3; $r = 0.83$ for 400 m Trial 2 Speed).

The results of the sub-group analyses (i.e., with the five fastest skiers excluded) resulted in lower correlations between all variables and skate sprint speed than when analyzing all subjects. Amongst the sub-group analyses, the highest correlations were found with relative $\text{VO}_{2\text{MAX}}$ ($r = 0.66$), LAT2-3 ($r = 0.65$) and TTE ($r = 0.63$), while 400 m Trial 1 Speed, 400 m Trial 2 Speed, Flying Sprint Speed, LAT1-3, LAT1-5 and LAT2-5 had moderate correlations ($r = 0.54 - 0.59$). All other variables had non-significant relationships with speed from the 1200 m time trial. It is interesting that no UBP or vertical jump variables were statistically significant within the sub-group analyses.

One scatter plot from each testing method versus skate sprint speed from the 1200 m time trial are shown in Figures 2 - 5, while the remaining scatter plots with similar relationships and trends are provided in Appendix C.

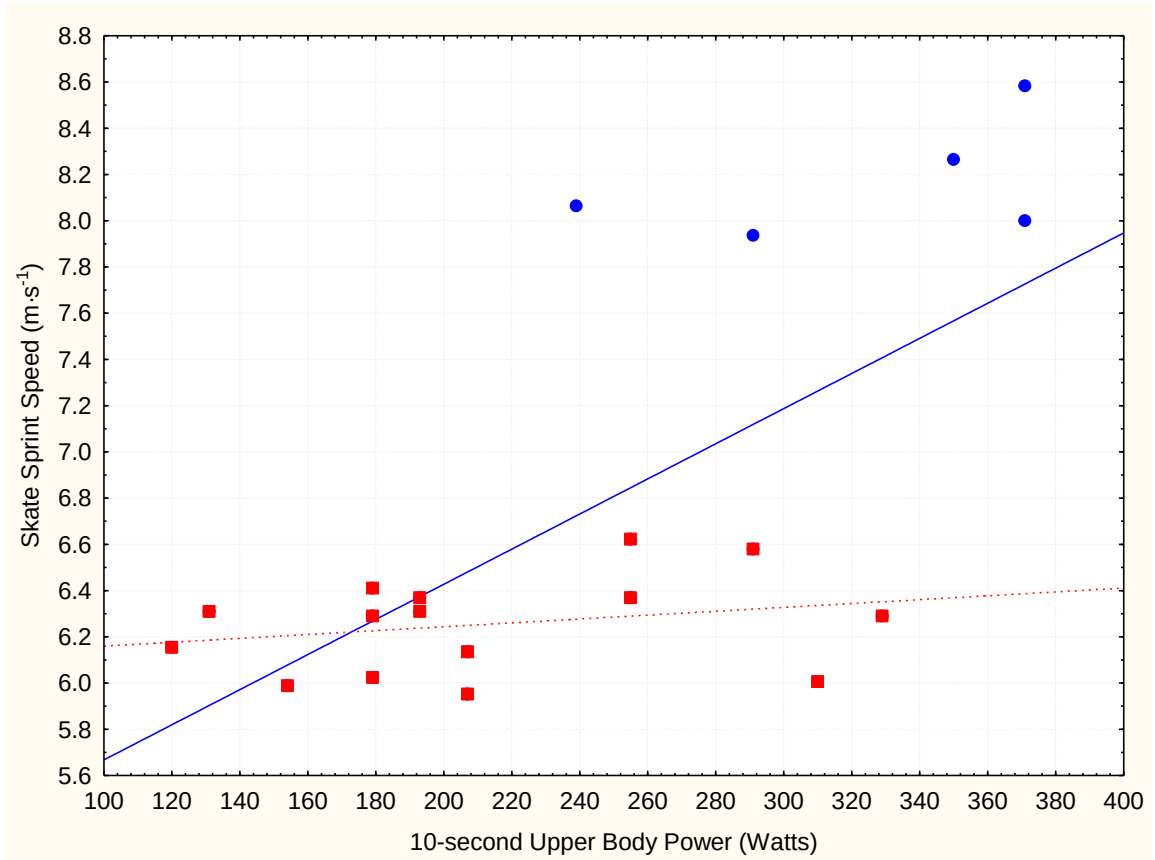


Figure 2. Scatter plot of relationship between 10-second upper body power (UBP10) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for UBP10 with all subjects included (Skate Sprint Speed = $4.91 + 0.0076x$ UBP10; $r = 0.68$; $P = 0.001$; $SEE = \pm 0.44$ m/sec). Dashed line is a regression for UBP10 with all subjects excluding the cluster of the five fastest skiers (Skate Sprint Speed = $6.07 + 0.0000x$ UBP10; $r = 0.26$; $P = 0.352$; $SEE = \pm 0.04$ m/sec).

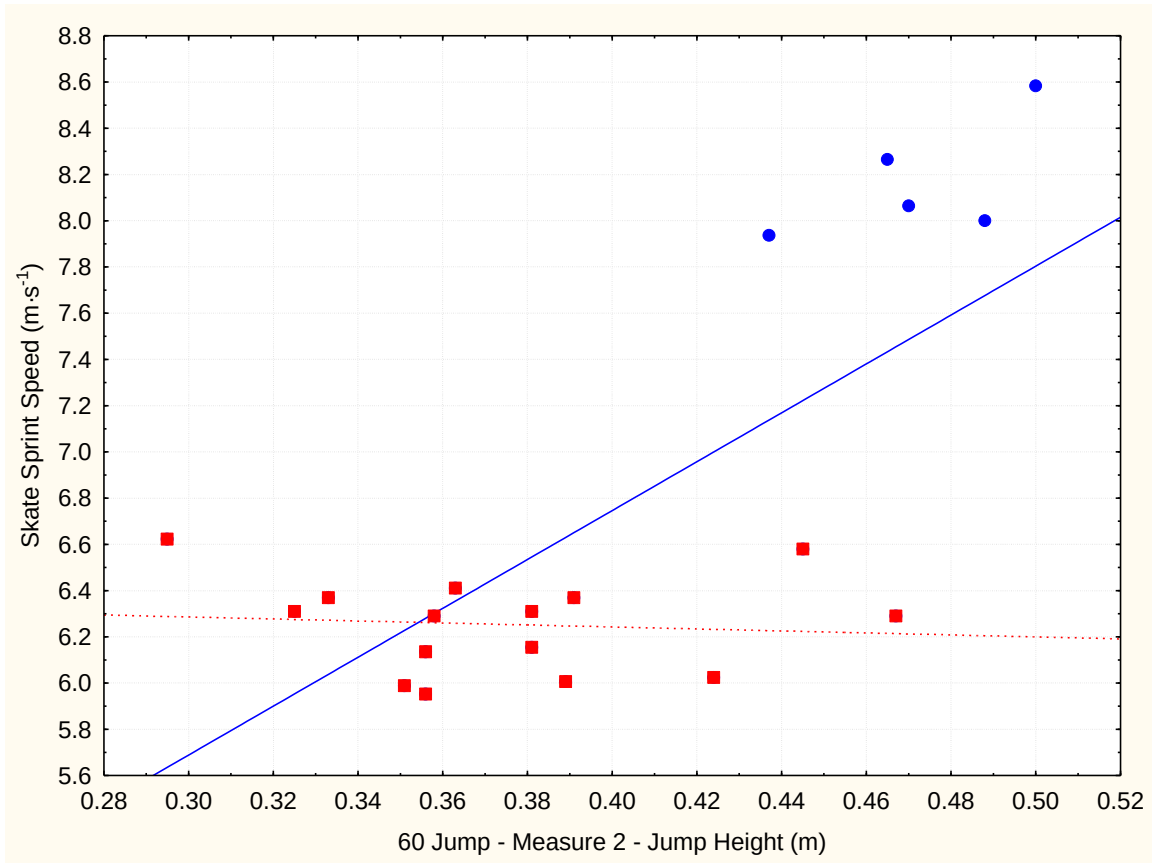


Figure 3. Scatter plot of relationship between measure 2 from 60 jump - jump height (60J-JH-2) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for 60J-JH-2 with all subjects included (Skate Sprint Speed = $2.53 + 0.2680 \times 60J-JH-2$; $r = 0.71$; $P < 0.001$; SEE = ± 0.40 m/sec). Dashed line is a regression for 60J-JH-2 with all subjects excluding the cluster of the five fastest skiers (Skate Sprint Speed = $6.41 + -0.0106 \times 60J-JH-2$; $r = -0.09$; $P = 0.746$; SEE = ± 0.05 m/sec).

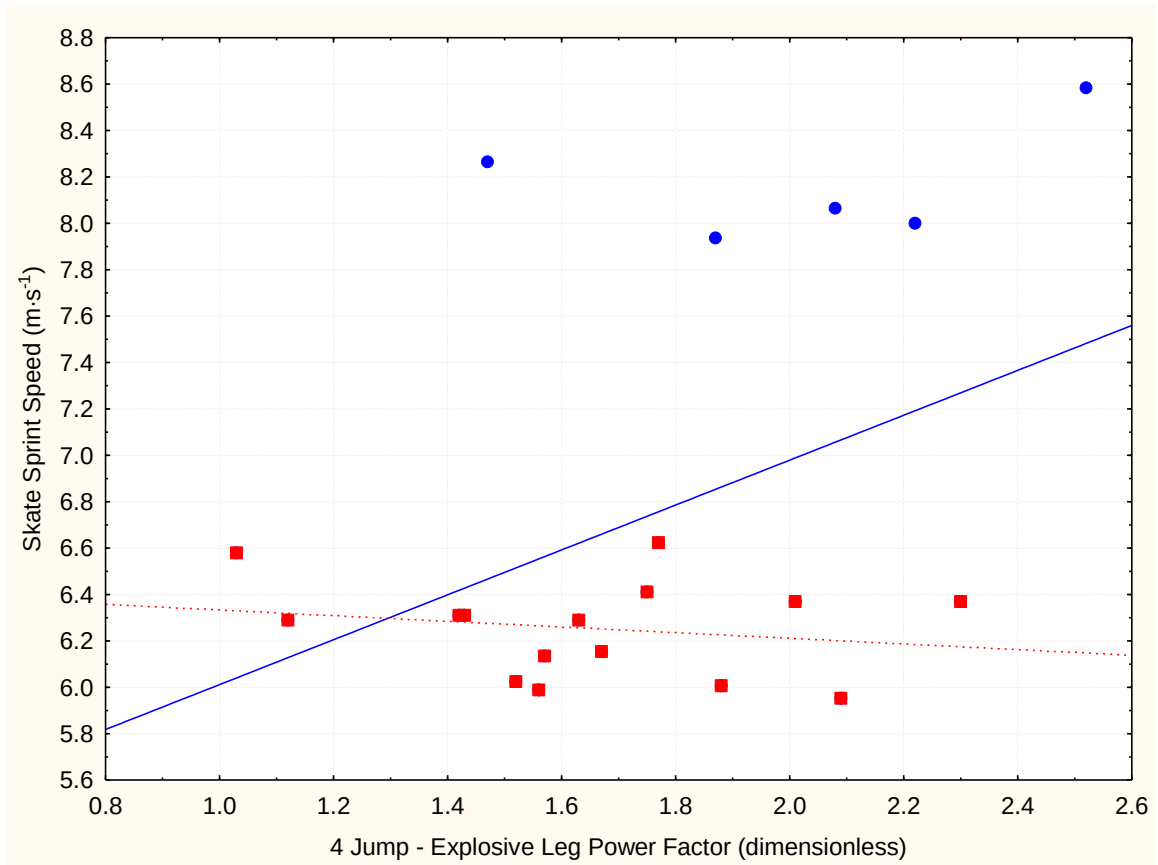


Figure 4. Scatter plot of relationship between 4 jump - explosive leg power factor (4J-ELPF) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for 4J-ELPF with all subjects included (Skate Sprint Speed = $5.05 + 0.9667 \times 4J\text{-ELPF}$; $r = 0.42$; $P = 0.064$; $SEE = \pm 0.67$ m/sec). Dashed line is a regression for 4J-ELPF with all subjects excluding the cluster of the five fastest skiers (Skate Sprint Speed = $6.46 + -0.1223 \times 4J\text{-ELPF}$; $r = -0.2$; $P = 0.474$; $SEE = \pm 0.05$ m/sec).

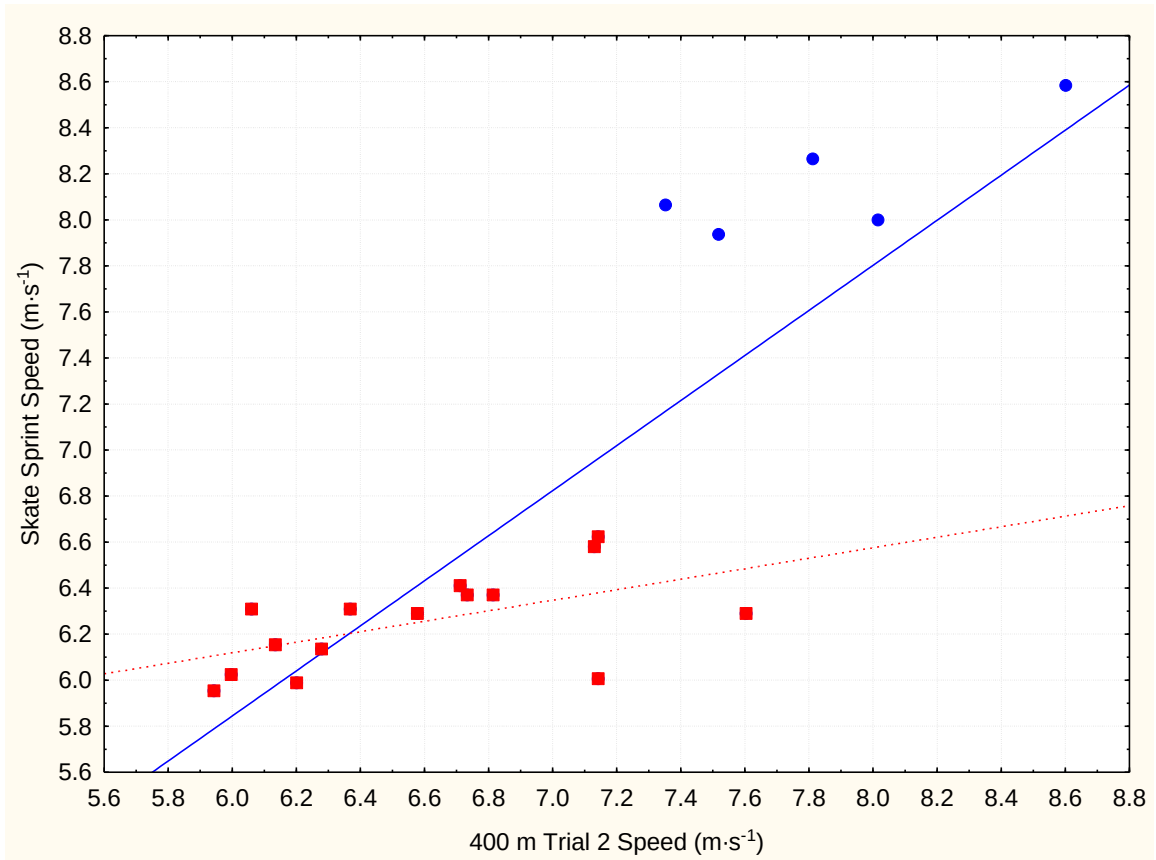


Figure 5. Scatter plot of relationship between 400 m trial 2 speed (400 m Trial 2 Speed) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for 400 m Trial 2 Speed with all subjects included ($\text{Skate Sprint Speed} = -0.03 + 0.9796 \times 400 \text{ m Trial 2 Speed}$; $r = 0.83$; $P < 0.001$; $\text{SEE} = \pm 0.25 \text{ m/sec}$). Dashed line is a regression for 400 m Trial 2 Speed with all subjects excluding the cluster of the five fastest skiers ($\text{Skate Sprint Speed} = 4.73 + 0.2311 \times 400 \text{ m Trial 2 Speed}$; $r = 0.56$; $P = 0.029$; $\text{SEE} = \pm 0.03 \text{ m/sec}$).

CHAPTER FIVE

DISCUSSION

While sprint racing is relatively new to the sport of cross-country skiing, previous researchers have established that maximal skiing speed is the most important predictor of sprint time trial speed (Stöggl, Lindinger, Müller, 2006, 2007a, b; Stöggl, Müller, & Lindinger, 2008). Maximal skiing speed as an indicator of sprint time trial speed has only been evaluated in classic skiing through the use of double pole (DP) and diagonal stride (DIAG) techniques in elite males (Stöggl, et al. 2006, 2007a, b; Holmberg, Lindinger, Stöggl, Eitzlmair, & Müller, 2005). Therefore, the present study sought to include junior and collegiate skiers, as well as both men and women during skate sprint skiing. Other determinants of sprint cross-country skiing speed have not been well studied, however, previous researchers have examined the determinants of endurance cross-country skiing performance in both laboratory and field settings (Mahood, Kenefick, Kertzer, & Quinn, 2001). The current study was the first to examine determinants of skate sprint time-trial speed on roller skis using a combination of three laboratory- and three field-based tests as potential correlates. All correlations discussed are for the entire study sample until further noted.

Ski-Striding Maximal Treadmill Test Correlations

Treadmill variables of relative VO_{2MAX} (maximal oxygen uptake) and TTE (time to exhaustion) correlated moderately with skate sprint time trial speed ($r = 0.80$ and $r =$

0.78, respectively) (Table 9). The treadmill variables were expected to correlate highly with sprint speed because previous research has established these variables as strong predictors of endurance performance. In a study by Staib, Im, Caldwell, and Rundell (2000), both double pole (DP) $\text{VO}_{2\text{PEAK}}$ and DP TTE had strong correlations with seasonal rank ($r = -0.74$ and $r = -0.80$, respectively). Similarly, numerous researchers have indicated that TTE is a strong correlate of racing season performance. For example, Mahood et al. (2001) found the highest correlations between the time to complete a 1-km upper body roller skiing time trial and seasonal rank ($r = 0.95$). Furthermore, Rundell and Bacharach (1995) reported strong correlations between seasonal rank and time to complete a 1-km double poling on-snow time trial ($r = -0.84$). Similar to previous TTE findings, Stöggl et al. (2007b) found significant correlations between time of $\text{VO}_{2\text{MAX}}$ test ($t\text{VO}_{2\text{MAX}}$) (the same as correlations for TTE in the present study) and sprint speed ($0.70 < r < 0.77$), however, a non-significant correlation with relative $\text{VO}_{2\text{MAX}}$ ($r = 0.51$). Researchers suggested that this result was due to an influence of endurance performance and peak speed parameters that include not only central fatigue factors (i.e., $\text{VO}_{2\text{MAX}}$) but also neuromuscular and anaerobic characteristics (i.e., neural activity, cross-bridge formation, muscle force, etc.). Therefore, the diagonal stride protocol used in the study by Stöggl et al. (2007b) may have limited $\text{VO}_{2\text{MAX}}$ due to the speed of muscle contraction and not due to oxygen uptake. Furthermore, according to the present study and Mahood et al. (2001), that while $\text{VO}_{2\text{MAX}}$ was not the highest correlate with skiing speed, it was a contributing factor to determining cross-country skiing time trial speed.

