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PHYSIOLOGICAL RESPONSES TO DOUBLE-POLE ERGOMETRY: STANDING VS. SITTING

Jodi Lynn Tervo
Northern Michigan University

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By

Jodi Lynn Tervo

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This thesis by Jodi Lynn Tervo is recommended for approval by the student's thesis committee in the Department of Health, Physical Education, and Recreation and by the Dean of Graduate Studies.

Committee Chair: Dr. Phillip B. Watts Date

First Reader: Dr. Randall L. Jensen Date

Second Reader: Nancy Uschold Date

Department Head: Dr. Harvey Wallace Date

Dean of Graduate Studies: Dr. Terrance L. Seethoff Date

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ABSTRACT

PHYSIOLOGICAL RESPONSES TO DOUBLE-POLE ERGOMETRY:
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Studies have shown that double poling involves the lower extremities during cross-country skiing. This lower extremity contribution would not be available to the Paralympic sit-skier nor the able-bodied athlete with a lower extremity injury. Objective: There is a lack of available research to describe physiological responses of seated double pole ergometry, therefore the purpose of this study was to determine if physiological differences exist between the seated versus standing positions. Methods: Twenty collegiate Nordic skiers performed two maximum work tests, at least 24 hours apart, using the double pole technique on a modified VASA Ergometer. One test was performed in the Stand position and the other in a Seated position. Expired air analysis data were collected continuously and averaged over 60 sec intervals. Data analysis employed a paired T-test with the alpha level set at $p \leq 0.05$. Results: The subjects used in this study attained higher physiological demands during the Stand test. Conclusions: The data from this study show significant differences between the physiological responses of Seated versus Stand double pole ergometry. Part of the observed difference is likely due to the subjects being more specifically trained in the familiar standing position. The results may have implications when using sit-skiing or seated ergometry as a training mode.

DEDICATION

This thesis is dedicated to all individuals who have been born with or acquired a physical or visual impairment. This paper is written to advance coaching and sport and recreation programs for you.

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PREFACE

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This thesis follows the format of the *Journal of Sports Science and Medicine*, and the Health, Physical Education, and Recreation Department.

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LIST OF SYMBOLS AND ABBREVIATIONS

DP, Double Pole

DS, Diagonal Stride

FIS, International Ski Federation

HR, Heart Rate

HR_{max}, Maximal Heart Rate

HR_{peak}, Peak Heart Rate

RER, Respiratory Exchange Ratio

SD, Standard Deviation

$\dot{V}_E$, Ventilation

$\dot{V}O_2$, Oxygen Consumption

$\dot{V}O_{2max}$, Maximal Oxygen Consumption

$\dot{V}O_{2peak}$, Peak Oxygen Consumption

CHAPTER I

PHYSIOLOGICAL RESPONSES OF DOUBLE POLE ERGOMETRY: STANDING VS. SITTING

Tervo, J.L. and Watts, P.B.

Exercise Science Laboratory, Northern Michigan University, Marquette, MI, USA

KEY WORDS: Cross-country skiing, sit-skiing, oxygen consumption, ventilation.

INTRODUCTION

The double pole (DP) technique involves propulsion via bilateral pole push forces generated by the upper body (Holmberg and Wagenius, 2003), and is a common technique for both stand-up and sit-skiing. The DP technique has greatly developed over the past fifteen years (Lindinger et al., 2009). A number of research articles have been published related to performance and evaluation of the physiological and biomechanical aspects of double poling in the standing position. This previous research has found that double poling requires high levels of upper body fitness, and ski specific upper body fitness is an important predictor of cross-country ski performance (Mahood et al., 2001). Thus, training modes should involve movements and intensities specific to cross-country ski techniques. Although competitive cross-country skiing requires snow, coaches and athletes commonly use dry-land training methods during the off-season. Training modes such as roller skiing and upper body ergometry work simulate skiing movements and are considered to be sport specific (Nesser et al., 2004).

