ASSESSMENT OF AEROBIC AND ANAEROBIC THRESHOLDS IN FIVE DIFFERENT TECHNIQUE SPECIFIC INCREMENTAL TREADMILL TESTS IN CROSS COUNTRY SKIERS

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ABSTRACT

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The use of incremental tests to exhaustion is widely accepted in the field of exercise physiology in the assessment of athletes. These tests which can measure a number of physiological parameters can help coaches and athletes optimize training. Blood lactate concentrations (bLa) corresponding to heart rate (HR) provides insight on the athlete's aerobic threshold (AerT) and anaerobic threshold (AnT). Cross country skiing is a sport where the selection of technique may influence the HR at which AerT and AnT occurs, eliciting higher bLa corresponding to lower HR depending on technique. Because of this, laboratory testing is crucial to provide coaches and athletes with the necessary information to help optimize training. Research has compared two to three techniques in cross country skiing in regards to variations in HR at AnT, nowhere has there been a study which has tried comparing AerT and AnT as well as maximal oxygen consumption (VO_{2max}) in 5 different techniques (Nordic walking, double poling, diagonal striding, V1, and V2 skate). Therefore, the purpose of this study is to determine the AerT and AnT from a physiological examination of bLa, HR and VO_{2max}. Ten national level skiers completed five incremental treadmill tests to exhaustion. Results were analyzed with both genders and split by genders. In all groups tested significant differences were found, DP being the main technique affected, lower HRs were observed in DP at AerT and AnT compared to the other techniques. VO_{2max} in women's DP were significantly lower than all techniques. The results demonstrated technique specific laboratory treadmill tests can be used to evaluate HR training zones for athletes as well as individuals VO_{2max}. It is recommended to choose a test incorporating whole body musculature, (NW, DS or V2), and a test that represents upper body musculature, (DP or V1). In this way, two tests can be compared that will provide information on training intensities, and possible differences between whole and upper body musculature. With this information the coaches are able to help guide the athlete in future training goals for optimal performance. Results between different techniques at group levels should be used with discretion, inter-individual differences exist among athletes.

Keywords: Blood Lactate Concentrations, Heart Rate, Aerobic Threshold, Anaerobic Threshold, Cross Country Skiing.

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ABBREVIATIONS

- AerT - aerobic threshold
- AnT - anaerobic threshold
- $AerT_{LA}$ – aerobic blood lactate threshold
- AnT_{LA} – anaerobic blood lactate threshold
- bLa – blood lactate concentrations
- DP – double poling
- DS – diagonal striding
- HR - heart rate
- MLSS – maximal lactate steady state
- NW – Nordic walking
- RPE – rate of perceived exertion
- SD - standard deviation
- V1 - V1 skate technique
- V2 – V2 skate technique
- VO_{2max} – maximal oxygen consumption

CONTENTS

1 INTRODUCTION

Laboratory exercise testing is commonly used to evaluate the physiological capacity and to prescribe individual exercise intensity zones of an endurance athlete. In cross country skiing, there are a number of different skiing techniques used in training and differences exist, especially, between classic and skating styles (Rusko 2003, 74). The assessment of blood lactate concentrations is commonplace in exercise physiology laboratories, normally as a marker of the metabolic strain being experienced by the body (Jacobs 1986). Measurement during exercise is frequently used as an indicator of performance ability and also to determine appropriate training intensities (Billat 1996). Lactate analysis is performed for the prescription of training velocities, to evaluate longitudinal changes in aerobic and anaerobic fitness, and to evaluate individual responses to specific training sessions. Most of the prescriptive work is directed towards determination of the anaerobic threshold and estimation of the relative anaerobic contribution to exercise from lactate formation. Research has demonstrated a strong correlation between endurance performance and the anaerobic threshold determined from lactate profiling (Pyne et al. 2000). Significant relationships between anaerobic threshold and race performance have been documented for several activities (Fabre et al. 2010). The anaerobic threshold is commonly associated with a heart rate and used to prescribe exercise intensities or training zones for an athlete. With this knowledge, the athlete often uses a heart rate monitor to ensure that training is completed at the proper intensity for any given workout (Larson 2006).

Most protocols that evaluate the physiological capacity of cross country skiers are running tests, which do not account for upper-body fitness or sports specific exercise modes. Given the large contribution of the upper body in cross country skiing, evaluations with ski-specific testing might be more appropriate. This point is largely documented in the literature evaluating the differences between standard running or cycling tests and specific cross country skiing tests (Fabre et al. 2010). There has been success in regards to the usefulness of measurements of blood lactate concentrations and heart rate at anaerobic threshold in a plethora of studies. Significant differences in heart rate at blood lactate anaerobic threshold exist across technique specific tests used in cross country skiing and has been well documented (Mittelstadt et al. 1995; Kvamme et al. 2005; Larson 2006).

Blood lactate responses and heart rates along with other physiological parameters have been examined in arm cranking versus leg cycling, treadmill running versus treadmill roller skiing or ski ergometer, and specific skiing techniques such as diagonal stride versus double poling, V1 and V2 skating techniques. These parameters have also been examined when comparing running, skate skiing, and double poling techniques in cross country skiing (Borg et al. 1987; Mygind et al. 1991; Watts et al. 1993; Mittelstadt et al. 1995; Rundell 1995; Rundell 1996; Wisloff 1998; Millet et al. 2003; Van Hall et al. 2003; Kvamme et al. 2005; Larson 2006; Holmberg et al. 2007; Fabre et al. 2010). To our knowledge, no data are available concerning the relationship between five different exercise modes which are most commonly used in cross country skiing. Therefore, the purpose of the present study was to compare the Aerobic (AerT) and Anaerobic Threshold (AnT) from a physiological examination of blood lactate concentrations and heart rate in the five most commonly used techniques in cross country ski training; Nordic Walking (NW), Double Poling (DP), Diagonal Striding (DS), V1 skate, and V2 skate techniques.

2 LITERATURE REVIEW

2.1 Training for cross country skiers

Cross country skiing has been practiced for at least 4000 years, most of the time for basic transportation (Shephard & Åstrand 2000, 844). Nowadays, recreational touring and racing are more common. Cross country skiing consisted of the traditional classic style for years up until the '80's when freestyle, better known as skate skiing was introduced as a ski technique. Cross country ski racing has evolved rapidly in recent years, with technique and equipment always developing. In spite of changes in technique and equipment, the fact that cross country skiers have always had the highest VO_{2max} amongst all endurance athletes has not changed (Eisenman et al. 1989, Rusko 2003, 20). Bjorn Daehlie, a famous Norwegian cross country skier had a VO_{2max} recording of 96.0 milliliters of oxygen per kilogram of body mass per minute (Hutchinson 2014). In a study conducted by Burtscher et al. (2011), an elite cross country skier was evaluated 4 years before winning an Olympic gold medal; a VO_{2max} of 90.6 $ml\cdot kg^{-1}\cdot min^{-1}$ was recorded. A value of 93 $ml\cdot kg^{-1}\cdot min^{-1}$ was recorded for a male world champion cross country skier (Rusko 2003, 72). The highest individual value recorded for a female Finnish skier was 78 $ml\cdot kg^{-1}\cdot min^{-1}$ (Rusko 2003, 20). Compared to other athletes both men and women cross country skiers hold the highest VO_{2max} values, men 65-94 and women 60-75 $ml\cdot kg^{-1}\cdot min^{-1}$ respectively (Wilmore & Costill 2004, 295). Cross country ski competitions are anywhere from 1 to 90 kilometers. Within the two styles of skiing there are many different techniques. In classic skiing three main techniques are used: diagonal stride, double pole and double pole kick. In freestyle or skate skiing, three main techniques are used as well: V1, V2, and V2 alternate (Shephard & Åstrand 2000, 844). Roller skiing, Nordic walking (also known as ski walking), running, and cross country skiing are the most common modes of training for cross country skiers. In the off-snow season, roller skiing can account for 50-70% of the endurance training (Shephard & Åstrand 2000, 854-855). With the development of skiing over the years, there has also been a development in cross country ski training. With a sport consisting of so many different techniques, the training requires many technique and sports specific training and testing in order for the athlete to be successful.

2.1.1 Techniques used in cross country skiing

Diagonal stride technique. Diagonal striding is used in slower conditions and for climbing (Rusko 2003, 38). Timing of the diagonal stride mimics that of running stride. The skier's opposite arm and leg swing forward at the same time. In skiing the upper-body contributes forward momentum by applying power through the pole as the skier glides, plants, compresses and explodes forward. At the same time as the kicking ski and poling arm pass back behind the skier, the opposite arm and leg swing forward (US Ski Team Cross Country Technique Fundamentals). Rusko (2003, 38) describes the "kicking" phase of diagonal striding which allows the skier to propel forward from ski to ski. "Kicking" occurs from a ski which for a moment is stationary. The ski will slow to a stop allowing the skier to kick from it; this is followed by a glide on the opposite ski. There is a vertical force that compresses the mid-section or "kick-zone" of the ski against the snow which occurs during the brief stationary moment. The kick-zone briefly sticks to the snow because of the large normal force and high pressure. A brief propulsive component of force in the forward direction can be generated due to the large static frictional force in the kicking phase. See figure 1.

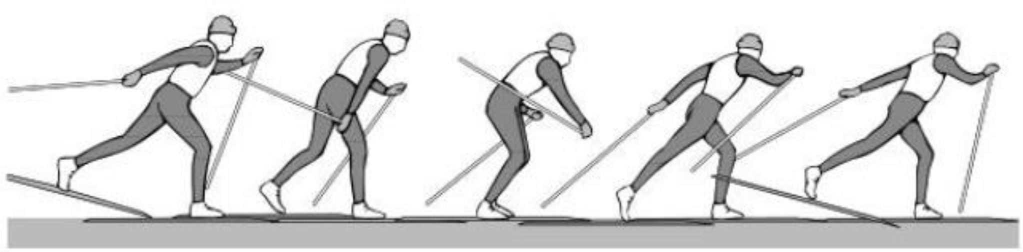

FIGURE 1. Diagonal stride technique. This figure illustrates a half cycle in DS starting with a left arm poling phase (position 1-4) and right leg kick (position 3 and 4) leading into a glide phase (position 4 and 5) (Rusko 2003, 38).

Double poling technique. Double poling is used in fast conditions, moderate uphills, downhills and fast, flat terrain. During double poling, arms work together and leg movement is minimal. Trunk flexion, shoulder, elbow, hand and pole contribute to enhanced poling forces. Propulsive force is generated via arm and trunk activity delivered axially through each pole. A glide phase is followed after the poling phase (Rusko 2003, 38). See figure 2.

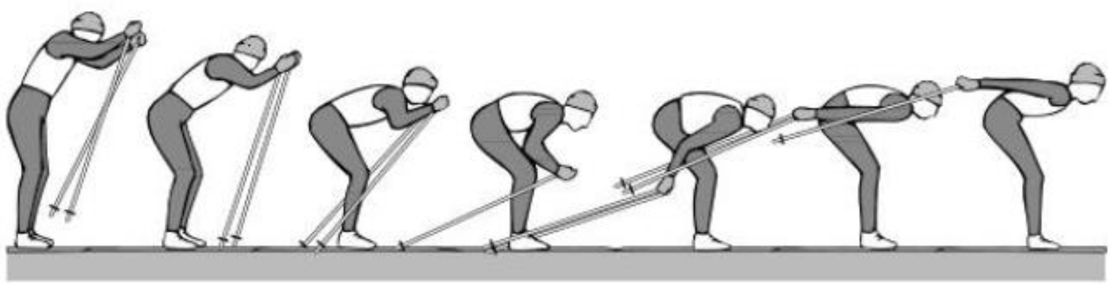

FIGURE 2. Double pole technique. This figure illustrates a cycle of DP starting with a high hand position to initiate the poling phase (positions 1-5) followed by a recovery phase (positions 6 and 7) (Rusko 2003, 42).

Double pole kick technique. Double pole kick is used on moderate conditions on flat or gentle uphills (Rusko 2003, 38). This technique begins with a double pole, leaving the arms slightly behind the skier, the upper body in a relatively low position and the skier’s weight spread evenly over both skis. The skier must then transfer all their weight to the kicking ski, plant, compress, and explode forward off the kicking ski, as in diagonal stride, in absolute synchrony with the forward swing of the arms, the return of the upper body back to a high double pole position, and the forward swing of the back leg. The opposite leg becomes the kicking leg in the next cycle. The “kick” propels the skier onto the other ski and into an extended position, leaving the skier gliding on one ski with both arms forward in a double pole position. (US Ski Team Cross Country Technique Fundamentals). See figure 3.

FIGURE 3. Double pole kick technique. Positions 1-3 illustrate the kicking phase and positions 4-7 the poling phase (Rusko 2003, 44).

Nordic walking technique. Nordic walking is used on uphill terrain. It simulates the classic technique of diagonal striding and is used during dryland training.

V1 skate technique. V1 is used when climbing steeper hills where V2 or V2 alternate will slow down the movements. V1 uses an offset position of the hands; the high hand belongs to what is called the hang arm. The hang arm delivers most the poling power and is close to the head at the initiation of the poling, it is also referred to as the poling side. The other hand is planted lower. On the poling-side the entire upper body and poling-side leg push simultaneously down and over to transfer weight to the non-poling side. Once the skier's weight is shifted onto the non-poling side, the arms begin to swing back up and forward as the skier begins the push-skate back onto the poling side. When the skier transfers weight back to the poling side the poles and poling-side ski meet the snow simultaneously. (US Ski Team Cross Country Technique Fundamentals). See figure 4.