In the current study, the treadmill test variables of VO_{2MAX} and TTE primarily assessed the aerobic energy system contributions. However, in a cross-country sprint of 800 – 1800 m in distance, there are contributions from each energy system (ATP-PCr, glycolysis, and oxidative metabolism) (Wilmore, Costill, & Kennedy, 2008). Furthermore, the aerobic energy system is the primary source of energy for exercise lasting longer than 60 seconds (Olds, Norton, Craig, Olive & Lowe, 1995). Since the cross-country sprint race lasts 2:30 – 4:00 minutes, the aerobic energy system is the dominant energy pathway. Contrarily, the anaerobic energy system (i.e. anaerobic glycolysis) is utilized in cross-country skiing mostly during steep climbs and sprint racing. Therefore, a short-duration test of both the aerobic and anaerobic energy systems is ideal for predicting skiing speed (Staib et al., 2000; Mahood et al., 2001). Ultimately, the moderate correlations from VO_{2MAX} and TTE in the current study support that a high aerobic capacity is needed for endurance performance and sets a foundation for sprint racing.

Correlations for Relative Versus Absolute Measures

In this study, both absolute and relative VO_{2MAX} were found to correlate positively with skate sprint speed, however, relative VO_{2MAX} correlated higher ($r = 0.80$) than absolute VO_{2MAX} ($r = 0.74$). Conversely, previous research by Alsobrook and Heil (2009) reported that absolute measures of upper body VO_{2PEAK} correlated higher with 10 km classic race speed than relative measures ($r = 0.88$ and $r = 0.73$, respectively). Similarly, Staib et al. (2000) found absolute double poling VO_{2PEAK} to be a higher

correlate with race speed ($r = -0.74$) than relative ($r = -0.49$) in male skiers. Although, contrary to these findings, Mahood et al. (2001) reported a relative upper body $\text{VO}_{2\text{PEAK}}$ ($r = -0.74$) where the absolute value was not reported. A possible explanation for these differences could be due to use of different skiing techniques for the performance variables. For example, Staib et al. (2000) and Alsobrook & Heil (2009) used classic skiing, while Mahood et al. (2000) analyzed skate skiing. Furthermore, there are different contributions of the upper and lower body during each style of skiing. The upper body is important for flat and shallow climbs for classic skiing as well as during uphill skate skiing (Street, 1989). Thus, according to the current study and Mahood et al. (2001), relative $\text{VO}_{2\text{MAX}}$ is a stronger correlate of skate skiing speed than an absolute measure.

Reasonable explanations for the difference in absolute versus relative variables have been addressed in the sport of cycling. Olds et al. (1995) introduced a modeling strategy for predicting time trial speed in cyclists that included the power supply available from physiological sources (i.e., aerobic and anaerobic energy systems) and the external power demand to overcome resistance to forward motion (i.e., aerodynamic, frictional, gravitational resistances). According to Olds et al. (1995), performance is optimized when speed increases to the point when power demand (external resistance) is exactly equal to the power supply (physiological). Thus, there may be a stronger correlation with time trial speed when the variable (i.e., $\text{VO}_{2\text{MAX}}$) includes an estimate of both power supply and power demand. For example, relative $\text{VO}_{2\text{MAX}}$ may be a better correlate of time trial speed because it includes an estimate of power supply (i.e., liters of

oxygen consumed per minute) and power demand (i.e., body mass), while absolute $\text{VO}_{2\text{MAX}}$ only includes an estimate of power supply (i.e., L/min of oxygen consumed). Indeed, the current study reported a higher correlation for relative $\text{VO}_{2\text{MAX}}$ (ml/kg/min) ($r = 0.80$) than absolute $\text{VO}_{2\text{MAX}}$ (L/min) ($r = 0.74$). Therefore, the current study suggests that relative measures of $\text{VO}_{2\text{MAX}}$ (that include body mass) are better correlates of cross-country skiing performance.

Bergh and Forsberg (1992) suggested that there is an influence of body mass on cross-country skiing performance. These researchers indicated that there is a difference between the body mass of skiers and their performances such that heavier skiers are slightly favored. As a result, it was recommended that the unit of $\text{ml} \cdot \text{kg}^{-2/3} \cdot \text{min}^{-1}$ was more appropriate for expressing maximal aerobic power.

Upper Body Power Test Correlations

Correlation coefficients for UBP with sprint speed for all subjects were moderate (UBP10, $r = 0.68$; UBP60, $r = 0.63$). However, it was expected that these relationships would be higher based on previous research of the relationship between 10 km classic skiing race speed and UBP ($r = 0.93$ for UBP10 and $r = 0.92$ for UBP60) (Alsobrook & Heil, 2009). Possible explanations for the lower correlations in the current study include the different surface conditions between the indoor track (present study) and on-snow skiing (Alsobrook & Heil, 2009), as well as different racing technique during a flat, multiple-loop time trial (present study) versus a 10 km skate race with rolling terrain and gradual climbs (Alsobrook & Heil, 2009). The track's surface in the present study may

have contributed to the lower correlations, where the fastest skiers were able to adjust better to the surface than other skiers. Therefore, the factors of surface condition, terrain, and course design probably contributed to the lower correlations in the present study than those previously reported.

Vertical Jumping Test Correlations

Correlation coefficients from all jump height variables were moderate when compared with skate sprint speed ($r = 0.59 - 0.71$) (Table 10). It was interesting that only the JH variables and not the ELPF variables correlated significantly (Tables 10 and 11). The lower ELPF correlations were not expected since researchers have previously established that a greater impulse of force during the push-off phase of skate skiing was prominent in elite skiers. The increased force of the push-off phase suggested an emphasis of an ability to quickly rebound off the ground with minimal contact time (Lindinger, Göpfert, Stöggl, Müller, & Holmberg, 2009). Stöggl, Müller, and Lindinger (2008) mentioned that the ability to move quickly from ski to ski was important to gain momentum and maintain speed. However, there may be kinematic limitations for the comparison between previous ski research and the current study. Specifically, the vertical jumping in the current study involved sagittal plane (division of the left and right side of the body) motion, while the skate skiing used in previous research emphasized frontal plane motion. Contrarily, there are similar demands placed upon the lower body in the sagittal plane for both vertical jumping and running. Furthermore, running research indicates that lower body plyometric training improves running economy and

distance running performance (Spurrs, Murphy, & Watsford, 2003). These researchers measured an increase in 5-bound distance and counter-movement jump height of 7.8 % and 13.2%, respectively, as a result of a plyometric training intervention. It was concluded that 3-km running performance significantly improved as a result of the plyometric training. Thus, in the current study, it was initially expected that ELPF variables ($\text{average air time} \cdot \text{average ground contact time}^{-1}$) would be important when determining skate sprint time trial speed. However, the plane of motion may not have been specific to skate skiing and resulted in lower ELPF correlations.

Not only are powerful movements necessary for gaining and maintaining speed during skate skiing, researchers have suggested that it improves classic skiing as well. Researchers suggested that faster skiing speed is obtained by a greater initial impulse of force and therefore higher pole force (Bilodeau et al., 1996; Holmberg et al., 2005; Stöggl et al., 2007b). A higher force placed on the poles allows for the body to travel farther with each stroke, which allows the cycle length to become longer. Bilodeau et al. (1996) noted that in order to increase skiing speed, there must be an increase in either cycle length, poling frequency, or both. Numerous researchers have determined that faster skiers have longer cycle lengths as well as higher poling frequencies than slower skiers (Bilodeau, Rundell, Roy, & Boulay, 1996; Hoffman, Clifford, & Bender, 1995; Holmberg et al., 2005; Stöggl et al., 2007a, b). It could be that faster skiers have greater muscular strength and power as well as enhanced neuromuscular adaptations to produce more effective and forceful leg pushes and pole plants compared to slower skiers. There may also be an interaction between experience and technique for increasing pole force,

cycle length, and poling frequency. Thus, the previous studies suggest that explosive movements of both the upper and lower body are important to analyze the determinants of sprint speed.

Another possible reason why measures of ELPF had lower correlations than JH variables may be due to the test-retest reliability of the ELPF variables. In a study performed by our lab (Taylor, Willis, & Heil, 2010), JH variables demonstrated high intraclass reliability (R_{XX}) while ELPF variables had consistently lower reliability regardless of the vertical jump test ($R_{XX} = 0.91 - 0.97$ and $R_{XX} = 0.66 - 0.87$, respectively). Lower reliability means that data were not similarly represented in the same test across two successive trials. Therefore, in the current study the ELPF variables had lower correlations than the JH variables possibly due to lower test-retest reliability.

Correlations for Field-Based Variables with Skate Sprint Speed

Correlation coefficients for the roller skiing sprint speed variables were considered moderate ($r = 0.74 - 0.83$), with 400 m Trial 2 Speed having the highest correlation of all variables in this study ($r = 0.83$) (Table 12). Since both flying sprint and 400 m sprint trial speed correlated significantly, the expectation that a maximal speed test of short duration (4 – 60 seconds) could predict skate sprint performance was supported. It was also expected that the variables for the shorter duration sprint roller ski tests correlated significantly because of the similar testing method (i.e., skate roller skiing). Furthermore, the 400 m sprint was the test most similar to the 1200 m time trial,

and thus was expected to have the highest correlation amongst all roller skiing sprint variables measured.

The current study supports previous research reporting significant correlations between maximal sprint speed during classic roller skiing techniques and cross-country skiing sprint performance ($r = 0.82 - 0.94$ for double poling (DP) and $r = 0.86 - 0.89$ for diagonal stride (DIAG)) (Stöggl et al., 2006, 2007b). Specifically, Stöggl et al. (2006) reported test-retest reliability of three sprint tests; 50 m DP sprint, DP sprint speed (maximal velocity), and 1000 m DP sprint on a treadmill using roller skis ($r = 0.78 - 0.99$). These researchers reported that these treadmill tests were valid based on correlations between the time of the 50 m DP sprint and the maximal velocity of the DP sprint ($r = 0.86$). Validity was also reported amongst a treadmill 1000 m sprint and a field-based 1000 m sprint ($r = 0.96$). After the development of these sprint tests, Stöggl et al. (2007b) analyzed a simulated classic sprint competition using treadmill roller skiing. Variables of maximal DP speed and maximal DIAG speed indicated the highest correlations to sprint performance ($r = 0.93$ and $r = 0.87$, respectively). As a result, previous research and the current study support using short-duration maximal speed tests to predict cross-country skiing sprint performance.

In the present study, the recovery parameters of blood lactate and heart rate were expected to have significant correlations with sprint time trial speed, although they were purely exploratory. Numerous studies have included measures of peak blood lactate during cross-country ski racing as a physiological marker of skiing performance to determine the body's ability to tolerate high work rates (Mygind, Andersen, &

Rasmussen, 1994; Staib et al., 2000; Stöggl et al., 2006; Stöggl et al., 2007a; Welde, Evertsen, Heimburg, & Medbo, 2003). Recovery blood lactate during cross-country ski racing was analyzed by Zory, Millet, Schena, Bortolan, & Rouard (2006) and Stöggl et al. (2007b) immediately after race efforts to analyze the high intensity effects on the body. According to Zory et al. (2006), blood lactate quickly increases after the first minutes post exercise and slows down thereafter due to the balancing of lactate production and removal by the body. In addition, Stöggl et al. (2007b) reported high correlations between classic sprint speed (DP and DIAG) and recovery blood lactate at 5, 7, and 10 minutes post sprint ($r = 0.81 - 0.84$). The current study supported these findings with moderate correlations from LAT2-3 ($r = 0.78$) and LAT1-3 ($r = 0.59$). Stöggl et al. (2007b) and Zory et al. (2006) both reported that the recovery blood lactate curve was a different shape for the faster skiers when comparing blood lactate and maximal speed tests in cross-country skiers. The differing curve may have been characterized by higher lactate levels over the entire recovery period as well as a larger increase in blood lactate from the immediate end of exercise to peak lactate during recovery. Furthermore, this suggested that faster athletes may be able to generate higher blood lactate values, which means that both a high anaerobic capacity and the ability to produce high lactate levels repeatedly is an important factor for sprint performance in cross-country skiing (Stöggl et al., 2007b).

Comparison of Laboratory- and Field-Based Tests

The present study suggests that both laboratory- and field-based test variables are significant correlates of skate sprint time trial speed. Laboratory-based variables are crucial for understanding an athlete's aerobic capacity and power produced by their upper and lower body. In addition, field-based variables closely represent the performance of a skier while using the same testing method (i.e., skate roller skiing) as the performance and therefore allowing for a practical interpretation. Using a combination of laboratory- and field-based testing variables allowed for a more complete analysis of skate sprint time trial speed.

For the current study, two short duration tests (one of ≤ 10 seconds and another of about 60 seconds) were performed within each testing method (i.e., UBP (UBP10, UBP60); vertical jumping (1J, 4J, 60J); roller skiing (flying sprint, 400 m)). When analyzing the combination of the laboratory- and field-based variables, it was interesting that for both vertical jump and roller ski testing, the longer duration test variables (i.e., 60J-JH-1 and 60J-JH-2 ($r = 0.63$ and $r = 0.71$) as well as 400 m T1 and T2 ($r = 0.78$ and $r = 0.83$)) were the higher correlates of skate sprint time trial speed. Therefore, it was expected that the relationship between UBP60 ($r = 0.63$) and skate sprint speed would have been higher than UBP10 ($r = 0.68$). A possible explanation for the lower correlation of UBP60 with skate sprint speed was that skiers may be able to ski fast in these types of conditions (flat course with multiple short loops) and maintain their speed without having a high 60-second upper body power output. Thus, based on the vertical jump and roller

ski testing, measures of about 60 seconds generally correlated higher with skate sprint time trial speed than the shorter duration ≤ 10 -second tests.

Sub-Group Correlations

During the initial data analysis, a cluster of subjects was observed that contained the five fastest skiers. A subsequent sub-group analysis was performed that excluded these five skiers and resulted in a decrease in all correlations with laboratory-based variables. However, the treadmill variables of relative VO_{2MAX} , TTE, and absolute VO_{2MAX} remained moderate correlates ($r = 0.55 - 0.66$) at an alpha level of 0.05 (Table 9). Similarly, correlations for the field-based variables decreased but were still moderate ($r = 0.51 - 0.56$) (Table 12). However, LAT1-5 ($r = 0.59$) and LAT2-5 ($r = 0.54$) correlations increased, which may have been due to the previously explained ability of sprint athletes to generate high lactate levels repeatedly. Unfortunately, the sub-group analysis was not definitive enough to distinguish any one variable as having allowed the cluster of the five fastest skiers to form. Therefore, a multiple regression analysis for this study would probably help to explain these data in the future.

Subject heterogeneity could explain why no one variable or type of testing distinguished this cluster of skiers. Skiers in this study could be described as generalists, where they competed in all disciplines of cross-country skiing (i.e., sprint and distance for both skate and classic techniques) at the amateur level. In contrast, previous researchers have primarily studied elite skiers that were sprinting specialists for both techniques. The current study sample also included both junior and collegiate skiers as

well as men and women. Due to a highly diverse sample of skiers amongst different classes, each variable had a wider spread when compared with skate sprint time trial speed. Thus, subject heterogeneity may have contributed to the formation of the cluster due to some combination of the factors mentioned above.

Some other possible reasons for the formation of the cluster include the technique and testing method of skate roller skiing, roller skiing on a rubber track surface, and the short testing duration (i.e., sprinting). From personal experience, the rubber track surface created a different feel for roller skiing that was more resistive during the push-off phase than roller skiing on pavement. The more experienced and fit skiers (the cluster) may have had a better tempo or an ability to counteract this feeling and therefore had better results than the other skiers. The combination of these circumstances as an interaction effect was also a possibility, such that skate sprint roller skiing on an indoor track created differences between skiers in which a cluster was formed. Based on previous studies in our laboratory on most of the same skiers, clusters were not formed when comparing laboratory measures (UBP and vertical jumping) and skiing performance (distance and sprint races from West Yellowstone Super Tour) (Alsobrook & Heil, 2009; Willis & Heil, 2010). Therefore, there must be uniqueness in the field measures from the current study (skate sprint roller skiing on an indoor track surface). This analysis suggests that an indoor rubber running track may not be an appropriate surface for evaluating skate sprint performance. However, further research may be warranted due to the moderate correlations reported for the present study.

Description of Correlational Analyses

When analyzing this data using correlational analysis, it is important to consider the assumptions before deciding how to approach the analysis. The linearity assumption is violated if the straight line is inadequate for the model (i.e., there is curvature of the line) or if there is contamination from outliers from different populations. The assumption of constant variance means that the variance of the data must be the same at all levels of the dependent variable (i.e. skate sprint speed). The assumption of normality means that the responses from each of the variables can be represented as normal distributions within a curve. Lastly, when the assumption of independence is not met (i.e., a lack of independence of the variables), the standard errors are affected even though there is no difference in the coefficients.

There are definite weaknesses with the current study analysis in which a cluster was present in the data. In this case, either a transformation of the data or an entirely different analysis needs to be performed. The strengths in this correlational analysis were that the data was summarized by a straight line that represents the mean of the dependent variable (i.e., skate sprint speed) as a function of the independent variables (Ramsey, Schafer, & Crockett, 2002). Even though it was concluded from an analysis of the influence of the interaction between gender and class that there were no differences in the correlations between samples, differences by gender and class could have influenced the correlations. Future analysis of these data should include a multiple regression analysis

to fully understand which collection of variables can best explain the variance in skate sprint speed.

Future Studies

Previously, researchers have concluded that skiers control their speed in double poling by increasing their poling frequency (or cadence) and cycle length (Lindinger, Stöggl, Müller, & Holmberg, 2009). The present study did not determine whether a skiers' maximal power output could have been limited by a high cadence. Consequently, the cadence may contribute to the ability of a skier to reach maximal power output during the 10-second test. Future studies using upper body power to predict cross-country skiing performance may be interested in conducting an initial upper body power test to select the appropriate resistance on the flywheel of the ergometer that is appropriate with the skier's poling frequency or cadence to generate maximal power output. Furthermore, this type of testing could measure the rate and amount of power applied at different flywheel resistances.

Future studies that include a VO_{2MAX} test should consider performing a skate roller skiing VO_{2MAX} test in order to evaluate the direct relationship to skate sprint time trial speed. The use of a similar technique (i.e., skate roller skiing) will likely have a stronger relationship with skate skiing performance than treadmill running based upon similar movement patterns.

Future research that includes vertical jump testing should primarily analyze JH variables as well as successive jumps (i.e., 4 to 60 jumps) to determine the power and

endurance of the lower body. It could be interesting to analyze the relationship between skate sprint speed and a test of successive forward jumps (i.e., broad jumps). Measures from this type of forward ski jumping test could include the speed over the distance, ground contact time, and jump height. These measures may be able to quantify the characteristics of jumping by simulating the dynamics of the skiing technique. A training study should also be conducted to develop the skill of continuous jumping in order to establish validity and reliability for all of the variables.