Wisloff et al. (1998) found upper body ergometry to be both a valid and reliable measure for evaluating upper body fitness levels. This suggests that DP ergometry may be one potential training tool, especially off-season. One upper body ergometer with potential for ski specific training is the VASA Ergometer (Essex Junction, Vermont, USA). The website for the VASA Ergometer suggests that it can be used to help improve endurance and anaerobic power (Training for Nordic Skiing); however, no available publications report use of the VASA Ergometer in cross-country ski research.

Although the previously mentioned studies discuss the upper body involvement in double poling, Holmberg et al. (2005) verified that cross-country skiing also involves lower extremity use. The lower extremity contribution as described by Holmberg et al. would not be available to the Paralympic sit-skier or for able-bodied athletes who may have a lower extremity injury and use upper-body only modes of training during recovery. Therefore, differences in physiological responses may be expected when performing double-poling with or without using the legs. Due to a lack of published studies, a question remains if there is a difference in physiological responses to DP ergometry when seated versus standing. The purpose of this study is to determine if maximal oxygen consumption differs in two different double pole positions, Seated and Stand.

METHODS

Twelve female and eight male collegiate athletes participated in a cross-country ski double pole ergometry study in two positions: Seated and Stand. The subjects were 21.5 ± 3.2 years old, and had participated in approximately 12-15 cross-country ski races within the past year. Ethical approval (#HS09-307) from the University Institutional Review Board was granted prior to beginning the study. The subjects signed an informed consent, and completed a Physical Activity Readiness Questionnaire (PAR-Q; Public

Health Agency of Canada, 2002). Each subject completed a survey to gather information on their competition schedule, typical race distance(s), and off-season training modes. Most of the male subjects raced in 10 and 15 km races, and used rollerskiing, running, biking, and weight training during off-season training. Most of the females skied in 1, 5, 10, and 15 km races, and used similar off-season training modes as the males, except more males included weight training than females. Prior to any physiological testing, the subjects stood on a Tanita Digital Scale BWB-800A Class III (Tanita Corp., Japan) to measure weight to the nearest 0.1 kilogram, and a Seca wall stadiometer was used to obtain height to the nearest 0.5 centimeter.

Subjects performed two maximal oxygen consumption tests using the DP technique on a modified VASA Ergometer (Essex Junction, Vermont, USA). The VASA Ergometer is an isokinetic machine in that the resistance increases as the subject's poling cadence increases. One maximal test was performed in a Stand position to simulate on-snow cross-country skiing (Figure 1). A second maximal test was performed in a Seated position on a modified sit-ski (Figure 2). Both tests were performed in the Exercise Science Laboratory, and took place at least 24 hours apart. To randomize the order of testing, a counterbalancing method was used. A standard VASA Ergometer was mounted at the base of a parallel vertical railing system. Two pull cords for poling were directed through pulleys which were mounted to an adjustable cross-bar attached to the railing system. The adjustable cross-bar enabled the height of the pull-point for poling to be adjusted for different heights for Stand versus Seated skier positions.

Each subject brought in a pair of their classic poles, and the pull height for the VASA Ergometer was set by positioning the bottom of the cross-bar at a point 15%

higher than the classic pole height to accommodate the slack at the beginning of the pull. The Seated test used the same procedures as the Stand test, except that the subject sat on a sit-ski and their pole height was determined by setting a pair of adjustable poles so that the top of the pole was at the level of the subject's eyebrow when seated on the sit-ski. This height was then measured and the pull height was set at 50% higher than the pole height. The discrepancy of the percentages is due to the fact that static nylon extenders (68 cm) were added to the VASA for the Seated test so that the length of the cords were long enough to complete a pole cycle. The height was set to provide a standardization of pole lengths that produced a close approximation of the usual pole-plant position for subjects of different sizes.

A continuous graded exercise test on the VASA Ergometer was used. The protocol involved a self selected warm-up pace and accommodation period of five minutes before the test. The VASA Ergometer uses "an 'aqua-flow' flywheel resistance" system with an adjustable damper, and a digital feedback screen which provided an image of cadence and total time of work-out. A damper setting of 3 out of a maximal of 7 was used for all tests and subjects. The protocol started with a cadence of 40 strokes per minute which was controlled via an auditory metronome and visual feedback from the Ergometer monitor. The stroke cadence was increased by five strokes per minute each 60 seconds of the test. The test was terminated when the subject chose to terminate due to exhaustion, or the subject was no longer able to keep up with the stage required cadence. The highest $\dot{V}O_2$ values were treated as technique-specific peak oxygen consumption ($\dot{V}O_{2peak}$).