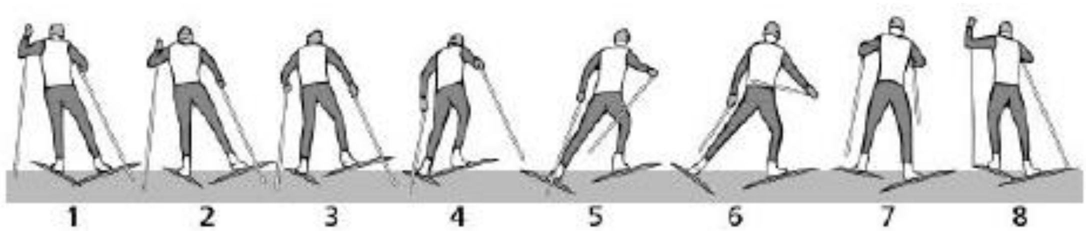

FIGURE 4. V1 skating technique. Positions 1-4 illustrate the skier poling with a left arm lead while skating on the left leg followed by a full weight transfer onto the right leg (positions 5-8) (Rusko 2003, 47).

V2 skate technique. V2 is used in fast conditions on flat, gradual uphill, and rolling terrain. The poling begins near the end of each skate stroke as the skier transfers their body laterally from the skating ski to the gliding ski (Rusko 2003, 50). The upper-body pushes in a double pole motion as the skier pushes simultaneously with the skating leg onto the gliding ski. The double pole and the skating push are complete as the gliding ski hits the snow and the skier's weight is transferred to that ski. While the skier is gliding the arms and whole body return to the high position to initiate the double pole and skate-push (US Ski Team Cross Country Technique Fundamentals). See figure 5.

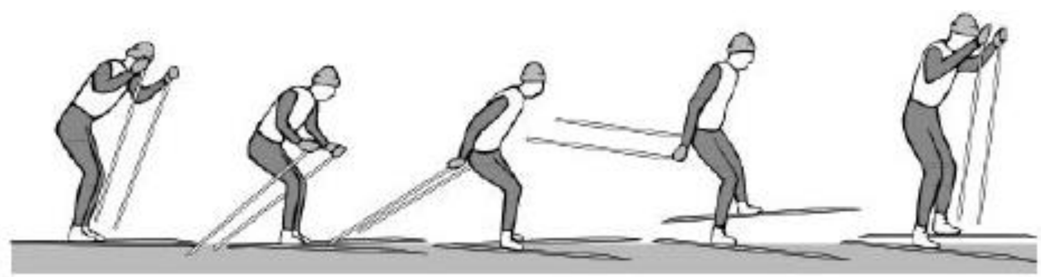

FIGURE 5. V2 skating technique. This figure illustrates the first half of the V2 cycle. Each skate stroke is accompanied by a double pole, and the arms require a quick return into a forward, and high position (Rusko 2003, 50).

V2 alternate skate technique. V2 alternate is used in gradual terrain where V1 and V2 would have too quick turnover for the given terrain. In V2 alternate, the method of propulsion on the poling-side is exactly the same as it is in V2. The upper-body and lower body compress together to transfer weight to the gliding ski. However, in V2 alternate the skier does not return to a high position on the gliding ski but stays in a relatively low position. The return to the poling-side is accomplished from this lower position with a skating push aided by the momentum of the arms swinging up, forward and back over the poling-side ski. While the skier is gliding on the non-poling side ski the arms are behind them. The skier is gliding on that ski in a relatively low position. From this position the arms swing dynamically forward in synchrony with a powerful skate push back onto the poling side ski. On the poling side, the whole body returns to the high position to initiate the double pole and skate-push (US Ski Team Cross Country Technique Fundamentals). See figure 6.

FIGURE 6. V2 alternate technique. (Rusko 2003, 49).

2.1.2 Understanding training for testing purposes

Cross country skiing is characterized by repeated contractions of multiple muscles over extended periods of time. Sometimes the active muscles involved are large enough to tax the cardiopulmonary system maximally, while in other occasions the active muscle groups are small. The attainable oxygen intake can vary considerably without any change in the maximal oxygen intake, and performance may vary to a large extent for a given maximal intake in small muscle groups. Therefore, both a high maximal oxygen intake and a high aerobic power of the respective muscles engaged in the assorted ski techniques are needed. These characteristics can be improved substantially by training (Shephard & Åstrand 2000, 852).

Endurance training, where intensities are sustained for hours below maximal aerobic power, causes adaptations in the muscles that increase fat metabolism, sparing glycogen. The ability to convert the available energy into the individuals skiing skill is extremely important. Therefore, training should include exercises that: (1) induce a high cardiovascular load to increase maximal oxygen intake; (2) comprise all muscles that are used during skiing, in order to increase the attainable oxygen intake in skiing techniques that exclusively involve a relatively smaller muscle mass, and to increase the capacity to spare glycogen; and (3) develop technique in order to increase skiing velocity at a given metabolic rate (Shephard & Åstrand 2000, 852-854).

As previously mentioned, roller skiing, ski walking, running, and cross country skiing are the most common modes of training for cross country skiers with roller skiing accounting for 50-70% of the endurance training. The attainable oxygen intake is of similar magnitude in running and in roller skiing, although, ski walking and cross country skiing produce slightly higher values compared with running in subjects who have trained for cross country skiing (Shephard & Åstrand 2000, 854). A critical benefit of roller skiing compared with running is that the upper body is utilized in a manner similar to actual cross country skiing. It is crucial that the muscles participating in poling have good endurance, since the use of these muscles during poling contributes considerably to most ski techniques; and also because double poling cannot be used extensively unless the skier can attain a high aerobic power during upper body exercises. Furthermore, a high aerobic power in the muscles of the upper body facilitates the attainment of maximal oxygen intake during combined arm and leg exercise (Shephard & Åstrand 2000, 854-855). Reported variables measured during roller skiing have been strongly correlated with on-snow skiing performance (Rundell 1995). Roller skiing is an important training method during dry-land training in cross country skiing. Therefore, roller skiing studies may play an important role for observing different aspects of ski technique and giving useful training suggestions for skiers (Kvamme et al. 2005).

Nordic walking, running, and especially roller skiing are of valuable importance in a cross country skiers training plan. The literature has exemplified the strong correlation between treadmill testing and on snow ski performance (Doyon et al. 2001; Larsson et al. 2002; Millet et al. 2003; Fabre et al. 2010). Taking into consideration that it is not always possible for cross country skiers to be able to perform training on snow all year round, it is crucial to evaluate and explore the best off-snow training modalities that will best advance the athlete in their development in cross country skiing through training.

2.2 How cross country skiers have been tested

As early as 1973, elite cross country skiers were tested running on motor driven treadmills (Hanson 1973). Laboratory running or cycling tests were previously used to determine maximal oxygen uptake and training intensities in cross country skiers. Most protocols that evaluate the physiological capacity of cross country skiers are running tests, which do not account for upper-body fitness or sports specific exercise modes. Given the large contribution of the upper body in cross country skiing, evaluations with ski-specific testing might be more appropriate. This point is largely documented in the literature evaluating the differences between standard running or cycling tests and specific cross country skiing tests (Fabre et al. 2010). Upper-body has become increasingly important in modern cross country ski racing, with the introduction of the skating technique in the 1980s, sprinting, and with the increase of the fractional use of double poling during classic technique races (Fabre et al. 2010).

Many studies conducted from the 1990s used double pole ski ergometers and running tests to assess physiological parameters in cross country skiers. Mygind et al. (1991) measured maximal oxygen uptake during treadmill running and double-poling on a ski ergometer in six Danish male cross country skiers and found that maximal oxygen uptake measured using the ski ergometer during double-poling was significantly correlated with performance. A later study, administered by Wisloff et al. (1998), evaluated a double pole ski ergometer for cross country skiers that was developed to study aerobic endurance and force development in the upper body of cross country skiers. Eleven male cross country skiers were examined using the double-poling technique on the ski ergometer, a treadmill running test, and an uphill double poling field test. The findings revealed the ski ergometer to be both reliable and valid for evaluating oxygen uptake and force development in the upper body at submaximal and maximal workloads. Thus, indicating that the double poling ski ergometer can be used in the evaluation of elite cross country skiers.

Rundell (1995) was one of the first researchers who evaluated cross country skiers with roller skis on a large motorized treadmill. Results indicated that lactate threshold, oxygen consumption, and heart rate were significantly lower during roller skiing than treadmill running. Similarly, another study from Rundell (1996) compared the physiological responses of top Nordic skiers from treadmill running and treadmill roller ski skating tests. The results revealed that peak physiological parameters during treadmill roller skiing tests were significantly lower than those during treadmill running tests, blood lactate was one of the physiological parameters tested that revealed significantly lower levels during roller ski skating. Submaximal O_2 values were significantly lower at intensities above 84% peak heart rate, and blood lactate was significantly higher for a given submaximal O_2 for roller ski skating. In older studies as well as relatively recent studies (Borg et al. 1987; Larsson et al. 2002), the capacity to predict performance on snow was usually assessed through a non-ski specific test, such as arm cranking, running or cycling. A better correlation identified performance and maximal oxygen consumption during an incremental DP test on a ski ergometer than during a running test in elite skiers (Fabre et al. 2010).

It is easily seen from the literature that in the year 1995 cross country ski laboratory testing begins to shift to incorporate roller ski treadmill and technique specific testing. Mittelstadt et al. (1995) found that blood lactate concentrations were higher at a given heart rate and rate of perceived exertion (RPE), when double poling up a 7.1% grade compared to diagonal striding up the same grade on a motor driven roller ski treadmill. In a relatively recent study, Kvamme et al. (2005) showed a significant technique slope interaction observed when the V1 technique elicited relatively lower lactate accumulation in the blood as the incline increased compared to V2, while V2 elicited lower blood lactate on low angled slopes. Larson (2006) explains that a significant difference in heart rate at blood lactate threshold (Tbla) was found for treadmill running versus the double poling technique as well as skating technique versus double poling technique during roller ski treadmill tests. More recently, Fabre et al. (2010) observed high differences in heart rate responses between both DP and DS roller ski tests.

Cross country skiers have been tested for physiological parameters, prediction of ski performance, and training intensities in a laboratory setting for many years. The development of laboratory testing is seen in the aforementioned literature, starting with the most basic running treadmill tests, to cycle ergometer, arm cranking, to more sports specific roller ski treadmill testing and technique specific testing. With this knowledge, laboratory testing can be improved upon in order to create the most effective tests to excel athletes' training and performance as well as the knowledge of coaches to prescribe the most effective training.

2.3 Sports and technique specific testing

There are many proven exercise test protocols for treadmill running and cycle ergometer tests, although they present potential sport-specific problems when used to assess cross country skiers (Watts et al. 1993). Skiing and roller skiing involve considerable upper-body and trunk power output. The double pole technique utilizes primarily upper-body musculature while freestyle, or skating combines arm and leg work as does diagonal striding. The different muscle recruitment patterns between skate, double pole, diagonal striding, and running affects the physiological demands for each exercise mode (Larson, 2006). During cross country skiing muscle glycogen is extensively used during uphill skiing for anaerobic energy yield. Double poling imposes an extra load on the upper body. During double poling, when small muscle mass is working, muscle glycogen is used faster from the recruited arm muscles than during diagonal striding (Rusko 2003, 9), and as slopes increase there is a greater use of the upper body with V2 technique compared to V1 (Kvamme et al. 2005).

There are many different factors affecting each ski technique used, style of skiing, technique, terrain, muscle mass involved in the exercise, and training modes are some of the few, with all of these factors it is wise to assess athletes using sports specific tests and even more targeted, technique specific tests must be emphasized. Such tests should involve the whole muscle mass corresponding to the particular activity (i.e. skiing test for skiers or swimming tests for swimmers). There are a plethora of studies that have been administered which have documented differences in physiological parameters depending on the technique or mode of exercise used in cross country ski training. This is why it is of great importance to study the physiological differences within different techniques of cross country skiing. Tests to evaluate maximal oxygen uptake in athletes should involve a large muscle mass and should maximize optimal use of specifically trained muscle fibers, preferably the test should be as close to identical with the athletes' specific sport activity as possible (Stromme et al. 1977)

A number of studies have compared blood lactate concentrations during arm cranking and leg cycling, the blood lactate concentrations were greater during arm cranking than during leg exercise at the same submaximal workloads. Borg et al. (1987) found lactate concentrations to be higher at the same heart rate and rating of perceived exertion during arm cranking when compared to leg cycling. Watts et al. (1993) compared NW, DP, and DS on a roller ski treadmill with six expert cross country skiers, peak heart rate values and blood lactate did not differ among techniques, although peak oxygen uptake was higher for NW and DS compared to DP. There were no differences found between NW and DS. Peak oxygen uptake for DP was 81% of NW and DS. Despite similar heart rate and blood lactate values, DP elicited a lower peak oxygen uptake than DS and NW and not surprisingly, NW and DS closely reflected each other. A later study conducted by Mittelstadt et al. (1995) found that the double pole technique is the only technique which relied entirely on the arms and trunk for propulsion. Eight national level cross country ski racers were evaluated during uphill roller skiing in diagonal striding versus double poling on a roller ski treadmill. Blood lactate concentrations were not significantly different between double poling and diagonal striding at 1.7% grade. However, at 7.1% grade, blood lactate concentrations were significantly higher during double poling than diagonal striding at all speeds. Specifically, the relationship between blood lactate concentration and heart rate at 7.1% grade were significantly higher during double poling than diagonal striding at a heart rate of 145 beats per minute. Blood lactate concentrations were also higher when plotted against percentage of technique specific VO_2, at 70% of technique specific peak VO_2 blood lactate concentrations were higher for double poling at the 7.1% grade. It was also found that lactate versus RPE and lactate versus heart rate relationships are not the same for double poling and diagonal striding techniques at the 7.1% grade.