When examining the determinants of sprint skiing, future studies should incorporate on-snow performances. This would require all subjects and all trials for each subject to be completed in a small window of time on the same day to minimize the influence of changes in the snow conditions. If using roller ski testing, another option would be to include an outdoor testing course that had uphill sections to make the course more similar to an on-snow race course.

Future analyses of the present study data should focus on multiple regression analyses which would help understand the combination of variables that best explain the variance in skate sprint speed. Ultimately, further research should determine if these testing measures could improve skate sprint time trial speed with specific training interventions.

CHAPTER SIX

CONCLUSION

Findings from this study indicated that both laboratory- and field-based measures can predict skate sprint roller skiing performance on an indoor track. Laboratory-based measures were evaluated during a maximal oxygen uptake ($\text{VO}_{2\text{MAX}}$) test to exhaustion, 10- and 60-second upper body power (UBP) tests, and 1-, 4-, and 60-jump tests to measure lower body power (LBP). These laboratory-based measures as well as field-based measures of skate roller skiing speed (Flying Sprint, and 400 m Trial 1 and 2) and recovery (blood lactate and heart rate at 3 and 5 minutes post finish of the 400 m) were compared with average speed (m/sec) from a 1200 m skate roller ski time trial. Roller skiing measures of speed (Flying Sprint, 400 m Trial 1 and 2) and recovery (LAT2-3 and LAT1-3) as well as relative $\text{VO}_{2\text{MAX}}$ (RVO2MX) were moderate to high in predicting skate sprint performance. Other important variables included all jump height (JH) and UBP measures, which were moderate correlates of skate sprint performance. The laboratory- and field-based variables correlated moderate to high with skate sprint performance, except for the non-significant relationship between the ELPF variables. Therefore, despite the lack of significance with the ELPF variables, collectively, the evidence suggests that the null hypothesis be rejected in favor of the alternative hypothesis.

When analyzing the data, a distinct cluster of the five fastest skiers was formed. Although correlations amongst all variables decreased when excluding these five skiers, researchers recommend that a multiple regression analysis should be performed in the future. This analysis would be able to distinguish differences within this cluster of skiers and determine the variable (s) that explain the variance in skate sprint roller skiing performance.

This study has several practical implications for the future. First, it is important to have a field-based test of short duration and maximal speed, such as a 400 m, that simulates race performance while skiing or roller skiing. This test is a practical tool for coaches to test athletes' performance and it is feasible and inexpensive to include in training. Measures of JH and continuous jumps had significant correlations and are also a practical and quick test to administer to athletes. Furthermore, short duration UBP measures of 10 and 60 seconds can also be important for predicting sprint performance, especially since UBP ergometers are becoming more popular and are available for coaches and athletes for training and testing. A test of endurance, such as a VO_{2MAX} test (preferably roller skiing) also has significant contributions to skate sprint performance.

The next step for future research is to conduct a training study to determine if specific training with each of these testing measures can improve skate sprint performance. Ultimately, research in sprint performance of cross-country skiers may be able to distinguish between athletes who should focus on sprint versus distance racing or vice versa, as well as provide practical training and testing measures to assess progress and improve performance.

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APPENDICES

APPENDIX A

SUBJECT CONSENT FORM

SUBJECT CONSENT FORM
FOR PARTICIPATION IN HUMAN RESEARCH
MONTANA STATE UNIVERSITY

Project Title: Determinants of Skate Sprint Cross-Country Skiing Performance for Junior and Collegiate Skiers.

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Associate Professor, Exercise Physiology
Department of Health and Human Development
Movement Science Laboratory
Health & Physical Education Complex, Montana State University
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(406) 994-6324 dheil@montana.edu

Purpose of the study:

Prior to any testing, each subject is required to read and sign a Subject Consent Form. Medical clearance will be obtained using the Health Status Questionnaire. The medical questionnaires will be used for identification and exclusion of subjects with medical contraindications to the level of exercise required by the protocol. All testing and screening procedures are in accordance with those outlined for testing “low risk” adults by the American College of Sports Medicine¹. You will also be asked to fill out a ski training history questionnaire prior to any testing.

Testing Procedures:

¹ American College of Sports Medicine (2006). *ACSM=s Guidelines for Exercise Testing and Prescription* (6th edition). Williams & Wilkins, Philadelphia, Pa.

If you agree to participate in this study, you will be required to make two visits to the Movement Science / Human Performance Lab in the basement of the Romney gymnasium on the Montana State University campus. You will also be required to make two visits to the indoor track located on the main floor of the Brick Breeden Fieldhouse at Montana State University. You should expect to spend approximately 1 hour during the first lab visit, approximately forty-five minutes during the second lab visit, about 1 $\frac{3}{4}$ to 2 hours for the third visit, and roughly 1 hour for the fourth visit. Each test will be scheduled at least 48 hours AFTER your last hard workout. Please prepare for each lab visit as you would before a race so you are ready for strenuous exercise. Please avoid ingesting any medications, including caffeine and/or aspirin, for at least 2 hours before arriving at the lab. You should inform the lab personnel of any medications that were taken prior to the visit (including cold or allergy medicine) BEFORE any testing so that we can reschedule your visit. *If you use an inhaler to treat asthma, please bring the inhaler with you each time you visit the lab.* We ask participants to arrive at the lab ready to engage in exercise, which means you should arrive dressed in appropriate athletic clothing (i.e., running shoes, shorts, short-sleeved top, etc.), properly hydrated and nourished. Additionally, you should be prepared with your boots and poles to roller ski for visits three and four to the indoor track.

Each visit to the lab is described as follows:

First lab Visit

During the initial visit to the Movement Science / Human Performance Lab and after all necessary forms are completed, anthropometric and demographic data such as age, height, weight, and gender will be collected. You will then be asked to participate in a ski walking/running protocol VO_{2max} test on the treadmill, which will be used to assess your aerobic capacity. This test determines your body's maximal ability to absorb, transport, and then utilize oxygen in the working muscles while ski walking/running on an oversized treadmill. After measuring body weight and height, you will be allowed to warm-up on the treadmill at a self-selected speed and grade for 5-10 minutes (or until you feel comfortable with the testing environment). Using ski poles with rubber tips, you will simulate diagonal stride skiing by poling with the upper body while walking with long strides. Use of the poles on the treadmill allows the upper body to assist the lower body in propelling yourself forward. As the speed of the treadmill increases, it will be easier to change from long walking strides to hill-bounding and finally running. The test itself will start out easy (low treadmill grades and speeds) and gradually increase in difficulty every with each successive stage by increasing both speed and grade. The first 3-5 stages will last 3-minutes each with 1-min of standing rest for a total of 4-mins per stage. While standing at rest, one of the lab technicians will draw a fingertip blood sample from the left hand. This involves a

poking the end of a finger with a sterile lancet until a small blood droplet forms on the end of the finger. This blood sample is then absorbed onto a blood lactate test strip, the finger is wrapped with a bandage, and the next stage begins. These blood sampling stages continue until the technicians observe a significant spike in blood lactate which means that you have crossed what is often called the Lactate Threshold. Once this happens, the treadmill stages change to lasting only 1-minute each and your goal is to last as long as possible while the stages continue to get more and more difficult. The test will end when you literally cannot maintain the pace of the treadmill any longer. These tests typically last a total of 15-20 minutes. The effort put forth at the highest intensity of exercise in the test is comparable to that of competing in a 800 meter running race. *The goal of this test is for you to last as long as you possibly can into the protocol before you reach the point where you must stop.* During the exercise test you will be breathing through a mouthpiece (like a snorkel mouthpiece) so that the amount of oxygen you are using can be measured. As the same time, you will be wearing a *heart rate monitor* strap around your chest to measure heart rate via telemetry.

Second Lab Visit

During the second lab visit, you will perform the upper body power test. The upper body power (UBP) test will evaluate **maximal anaerobic upper body power** using a custom-built stationary ergometer. The ergometer includes ski poles mounted onto pulleys within fixed tracks such that pushing on the ski poles, which are attached to the ergometer via cables, spins the ergometer flywheel to create resistance. The net effect is a stationary activity that effectively simulates the double poling motion of the upper body. After a 5 minute warmup, you will perform the first of four UBPs. The first 3 tests are the same 30-sec test where the first test is a practice that requires only 80% of maximal effort, while the last 2 tests require maximal effort. The goal for the latter two tests is to generate as much UBPs as possible during the last 10-sec. The forth and last test lasts 60 seconds and the goal is to maintain the highest average UBPs possible during the entire 60 sec. All tests are separated by 3-mins of rest with the total test time lasting 15-20 mins.

After approximately a 15 minute break, you will warmup using a cycle ergometer or a running treadmill for about 5 minutes. You will then perform the first of a series of vertical jumping tests. The first test is a maximal 1-jump test, where you will jump vertically one time starting in a standing position with thighs parallel with the floor and hands on hips. Three trials of the 1-jump test were performed (the first was a practice at about 80% of maximal effort, the second and third trials were maximal effort). You will also perform three trials of the 1-jump test with a counter-movement protocol. For the counter-movement protocol, you will start in a standing position with knees and hips extended and hands on hips. Next, you will perform two trials of a four consecutive jump test, during which you will jump as high and as quickly as possible four successive times. You will start in a

standing position with knees and hips extended and be able to use an arm swing for the test. The two trials will be held about 2 minutes apart with the first trial being a practice and the second being a maximal effort. The third and final vertical jump test was one trial of 60 seconds of jumping. For this last test, you start from a standing position with knees and hips extended and are allowed to swing your arms to maintain stability while jumping. The total test will last about 15-20 minutes.

Third Visit

During the third visit, you will perform tests of peak skate speed and 400 m sprint speed. After warming up for 20 minutes on the indoor track with roller skis and poles, you will perform 2-3 intervals of 10-15 seconds at about 90% maximal effort. These intervals are so you can familiarize yourself with the track's surface at fast roller skiing speeds. For the peak skate speed test you will use a "flying start" that allows for you to build up speed around a corner of the track and then you will sprint maximally, using either the V2 alternate or V2 technique, along a 40 m straight away. You will perform three trials allowing adequate recovery between trials lasting no more than three minutes. Following the peak skate speed test, you will roller ski easily around the indoor track for about 10 minutes to recover and prepare for the 400 m sprint. You will use a standing start and be given a 5-second count down before performing a two-lap sprint around the 200 m track at maximal effort using a combination of V2 and V2 alternate techniques. You will perform two trials of this test with about 10 minutes between trials. Immediately after you finish the sprint, recovery measures of heart rate and blood lactate were collected at 1, 3, and 5 minutes after the sprint. During the time between trials, you will be required to keep the body moving at minimal intensity to facilitate recovery.

Fourth Visit

During the fourth visit, you will perform a time trial on roller skis. After warming up for 30 minutes, you will immediately prepare for the race (i.e., clothes, drink, and 10-15 second intervals of about 90% of maximal effort). You will perform a 1200 m time trial at maximal effort by roller skiing 6 laps around the 200 m indoor track, using combinations of V2 alternate and V2 techniques.

Potential Risks:

You should be aware that a VO_{2max} test, UBP test, vertical jump test, peak skate speed test, 400 m sprint, and time trial can cause extreme fatigue immediately after the test as well the next day. Because VO_{2max} testing involves such high intensity exercise, there is a chance of precipitating a cardiac event (such as abnormal heart rhythms) or even death during the test. The possibility, however, of such an occurrence is very slight (less than 1 in 10,000) because of you are in good physical condition with no known symptoms of heart disease. Additionally, the test

will be administered by trained personnel (American Red Cross CPR certified) who are familiar with the lab's emergency action plan. *These risks are certainly no greater than those experienced by trained athletes in actual race competition.*

During the first lab visit, you will be required to wear headgear with an attached mouthpiece for the test. As a result, you may experience some degree of discomfort during the test. The headgear and mouthpiece support the gas collection tube during exercise and, despite being uncomfortable, are required to accurately assess your aerobic capacity. Provisions will be made to ensure each subject is as comfortable as possible during all procedures in the testing sessions.

In addition to wearing the gas-collection headgear, samples of blood will be drawn via a finger stick periodically the first and third testing sessions. Although the amount of blood drawn per sample is minimal (5-10 drops), each sample is vital to assess the intensity of exercise (as determined by blood lactate) during the testing procedure. You may experience some degree of discomfort during this process, and some minor bruising at the site of the finger stick may occur after the testing is done. The risk of local infection is less than 1 in 1,000. Provisions will be made to ensure that this procedure is as safe, efficient, and painless as possible.

Subject Compensation:

You will receive a copy of your own test results through your coach, Dragan Danevski. There are no other forms of compensation available for this participating in this project.

Benefits:

There are no direct benefits to you as a volunteer for this project. The principle investigator, however, is willing to discuss the interpretation of your own test results, as well as those for the study upon completion. You may contact the principle investigator, Sarah Willis, by phone at (320) 894-7006 or by email at skierwillie@gmail.com to discuss this option further.

Confidentiality:

The data and personal information obtained from this study will be regarded as privileged and confidential. They will not be released 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 subject'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 this 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 your appointments at the Movement Science / Human Performance Laboratory. *Further information regarding medical treatment may be obtained by calling the Project Director, Sarah Willis, at 320-894-7006.* 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 their ability prior to any testing. The Project Director fully intends to conduct the study with your best interest, safety and comfort in mind. *Additional questions about the rights of human subjects can be answered by the Chairman of the Human Subjects Committee, Mark Quinn, at 406-994-5721.*

PROJECT TITLE: *Determinants of Skate Sprint Cross-Country Skiing Performance for Junior and Collegiate Skiers*

STATEMENT OF AUTHORIZATION

I, *the participant*, have read the Informed Consent Document and understand the discomforts, inconvenience, risks, and benefits of this project. I,
 _____ (*print your name*), agree to participate in the project described in the preceding pages. 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.

Signed: _____ **Age** _____ **Date** _____

Subject's Signature

APPENDIX B

TRAINING HISTORY QUESTIONNAIRE

Training and Experience Questionnaire

Name:

Please include an address if you would like a copy of your test results.

How do you classify yourself as an athlete (e.g. runner, cross-country skier, triathlete etc.)?

How many months out of the year do you train/race consistently? Please specify the time period for each year.

How many hours of general training did you complete in the last year? In the last week?

Please describe the type and frequency of your racing in the past two months.

How many years have you been training/racing competitively?

What percentage of your ski training is high intensity (at or above threshold ~ 85% of maximal effort)?

What percentage of your ski training is at low intensity (below threshold ~ 50 – 85%)?

What percentage of your ski training is classic technique? What percentage is skate technique? What percentage is on roller skis during the summer?

Have you had any recent injuries that may adversely affect your performance? If so, please describe.

Please list any medications, supplements, or ergogenic aids that you are currently using.

APPENDIX C

SCATTER PLOTS OF ALL DEPENDENT VARIABLES VERSUS
SKATE SPRINT SPEED

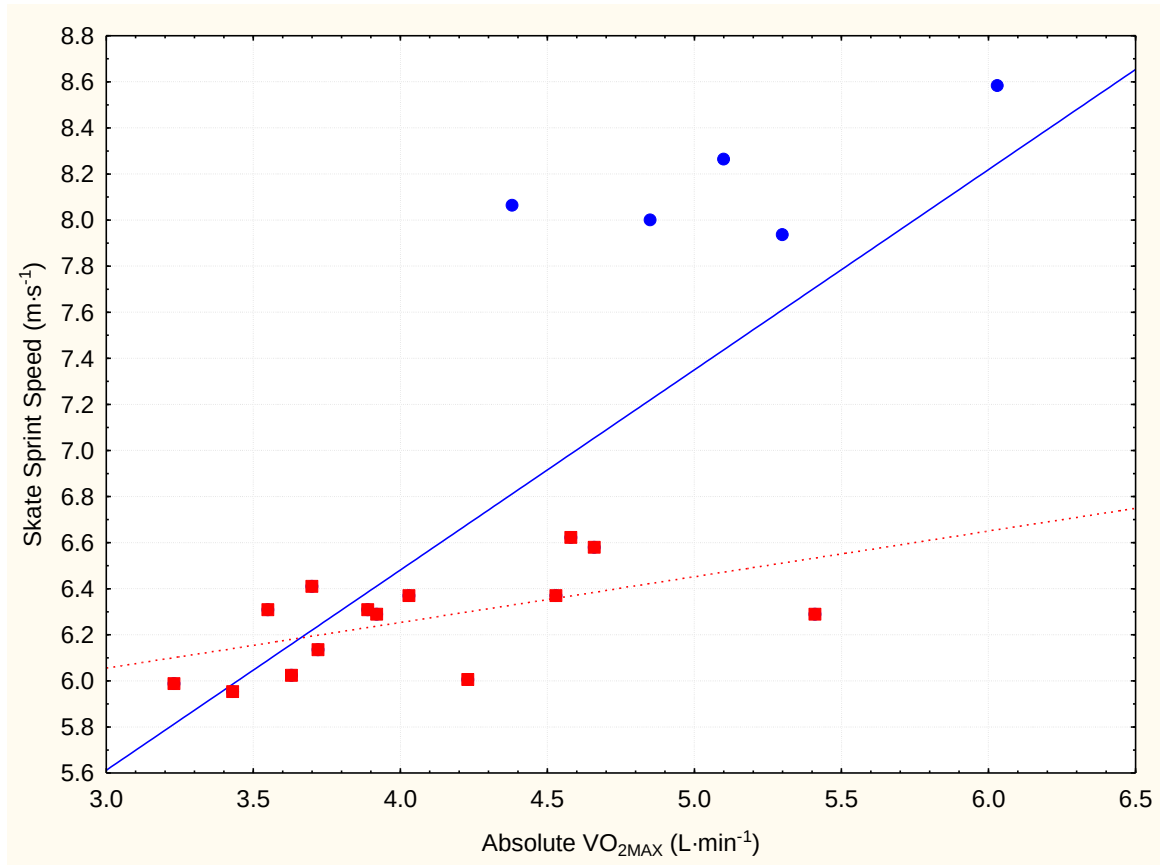


Figure 6. Scatter plot of relationship between absolute VO₂MAX (absolute VO₂MAX) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for absolute VO₂MAX with all subjects included (Skate Sprint Speed = $3.00 + 0.8689 \times \text{absolute VO}_{2\text{MAX}}$; $r = 0.74$; $P < 0.001$; SEE = ± 0.38 m/sec). Dashed line is a regression for absolute VO₂MAX with all subjects excluding the cluster of the five fastest skiers (Skate Sprint Speed = $5.46 + 0.1992 \times \text{absolute VO}_{2\text{MAX}}$; $r = 0.55$; $P = 0.034$; SEE = ± 0.03 m/sec).