The subject was fitted with a portable breath-by-breath expired air analysis system (Oxycon Mobile; CareFusion, CA). The Oxycon Mobile instrumentation weighed approximately 950 grams and was carried via an adjustable vest harness sized to each subject. The instrument flow sensor was calibrated according to manufacturer's auto-cal procedure and the oxygen and carbon dioxide sensors were calibrated with known calibration gases prior to each test. Breath by breath data were collected and averaged over 60-second time intervals. Heart rate (HR) was recorded via a chest-strap monitor (Polar USA) coded for the expired air analysis system. Data were averaged over 60 seconds and stored via the OxyconMobile; LabManager V5.3.0 along with the expired air analysis data.

The test conditions were analyzed using a paired T-test to assess the differences between the two testing positions, using SPSS 17.0 (SPSS Inc., Illinois, USA). The predetermined alpha level was set at $p \leq 0.05$.

RESULTS

The number of stages completed was not statistically different between test conditions. The skiers were able to complete 9.2 ± 2.21 stages during the Seated test, while the subjects were able to complete 9.8 ± 1.88 stages during the Stand test. Table 1 presents means (±SD) for the physiological responses during the two tests. All physiological responses were significantly different between the two test positions. As noted in Table 1, the heart rate data only includes 16 subjects and is due to the fact that the heart rate monitor failed to read the other four subjects heart rate response. Figures 3 and 4 provide the mean (±SD) data for each stage during the Seated and Stand tests.

DISCUSSION

When comparing DP ergometry in the two positions of Seated versus Stand, the subjects used in this study were able to produce more demanding physiological responses during the Stand test as evidenced by higher oxygen consumption and ventilation. Multiple factors may explain these responses, including a greater active muscle mass in the Stand position as suggested by Holmberg et al., (2006), the possibility that subjects cannot produce equivalent work in the Seated position, or subjects being more specifically trained in the standing position.

In 2006 Holmberg et al. performed a study to look at the lower body contribution to the DP technique. During both tests the skiers wore knee braces, however, during one of the tests the knee brace did not allow for any knee movement and a strap was used to lock the skier's ankle in place. During the other test the knee and ankle were able to move as normal during roller skiing. The results clearly revealed that the lower extremity contribution to the DP technique is vital to ski performance. The skiers obtained a 7.7% higher $\dot{V}O_{2peak}$, 9.4% higher maximal velocity, and an 11.7% longer time to exhaustion during the DP free than the DP locked. This may be one reason that the current Seated test produced lower physiological values than the Stand test. It is also possible that the Stand position requires more active musculature for postural support.

In 2010 Fabre and colleagues performed a study on elite female skiers, including a maximal DP test on a ski treadmill. During the DP test, the subjects were able to reach a $\dot{V}O_2$ of 55.0 ± 5.8 ml·kg^{-1}·min^{-1}, a HR of 178 ± 9 b·min^{-1}, and $\dot{V}_E$ 121.7 ± 16.8 L·min^{-1}. All of these values are more closely related to those of the current Stand test.

The response of ventilation (Figure 3) shows that there is a plateau in mean $\dot{V}_E$ under both conditions, however it is more pronounced for the Seated position. The slight increase in ventilation for stage 12 is likely due to the lower number of subjects that finished this stage. Subsequent analysis found that $\dot{V}_E$ was not significantly different between Seated and Stand at stage 4 ($p=0.331$), which all subjects completed.

The trend for a decreasing slope in the oxygen consumption response depicted in Figure 4 could also be related to the different number of subjects completing the latter stages of the protocol. Further analysis of the stage 4 responses found a significantly lower oxygen consumption for Seated versus Stand ($p<0.001$). Thus, $\dot{V}O_2$ appears to be consistently less for the Seated relative to the Stand condition. These results suggest that, although cadence was the same, the work performed differed between Seated and Stand for a given stage. It was not possible to quantify the work per stage because the VASA Ergometer digital read-out does not provide this information.