In a study conducted by Van Hall et al. (2003), six elite cross country skiers were studied during diagonal stride roller skiing for 40 minutes continuously (continuous arm + leg) and 10 minutes of double poling and diagonal striding (arm and arm + leg skiing) on a roller ski treadmill. During continuous Arm + Leg, the leg and arm net glucose uptake values were similar. Despite similar work and net glucose uptake, the leg lactate uptake was higher and the leg lactate release was lower than for the arm, suggesting that the arm muscles have a lower ability to utilize lactate and a higher ability to produce lactate when moderately to highly active. There was a lower lactate utilization and higher production of the arm versus the leg muscle. With a similar focus on the classical techniques, Holmberg et al. (2007) carried out a study with seven international-level cross country skiers who were members of the Swedish National team. The skiers performed both submaximal and maximal treadmill running, and double poling and diagonal striding tests on a roller ski treadmill. Blood lactate and respiratory exchange ratio at submaximal exercise were higher in double poling compared with running and diagonal striding. At maximal exercise and at similar heart rates, VO_2 was 3.8% higher in diagonal striding as compared with running. Furthermore, VO_2 in diagonal striding and running was higher than in double poling. Skiers were able to reach higher VO_{2max} when combining arm and leg exercise compared with running, in spite of a similar maximal heart rate. Another study with a focus on classic technique from Fabre et al. (2010) compared physiological parameters for double poling versus diagonal stride with elite female cross country skiers. There was a significant difference between the double pole and diagonal stride tests in heart rates at anaerobic threshold. Incremental roller ski tests to exhaustion reported a significantly higher peak heart rate, heart rate at anaerobic threshold, and oxygen uptake at anaerobic threshold during DS when compared to DP. There was a difference of about eight beats per minute at anaerobic threshold; double poling elicited a lower heart rate at anaerobic threshold compared to diagonal striding which elicited a higher heart rate at anaerobic threshold.

Although the aforementioned literature explains double poling as mainly an upper body exercise, a relatively recent study by Holmberg et al. (2005) found contrasting results. This study explored the biomechanical analysis of double poling on a roller ski treadmill and obtained electromyography (EMG) activity in the trunk and hip flexors, shoulder extensors, and the elbow extensor triceps brachii. EMG activity in the lower body muscles demonstrated that the DP technique for competitive cross country skiers is more than only upper body work but concludes that the lower leg muscles are mainly acting as stabilizer muscles. Another study carried out by Bojsen-Møller et al. (2010) reported that double poling engages not only upper body limbs, i.e. the muscles that span shoulders and elbow joins, but also the muscles spanning the lower body limbs, hips and knees are contributing to generation of power output as well. This should be taken into consideration when classifying double poling as solely an "upper body" exercise.

As observed from the literature, there is a larger focus on the classical techniques with an emphasis on the comparison between a more focused upper body muscle mass technique, double poling, and a combination of both the upper body and lower body as seen in diagonal striding or Nordic walking. The literature, thus far, documents a lucid difference among techniques in regards to the physiological parameters measured, heart rate, blood lactate concentrations, respiratory exchange ratio, maximal oxygen uptake, peak maximal oxygen uptake, lactate uptake and release have revealed significant variations across techniques. There is less documentation found comparing skating techniques, but from the limited studies there are still confirmations that physiological differences exist within different skating techniques.

V1 and V2 skating involves both leg and arm exercise, but with different movement patterns, V1 has one pole plant per cycle, whereas V2 has two pole plants per cycle. Consequently, at a given intensity, V2 technique often requires a higher working frequency with the arms compared to V1 (Kvamme et al. 2005). In a study carried out by Kvamme et al. (2005), V1 and V2 skating techniques were compared across different slopes for their physiological responses on a roller ski treadmill with six skiers from B-level national ski teams. The pattern of VO_2 consumption suggested a similar energy cost for V1 and V2 skating on smaller inclines, but on steeper up-hills, V1 had a clear advantage. A significant technique slope interaction was observed where V1 technique elicited relatively lower lactate accumulation in the blood as the incline increased compared to V2, while V2 had lower lactate on low angled slopes. Other characteristics such as heart rate, lactate, and RPE were consistently trending higher for V1 at the 3 degree condition. Kvamme et al. (2005) also performed treadmill economy tests with four senior level international skiers, elevated VO_2, HR, and lactate responses for V2 compared to V1 skating on slopes 5, 6, and 7 degrees at 3 m/s were observed with confirmation that the observed crossover point of advantage and / or disadvantage between V2 and V1 skating applies even with international skiers.

Millet et al. (2003) examined twelve male skiers from recreational to national standard who executed four different skating techniques at submaximal velocity on snow. V1, V2 alternate, V2, and skating without poles were assessed for oxygen uptake, pulmonary ventilation, respiratory exchange ratio, and heart rate. The aerobic energy cost (oxygen uptake/mean speed) and heart rate were higher in V2 than V1. The aerobic energy cost was 5-9% higher in skating without poles technique than in other techniques.

Differences in physiological parameters can also be seen across styles of skiing. In a study administered by Larson (2006), heart rate was significantly lower at blood lactate threshold for DP versus skating, and the mean exercise protocol stage that induced a blood lactate value which exceeded the blood lactate threshold was significantly different for skate versus DP. Blood lactate threshold occurred at a lower heart rate and exercise stage during DP than skating.

Given the particularity of the cross country skiing activity with the use of both upper and lower limbs, a specific physical evaluation is needed in order to be more precise in the determination of optimal training intensities (Fabre et al. 2010). Interests in terms of training prescription and performance prediction of running tests vs. roller skiing tests and even a technique specific roller ski test versus another technique specific roller ski test for cross country skiers is thus raised. Roller skiing is an important training method during dry-land training in cross country skiing, and roller ski studies play an extremely important role for observing different aspects of ski technique and giving useful training suggestions for skiers (Kvamme et al. 2005). With the aforementioned supporting results, it seems necessary to perform technique specific tests to precisely determine specific technique training intensities. The large difference observed across classic techniques, skate techniques, running versus ski techniques, skate and classic techniques versus running, demonstrates the importance of testing ski specific, and to a greater extent, technique specific ski tests performed on roller ski treadmills. Fabre et al. (2010) reported that for a valid evaluation of athletes' capacities, discipline-specific test should be used in regards to cross country skiing, the tests should involve the whole muscle mass corresponding to the particular physical activity of interest.

2.4 Use of blood lactate measurements for prediction of exercise performance and control of training

Lactate analysis is performed for the prescription of training velocities, to evaluate longitudinal changes in aerobic and anaerobic fitness, to evaluate individual responses to specific training sessions, and to evaluate anaerobic capacity e.g. in competitions. Most of the prescriptive work is directed towards determination of the anaerobic threshold and estimation of the relative anaerobic contribution to exercise from lactate formation. Research has demonstrated a strong correlation between endurance performance and the anaerobic threshold determined from lactate profiling (Pyne et al. 2000).

2.4.1 Lactic acid and blood lactate concentrations

Lactic acid and lactate are not the same compound. The glycolytic pathway produces lactic acid, which then quickly dissociates releasing hydrogen ions (H^+). The remaining compound then combines with sodium ions (Na^+) or potassium ions (K^+) to form a salt called lactate. Blood lactate *not* lactic acid, is the substance usually measured in athletes under laboratory conditions (Wilmore & Costill 2004, 125).

It has been mistaken that blood lactate or even lactic acid has a detrimental effect on muscle performance, however, researchers agree that the negative effect on performance associated with blood lactate accumulation is because of an increase in hydrogen ions. When lactic acid dissociates, it forms lactate and hydrogen ions, resulting in an increase in acidity. Acidosis is a result from the increase in hydrogen ions and subsequent acidity of the internal environment, which has a negative effect on muscle contraction (Fitts 2003).

It may seem that any increase in production of lactic acid and hence lactate is detrimental as it will make for an increase in the production of hydrogen ions. Accumulation is important because the increased production of hydrogen ions, which is a result of the increased production of lactic acid, will not have a negative effect if the clearance is just as fast. If accompanied by a high capacity for lactate removal, lactate production may be more likely to delay the onset of acidosis. Lactate serves to consumer hydrogen ions and allows the transport of hydrogen ions from the cell (Robergs et al. 2004). The increase concentration of hydrogen ions and a decrease in pH (increase in acidity) within muscle or plasma causes fatigue (Brooks 2001).

Billat (1996) describes the metabolic reaction to longer lasting dynamic exercise can be separated into two stages, first a load which can be sustained at steady-state for a long time. After 2-5 minutes, a state of overall oxidative energy supply is established which is characterized by a balance of lactate production and elimination at a low level. Lipid metabolism is a significant energy supply at slow to moderate speeds during endurance exercise. Secondly, a load during which an additional net formation and accumulation of lactate is necessary to maintain power output, leading to exhaustion and fatigue through the disturbance of the internal biochemical environment of the working muscles and whole body caused by a high or maximal acidosis.

There is a transition called ‘anaerobic threshold or lactate threshold’ between these two stages. There is a shift from a solely oxidative to an additional glycolytic energy supply. Lactic acid production is due to activation of glycolysis being more rapid than activation of the oxidative phosphorylation, resulting in a transient elevation of NAHD in the cytoplasm and net lactic acid production, which is indicated by a steep nonlinear increase of blood lactate in relation to power output and time. The lactate accumulation with the increase of power output can be attributed to disparities in the rate of lactate production and removal, even if for these intensities under VO_{2max}, lactate production is not related to an oxygen deficit but rather to the increase of the glycolysis flux (Billat 1996).

Lactic acid is produced constantly, not just during hard exercise, lactic acid may be the most dynamic metabolite produced during exercise; lactate turnover exceeds that of any other metabolite yet studied. The constancy of blood lactic acid level during rest or exercise means that the entry into and removal of lactate from the blood are in balance. Increasing blood lactate levels indicate the entry exceeds removal; declining levels indicate the opposite. The turnover for lactic acid during exercise is several times greater for a given blood lactate level during exercise than during rest. Similarly, for a given blood lactate level, blood lactate removal is several times greater in trained than in untrained individuals (Billat 1996).

Several factors appear to be responsible for lactate inflection point during graded exercise: contraction itself stimulates glycogenolysis and lactate production. In addition, hormone-mediated accelerations in glycogenolysis and glycolysis, recruitment of fast-glycolytic muscle fibers, and a redistribution of blood flow from lactate-removing gluconeogenic tissues to lactate-producing glycolytic tissues cause blood lactate to rise during exercise protocols that call for continually increasing power output (Billat 1996).

2.4.2 Blood lactate concentrations as a prediction of performance

There is an abundant supply of research which demonstrates that blood lactate concentrations can be used as a valid tool for the prediction of performance and prescription of training zones and exercise intensities. Billat (1996) explains measuring blood lactate concentrations during exercise in a laboratory setting using incremental protocols to exhaustion or submaximal tests and field tests can give coaches, athletes and researchers important information about training intensities/training zones and can be a good prediction of performance. Billat (1996) found performance in long-distance running is related to several physiological variables, one variable being the anaerobic threshold. Anaerobic threshold determines or is related to the fraction of VO_{2max} that can be sustained by an individual in events lasting beyond 10 to 15 minutes. This value interacts with running economy to determine the actual running speed in competition. Billat (1996) research also explains the running speed at anaerobic threshold appears to be highly predictive of the 10 000 meter run and marathon. Anaerobic threshold and fixed blood lactate levels of 2.0, 2.5, and 4 $mmol{\cdot}L^{-1}$ predicted a 3000 or 3200-meter trial in trained and untrained women. Maximal blood lactate values in competitions are a good prediction of performance (Billat 1996). Lacour et al. (1990) found in both male and female runners there was a significant relationship between bLa and their relative performance, the mean bLa was measured to be 20.8 $mmol{\cdot}L^{-1}$ with a standard deviation of 2.34, neither race distances nor gender influenced bLa. The measurements were obtained from top level runners competing in major competitions, including world championships in the 400, 800, and 1500 meter runs. Kindermann and Kuel (1977) recorded peak lactate levels of 25.5 $mmol{\cdot}L^{-1}$ in an individual.

2.4.3 Using aerobic and anaerobic thresholds in the prescription of training

In sports physiology, both aerobic and anaerobic thresholds have been used to evaluate submaximal endurance capacity and to guide training programs and often the criterion of the achieved threshold has been fixed at a certain blood lactate. These kinds of threshold evaluations are suitable whenever the training effects are followed up (Aunola 1991, 2).

The aerobic and anaerobic thresholds (AerT and AnT), serve as a reflection of changes in interplay and in the mutual dominance of aerobic and anaerobic energy yields. They can be determined from the functions of blood lactate, ventilation (Ve), oxygen uptake (VO_2) or carbon dioxide production (VCO_2) on work rate (WR) or VO_2 during progressive exercise test up to 85-95% of exhaustion (Aunola 1991, 2). AerT can be defined as the highest level of energy expenditure at which the liver, heart and skeletal muscles are capable, under normal conditions, of eliminating lactate to the extent that its venous (or capillary) concentration does not exceed the resting level. AnT can be defined as the level of energy expenditure at which the maximal elimination rate of lactate can be achieved, or the highest level of energy expenditure at which a person can work so that lactate in their venous (or capillary) blood does not increase continuously (Aunola 1991, 10).