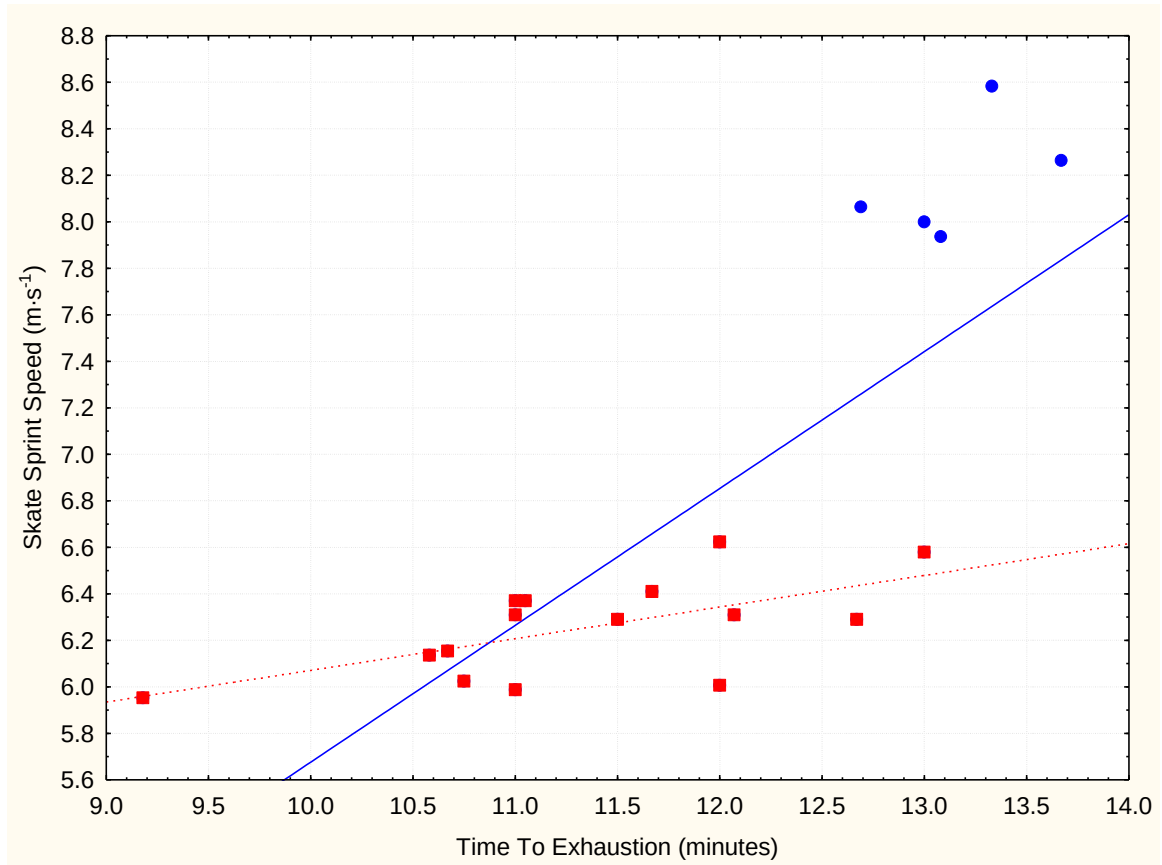


Figure 7. Scatter plot of relationship between time to exhaustion (TTE) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for TTE with all subjects included (Skate Sprint Speed = $-0.21 + 0.5888 \times \text{TTE}$; $r = 0.78$; $P < 0.001$; $\text{SEE} = \pm 0.32 \text{ m/sec}$). Dashed line is a regression for TTE with all subjects excluding the cluster of the five fastest skiers (Skate Sprint Speed = $4.69 + 0.1375 \times \text{TTE}$; $r = 0.63$; $P = 0.012$; $\text{SEE} = \pm 0.03 \text{ m/sec}$).

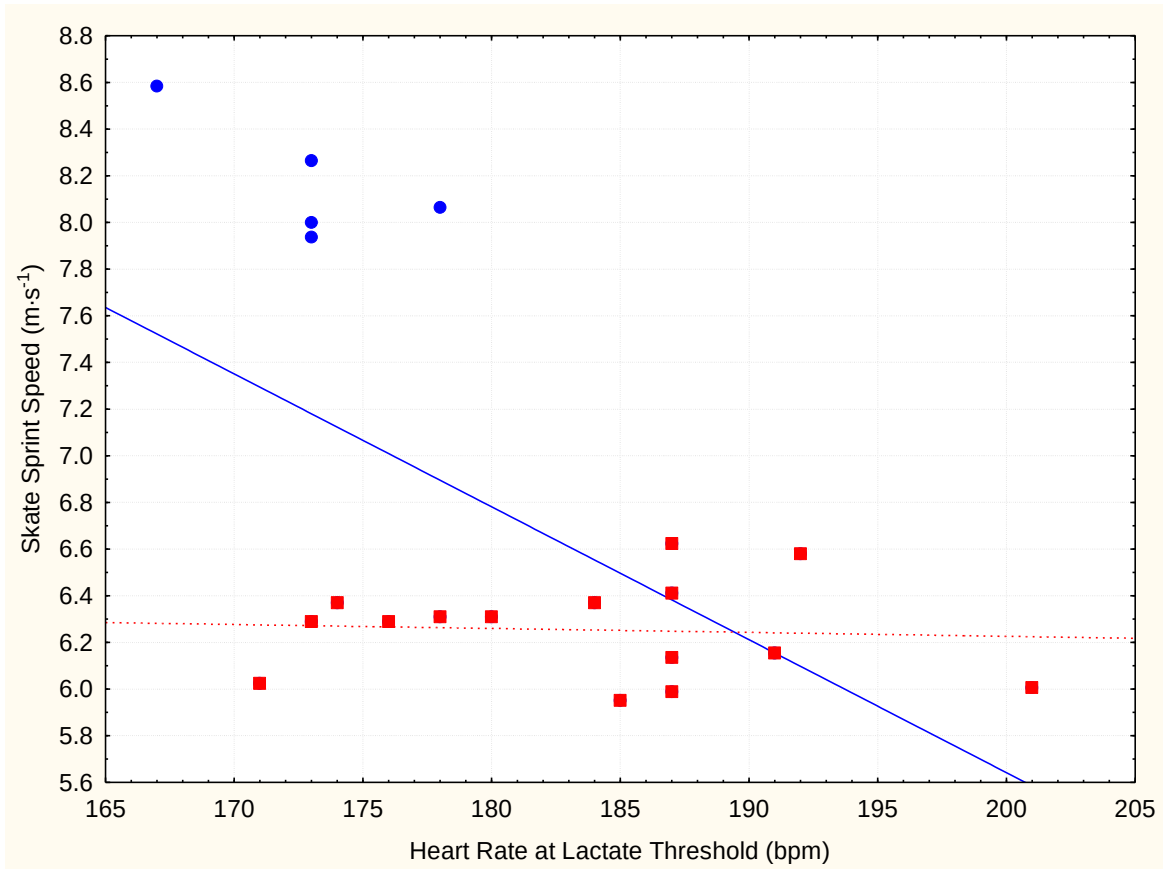


Figure 8. Scatter plot of relationship between heart rate at lactate threshold (HR_{LT}) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for HR_{LT} with all subjects included ($\text{Skate Sprint Speed} = 17.02 + -0.0569 \times HR_{LT}$; $r = -0.56$; $P = 0.010$; $SEE = \pm 0.55 \text{ m/sec}$). Dashed line is a regression for HR_{LT} with all subjects excluding the cluster of the five fastest skiers ($\text{Skate Sprint Speed} = 6.55 + -0.0016 \times HR_{LT}$; $r = -0.07$; $P = 0.819$; $SEE = \pm 0.05 \text{ m/sec}$).

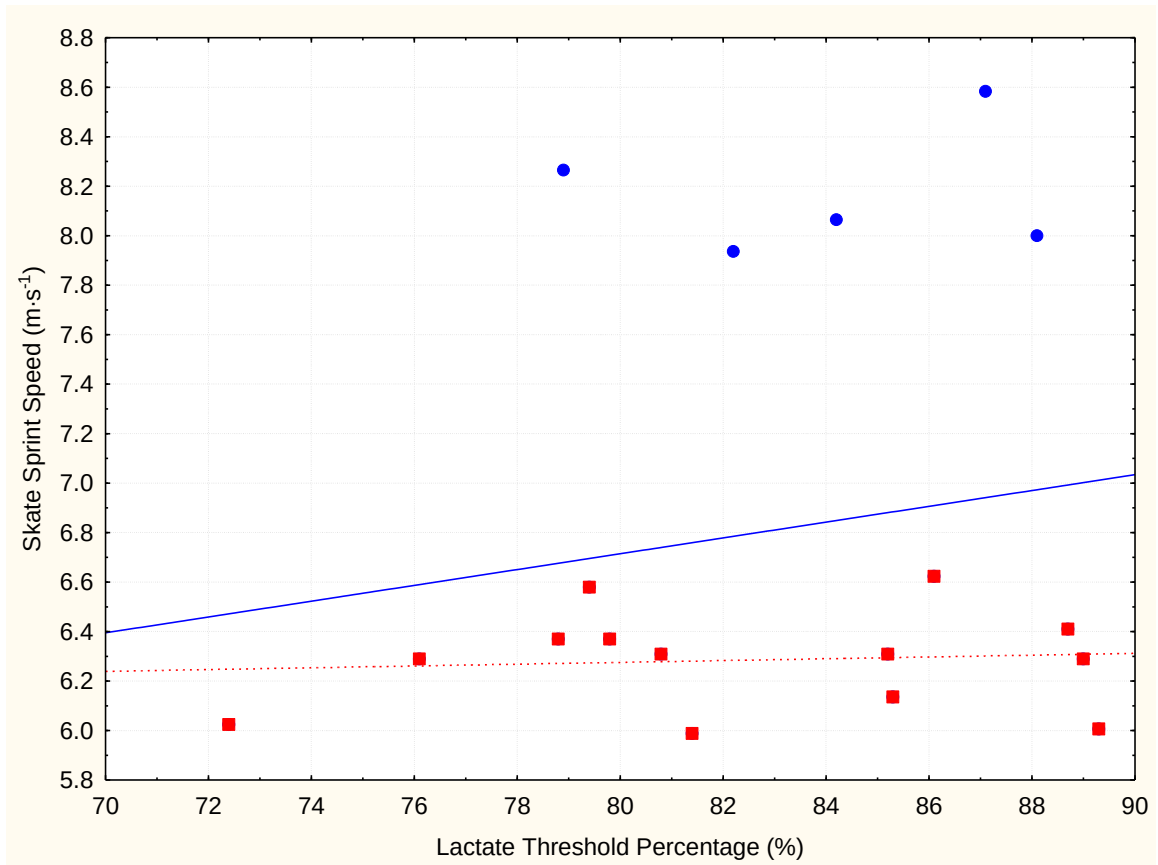


Figure 9. Scatter plot of relationship between lactate threshold percentage (LT %) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for LT % with all subjects included (Skate Sprint Speed = $4.15 + 0.0320 \times \text{LT \%}$; $r = 0.17$; $P = 0.491$; $\text{SEE} = \pm 0.82 \text{ m/sec}$). Dashed line is a regression for LT % with all subjects excluding the cluster of the five fastest skiers (Skate Sprint Speed = $5.98 + 0.0037 \times \text{LT \%}$; $r = 0.1$; $P = 0.751$; $\text{SEE} = \pm 0.04 \text{ m/sec}$).

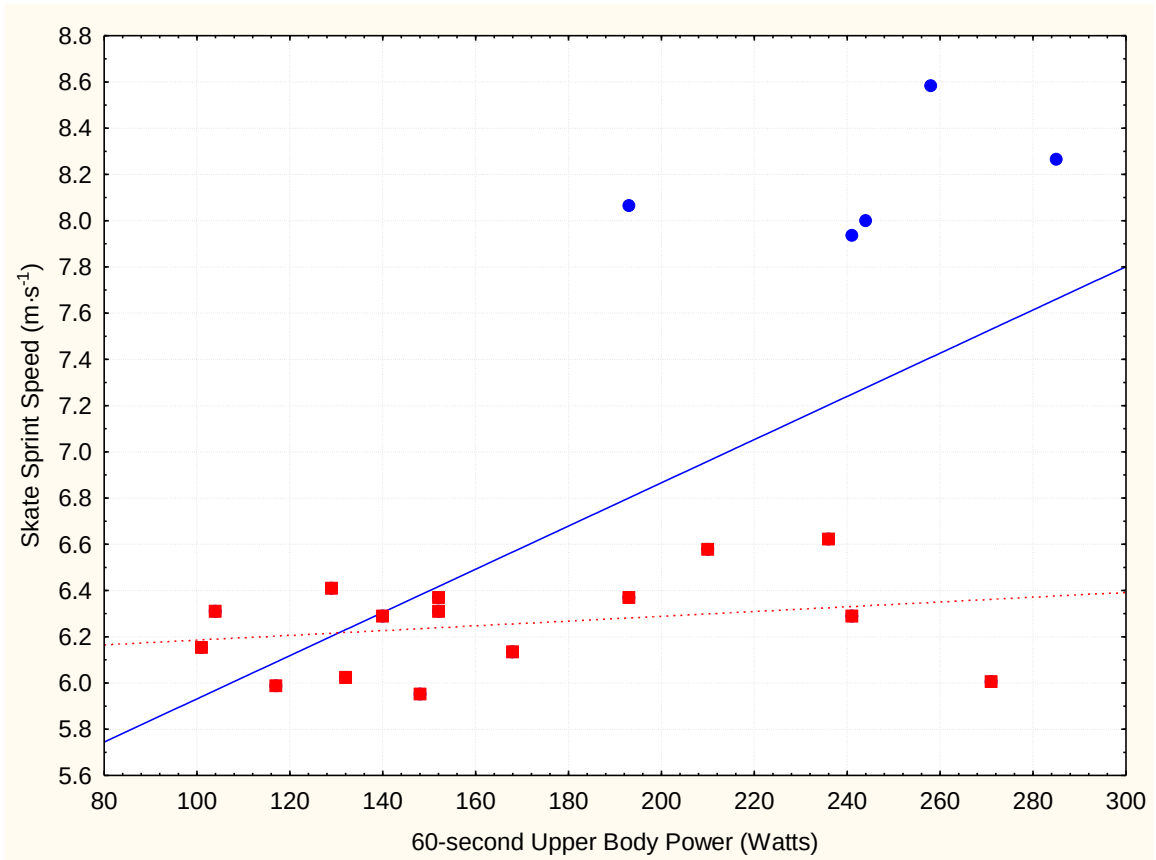


Figure 10. Scatter plot of relationship between 60-second upper body power (UBP60) and skate sprint speed. Circles represent the cluster of the five fastest skiers. Squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for UBP60 with all subjects included (Skate Sprint Speed = $5.00 + 0.0094x$ UBP60; $r = 0.63$; $P = 0.003$; $SEE = \pm 0.49$ m/sec). Dashed line is a regression for UBP60 with all subjects excluding the cluster of the five fastest skiers (Skate Sprint Speed = $6.08 + 0.0011x$ UBP60; $r = 0.27$; $P = 0.339$; $SEE = \pm 0.04$ m/sec).

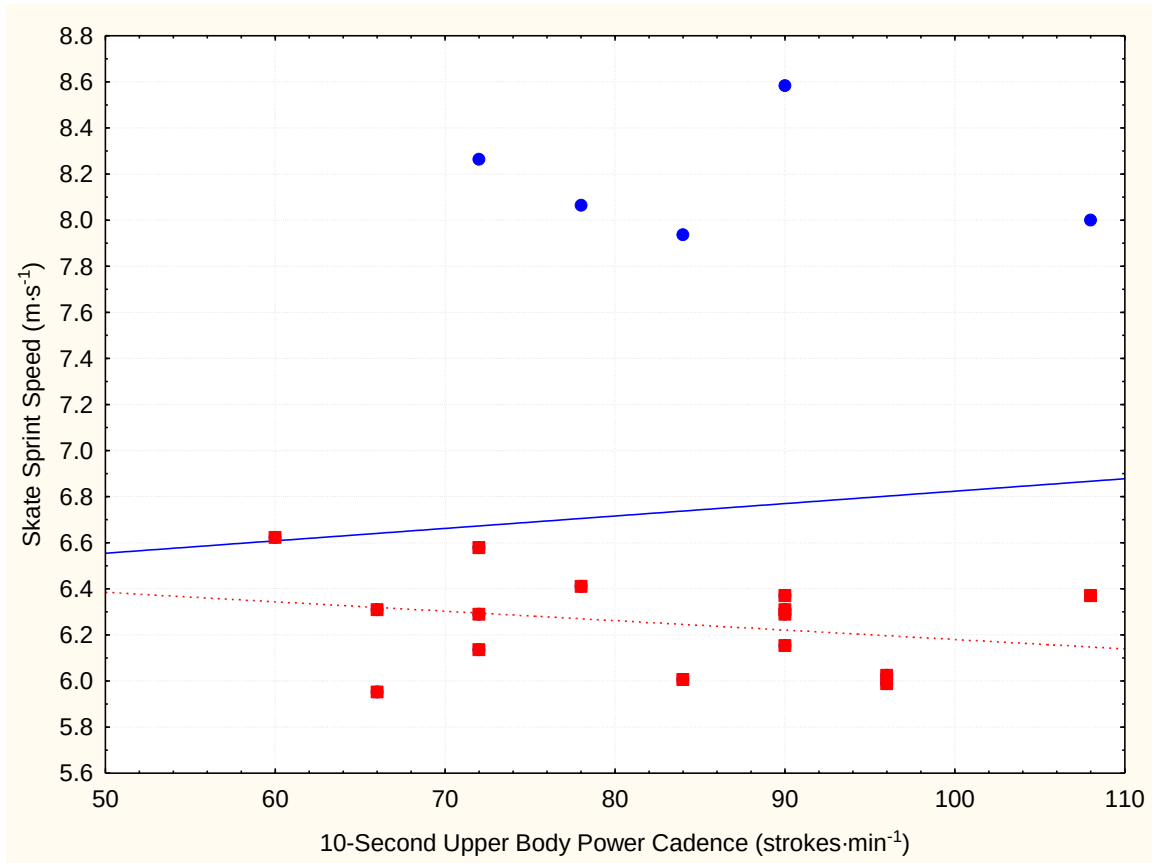


Figure 11. Scatter plot of relationship between 10-second upper body power cadence (UBP10-C) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for UBP10-C with all subjects included (Skate Sprint Speed = $6.28 + 0.0054x$ UBP10-C; $r = 0.10$; $P = 0.675$; $SEE = \pm 0.81$ m/sec). Dashed line is a regression for UBP10-C with all subjects excluding the cluster of the five fastest skiers (Skate Sprint Speed = $6.59 + -0.0041x$ UBP10-C; $r = 0.27$; $P = 0.330$; $SEE = \pm 0.04$ m/sec).