In a typical graded exercise test, we would expect $\dot{V}_E$ to continue to increase even when $\dot{V}O_{2peak}$ is attained. For the Seated condition, since the $\dot{V}O_2$ response with increasing cadence levels off around stage 8, and $\dot{V}_E$ also levels off around stage 8, it could be that there is some artifact with the VASA Ergometer work rate requirement when the cadence becomes fast. It could be that the subjects do not completely "pull through" each DP stroke and thereby decrease the work rate even when the cadence increases. If this is the case, motivation and biofeedback for full stroke range of motion would be critical when using the VASA as a maximum graded exercise test device. A separate study concurrent with the present study found that trunk range of motion decreased and shoulder range of motion increased in the Seated position (Jensen et al., 2010). Thus some differences in kinematics are evident though the final effects on the full stroke mechanics and kinetics remain unknown. Kinetic analysis of multistage work on the VASA Ergometer would help answer these questions.

The lack of a clear hyperventilation response for the Stand test ($\dot{V}_E$ plateaus while $\dot{V}O_2$ continues to increase) is more troublesome. This could also be related to the same artifact as the Seated test where the VASA Ergometer allows one to "cheat" and work at a lower overall work rate with a faster cadence but shorter pull distance. Taken together these results suggest that the work is different for Seated versus Stand, and that use of the VASA Ergometer for controlled testing and/or training will require care and highly motivated subjects.

It is possible that the Seated position involves significantly more compression of the abdominal and thoracic areas which could limit lung inflation and adequate ventilation. The lower ventilation for the Seated condition beyond stage 7 may reflect this. Whether limited lung capacity was a factor in the current test is unknown, however, recent evidence shows that expiratory flow is not affected by body position and suggests this was not a factor in the present study (McCoy et al., 2010). It is more likely that the lower ventilation mean beyond stage 7 is caused by a lower number of subjects completing subsequent stages.

It is common to find technique specific physiological responses (Larson, 2006; Staib et al., 2000). The subjects used in this study were more specifically trained and familiar with the standing position. Responses may be expected to differ with subjects specifically trained in the Seated position. Bernardi et al. (2010) have studied well-trained sit-skiers during actual ski conditions. They studied five cross-country sit-skiers with physical abilities ranging from normal trunk control to the inability to sit without trunk and arm support, and all completed a 5 km simulated race. The peak oxygen consumption of these athletes during the simulated race was 49.9 ± 7.8 $ml \cdot kg^{-1} \cdot min^{-1}$, with a peak heart rate of 181.4 ± 10.0 $b \cdot min^{-1}$. These race performance $\dot{V}O_2$ values are much higher than observed as peak values in the Seated test of the present study. Bernardi et al.'s results are more closely related to the current study's $\dot{V}O_{2peak}$ values for the Stand test, demonstrating that the current testing method may not accurately represent an elite Paralympic athlete who uses a sit-ski.

CONCLUSION

The data from this study show significant differences between the physiological responses of Seated versus Stand double pole ergometry when using able-bodied collegiate athletes. The results may be of interest to a coach who is creating training programs using double pole ergometry for athletes with lower extremity injuries, knowing that seated double pole ergometry does not produce as demanding physiological responses as when standing.

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Table 1. Peak Physiological Responses to Double Pole Ergometry in Seated and Stand conditions.

Position	$\dot{V}_E$ (L·min^{-1})	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	RER	HR (n=16) (b·min^{-1})
Sit	113.8 ± 31.5	39.2 ± 5.2	1.03 ± 0.07	168.2 ± 6.3
Stand	132.5 ± 25.6*	54.4 ± 6.6*	0.99 ± 0.05*	186.1 ± 12.2*

*indicates significantly different from seated, $p \leq 0.05$.