During exercise at the level of VO_{2max}, energy supply is both aerobic and anaerobic. Because anaerobic energy supply is limited, the athlete will have to decrease the exercise intensity after a short time. Therefore, an endurance effort is performed at an intensity less than VO_{2max}. Training increases the VO_{2max}, but it is of far greater importance that training shifts the anaerobic threshold. The anaerobic threshold may increase from 40% to 65% of the VO_{2max} from just a few months of training. Meaning that with the influence of training, lactate will only be formed at an intensity corresponding to a higher percentage of VO_{2max}. In other words, the pace may increase significantly before acidosis takes place. Training increases the VO_{2max}, but more importantly, it increases the percentage of the VO_{2max} at which exercise can be maintained for a long period of time (Janssen 2001, 34).

It is an art to assess training intensity correctly. An intensity that is too low will not improve performance, but an intensity that is too high may actually decrease performance and result in overtraining (Janssen 2001, 15). Training analyses as well as research literature show that athletes often train at the wrong intensities. Blood lactate concentration determination has become an essential element of coaching. After blood lactate concentrations are determined, the exact methods and intensities of training can be assessed (Janssen 2001, 229). Within the last two decades, performance diagnoses and training prescriptions in endurance sport have often relied upon blood lactate curves from incremental exercise tests (Meyer et al. 2005). Blood lactate concentrations are commonly used to prescribe exercise intensities for training. Eisenman et al. (1989) suggested that endurance athletes should train at or slightly above the lactate threshold to increase peak VO_2. Generally during cross country ski training sessions, skiers are unable to determine their training intensity using speed, such as a runner on a track, because of the variations in snow conditions and trail profiles. And, unfortunately, it is not always convenient to measure blood lactate concentrations during training. RPE and heart rate monitors are and can be used to measure intensity during training (Mittelstadt et al. 1995). The athletes can use HR or exercise perception which is learned over time to assess exercise intensity. For this reason, the HR value at anaerobic threshold could be useful to set training parameters close to the competitive intensity. To improve their capacity (i.e., capacity of the athletes to use an important part of their maximum oxygen consumption) and therefore their race performances, skiers have to perform some specific training sessions (usually interval training sessions), precisely at this intensity (Fabre et al. 2010).

With increasing affirmation from the literature, it has been found in numerous studies that there were variations in heart rate at the anaerobic threshold depending on the ski specific technique or mode of exercise executed during lab testing; indicating that, different techniques used during cross country skiing elicit different heart rates at aerobic and anaerobic thresholds. Significant differences were found among physiological responses in arm cranking when compared to leg cycling (Borg et al. 1987), treadmill running compared to treadmill roller skiing or double pole ski ergometer (Mygind et al. 1991; Rundell 1995; Rundell 1996; Wilsoff 1998; Larson 2006; Holmberg et al. 2007), and specific ski techniques compared to other ski techniques (Watts et al. 1993; Mittelstadt et al. 1995; Millet et al. 2003; Van Hall et al. 2003; Kvamme et al. 2005; Fabre et al. 2010). Therefore, the results derived from the literature are important when determining appropriate heart rate-based intensity zones for sport and technique specific training for cross country skiers. The relationship between blood lactate concentration and heart rate is important in the prescription of intensity-based training zones for cross country skiers and other endurance athletes to optimize training and prevent over-reaching (Larson 2006). Particularly, the use of heart rate-based intensity prescriptions from running anaerobic threshold tests to roller ski and snow ski training may not be valid (Larson 2006).

3 RESEARCH PROBLEMS AND HYPOTHESES

The present study was brought forth in the attempt to build upon the documented literature and be the first study to compare Nordic walking (NW) with the two most commonly used techniques in classic skiing, double poling (DP), and diagonal striding (DS), along with the two most commonly used techniques in skate skiing, V1 and V2 skate techniques. Many times the heart rate-based intensity results from a running test or Nordic walking test are used to prescribe anaerobic thresholds for roller skiing and on snow skiing, which are not sports specific and not valid. For this reason, it is crucial to get correct results for athletes from performing as many technique specific tests as possible. To the best of our knowledge, no data are available concerning the relationship between the five different exercise modes which are most commonly used in cross country ski training and racing. Therefore, the purpose of the present study was to compare $VO_{2max,}$ and the Aerobic (AerT) and Anaerobic Threshold (AnT) from a physiological examination of blood lactate concentrations and heart rate in the five most commonly used techniques in cross country ski training; Nordic Walking (NW), Double Poling (DP), Diagonal Striding (DS), V1 skate, and V2 skate techniques. Subjects performed five incremental treadmill tests until exhaustion by using these five most common exercise modes for training in cross country skiing to assess $VO_{2max,}$ and the Aerobic (AerT) and Anaerobic Threshold (AnT) from blood lactate concentrations and heart rate data in different techniques / modes of exercise. From the literature a number of hypotheses arise in order to answer our research questions.

1. Are there variations in the physiological responses measured across the five most common techniques used in cross country skiing? Specifically, will the aerobic and anaerobic thresholds occur at significantly different heart rates between techniques?

Based on the literature it is hypothesized that each training mode presents different physiological demands, which will affect the heart rate at which anaerobic threshold occurs. Anaerobic threshold will occur at lower heart rates with the technique that demands more use of the upper body. The results from Millet et al. (1998) indicated a greater use of the upper body with V2 technique compared to other skating techniques. The findings of Kvamme et al. (2005) are in line as the V2 skate technique produced greater lactate accumulation in the blood compared to V1 skating at the same speed as the slope increased.

2. Does DP elicit a lower heart rate at anaerobic threshold? And does DP elicit a lower VO_{2max} when compared to NW, DS, V1, and V2?

Based on the literature, it is hypothesized that anaerobic threshold will occur at a much lower heart rate in the double pole technique compared to NW, DS, V1, and V2. As seen in Larson (2006), heart rate was significantly lower at anaerobic threshold for DP compared with running and skate skiing. It is also hypothesized that VO_{2max} will be lower in DP compared to NW, DS, V1, and V2. Elite cross country skiers reach higher VO_{2max} when combining arm and leg exercise (Holmberg et al. 2007). Peak oxygen uptake was higher for NW and DS versus DP in a study conducted by Watts et al. (1993). Another similar finding from Holmberg et al. (2007) found VO_{2max} to be 13.9% higher in DS compared to DP.

4 METHODS

4.1 Subjects

10 national and international level cross country skiers (5 male and 5 female) took part in this study. The athletes were between the ages of 19 and 30 years old. All of the athletes had just completed their cross country ski race season in Finland and were healthy. A consent form was signed by the subjects agreeing to the terms and conditions of the study before participation. View characteristics in table 1.

TABLE 1. Mean ± SD characteristics of the subjects.

	Males (n=5)	**Females (n=5)**
Age (years)	23.4 ± 4.5	26.0 ± 3.9
Height (cm)	180.1 ± 3.2	166.6 ± 4.6
Body mass (kg)	72.2 ± 2.7	60.0 ± 3.8
Fat (%)	10.3 ± 1.5	19.4 ± 2.9

4.2 Study design

A group of national and international level cross country skiers performed five different technique specific incremental tests to volitional exhaustion on a large motor-driven treadmill (2.7x3.5m; Rodby RL3500E, Rodby Innovations, Vänge, Sweden). The tests were performed in April through June 2013 after the competition season was completed. Each subject began their first test and completed their last test in a time frame of 2 to 3 weeks with a minimum of 48 hours between each test. The tests were performed in randomized order between the times of 8 a.m. to 4 p.m.

During each test, respiratory gases were analyzed using breath-by-breath and heart rate was measured on a beat-by-beat basis. Capillary blood samples (20 μl) were collected after the warm up, after each three-minute stage of the test, and at one and three minutes after the test was completed for lactate analysis. AerT and AnT were analyzed visually from HR and blood lactate data according to Faude et al. (2009). Volume and gas calibrations were performed twice before each test. Body mass and air pressure were measured before each test. Height was measured the first day of the subject's first test. Before the warm up of the Nordic walking test four site skinfold measurement were obtained (biceps, triceps, subscapular, and suprailiac). The body fat procedure and estimation was based on Durnin and Rahaman (1967). The study was approved by the Ethics Committee of the University of Jyväskylä.

4.3 Procedure and protocols

NW, DP, DS, V1, and V2 were the techniques used for the five incremental tests. All of the tests were executed on a large motor-driven treadmill at the indoor laboratory facility in the Research Institute for Olympic Sports (KIHU, Jyväskylä, Finland).

The roller skis used during the tests were the classic Marwe 800 C (Marwe Oy, Hyvinkää, Finland) (rolling resistance standard / 6) and the skating Marwe 610 A (rolling resistance fast / 0). Both Salomon and Rottefella binding systems were available for classic and skate roller skis so that the athlete could use the binding/boot system that they were familiar with in training and racing. The subjects brought and used their own boots for the tests. Before each test, the athletes self-selected their poles based on their normal pole length. One Way poles (One Way Sport Oy, Vantaa, Finland) were provided for the subjects in every length to ensure the athlete was able to use the length they were accustomed with for training and racing. The poles had specially designed rubber tips created for roller ski treadmills (Biomekanikk AS, Oslo, Norway). The subjects were allowed to use their own poles if desired, and in that case, the rubber tip replaced their training tips.

Before each test, subjects were secured into a harness attached through a system which hung from the ceiling over the treadmill for safety. The subject then performed a 10 to 15 minute warm up. The subject warmed up with the technique that would be performed on that day (i.e. DP warm up for the DP test). Rolling resistance was achieved from the warm up. After the warm up, the treadmill was stopped, during this time resting capillary blood sample were obtained, all necessary equipment; mask, portable spiroergometer, were attached to the subject. After the pretest protocol was achieved and the subject and researchers were ready to begin, the test proceeded.

Each protocol's workload lasted three minutes. At the end of each three-minute stage the treadmill was stopped for capillary blood samples of 20 µl. Samples were obtained from the subject's fingertip using 25 ml blood capillary tubes for the assessment of blood lactate concentrations from the BIOSEN S_ line Lab+ (EKF – diagnostic GmbH, Barleben, Germany). Each measurement took about 10 to 15 seconds while the subject stood on the treadmill. The time used for the capillary blood measurement was included in that stage of the test, the time was not stopped for the measurement. The next stage proceeded with either an increase in speed or inclination, with the exception of the NW test, in some stages both the speed and inclination were increased. After each test was completed the athlete performed a 10 to 15-minute cool down.

Heart rate was recorded in RR-intervals with a Suunto t6 heart rate monitor (Suunto Oy, Vantaa, Finland). Gases were measured using a Spiroergometer: Oxycon Mobile (Viasys Healthcare GmbH, Hoechberg, Germany). Detailed procedures for each test are described below and a template for each test can be viewed in appendixes 1 through 4.

NW Test. Either an increase in speed, inclination or a combination of both speed and inclination was used to increase the workload.

DP Test. The men's protocol started at 8.0 km/h and a 3% inclination. The speed increased by 2 km/h each stage while the inclination stayed the same throughout the test. The women's protocol started at 7.0 km/h and a 3% inclination. The speed increased 2 km/h while the inclination stayed the same throughout the test. The speed was increased until the subject reached exhaustion.

DS Test. The men's protocol started at 10 km/h and a 3% inclination. The speed stayed the same throughout the test while the inclination increased by 2% each stage. The women's protocol started at 9 km/h and a 3% inclination. The speed stayed the same throughout the test while the inclination increased by 2% each stage. The inclination was increased until the subject reached exhaustion.

V1 Test. The men's protocol started at 10 km/h and a 3% inclination. The speed stayed the same throughout the test while the inclination increased by 2% each stage. The women's protocol started at 9 km/h and a 3% inclination. The speed stayed the same throughout the test while the inclination increased by 2 % each stage. The inclination was increased until the subject reached exhaustion.

V2 Test. The men's protocol started at 8 km/h and a 5% inclination. The speed increased 2 km/h each stage while the inclination stayed the same throughout the test. The women's protocol started at 7.0 km/h and a 5% inclination. The speed increased 2 km/h each stage while the inclination stayed the same throughout the test. The speed was increased until the subject reached exhaustion.

4.4 Data analysis

The highest values obtained during the test for a 30 second average were defined as the peak values. The highest VO2peak value achieved during the test was defined as the VO_{2max} value if two or more of the following criteria were met (1) a respiratory exchange ratio at or above 1.10, (2) a heart rate value within 10 beats per minute of the age predicted maximal HR (220-age), (3) a blood lactate concentration at or above 8 $mmol \cdot L^{-1}$ (4) or a plateau in the VO_2 with increasing workload. A plateau of VO_2 existed if the VO_2 of the workload before the plateau was equal to or less than 1.75 $ml \cdot kg^{-1} \cdot min^{-1}$ (Mourot et al. 2013). The highest heart rate recorded for each individual test was used for peak physiological parameters and considered the maximal heart rate; the highest blood lactate concentration recorded during each test was used as the maximal lactate.

Ventilation and HR were averaged the last one minute of every stage for the data analysis. All final stages were included even if the three-minute stage was not completed; this was in order to observe peak blood lactate and heart rate values. In the situation of an unfinished stage, the last 30 seconds of ventilation and HR were averaged instead of the last minute.