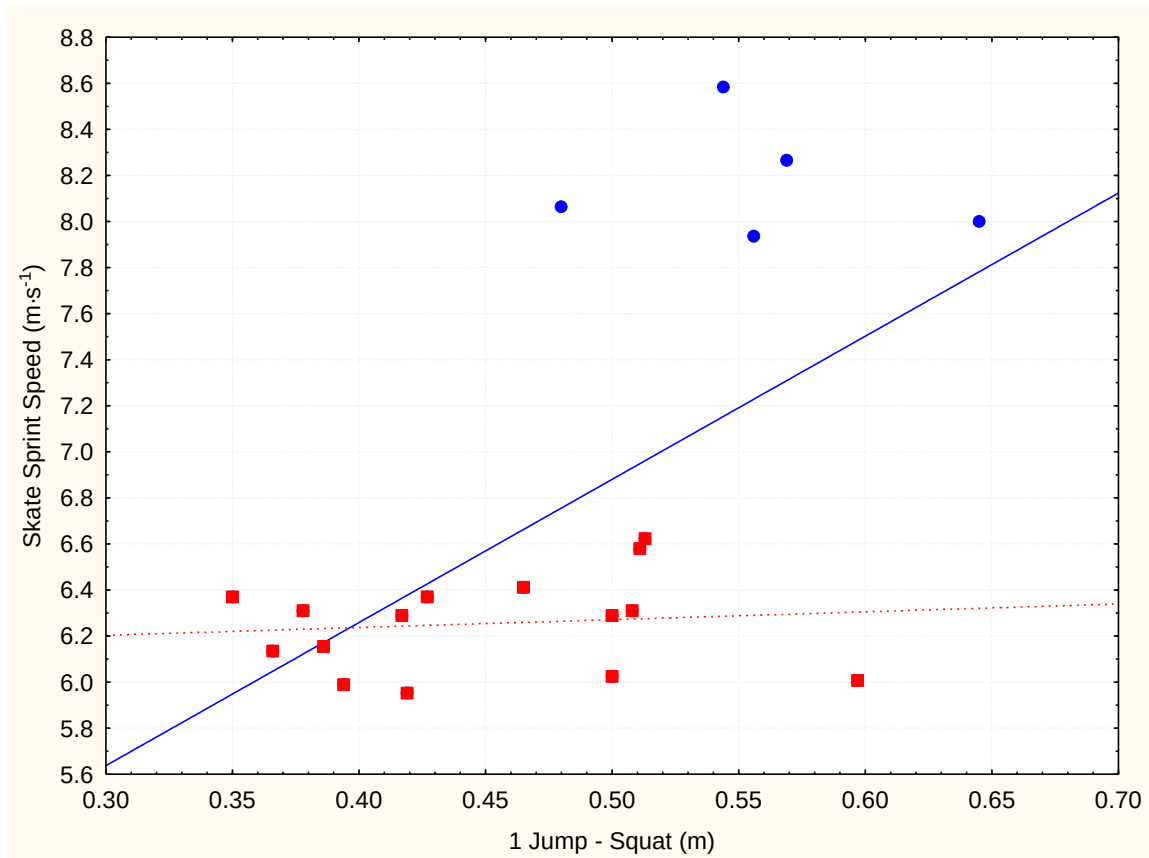


Figure 12. Scatter plot of relationship between 1 jump squat jump height (1J-S) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for 1J-S with all subjects included (Skate Sprint Speed = $3.77 + 0.1580 \times 1J-S$; $r = 0.59$; $P = 0.007$; $SEE = \pm 0.54$ m/sec). Dashed line is a regression for 1J-S with all subjects excluding the cluster of the five fastest skiers (Skate Sprint Speed = $6.10 + 0.0089 \times 1J-S$; $r = 0.12$; $P = 0.672$; $SEE = \pm 0.05$ m/sec).

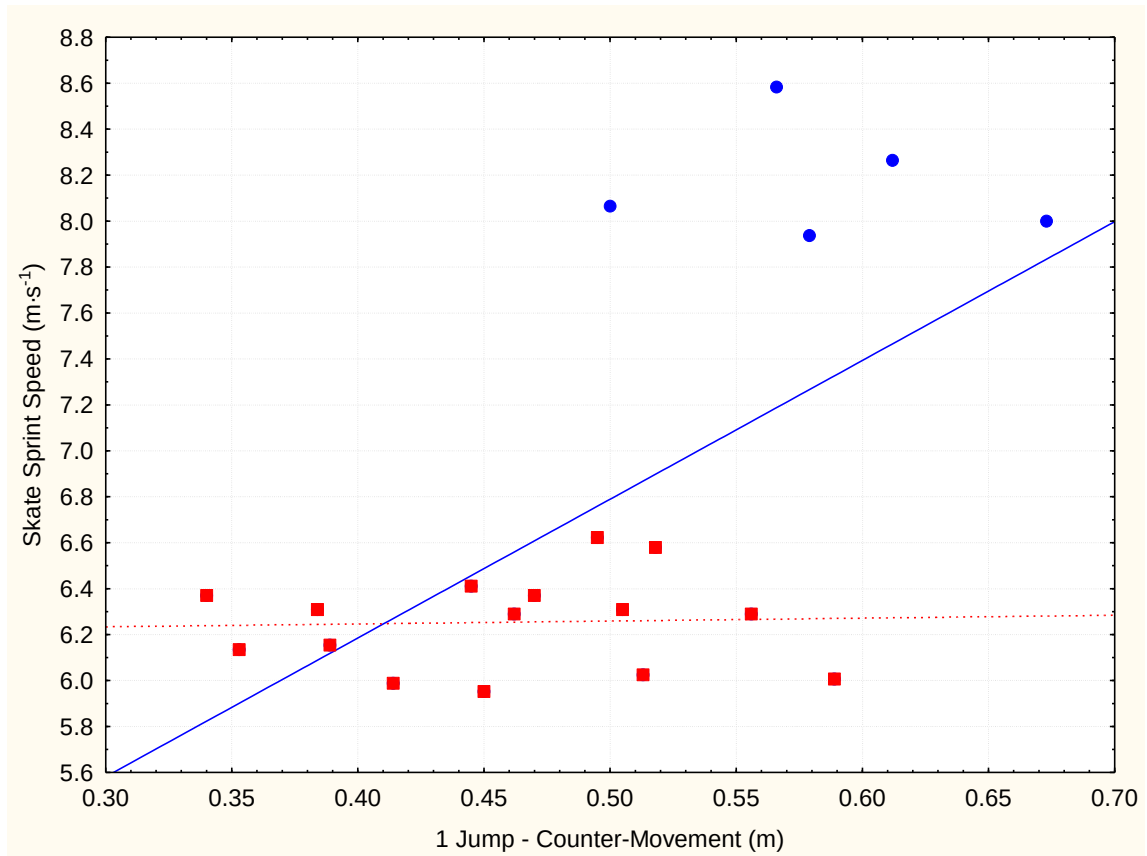


Figure 13. Scatter plot of relationship between 1 jump - counter-movement jump height (1J-CM) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for 1J-CM with all subjects included (Skate Sprint Speed = $3.77 + 0.1534 \times 1J\text{-CM}$; $r = 0.62$; $P = 0.004$; $SEE = \pm 0.51$ m/sec). Dashed line is a regression for 1J-CM with all subjects excluding the cluster of the five fastest skiers (Skate Sprint Speed = $6.19 + 0.0036 \times 1J\text{-CM}$; $r = 0.05$; $P = 0.860$; $SEE = \pm 0.05$ m/sec).

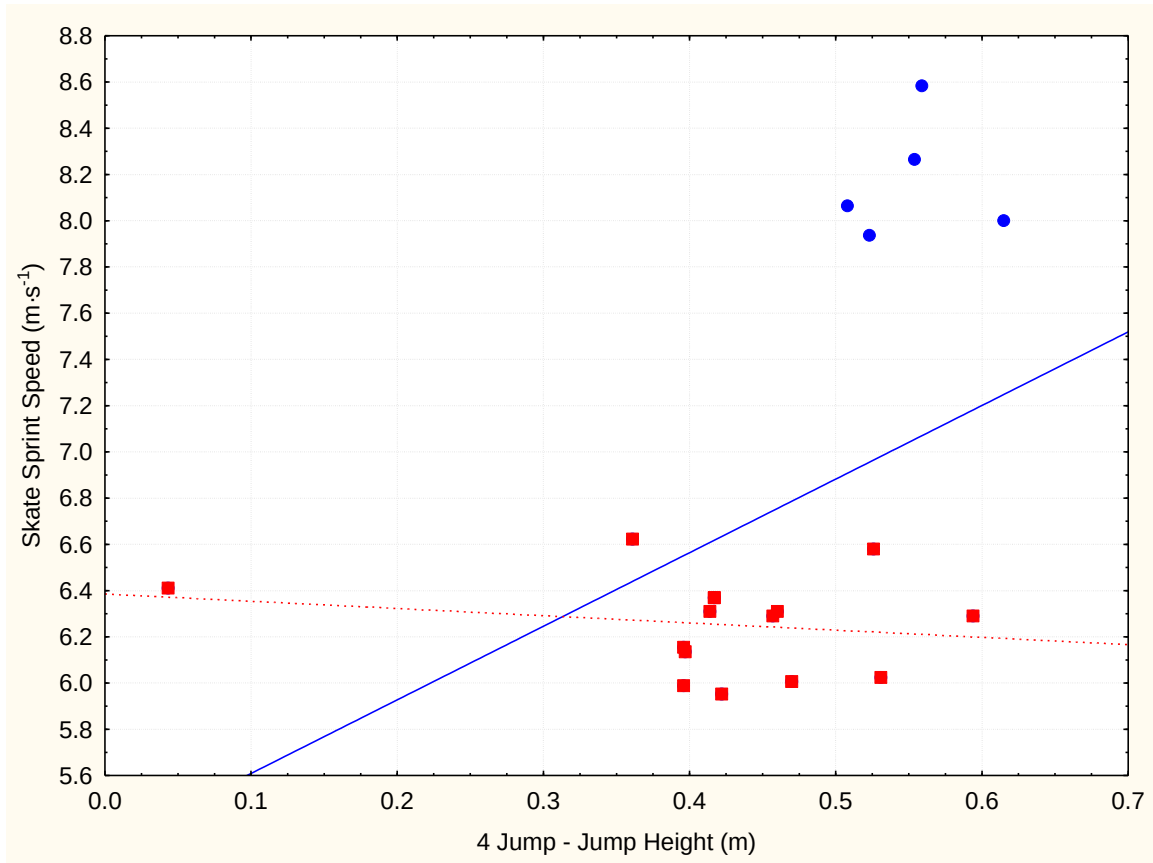


Figure 14. Scatter plot of relationship between 4 jump - jump height (4J-JH) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for 4J-JH with all subjects included (Skate Sprint Speed = $3.26 + 0.1865 \times 4J\text{-}JH$; $r = 0.62$; $P = 0.004$; $SEE = \pm 0.50$ m/sec). Dashed line is a regression for 4J-JH with all subjects excluding the cluster of the five fastest skiers (Skate Sprint Speed = $6.28 - 0.0012 \times 4J\text{-}JH$; $r = -0.02$; $P = 0.959$; $SEE = \pm 0.05$ m/sec).

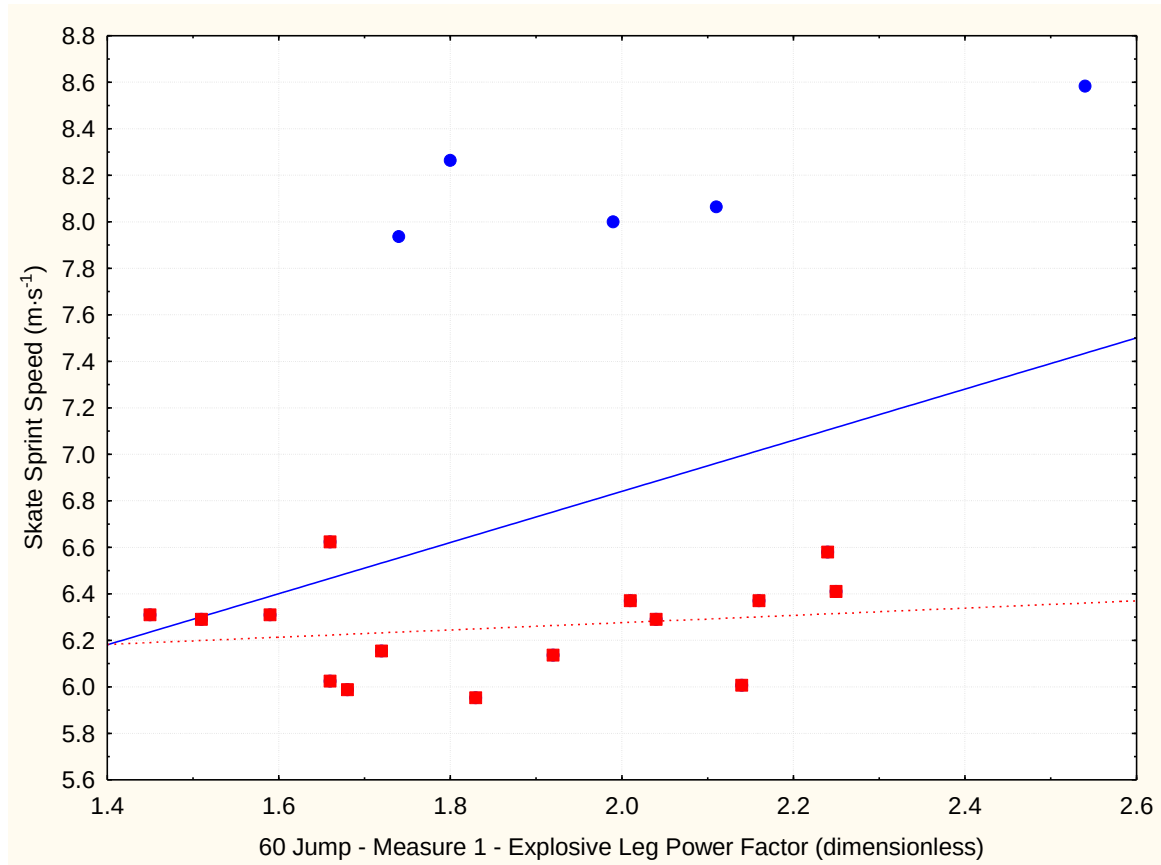


Figure 15. Scatter plot of relationship between measure 1 from 60 jump explosive leg power factor (60J-ELPF-1) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for 60J-ELPF-1 with all subjects included (Skate Sprint Speed = $4.64 + 1.0993 \times 60J\text{-ELPF-1}$; $r = 0.36$; $P = 0.122$; $SEE = \pm 0.71$ m/sec). Dashed line is a regression for 60J-ELPF-1 with all subjects excluding the cluster of the five fastest skiers (Skate Sprint Speed = $5.96 + 0.1586 \times 60J\text{-ELPF-1}$; $r = 0.21$; $P = 0.461$; $SEE = \pm 0.04$ m/sec).

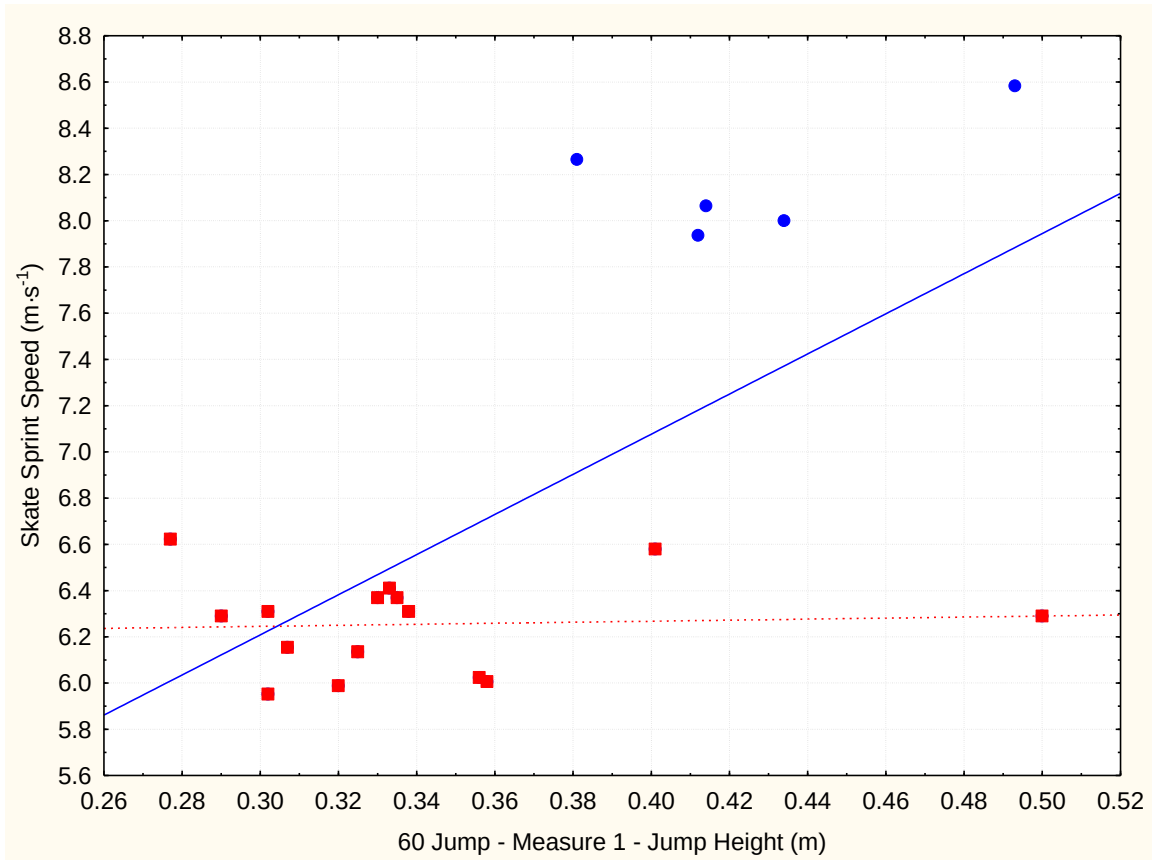


Figure 16. Scatter plot of relationship between measure 1 from 60 jump - jump height (60J-JH-1) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for 60J-JH-1 with all subjects included (Skate Sprint Speed = $3.61 + 0.2200 \times 60J-JH-1$; $r = 0.63$; $P = 0.003$; $SEE = \pm 0.49$ m/sec). Dashed line is a regression for 60J-JH-1 with all subjects excluding the cluster of the five fastest skiers (Skate Sprint Speed = $6.17 + 0.0060 \times 60J-JH-1$; $r = 0.06$; $P = 0.828$; $SEE = \pm 0.05$ m/sec).