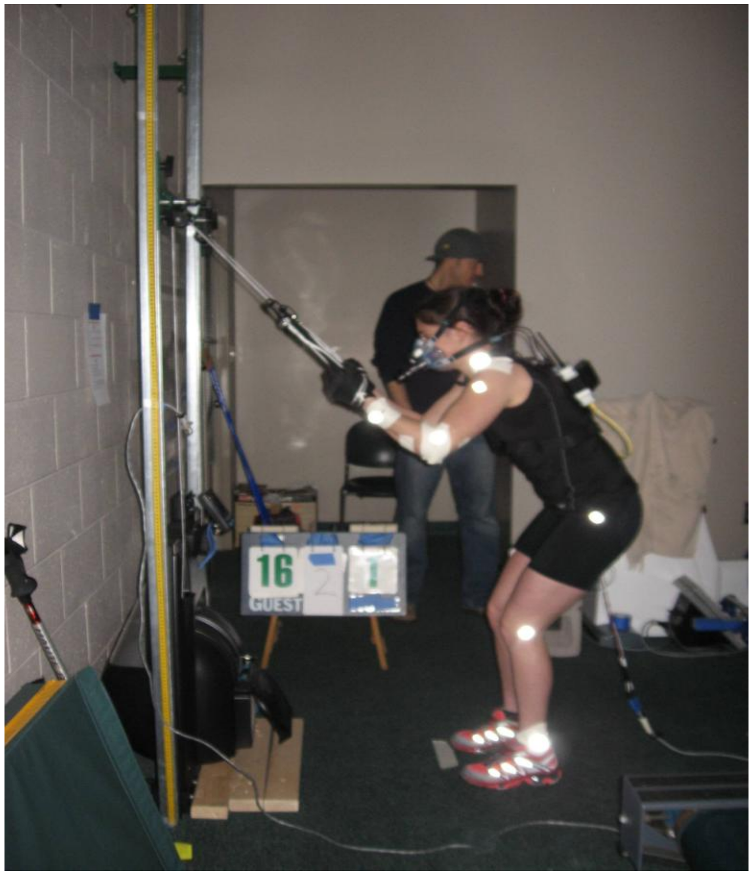

Figure 1. The modified VASA Ergometer, during a Stand test.

Figure 2. The modified VASA Ergometer, during a Seated test.

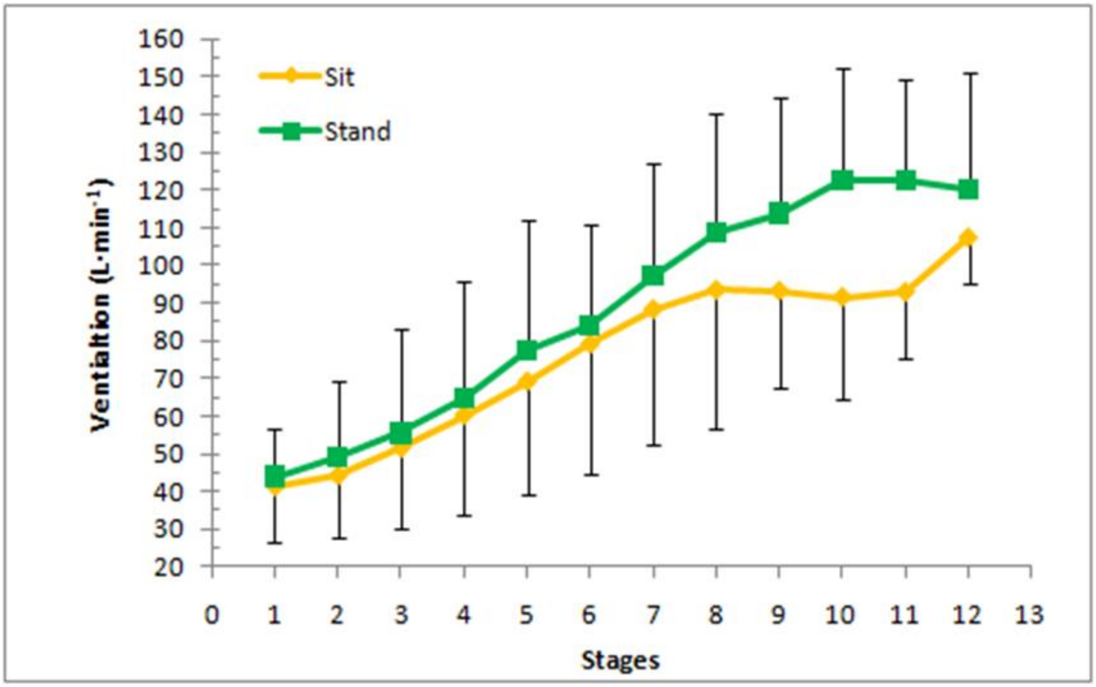

Figure 3. The mean ventilation data for individual stages during the Seated and Stand tests.