4.4.1 Assessment of aerobic and anaerobic thresholds

The aerobic and anaerobic thresholds were assessed visually using the heart rate and the lactate data. The first increase in bLa above resting values during incremental exercise was termed as the aerobic blood lactate threshold ($AerT_{LA}$). This point provides the athlete with their upper limit HR and bLa intensity for longer aerobic training. Above the $AerT_{LA}$ and below the AnT_{LA} is the aerobic-anaerobic transition, which results in elevated but constant bLa during steady-state exercise and can be maintained for prolonged periods of time. The lactate turnpoint representing the exercise intensity at which there is a sudden and sustained increase in bLa between the $AerT_{LA}$ and VO_{2max} was termed as the anaerobic blood lactate threshold (AnT_{LA}) adopted from Faude et al. (2009). This point estimates the HR and bLa values at which the athlete should be training at or slightly below this intensity to obtain training adaptations. This point also estimates the maximal lactate steady state, which is described as the highest constant workload that can be maintained for a longer period of time that still leads to an equilibrium between lactate production and lactate elimination. See figure 7 and 8.

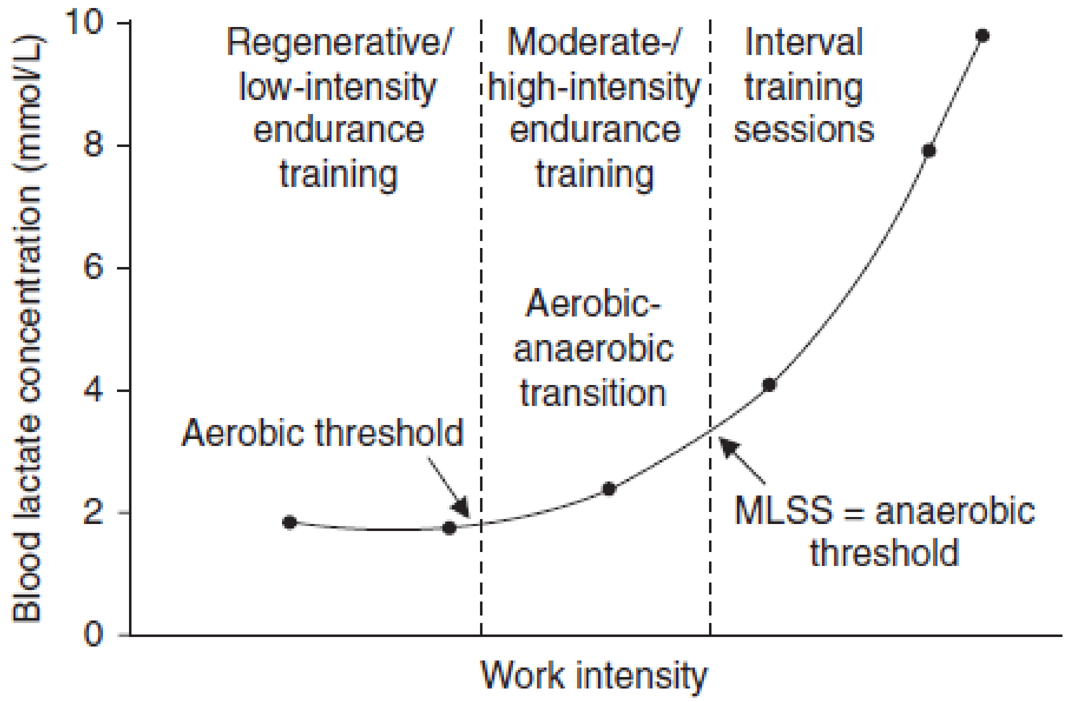

FIGURE 7. A lactate-workload plot to derive endurance training intensities for different intensity zones adopted from Faude et al. (2009).

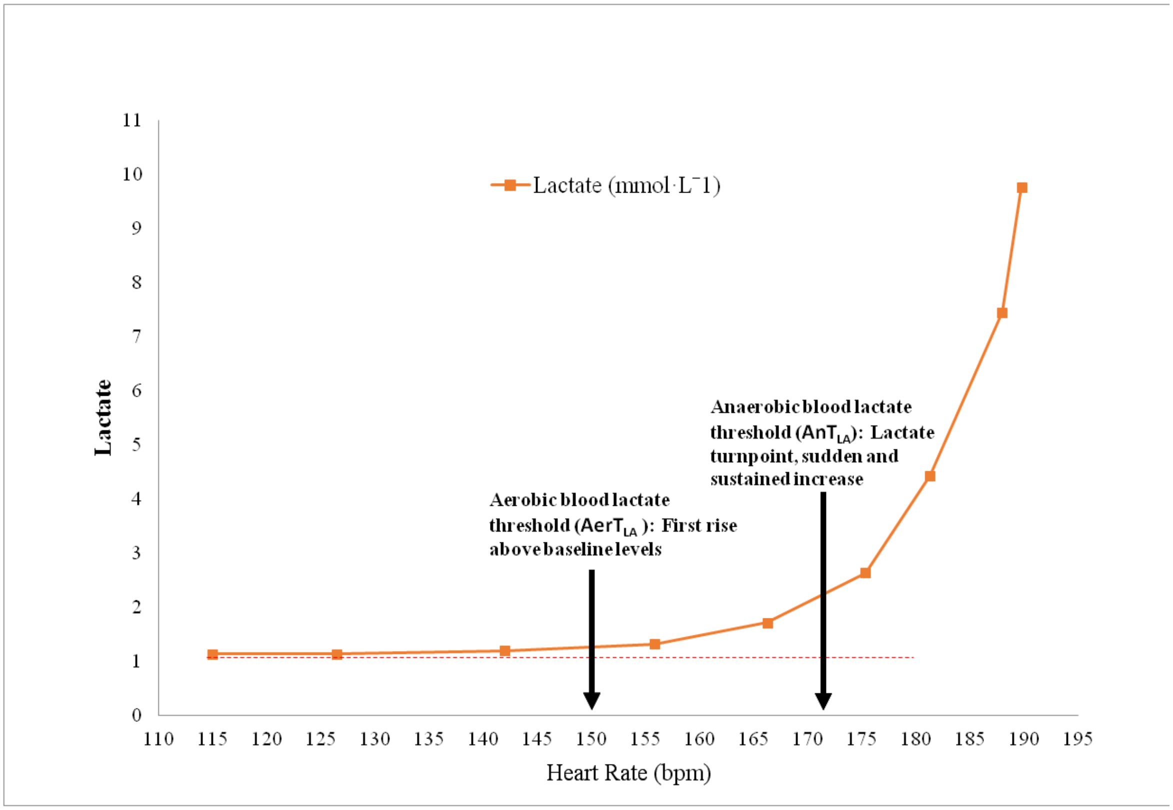

FIGURE 8. A graph from one subject's DS test with arrows marking the thresholds from visual assessment of aerobic and anaerobic thresholds adopted from Faude et al. (2009)

4.5 Statistical Analyses

All statistical analyses were performed using the IBM SPSS Statistics 20.0.02 software (SPSS Inc, Chicago, IL, USA). After all assumptions were met, repeated measures ANOVA were used to evaluate the five different technique specific tests with three different variables. Heart rate at aerobic threshold, heart rate at anaerobic threshold, lactate at aerobic threshold, lactate at anaerobic threshold, and VO_{2max}, these were evaluated and tested separately. Repeated measures ANOVA was first used with all 10 subjects and used again splitting the genders, men, and women separately. Descriptive statistics were calculated. All data and results are reported as the mean $\pm$ SD and statistical significance was set at $P \leq 0.05$. In this study "*" represents significant ($p \leq 0.05$), "**" represents significant ($p \leq 0.01$), and "***" represents highly significant ($p \leq 0.001$). "†" represents a non-significant trend which is defined as a p-value between 0.05 and 0.10.

5 RESULTS

Peak physiological parameters for the subjects can be viewed in table 2. Peak lactate was the highest blood lactate value recorded in each test. Maximum heart rate was the highest heart rate recorded in each test.

TABLE 2. Mean + SD peak blood lactate concentrations ($mmol·L^{-1}$) and heart rate (bpm) values for each technique specific test in men and women.

		NW	**DP**	**DS**	**V2**	**V1**
Men	**bLa ($mmol·L^{-1}$)**	12.12 ± 1.76	11.97 ± 2.23	10.63 ± 3.02	11.94 ± 2.84	10.57 ± 1.69
	HR (bpm)	193 ± 2	193 ± 5	194 ± 4	194 ± 5	192 ± 3
Women	**bLa ($mmol·L^{-1}$)**	14.15 ± 2.03	9.85 ± 2.71	11.96 ± 1.73	11.67 ± 1.80	12.03 ± 3.23
	HR (bpm)	190 ± 12	186 ± 11	192 ± 8	190 ± 9	189 ± 9

5.1 Heart rate at aerobic threshold

In all subjects, HR at aerobic threshold was significantly lower in DP than in NW (p=0.014) and V2 (p=0.013) (DP: 134 ± 13 bpm < NW: 143 ± 9 bpm, V2: 148 ± 10 bpm). The mean HR at AerT in the DS test was significantly higher than mean HR in V2 (p=0.030), NW (p=0.004), V1 (p=0.004), and highly significantly lower in DP (p=0.000), (DS: 155 ± 9 bpm > V2: 148 ± 10 bpm, NW: 143 ± 9 bpm, V1: 142 ± 9 bpm, DP: 134 ± 13 bpm). V2 was found to have a significantly higher HR at AerT than V1 (p=0.046) (V2: 148 ± 10 bpm > V1: 142 ± 9 bpm). See figure 9.

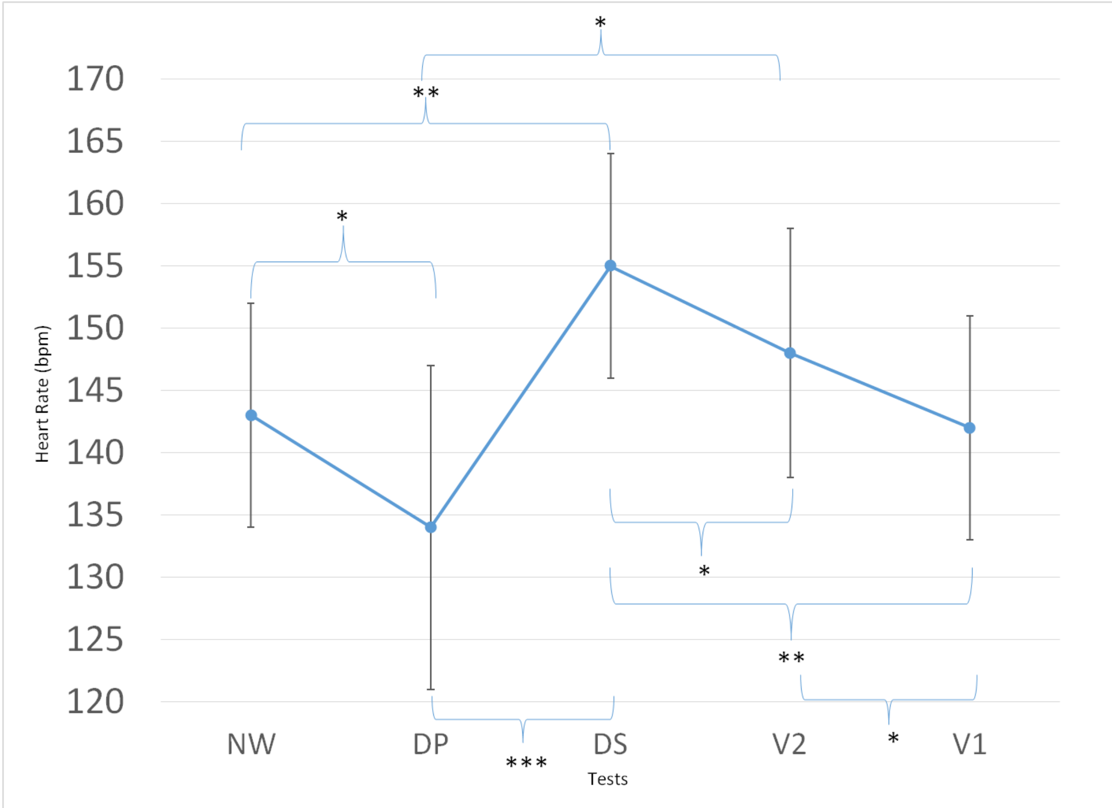

FIGURE 9. Mean + SD heart rate (bpm) values for each technique specific test at aerobic threshold in all subjects.

In men, mean HR at AerT in DS was significantly higher than DP (p=0.007), and V1 (p=0.018). See table 3.

In women, statistically significant differences were found in heart rates at aerobic threshold for the following tests: DP was significantly lower than NW (p=0.034), DS (p=0.033), and the V2 tests (p=0.038), and a non-significant trend existed with the DP and V1 tests, DP elicited a lower mean HR at AerT than the V1 technique (p=0.072). NW mean HR at AerT was significantly lower than the DS test (p=0.036). See table 3.

TABLE 3. Mean ± SD heart rate (bpm) for each technique specific test at aerobic threshold for men and women separately.