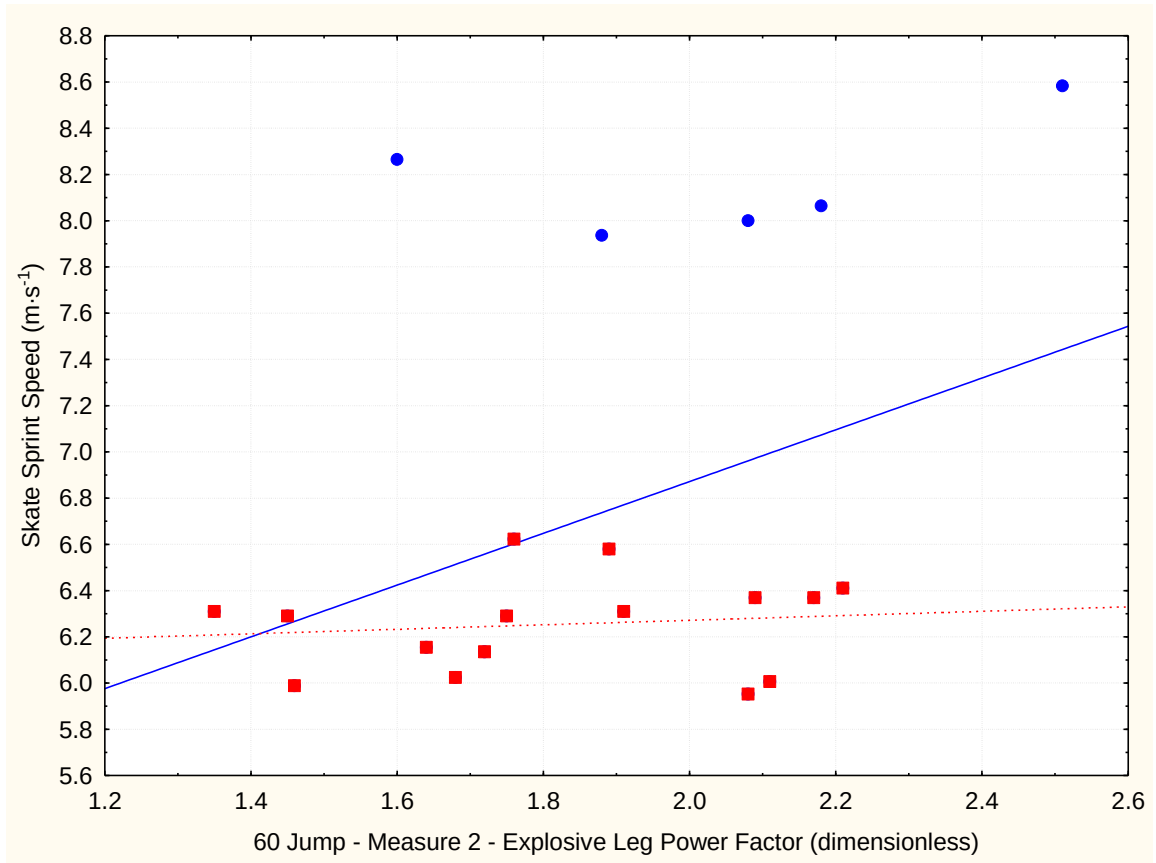


Figure 17. Scatter plot of relationship between measure 2 from 60 jump explosive leg power factor (60J-ELPF-2) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for 60J-ELPF-2 with all subjects included (Skate Sprint Speed = $4.63 + 1.1192 \times 60\text{J-ELPF-2}$; $r = 0.39$; $P = 0.093$; $\text{SEE} = \pm 0.69 \text{ m/sec}$). Dashed line is a regression for 60J-ELPF-2 with all subjects excluding the cluster of the five fastest skiers (Skate Sprint Speed = $6.07 + 0.0987 \times 60\text{J-ELPF-2}$; $r = 0.13$; $P = 0.641$; $\text{SEE} = \pm 0.05 \text{ m/sec}$).

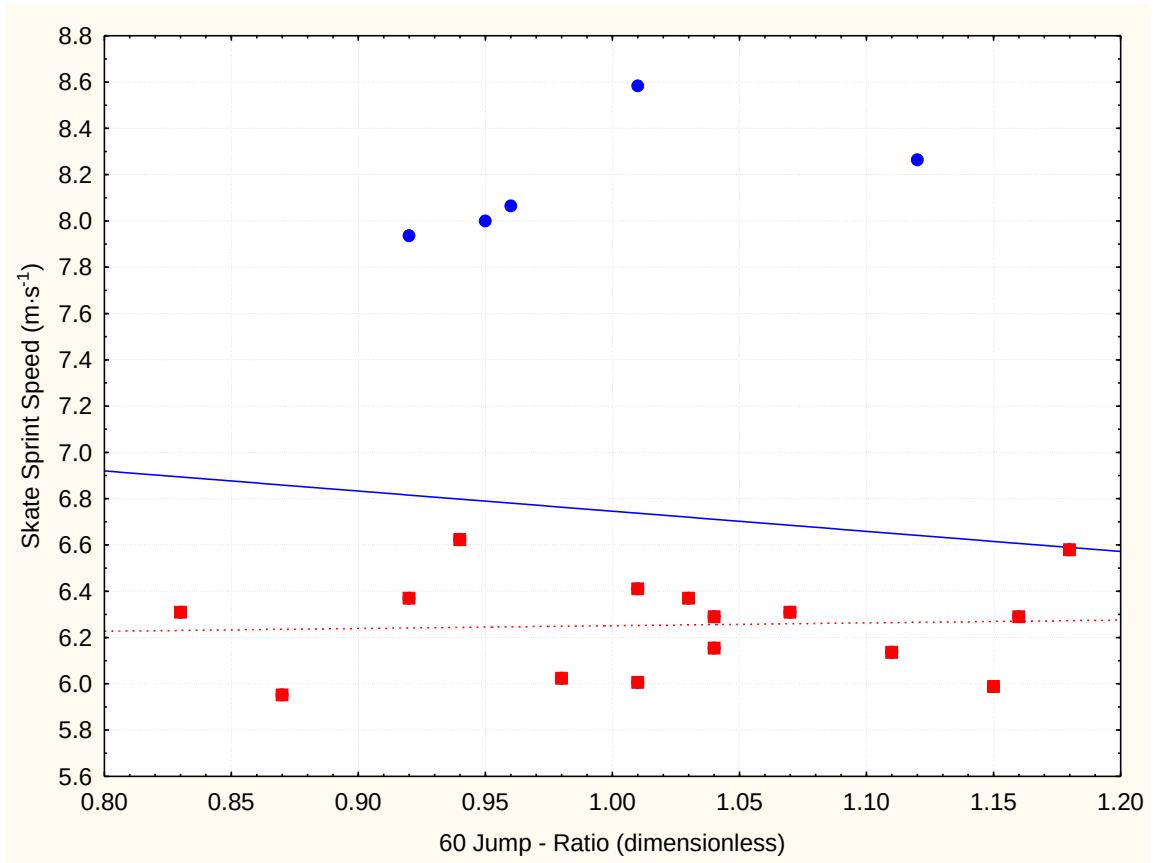


Figure 18. Scatter plot of relationship between 60 jump ratio (60J-Ratio) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for 60J-Ratio with all subjects included (Skate Sprint Speed = $7.62 + -0.8706 \times 60J\text{-Ratio}$; $r = -0.1$; $P = 0.687$; $SEE = \pm 0.81$ m/sec). Dashed line is a regression for 60J-Ratio with all subjects excluding the cluster of the five fastest skiers (Skate Sprint Speed = $6.13 + 0.1242 \times 60J\text{-Ratio}$; $r = 0.06$; $P = 0.826$; $SEE = \pm 0.05$ m/sec).

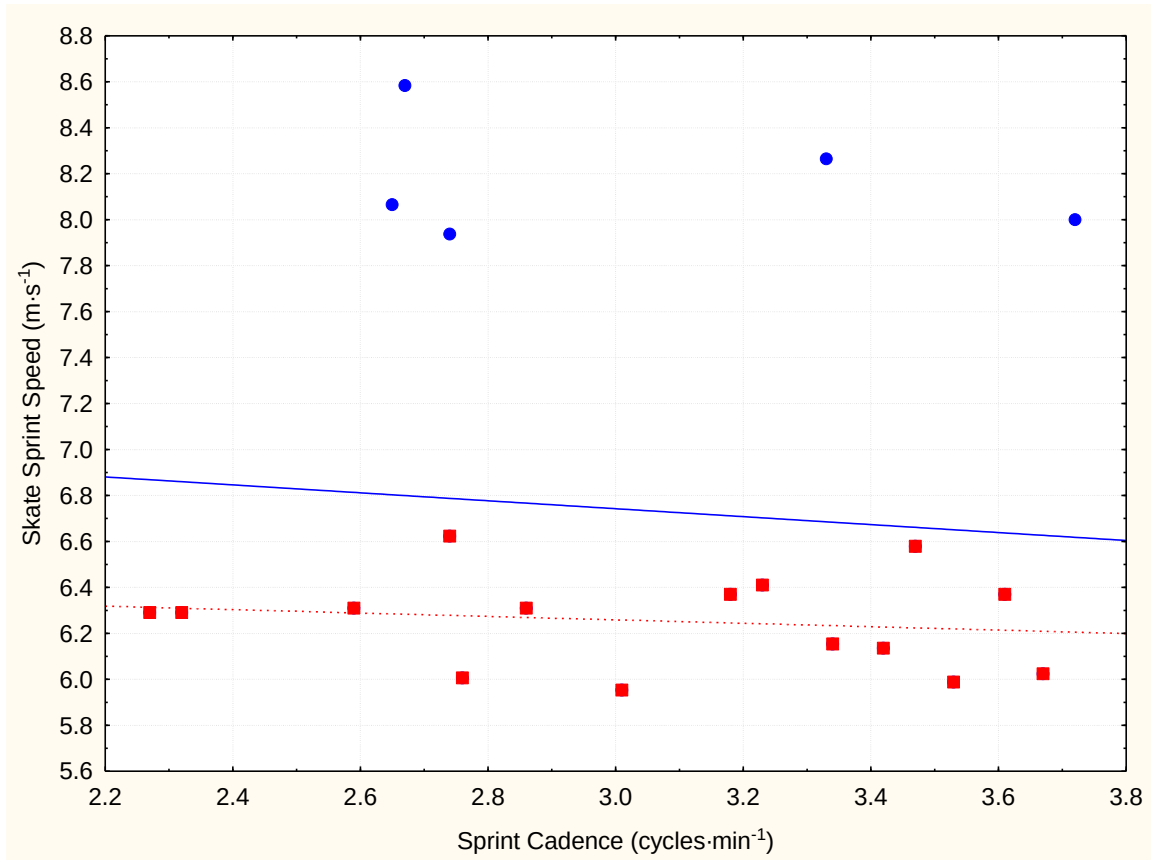


Figure 19. Scatter plot of relationship between sprint cadence (Spr-Cad) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for Spr-Cad with all subjects included (Skate Sprint Speed = $7.26 + -0.1741 \times \text{Spr-Cad}$; $r = -0.1$; $P = 0.675$; $\text{SEE} = \pm 0.81 \text{ m/sec}$). Dashed line is a regression for Spr-Cad with all subjects excluding the cluster of the five fastest skiers (Skate Sprint Speed = $6.49 + -0.0761 \times \text{Spr-Cad}$; $r = -0.17$; $P = 0.545$; $\text{SEE} = \pm 0.05 \text{ m/sec}$).

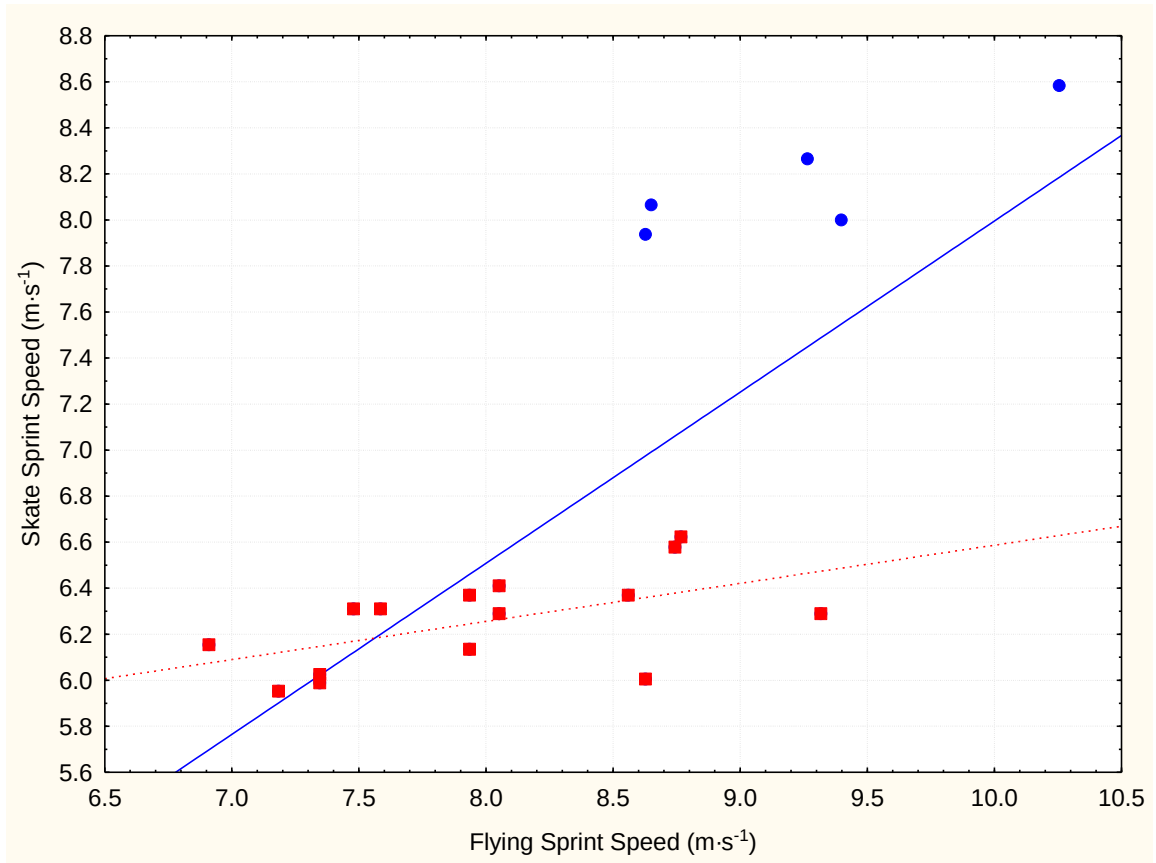


Figure 20. Scatter plot of relationship between flying sprint speed (Flying Sprint Speed) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for Flying Sprint Speed with all subjects included (Skate Sprint Speed = $0.56 + 0.7429 \times \text{Flying Sprint Speed}$; $r = 0.74$; $P < 0.001$; SEE = ± 0.37 m/sec). Dashed line is a regression for Flying Sprint Speed with all subjects excluding the cluster of the five fastest skiers (Skate Sprint Speed = $4.92 + 0.1666 \times \text{Flying Sprint Speed}$; $r = 0.56$; $P = 0.031$; SEE = ± 0.03 m/sec).

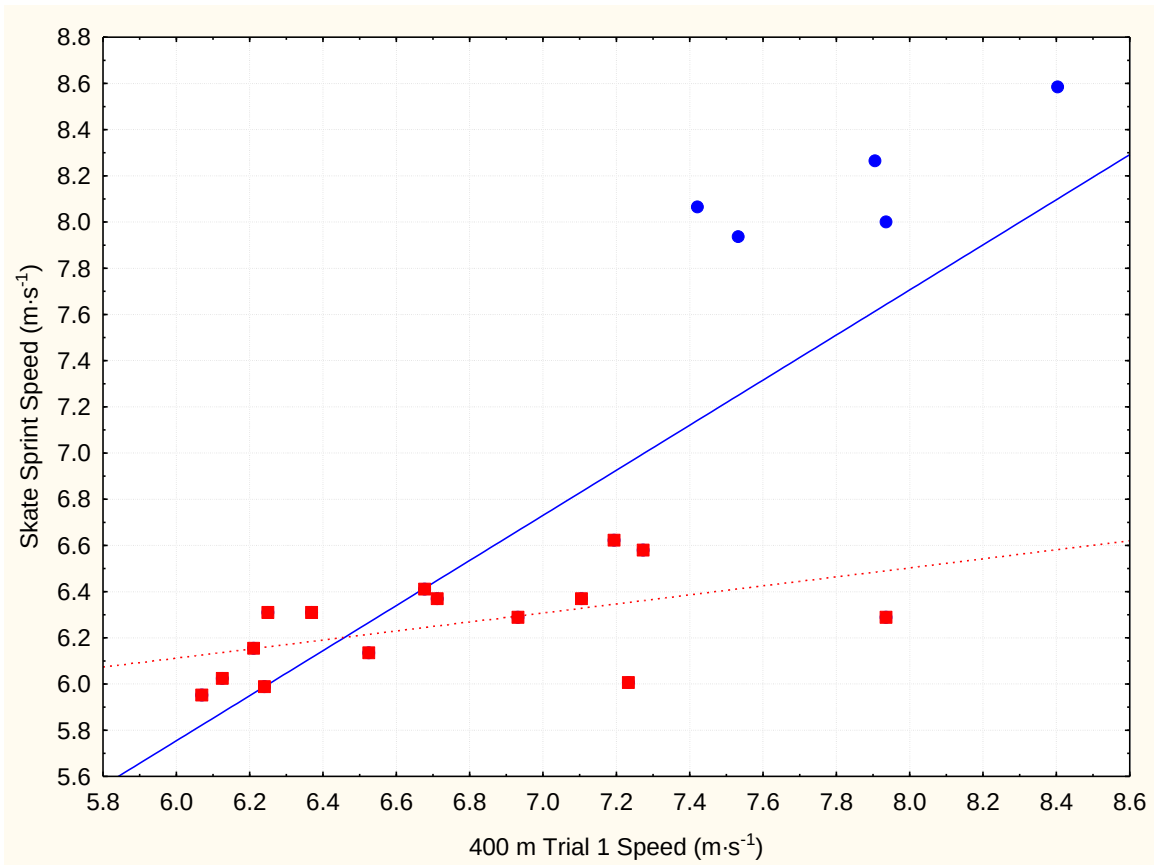


Figure 21. Scatter plot of relationship between 400 m trial 1 speed (400 m Trial 1 Speed) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for 400 m Trial 1 Speed with all subjects included (Skate Sprint Speed = $-0.11 + 0.9768 \times 400 \text{ m Trial 1 Speed}$; $r = 0.78$; $P < 0.001$; $\text{SEE} = \pm 0.32 \text{ m/sec}$). Dashed line is a regression for 400 m Trial 1 Speed with all subjects excluding the cluster of the five fastest skiers (Skate Sprint Speed = $4.93 + 0.1970 \times 400 \text{ m Trial 1 Speed}$; $r = 0.51$; $P = 0.050$; $\text{SEE} = \pm 0.03 \text{ m/sec}$).