	Men (n=5)	Women (n=5)
NW	144 ± 13	141 ± 5
DP	137 ± 15	130 ± 11
DS	157 ± 11	153 ± 7
V2	147 ± 14	148 ± 6
V1	138 ± 9	146 ± 9

5.2 Heart rate at anaerobic threshold

In all subjects the V1 skating technique had a significantly lower mean HR at anaerobic threshold compared to the V2 skating technique (p=0.049) (V1: 176 ± 8 bpm < V2: 179 ± 6 bpm). HR at AnT in the DP test was highly significantly lower than NW (p=0.001), V2 (p=0.001), and the DS tests (p=0.000), and significantly lower in V1 skating (p=0.005) (DP: 168 ± 9 bpm < NW: 177 ± 7 bpm, V2: 179 ± 6 bpm, DS: 179 ± 6 bpm, V1: 176 ± 8 bpm). See figure 10.

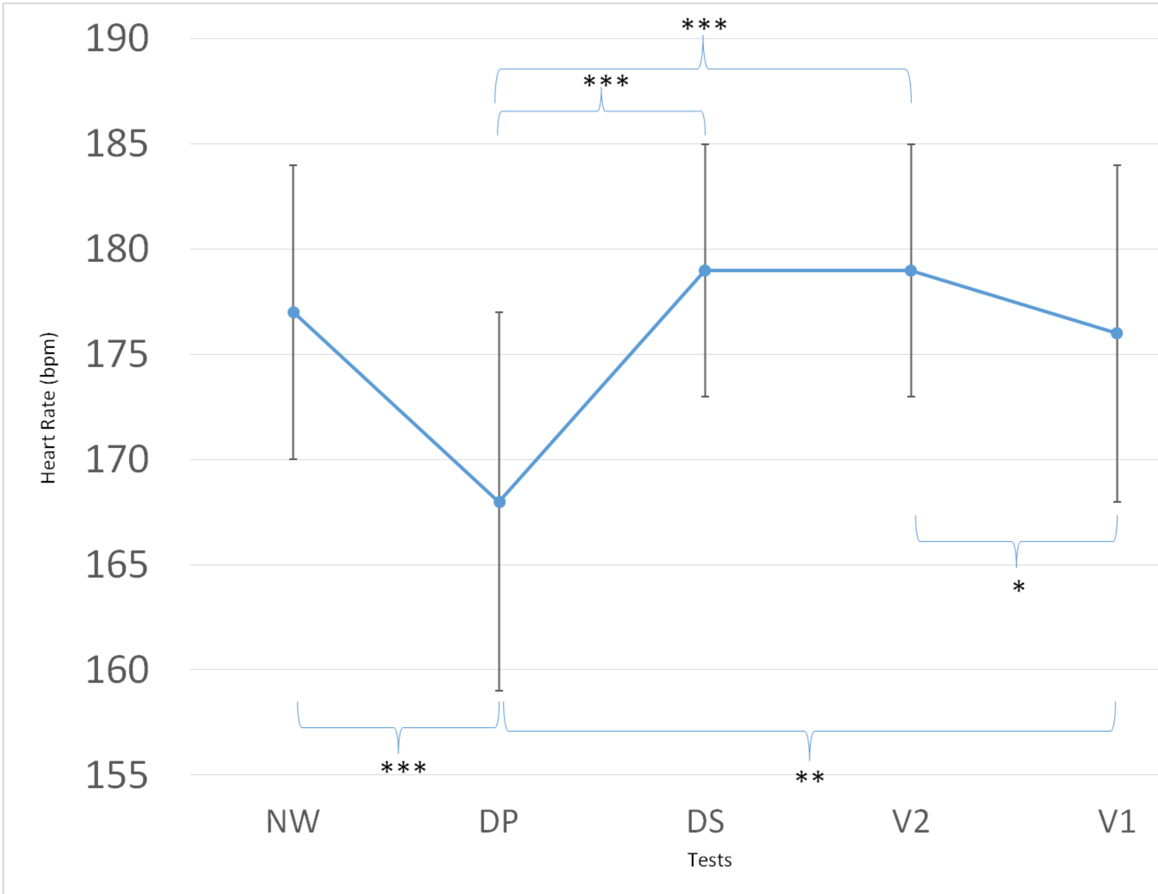

FIGURE 10. Mean + SD heart rate (bpm) values for each technique specific test at anaerobic threshold in all subjects.

When comparing heart rates at anaerobic threshold in men a statistically significant difference existed. DP was significantly lower than DS (p=0.034). See table 4.

Heart rates at anaerobic threshold in women showed statistically significant differences. Mean HR in the DP test was significantly lower than the NW (p=0.004), V1 (p=0.010), V2 (p=0.002), and highly significantly lower than DS (p=0.001). Mean + SD heart rate for each technique specific test at anaerobic threshold for men and women separately can be viewed in table 4.

TABLE 4. Mean ± SD heart rate (bpm) for each technique specific test at anaerobic threshold for men and women separately.

	Men (n=5)	Women (n=5)
NW	177 ± 2	177 ± 10
DP	171 ± 6	164 ± 10
DS	179 ± 7	180 ± 6
V2	178 ± 5	180 ± 6
V1	175 ± 5	176 ± 10

(Brackets in the table: Men: DP–DS *; Women: NW–DP **, DP–DS ***, DP–V2 **, DP–V1 **)

5.3 Blood lactate concentrations at aerobic threshold

No statistically significant differences were found at AerT from blood lactate concentrations in all subjects. See table 6.

As seen in the group findings, there were no statistically significant differences found for both the men and women in blood lactate concentrations at aerobic threshold. See table 5.

TABLE 5. Mean ± SD blood lactate concentrations ($mmol \cdot L^{-1}$) for each technique specific test at aerobic threshold for men and women separately.

	Men (n=5)	**Women (n=5)**
NW	1.39 ± 0.15	1.59 ± 0.08
DP	1.51 ± 0.36	1.79 ± 0.32
DS	1.41 ± 0.25	1.61 ± 0.28
V2	1.50 ± 0.23	1.62 ± 0.23
V1	1.28 ± 0.27	1.52 ± 0.19

5.4 Blood lactate concentrations at anaerobic threshold

No statistically significant differences were found at AnT from blood lactate concentrations in all subjects. See table 6.

TABLE 6. Mean ± SD blood lactate concentrations ($mmol \cdot L^{-1}$) for each technique specific test at aerobic and anaerobic threshold in all subjects.

	NW	**DP**	**DS**	**V2**	**V1**
bLa at $AerT_{LA}$ ($mmol \cdot L^{-1}$)	1.49 ± 0.16	1.65 ± 0.35	1.51 ± 0.16	1.56 ± 0.23	1.40 ± 0.26
bLa at AnT_{LA} ($mmol \cdot L^{-1}$)	3.80 ± 0.61	3.35 ± 0.82	3.33 ± 0.72	3.88 ± 0.52	3.47 ± 0.39

No statistically significant differences were found for both the men and women analyzed separately in blood lactate concentrations at anaerobic threshold. See table 7.

TABLE 7. Mean ± SD blood lactate concentrations ($mmol \cdot L^{-1}$) for each technique specific test at anaerobic threshold for men and women separately.

	Men (n=5)	**Women (n=5)**
NW	3.53 ± 0.39	4.07 ± 0.7
DP	3.27 ± 0.87	3.43 ± 0.86
DS	2.81 ± 0.45	3.85 ± 0.53
V2	3.48 ± 0.40	4.27 ± 0.25
V1	3.26 ± 0.36	3.68 ± 0.31

5.5 Maximal oxygen uptake

No statistically significant differences were found between tests for VO_{2max} in all subjects.

No significant differences were found in men's maximal oxygen uptake between studied techniques. See table 8.

Women's VO_{2max} in the DP test was significantly lower than in the NW ($p=0.021$), DS ($p=0.029$), and V2 tests ($p=0.037$), and a non significant trend existed where DP elicited a lower VO_{2max} value compared to V1 ($p=0.065$). See table 8.

TABLE 8. Mean ± SD VO_{2max} (ml·kg^{-1}·min^{-1}) values for each technique specific test for men and women separately.

	Men (n=5)	Women (n=5)
NW	70.5 ± 1.7	58.7 ± 3.4
DP	70.2 ± 4.0	51.4 ± 3.8
DS	71.1 ± 1.5	58.8 ± 2.1
V2	69.9 ± 5.0	56.7 ± 2.2
V1	68.5 ± 3.8	58.4 ± 3.3

In the Women column, brackets mark significant differences: * NW vs DP; * DP vs DS; * DP vs V2; † DP vs V1.

6 DISCUSSION

The main findings of this study present interesting data for coaches and athletes to implement into their training regimen as well as future research within this field. A large number of significant differences were found in heart rates at aerobic threshold. In all subjects, double poling was significantly lower than Nordic walking, diagonal striding, and V2 skating. Diagonal striding had significantly higher heart rates than Nordic walking, V2 and V1 skating techniques, and V2 had significantly higher heart rates than V1 skating. Fewer differences were found in men's heart rate at aerobic threshold. Diagonal striding was significantly higher than double poling and V1 skating. Many differences were found among women's heart rate at aerobic threshold. Double poling was significantly lower than Nordic walking, diagonal striding, V2 and V1 skating. Nordic walking was significantly lower than diagonal striding.

In all subjects many significant differences were observed in heart rate at anaerobic threshold. Double poling was significantly lower than Nordic walking, diagonal striding, V2 and V1 skating techniques. V1 had significantly lower heart rates than V2. Again, fewer differences existed in men. Men's heart rate at anaerobic threshold was significantly lower in double poling than diagonal striding. Many differences were observed in women's heart rate at anaerobic threshold. Double poling elicited significantly lower heart rates than Nordic walking, diagonal striding, V2 and V1 skating techniques. The main findings show that throughout statistical analysis among all subjects, men, and women, double poling elicited significantly lower heart rates than at least one other technique in both aerobic and anaerobic thresholds. Within the classical techniques, diagonal striding elicited a significantly higher heart rate than double poling at both aerobic and anaerobic thresholds within all groups tested.

No differences were found in all subjects, men, and women from blood lactate concentrations at aerobic and anaerobic thresholds. There were no differences found in all subjects and in men for maximal oxygen uptake. Women’s double poling maximal oxygen uptake was significantly lower than all other techniques tested.

6.1 Heart rate at aerobic threshold

Results from heart rate at aerobic threshold in this study support the hypothesis, variations in HR at aerobic threshold were found. Comparisons within all subjects were made to see if differences existed between all subjects, men and women tested separately. When all subjects’ results are compared with men’s and women’s results tested separately, there are a number of differences that exist among all groups which are crucial for coaches, athletes, and researchers to consider. The results from all subjects differ from men and women tested separately in the number of tests that show significant differences. There were many significant differences in all subjects’ results compared to men’s results. The women’s results are more similar to all subjects’ results, which may imply that the women’s results had a large effect on all subjects’ results. Fewer differences were observed within men in HR at AerT than in women.

Regardless of fewer differences observed in men, the DP technique seems to be a large concern among groups. The results reveal significantly lower mean HR values in DP at aerobic threshold, implying that the long distance endurance capacity in DP is lacking compared to the other techniques observed in all subjects, men, and women. The DS technique reveals a much higher long distance endurance capacity compared to DP and V1 in men, DP and NW in women, and DP, NW, V2, and V1 in all subjects. These results disclose that the skiers in this study have a more efficient endurance capacity when the whole body musculature is involved compared to a smaller muscle mass. The athlete is able to work aerobically for a longer period of time when whole body musculature is utilized. When using a technique which has a greater emphasis on upper body musculature, the athlete is not able to work aerobically as long, resulting in the reliance on anaerobic metabolism and a more rapid production of lactate in the blood. Rusko et al. (1978) found succinate dehydrogenase activity of skeletal muscle from the vastus lateralis was higher than that in the deltoid muscle of cross country skiers, suggesting that the oxidative capacity of skeletal muscle is higher in the legs than in the arms of cross country skiers, which reiterates the idea that whole body musculature utilization, especially when the legs are involved, results in a higher endurance capacity (i.e. higher HR at AerT as observed in NW, DS, V2, V1 depending on group) compared to upper body exercise.

As a whole, the skiers in this study have a more efficient aerobic capacity when whole body musculature is involved but differences are observed among groups. Although all groups (all subjects, men, and women), showed significant differences in the technique which possessed solely an upper body musculature (DP) compared to other techniques (NW, DS, V2, V1), men's results revealed they had less of a discrepancy than all subjects and women's results. Men's results had significantly lower HR at AerT in DP and V1 compared to DS. Whereas all subjects showed significantly lower HR in DP compared to NW, DS and V2, and women's results had significantly lower HR in DP compared to all other techniques. This signifies that when using combined upper and lower body techniques (NW, DS, V2 & V1), the women were able to perform at similar HR intensities for whole body techniques. When the technique had a bigger reliance on upper body musculature, more significant differences were observed in women which may have also had a large impact on all subjects' results. The men's results revealed significant differences in techniques utilizing more upper body musculature (i.e. DP and V1) compared to whole body musculature (i.e. DS). Although, fewer differences were observed in men, they were able to work at more closely matched intensities at AerT for more techniques compared to all subjects and women. This may imply a more efficient aerobic capacity and larger muscle mass in the upper body for men in this study. It is important to note that the amount of upper body muscle mass varies considerably between skiers (Rusko 2003, 22).

The differences observed may also be due to technique differences in men and women. The men may have been able to engage their lower body in DP more so than the women, adding a greater reliance on whole body musculature to perform the task rather than upper body musculature only. Because significant differences were observed in men's V1 eliciting a lower HR at AerT than DS compared to women, men may be engaging more upper body in the V1 technique than women as well.

The significantly lower HR at AerT observed in the V1 test compared to the higher HR observed in the V2 tests in all subjects could be due to the greater utilization of the upper body in the V1 skating technique. Because this technique is used during uphill terrain only, it relates to DP in a way that a smaller muscle mass is being utilized. During V1, the upper body musculature may assume 50% of the force production load, and during DP on flat terrain, the upper body musculature assumes the full burden of propulsion (Hoff et al. 1999). Millet et al. (2003) found V1 skate technique to have a greater and more efficient use of the upper body, a lower stretching velocity and a shorter eccentric time of the vastus lateralis, and a shorter recovery time in the upper body compared to the V2 skating technique. The V2 technique was reported to elicit the most efficient lower-limb propulsion on flat terrain, signifying V1 as more of an upper body technique and V2 as a whole body technique with a slightly higher emphasis on the lower body. These findings from Millet et al. (2003) may help explain why lower heart rates were found in V1 compared to V2 at AerT.

One result that does not support upper body versus whole body musculature is the significantly lower HR observed in NW compared to DS in all subjects and women's results. These two techniques are very similar to each other, and NW is used in dryland training to mimic DS. Because the athletes had just completed their on snow race season their bodies may not have yet been adapted to dryland training which may have lead to this finding.

6.2 Heart rate at anaerobic threshold

Results from HR at anaerobic threshold in this study support the hypothesis. Variations in HR at AnT were observed among all groups. Again, fewer differences were observed within men in HR at AnT than in women. Regardless of fewer differences observed in men, the DP test is the technique in all subjects, and in both men and women, that reveal significantly lower mean HR values at anaerobic threshold. Training intensity during DP may play a role in differences observed. Lower mean HR values at AnT may indicate that the utilization of smaller muscle mass impacts the anaerobic thresholds compared to other techniques. This could be due to a number of different mechanisms that may somehow be related to the smaller muscle mass utilized during upper body exercise. Differences in lactate production and lactate removal, earlier recruitment of fast twitch muscle fibers, and greater aerobic capacity in the legs compared to the arms are potential explanations for the present study's findings. Lack of technique specific training may have impacted lower HRs in DP. And finally, a potential reason for fewer differences found among men could be due to the men in this study having a more developed upper body aerobic capacity and greater strength capacity compared to the women in this study.

The cross country skiers in the present study both have well trained leg and arm muscles. However, differences are still observed, especially in women. A smaller muscle mass is utilized during upper body exercise (Mittelstadt et al. 1995; Kvamme et al. 2005; Larson 2006; Fabre et al. 2010). Although studies from Bojsen-Møller et al. (2010) and Holmberg et al. (2005) found that both upper and lower limb muscles were involved in DP, Bojsen-Møller et al. (2010) reported the lower limb muscles became more active as intensity increased, and Holmberg et al. (2005) found lower limb muscles are mainly acting as stabilizer muscles. Because of this, low intensity training may not be sufficient to target all muscles that are involved in high speed DP; training intensity must be high in order to impact the muscles of the lower body. The men in this study may have performed more DP training at high intensity than women resulting in better trained muscles and the ability to engage lower body muscles. Regardless of these findings, the DP technique is still utilizing a smaller muscle mass compared to the other techniques tested in this study.

Van Hall et al. (2003) found leg lactate uptake was higher and the leg lactate release was lower than for the arm. Therefore, suggesting the arm muscles have a lower ability to utilize lactate and a higher ability to produce lactate when moderately to highly active. If the HR at anaerobic threshold in NW, DS, V2 or V1 were prescribed for the DP test in the present study the athletes would be working at a much higher HR value which would result in a much higher blood lactate value. Van Hall et al. (2003) found skeletal muscles are the most important tissue for lactate clearance during exercise, and active skeletal muscles can be a substantial net lactate consumer. Only active skeletal muscles, due to increased energy expenditure, are able to oxidize the large amounts of lactate produced during exercise. Since a smaller muscle mass is utilized during DP and upper body exercises, the amount of active skeletal muscles are limited. If active skeletal muscles are the only muscles able to oxidize the large amounts of lactate created, then a smaller percentage of active skeletal muscles are working to oxidize lactate. Similar blood lactate concentrations are reflected at AnT in all techniques. However, the AnT in DP occurs at a lower HR, meaning lactate concentrations in DP are produced at a more rapid rate compared to NW, DS, V2, and V1 at comparative workloads. This indicates that the muscles used for double poling have a greater reliance on anaerobic energy sources. Since a smaller muscle mass is utilized when double poling, a greater tension per kilogram of muscle mass is likely required to maintain AnT for the DP technique compared to the other techniques. Higher intramuscular pressures would limit perfusion of the working muscles and an increase in anaerobic metabolism and lactate production would result from a reduction in blood flow to the working muscles (Mittelstadt et al. 1995).

The significantly lower HR at AnT in DP compared to the other techniques could be related to a greater and earlier recruitment rate of fast twitch muscle fibers. Higher lactate values are usually larger in individuals who have high proportion of fast twitch muscle fibers, and the energy supply from fast twitch muscles are solely anaerobic (Janssen 2001, 13). Mygind (1995) found in elite cross country skiers that 69% of the muscle fibers in the vastus lateralis consisted of slow twitch muscle fibers and the triceps brachii consisted of 51% slow twitch muscle fibers. These results imply that the arm muscles contain a higher percentage of fast twitch muscle fibers resulting in a greater reliance on anaerobic energy supply. Therefore, higher lactate values are achieved much faster and at a lower HR as observed in DP compared to NW, DS, V2, and V1. The study of Van Hall et al. (2003)

relates to the aforementioned results as they suggest the arm's lower lactate utilization and higher production vs. the leg muscle might be due to differences in arm and leg muscle fiber type and LDH (lactate dehydrogenase) isoform composition. Lower LDH activity in the vastus lateralis compared with deltoid was observed indicating markedly higher slow twitch fiber content in legs compared with arm muscles.

Rusko (2003, 24) explains during lower body exercise, the AnT is 85-90% of VO_{2max} and during upper body exercise the AnT is 80-85% VO_{2max}, implying there is a greater aerobic capacity in the legs compared to the arms. Because VO_2 and HR are linear, a higher HR will occur with a higher VO_2, and a lower HR will occur with a lower VO_2. The cross country skiers in this study were able to work closer to their VO_{2max} in the NW, DS, V2 and V1 techniques at AnT. In DP the AnT occurred at a lower HR implying a work rate further away from their VO_{2max}. The exception lies in the men's results; DP elicited significantly lower HRs at AnT only compared to DS. This result still confirms that AnT in upper body exercise occurs at a lower percentage of VO_{2max}. The greater aerobic capacity in the legs compared to the arms helps explain why HR at AnT occurs at a lower HR in DP compared to the techniques utilizing both the upper and lower body. As previously mentioned, succinate dehydrogenase activity of skeletal muscle from the vastus lateralis was higher than that in the deltoid muscle of cross country skiers, suggesting that the oxidative capacity of skeletal muscle is higher in the legs than in the arms of cross country skiers (Rusko et al. 1978). The higher composition of slow twitch muscle fibers found in the legs of cross country skiers also support a large aerobic capacity compared to a lower aerobic capacity observed in the arms. The higher aerobic capacity enables the aerobic system to actively supply energy through fat and carbohydrate oxidation up to the intensity level at which accumulation of lactate is no longer at equilibrium between formation and breakdown (Janssen 2001, 13). A smaller aerobic capacity exists in the arms and there is a dependence on anaerobic metabolism resulting in an increased rate of lactate production at an earlier HR in DP.

Another factor that may have played a role in the results in this study is the lack of DP specific roller skiing or on snow ski training leading up to the data collection. Since the data was collected at the end of the skier's race season many of the athletes were in a tapering mode. DP specific roller ski training or snow training may not have been performed for a long period of time before the data was collected. This could have led to physiological detraining effects, such as a decrease in the oxidative capacity of muscles and fat utilization in the upper body. If the total training load decreases during the race season the adaptations related to structural changes such as the heart size, maximal cardiac output, and VO_{2max} can be maintained more easily by racing, but the oxidative capacity of muscles and fat utilization can decrease in just a few weeks. Decreases were observed in the arm and upper body muscles at a much faster rate than in the leg muscles (Rusko 2003, 65). The effects of detraining from the lack of specific training can help explain why AnT occurred at a lower HR in DP.

In contrast to detraining, the men in this study revealed fewer significant differences which may be related to a greater aerobic and strength capacity compared to the women in this study. Having higher maximal strength in the upper body may reduce relative force generation required by the upper body, resulting in reduced intramuscular pressure and enhanced blood perfusion of the working muscles (Hoff et al. 1999). The women in the study may have been limited in upper body musculature which could have had an effect on the lower HRs observed at AnT in the upper body technique, double poling. Less blood perfusion of the working muscles would increase the rate of lactate production and in turn AnT would be attained at a faster rate than the combined upper and lower body techniques. Research has shown female World Championship sprint medalists could not reach as high of upper body VO_{2max} as elite males. The upper body VO_{2max} was 90% of combined upper and lower body VO_{2max} in women and 95% in men (Rusko 2003, 22). Although this refers to VO_{2max} values, the AnT corresponds to a percentage of VO_{2max}. The elite men were able to reach and hold higher aerobic capacities in their upper body than the female world championship medalist. Since maximal upper body aerobic capacity was lower in female World Championship medalists, the anaerobic threshold would most likely occur at a lower percent VO_2 relative to upper body VO_{2max}, and a lower HR compared to combined upper and lower body techniques than in men. Although the elite men were not able to reach their maximal aerobic capacity values in upper body exercise, they were still able to achieve higher maximal upper body aerobic capacity than women. This implies AnT will occur at a higher percent VO_2 relative to VO_{2max} and a higher HR than in women. The results observed in these world class athletes transfer to the results in the present study. The women in the present study elicited a lower HR at AnT in the upper body technique (DP) compared to all other combined upper and lower body techniques (NW, DS, V2, V1), relating to a lower upper body aerobic capacity observed in female World Championship medalists. The men in the present study elicited a lower HR at AnT in the upper body technique (DP) compared to the combined upper and lower body technique (DS), relating to a lower upper body aerobic capacity but still a higher upper body aerobic capacity than the women in the present study. This is confirmed by the results in this study. A profound amount of significant differences were reported from women's results compared to men's results, reiterating that the women in the present study may have had a lower aerobic and strength capacity than the men.

It is also important to consider which tests elicited significantly lower HR at AnT among the different groups tested (i.e. in all subjects, men and women tested separately). The highest number of tests which elicited significant differences between techniques was observed when all subjects were tested. When men and women were tested separately the women showed a higher number of significant differences between techniques than the men. There are large variations in differences when the results are compared among groups. What may be observed at group levels may not be transferable for prescription of training intensities at an individual level since so many differences were identified.

6.3 Blood lactate concentrations at aerobic and anaerobic thresholds

There were no significant differences observed in blood lactate concentrations at aerobic threshold in all subjects, men, and women. No significant differences were observed in blood lactate concentrations at anaerobic threshold among all subjects, men, and women. This is not surprising as the aerobic and anaerobic thresholds were assessed in the same way throughout all subjects. The first rise in blood lactate concentrations above baseline was correlated to the $AerT_{LA}$ or aerobic threshold. The second rise known as the lactate turnpoint, a sudden and sustained increase in blood lactate concentrations was correlated to the AnT_{LA} or anaerobic threshold. With this consistency, no variations in the blood lactate concentrations at aerobic or anaerobic threshold should exist.

6.4 Maximal oxygen uptake

No differences were observed in VO_{2max} in all subjects. The men's results were in agreement with all subjects as no significant differences were reported in VO_{2max}. Interestingly, and as hypothesized, when women were tested separately significant differences were observed.

These results somewhat support the hypothesis of this study. It was hypothesized that there would be a lower VO_{2max} observed compared to the other techniques in both the men and the women. In the present study significant differences were only found in the women's results. These results are somewhat in line with other studies. Previous studies have found no differences in VO_{2max} between the DP technique and other ski specific techniques (Fabre et al. 2010) while others have found significant differences (Mittelstadt et al. 1995; Holmberg et al. 2007). It is important to note that the present study is the first study to compare VO_{2max} with the five most common training modes in cross country skiing. The aforementioned studies may have only compared two or three different techniques.

Because men's results showed no significant difference across techniques in VO_{2max} compared with women, the results suggest that women's DP performance may have been limited by some other factors other than maximal aerobic capacity. The women in this study may have been categorized as more "distance" skiers rather than "sprinters." The DP test's speed may have required a much faster turnover than what the women could actually perform; this may have resulted in an early end to the test before complete exhaustion and VO_{2max} was met. The men in this study may have been endowed with a greater sprinting ability. World class sprint skiers have a slightly higher upper body VO_{2max} (Rusko 2003, 22). Some of the men in the study were in fact world class sprinters, and the other men in this study could have been classified as a stronger sprinting group than the women.

The DP protocols did not differ very much between genders; the men had no problems reaching their VO_{2max} as no statistically significant differences were observed. It is important to remember that the amount of upper body muscle mass varies considerably between skiers (Rusko 2003, 22). The men in this study may have had a more developed maximal upper body aerobic capacity and maximal strength compared to the women as noted earlier. Having higher maximal strength in the upper body may reduce relative force generation required by the upper body, resulting in reduced intramuscular pressure and enhanced blood perfusion of the working muscles (Hoff et al. 1999). A less developed upper body musculature could have played a role in limiting the women from reaching their maximal aerobic capacity. Research has shown female World Championship sprint medalists could not reach as high of upper body VO_{2max} as elite males. The upper body VO_{2max} was 90% of combined upper and lower body VO_{2max} in women and 95% in men (Rusko 2003, 22). Even comparisons at the highest level with some of the best female and male cross country skiers in the world, females were still not able to reach as high values as males.