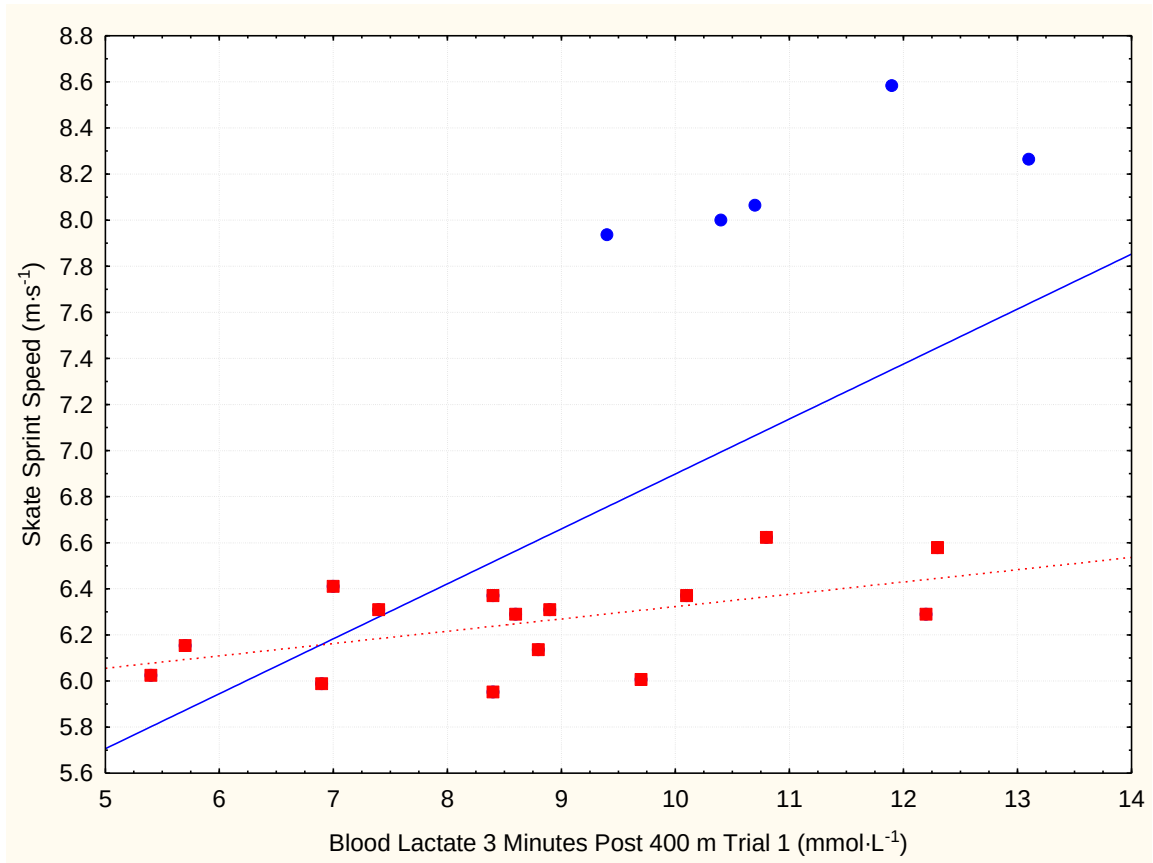


Figure 22. Scatter plot of relationship between 3 minutes post 400 m trial 1 blood lactate (LAT1-3) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for LAT1-3 with all subjects included (Skate Sprint Speed = $4.51 + 0.2385 \times \text{LAT1-3}$; $r = 0.59$; $P = 0.006$; $\text{SEE} = \pm 0.53 \text{ m/sec}$). Dashed line is a regression for LAT1-3 with all subjects excluding the cluster of the five fastest skiers (Skate Sprint Speed = $5.78 + 0.0539 \times \text{LAT1-3}$; $r = 0.54$; $P = 0.038$; $\text{SEE} = \pm 0.03 \text{ m/sec}$).

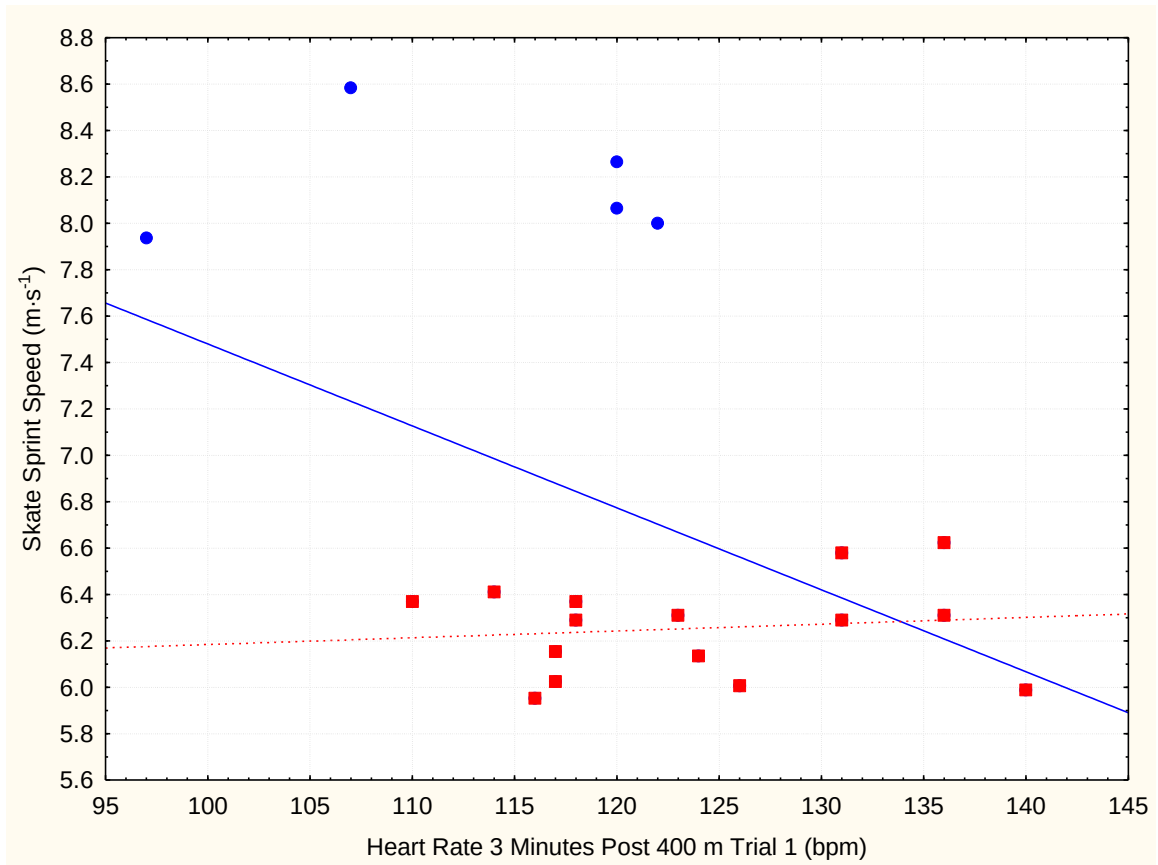


Figure 23. Scatter plot of relationship between 3 minutes post 400 m trial 1 heart rate (HRT1-3) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for HRT1-3 with all subjects included (Skate Sprint Speed = $11.01 + -0.0353 \times \text{HRT1-3}$; $r = -0.42$; $P = 0.065$; $\text{SEE} = \pm 0.67 \text{ m/sec}$). Dashed line is a regression for HRT1-3 with all subjects excluding the cluster of the five fastest skiers (Skate Sprint Speed = $5.88 + 0.0030 \times \text{HRT1-3}$; $r = 0.13$; $P = 0.638$; $\text{SEE} = \pm 0.05 \text{ m/sec}$).

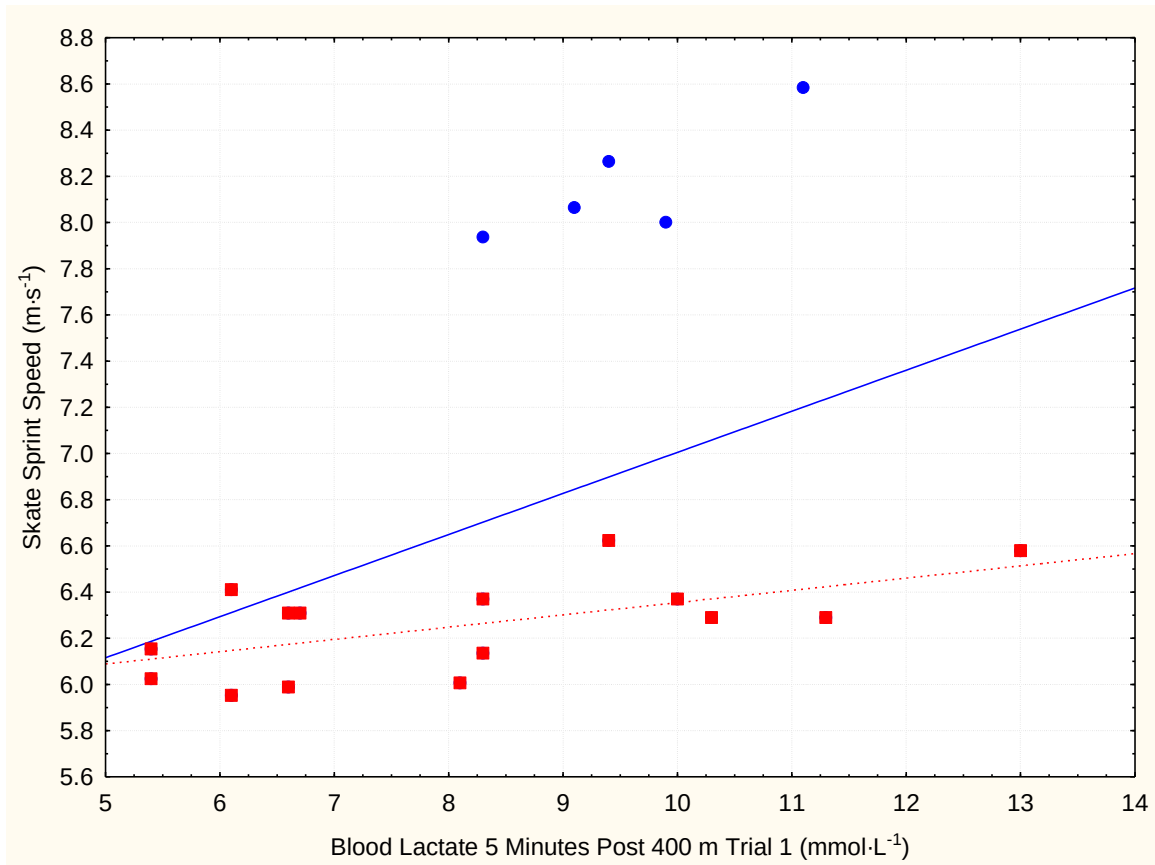


Figure 24. Scatter plot of relationship between 5 minutes post 400 m trial 1 blood lactate (LAT1-5) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for LAT1-5 with all subjects included (Skate Sprint Speed = $5.22 + 0.1780 \times \text{LAT1-5}$; $r = 0.43$; $P = 0.058$; $\text{SEE} = \pm 0.66 \text{ m/sec}$). Dashed line is a regression for LAT1-5 with all subjects excluding the cluster of the five fastest skiers (Skate Sprint Speed = $5.82 + 0.0534 \times \text{LAT1-5}$; $r = 0.59$; $P = 0.021$; $\text{SEE} = \pm 0.03 \text{ m/sec}$).

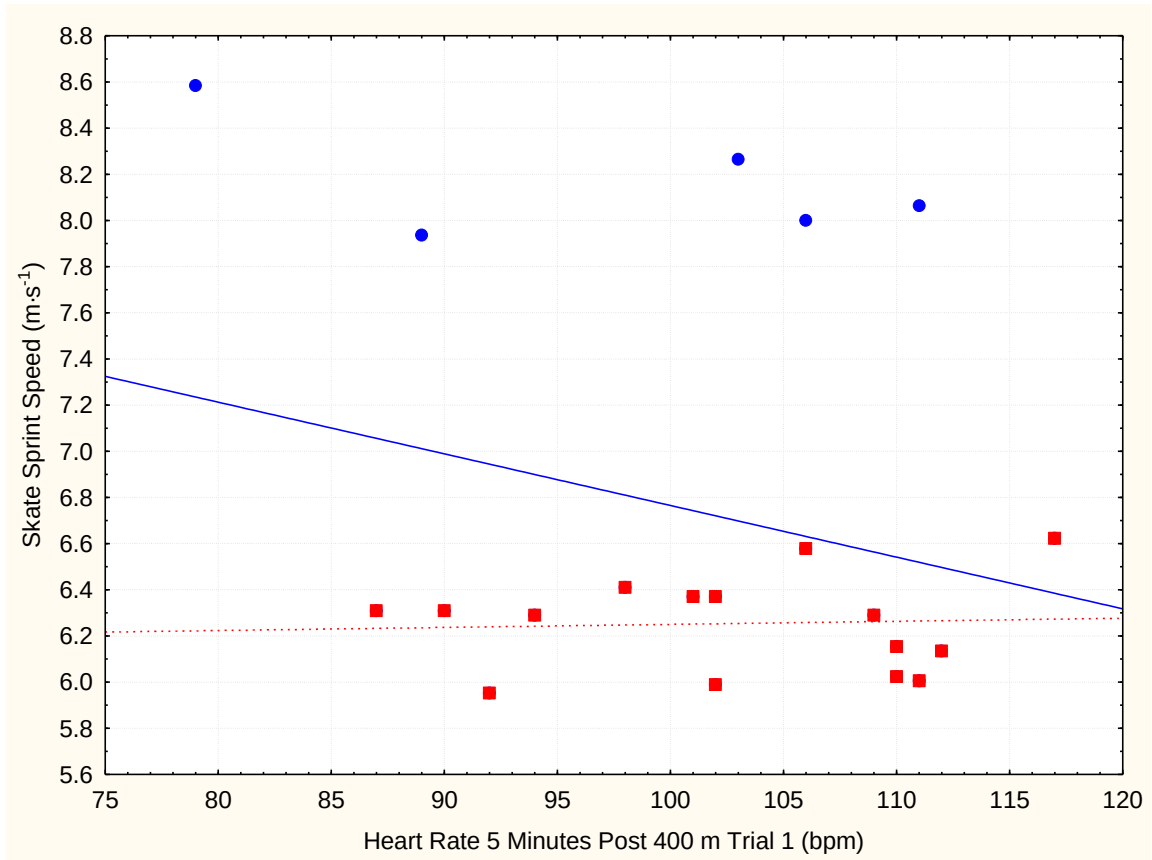


Figure 25. Scatter plot of relationship between 5 minutes post 400 m trial 1 heart rate (HRT1-5) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for HRT1-5 with all subjects included ($\text{Skate Sprint Speed} = 9.01 + -0.0224 \times \text{HRT1-5}$; $r = -0.26$; $P = 0.271$; $\text{SEE} = \pm 0.76 \text{ m/sec}$). Dashed line is a regression for HRT1-5 with all subjects excluding the cluster of the five fastest skiers ($\text{Skate Sprint Speed} = 6.13 + 0.0012 \times \text{HRT1-5}$; $r = 0.05$; $P = 0.849$; $\text{SEE} = \pm 0.05 \text{ m/sec}$).

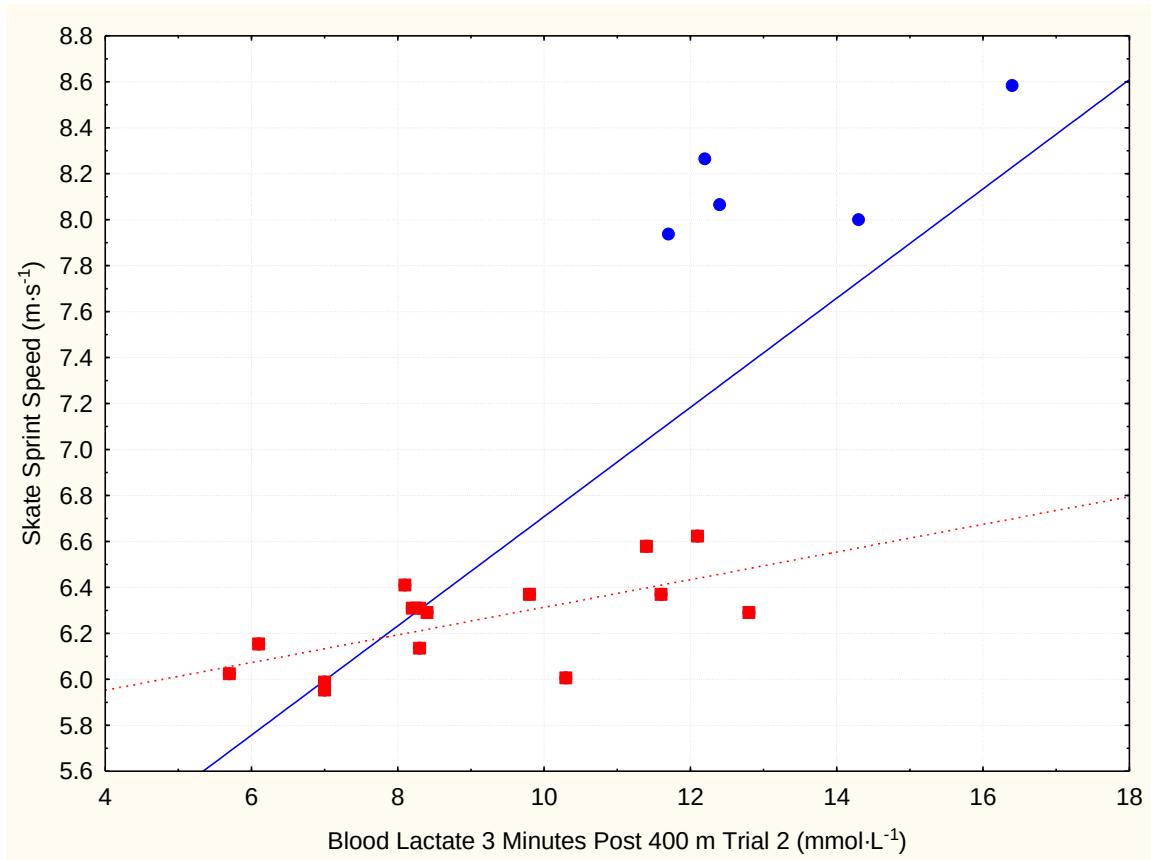


Figure 26. Scatter plot of relationship between 3 minutes post 400 m trial 2 blood lactate (LAT2-3) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for LAT2-3 with all subjects included ($\text{Skate Sprint Speed} = 4.33 + 0.2377 \times \text{LAT2-3}$; $r = 0.78$; $P < 0.001$; $\text{SEE} = \pm 0.32 \text{ m/sec}$). Dashed line is a regression for LAT2-3 with all subjects excluding the cluster of the five fastest skiers ($\text{Skate Sprint Speed} = 5.71 + 0.0606 \times \text{LAT2-3}$; $r = 0.65$; $P = 0.009$; $\text{SEE} = \pm 0.04 \text{ m/sec}$).

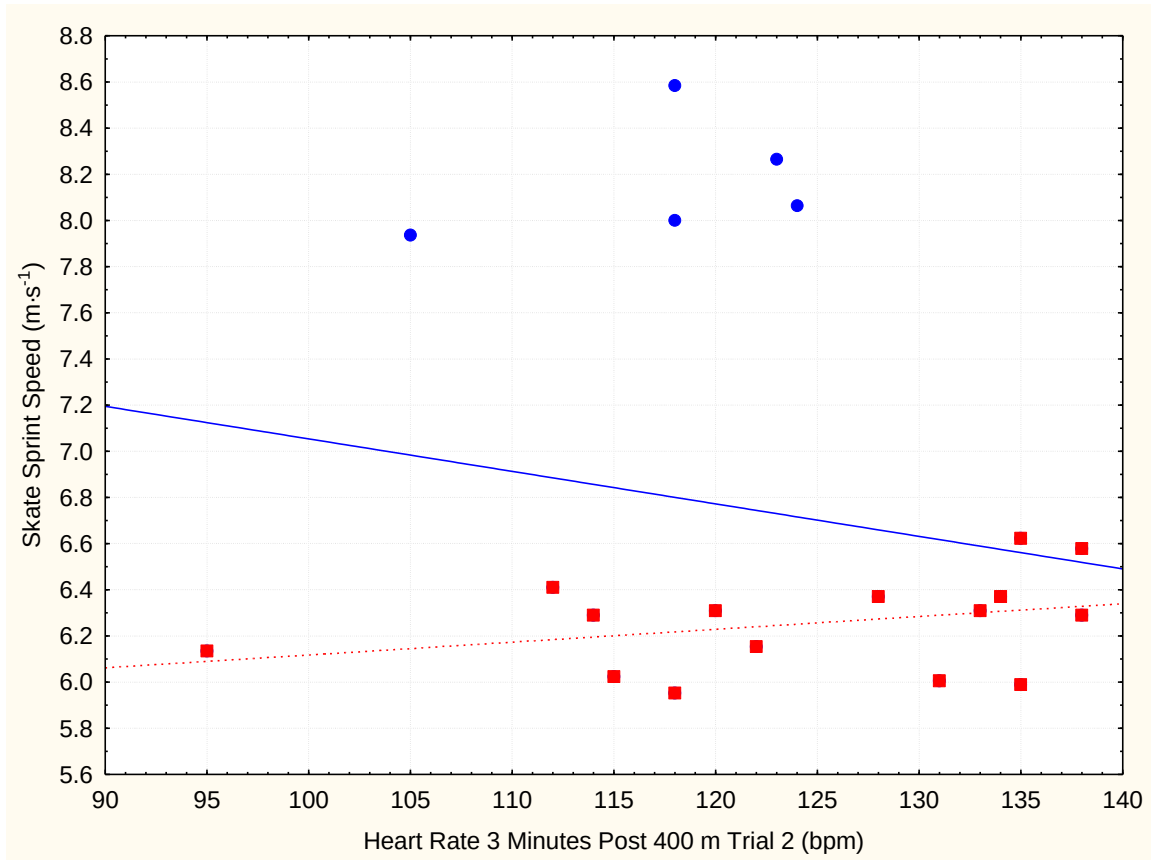


Figure 27. Scatter plot of relationship between 3 minutes post 400 m trial 2 heart rate (HRT2-3) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for HRT2-3 with all subjects included (Skate Sprint Speed = $8.45 + -0.0140 \times \text{HRT2-3}$; $r = -0.18$; $P = 0.439$; $\text{SEE} = \pm 0.79 \text{ m/sec}$). Dashed line is a regression for HRT2-3 with all subjects excluding the cluster of the five fastest skiers (Skate Sprint Speed = $5.55 + 0.0057 \times \text{HRT2-3}$; $r = 0.33$; $P = 0.223$; $\text{SEE} = \pm 0.04 \text{ m/sec}$).

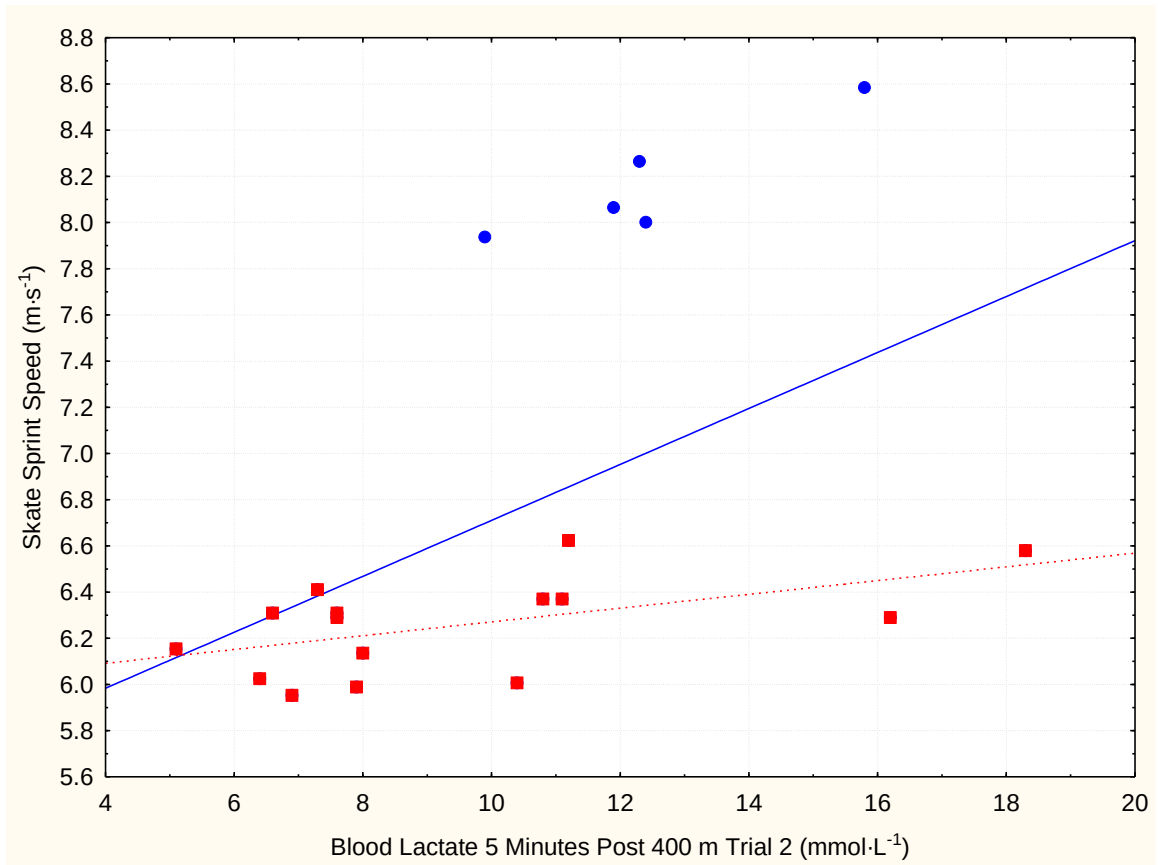


Figure 28. Scatter plot of relationship between 5 minutes post 400 m trial 2 blood lactate (LAT2-5) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for LAT2-5 with all subjects included (Skate Sprint Speed = $5.50 + 0.1212 \times \text{LAT2-5}$; $r = 0.50$; $P = 0.027$; $\text{SEE} = \pm 0.61 \text{ m/sec}$). Dashed line is a regression for LAT2-5 with all subjects excluding the cluster of the five fastest skiers (Skate Sprint Speed = $5.97 + 0.0301 \times \text{LAT2-5}$; $r = 0.54$; $P = 0.040$; $\text{SEE} = \pm 0.03 \text{ m/sec}$).

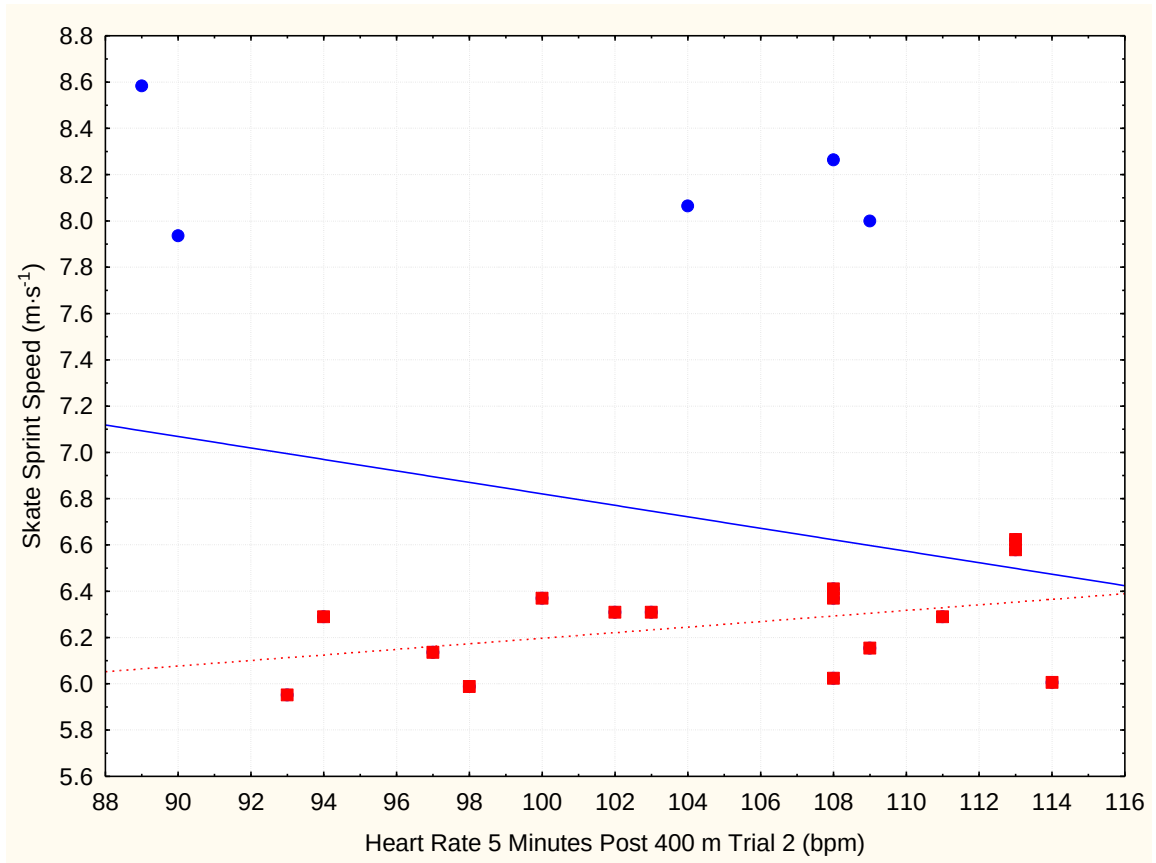


Figure 29. Scatter plot of relationship between 5 minutes post 400 m trial 2 heart rate (HRT2-5) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for HRT2-5 with all subjects included ($\text{Skate Sprint Speed} = 9.30 + -0.0248 \times \text{HRT2-5}$; $r = -0.22$; $P = 0.348$; $\text{SEE} = \pm 0.77 \text{ m/sec}$). Dashed line is a regression for HRT2-5 with all subjects excluding the cluster of the five fastest skiers ($\text{Skate Sprint Speed} = 4.99 + 0.0121 \times \text{HRT2-5}$; $r = 0.41$; $P = 0.127$; $\text{SEE} = \pm 0.04 \text{ m/sec}$).

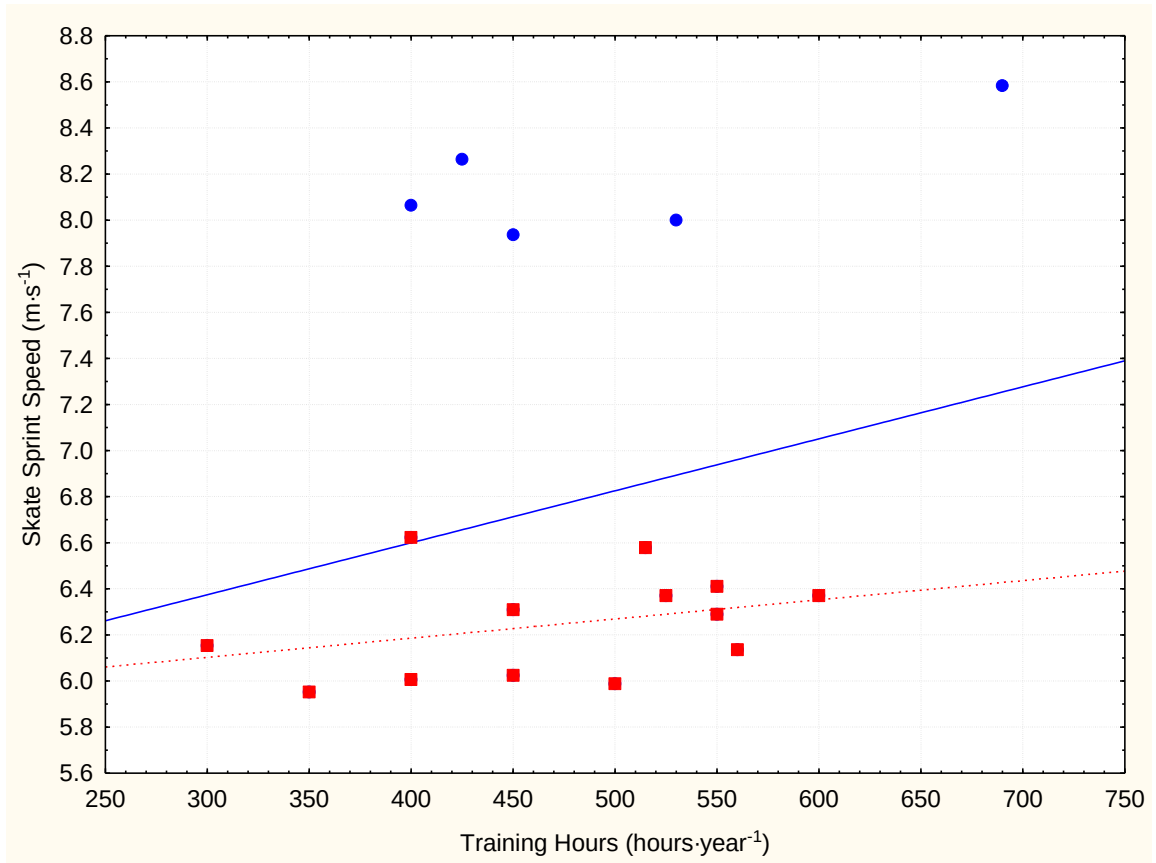


Figure 30. Scatter plot of relationship between training hours (Train-HRS) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for Train-HRS with all subjects included (Skate Sprint Speed = $5.79 + 0.0020 \times \text{Train-HRS}$; $r = 0.21$; $P = 0.387$; $\text{SEE} = \pm 0.81 \text{ m/sec}$). Dashed line is a regression for Train-HRS with all subjects excluding the cluster of the five fastest skiers (Skate Sprint Speed = $5.85 + 0.0001 \times \text{Train-HRS}$; $r = 0.35$; $P = 0.224$; $\text{SEE} = \pm 0.04 \text{ m/sec}$).

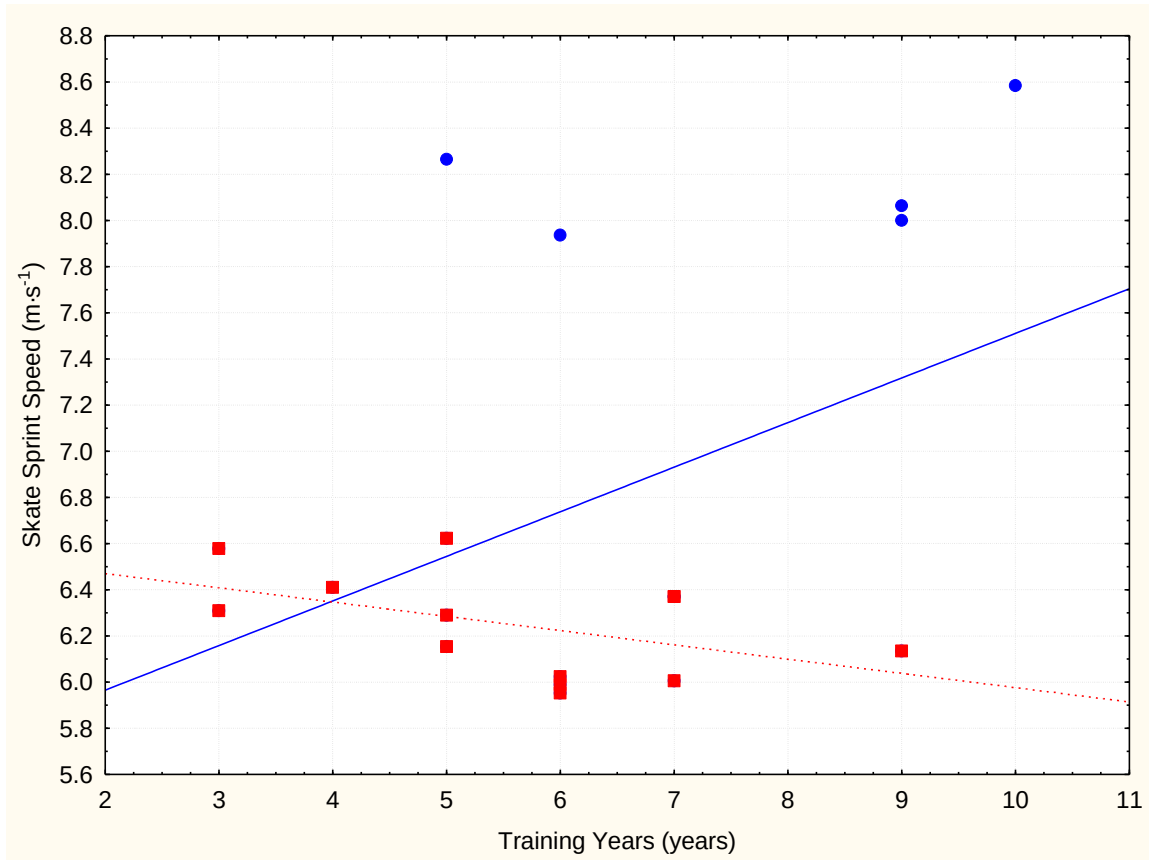


Figure 31. Scatter plot of relationship between training years (Train-YRS) and skate sprint speed. Circles represent the cluster of the five fastest skiers and the squares represent all subjects excluding the cluster of the five fastest skiers. Solid line is a regression for Train-YRS with all subjects included (Skate Sprint Speed = $5.59 + 0.1864 \times \text{Train-YRS}$; $r = 0.42$; $P = 0.077$; $\text{SEE} = \pm 0.70 \text{ m/sec}$). Dashed line is a regression for Train-YRS with all subjects excluding the cluster of the five fastest skiers (Skate Sprint Speed = $6.58 + -0.0569 \times \text{Train-YRS}$; $r = -0.45$; $P = 0.111$; $\text{SEE} = \pm 0.04 \text{ m/sec}$).