Because no differences were found in men, there could have been technical differences between the men and women. Holmberg et al (2005) found double poling is more than only upper body work, and Bojsen-Møller et al. (2010) reported that double poling engages muscles in the lower body limbs which contribute to generation of power output. The men may have engaged lower body muscles in double poling making the exercise not only an upper body exercise. As previously mentioned, the detraining leading up to the data collection could have had an effect on the results as well. The decrease in oxidative capacity of muscles and fat utilization in the arms and upper body may have limited the women in this study. A reduction of oxidative enzyme activity is reduced by 50% after a week of inactivity (Shephard & Åstrand 2000, 831). The women in our study were active during the data collection but there were no training requirements or training documentation throughout the study. A study which looked into a group of highly trained runners after 15 days of detraining resulted in a 4% decrease in maximal oxygen uptake, a 24% reduction of succinate dehydrogenase activity, and a 25% reduction in endurance during a 15-18 min run (Shepherd & Åstrand 2000, 831). The discrepancy in VO_{2max} could be due to the local fatigue in the arms from the reduction of oxidative capacity.

6.5 Practical applications

The relationship between HR and aerobic and anaerobic threshold has commonly been prescribed from a treadmill running protocol. Running tests utilize lower body musculature and cross country skiers perform whole body exercise with a large emphasis on the upper body. For this reason, the findings from the present study as well as previous confirm the need for sports and technique specific testing. There were large variations in HR at aerobic and anaerobic thresholds between techniques. Because of this, the implementation of data must be used with caution. The all subject's results may provide inaccurate data for the prescription of HR zones because many differences were found when examining men's and women's results independently. When determining appropriate heart rate based intensity zones for technique specific training in either men or women, it may be more valid to use the data from men's results for men and the data from women's results for women, not all subjects' results. The data presents variations that may occur when different groups are tested, and it is important to realize that every athlete presents different strengths, especially across genders. The data is providing information from a small sample size. Although this small sample size of results is in line with research within the field, it is important to interpret the data with that in mind.

If HR at aerobic or anaerobic threshold is prescribed to the athlete from one technique specific test to the other, the HR intensity may not be interchangeable to meet training needs and goals. For example, if the HR at anaerobic threshold in women from the NW, DS, V2, and V1 tests are prescribed for DP, blood lactate concentrations would accelerate and the time an athlete could train at that given HR intensity would decrease. Therefore, the same heart rate training zones from one technique specific test, in our study NW, DS, V2, or V1, cannot be interchanged with the DP technique if it is desirable to work at the same work load. Moreover, HR training intensities from a specific technique should be carefully examined before prescribing HR intensities to a modality which utilizes different musculature. Depending on the individual athlete this may or may not be true, but based on results in the present study individual guidance of training intensity zones from the athletes own tests are strongly recommended.

The main technique affected in this study was DP, significantly lower HRs were observed in DP at aerobic and anaerobic threshold compared to the other four tests, as well as a significantly lower VO_{2max} in the women's DP test compared to all other techniques. Upper body testing in cross country skiing is essential because the performance of upper body work is important for success in cross country skiing. There is a strong correlation between VO_{2max} and race performance. The performance of international level skiers is related to their VO_{2max}. (Rusko 2003, 21). The upper body muscle mass influences not only the upper body VO_{2max} but also the combined upper and lower body (i.e. skiing) VO_{2max} (Rusko 2003, 22). Many skiers could improve their performance by increasing their upper body VO_{2max} and thereby their combined upper and lower body VO_{2max} (Rusko 2003, 22). Furthermore, it is possible that greater emphasis on upper body training may reduce the difference in the oxidative capabilities between the arms and legs, thereby reducing dependence on anaerobic metabolism during double poling (Mittelstadt et al. 1995). There were many variables which could have affected the women's DP performance in this study as well as the fewer differences observed in men's DP. Because DP was the technique which was most prevalent in regards to significant differences observed among all groups tested, it must raise concern among coaches, athletes and researchers. The upper body strength in cross country skiers is increasing, but are we doing enough in training? From the present study, it is obvious women must emphasize upper body capacities in order to be successful and men still have room for improvement.

Given the high differences observed in heart rate responses at aerobic and anaerobic thresholds between the tests and among group levels, it would be ideal to perform all technique specific tests to determine specific technique training intensities, and to observe differences in the individual cross country skier for optimal training, although it is not likely to perform all five tests. With the lack of laboratories, accessibility to laboratories for human performance testing, and cost of multiple tests for athletes, it is more reasonable to perform a test that is as sports specific as possible that will give athletes and coaches a good representation of intensity zones to apply to the majority of training. Every athlete possesses different strengths, implying that test results will be different from athlete to athlete; because of this, individual guidance of intensity zones is essential for performance. In the present study the tests were each performed with a specific technique, where the subject could not self select. The tests were carefully matched for workloads and designed in a way that the technique felt “natural” in regards to the speed and grade of the test. It is important to note that in everyday skiing the athlete is transitioning from one technique to the next depending on speed and terrain. This is important for coaches and athletes to realize when choosing a test which best represent “all of skiing.” From the present studies results, it seems most reasonable to recommend choosing a test which incorporates whole body musculature, either NW, DS or V2 skating, and a test that represents upper body musculature, either DP or V1. In this way, the coaches and athletes can compare two tests that will provide information on training intensities, and possible differences between whole and upper body musculature. With this information the coaches are able to help guide the athlete in future training goals. If it is only possible to perform one test, it is recommended to perform a whole body test (i.e. NW, DS, or V2) with the knowledge from research that upper body techniques (i.e. DP, V1) may elicit lower HR at AerT and AnT.

6.6 Limitations

There are several areas of focus for additional research in relation to this study. The DP test in women may have some factor affecting the results, such as the speed of the test in the last stages, and thus, more tests should be performed to get closer to a more optimal test. The significance of the results may be questioned when such a small sample size was used. There may be better information gained from a larger sample size. Because so many differences were observed in women's results in the double pole technique, it may be valuable to perform these tests at a different time of year, perhaps in the fall when athletes are performing dry land training. The detraining effect may have had a larger impact on women in double poling and fall testing may eliminate that factor.

6.7 Conclusions

Roller skiing is an important training method during dry-land training in cross country skiing, and roller skiing studies play an extremely important role for observing different aspects of ski technique, and giving useful training suggestions for skiers. Tests to evaluate cross country skiers should involve the whole muscle mass corresponding to the particular technique or mode of exercise (Mygind et al. 1991). The present study demonstrated laboratory roller ski tests can be used to evaluate individual aerobic capacity and HR intensity zones for cross country ski endurance training in all of the most commonly used techniques. Results among different techniques at group levels should be used with discretion as many differences existed between all subjects, and men and women tested separately. It is important to consider there may be large differences between groups and among athletes. From science to coaching, the results from this study provide important scientific results that are necessary for coaches when prescribing training intensities and programs to the athlete.

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8 APPENDIXES

KIHU

JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

JYVÄSKYLÄN AMMATTIKORKEAKOULU

Nordic walking test / male protocol

Name: ______________________

Date of Birth: ______________________

Date:	
Weight:	
Height:	
Temperature:	
Air pressure:	
Mask:	
Sample line:	
Pole:	
Skinfolds:	
Scapula:	
Triceps:	
Biceps:	
Iliaca:	
Sum. / Fat %	/

Time	Speed	Inclination	Work	HR	La	Time for 10 cycles
0	-	-	-			
3	6,0	7 %	26			
6	6,6	9 %	32			
9	6,6	12 %	38			
12	7,0	14 %	44			
15	7,0	17 %	50			
18	7,0	20 %	56			
21	7,2	22 %	62			
24	7,6	23 %	68			
27	7,8	25 %	74			
30	7,8	27 %	80			
33	8,4	27 %	86			
36	8,8	28 %	92			
			Test time:			
RECOVERY						
1						
3						

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UNIVERSITY OF JYVÄSKYLÄ

JYVÄSKYLÄN AMMATTIKORKEAKOULU

Nordic walking test / female protocol

Name: ____________________

Date of Birth: ____________________

Date:	
Weight:	
Height:	
Temperature:	
Air pressure:	
Mask:	
Sample line:	
Pole:	
Skinfolds:	
Scapula:	
Triceps:	
Biceps:	
Iliaca:	
Sum. / Fat %	/

Time	Speed	Inclination	Work	HR	La	Time for 10 cycles
0	-	-	-			
3	6,0	4 %	20			
6	6,0	7 %	26			
9	6,6	9 %	32			
12	6,6	12 %	38			
15	7,0	14 %	44			
18	7,0	17 %	50			
21	7,0	20 %	56			
24	7,2	22 %	62			
27	7,6	23 %	68			
30	7,8	25 %	74			
33	7,8	27 %	80			
36	8,4	27 %	86			
			Test time:			

RECOVERY						
1						
3						

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JYVÄSKYLÄN
AMMATTIKORKEAKOULU

Roller skiing tests / male protocols

Name:

DP

Date:	
Weight:	
Pole:	
Mask:	
Sample line:	
Air pressure:	

min	km/h	%	HR	La	Time for 10 cycles
0	-	-			
3	8,0	3 %			
6	10,0	3 %			
9	12,0	3 %			
12	14,0	3 %			
15	16,0	3 %			
18	18,0	3 %			
21	20,0	3 %			
24	22,0	3 %			
27	24,0	3 %			
30	26,0	3 %			
33	28,0	3 %			
36	30,0	3 %			
		Test time:			
			+3':		

V2

Date:	
Weight:	
Pole:	
Mask:	
Sample line:	
Air pressure:	

min	km/h	%	HR	La	Time for 10 cycles
0	-	-			
3	8,0	5 %			
6	10,0	5 %			
9	12,0	5 %			
12	14,0	5 %			
15	16,0	5 %			
18	18,0	5 %			
21	20,0	5 %			
24	22,0	5 %			
27	24,0	5 %			
30	26,0	5 %			
33	28,0	5 %			
36	30,0	5 %			
		Test time:			
			+3':		

DS

Date:	
Weight:	
Pole:	
Mask:	
Sample line:	
Air pressure:	

min	km/h	%	HR	La	Time for 10 cycles
0	-	-			
3	10,0	3 %			
6	10,0	5 %			
9	10,0	7 %			
12	10,0	9 %			
15	10,0	11 %			
18	10,0	13 %			
21	10,0	15 %			
24	10,0	17 %			
27	10,0	19 %			
30	10,0	21 %			
33	10,0	23 %			
36	10,0	25 %			
		Test time:			
			+3':		

V1

Date:	
Weight:	
Pole:	
Mask:	
Sample line:	
Air pressure:	

min	km/h	%	HR	La	Time for 10 cycles
0	-	-			
3	10,0	3 %			
6	10,0	5 %			
9	10,0	7 %			
12	10,0	9 %			
15	10,0	11 %			
18	10,0	13 %			
21	10,0	15 %			
24	10,0	17 %			
27	10,0	19 %			
30	10,0	21 %			
33	10,0	23 %			
36	10,0	25 %			
		Test time:			
			+3':		

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UNIVERSITY OF JYVÄSKYLÄ

JYVÄSKYLÄN
AMMATTIKORKEAKOULU

Roller skiing tests / female protocols

Name:

DP

Date:	
Weight:	
Pole:	
Mask:	
Sample line:	
Air pressure:	

min	km/h	%	HR	La	Time for 10 cycles
0	-	-			
3	7,0	3 %			
6	9,0	3 %			
9	11,0	3 %			
12	13,0	3 %			
15	15,0	3 %			
18	17,0	3 %			
21	19,0	3 %			
24	21,0	3 %			
27	23,0	3 %			
30	25,0	3 %			
33	27,0	3 %			
36	29,0	3 %			
		Test time:			
			+3':		

V2

Date:	
Weight:	
Pole:	
Mask:	
Sample line:	
Air pressure:	

min	km/h	%	HR	La	Time for 10 cycles
0	-	-			
3	7,0	5 %			
6	9,0	5 %			
9	11,0	5 %			
12	13,0	5 %			
15	15,0	5 %			
18	17,0	5 %			
21	19,0	5 %			
24	21,0	5 %			
27	23,0	5 %			
30	25,0	5 %			
33	27,0	5 %			
36	29,0	5 %			
		Test time:			
			+3':		

DS

Date:	
Weight:	
Pole:	
Mask:	
Sample line:	
Air pressure:	

min	km/h	%	HR	La	Time for 10 cycles
0	-	-			
3	9,0	3 %			
6	9,0	5 %			
9	9,0	7 %			
12	9,0	9 %			
15	9,0	11 %			
18	9,0	13 %			
21	9,0	15 %			
24	9,0	17 %			
27	9,0	19 %			
30	9,0	21 %			
33	9,0	23 %			
36	9,0	25 %			
		Test time:			
			+3':		

V1

Date:	
Weight:	
Pole:	
Mask:	
Sample line:	
Air pressure:	

min	km/h	%	HR	La	Time for 10 cycles
0	-	-			
3	9,0	3 %			
6	9,0	5 %			
9	9,0	7 %			
12	9,0	9 %			
15	9,0	11 %			
18	9,0	13 %			
21	9,0	15 %			
24	9,0	17 %			
27	9,0	19 %			
30	9,0	21 %			
33	9,0	23 %			
36	9,0	25 %			
		Test time:			
			+3':		

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