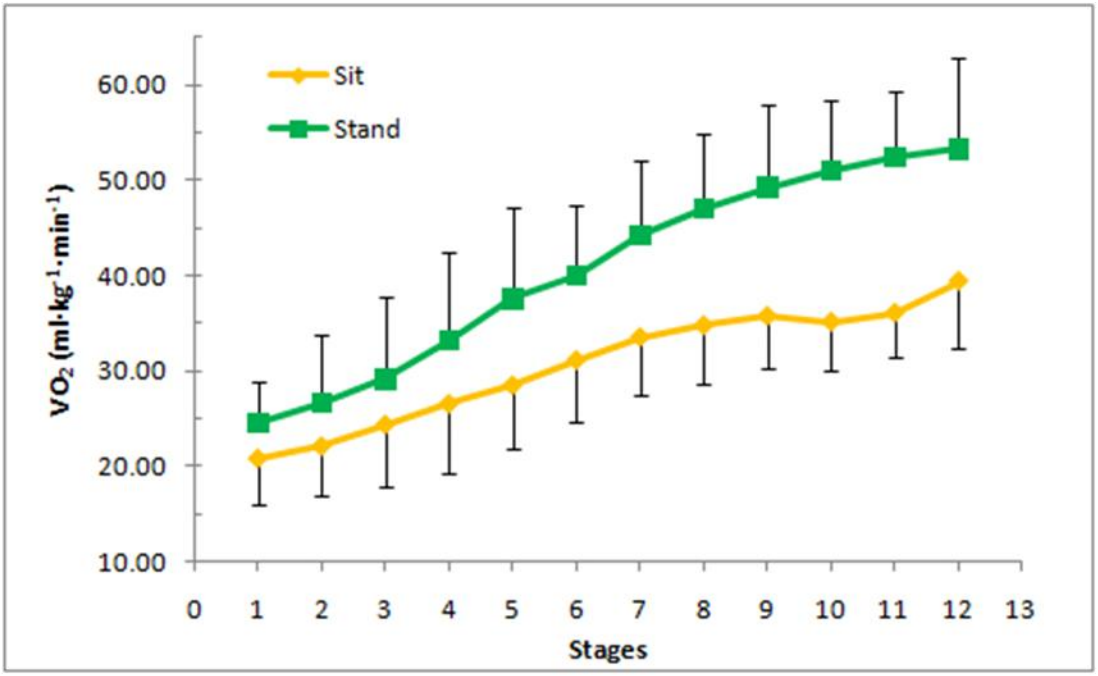

Figure 4. The mean oxygen consumption data for individual stages during the Seated and Stand tests.

CHAPTER II
LITERATURE REVIEW

Background

Cross-country skiing dates back to 5,000 BC according to cave drawings found in Norway (Clifford, 1992). Initially skis were used as a tool to assist in moving across the snow for practical purposes such as military pursuits (Holmberg and Wagenius, 2003). Many millennia later competitive skiing began, with evidence of competition dating back to 1520 in Norway (Holmberg and Wagenius, 2003). In 1924 cross-country skiing was declared a Winter Olympic sport (Clifford, 1992), and in 1976 it was added to the Paralympic Winter Games (Jahnke and Schüle, 2006). The International Paralympic Winter Games are an elite competition for persons with physical disabilities which parallel the Winter Olympics.

Competition leads to experimentation in order to improve ski performance. Nordic skiing has seen numerous equipment, technique, and ski trail preparation improvements over the past 7,000 years. Between 1932 and 1992 the speed at which skiers could complete a course doubled (Street, 1992). The decrease in equipment mass is estimated to contribute to a 12% improvement in ski performance (Street, 1992). Whereas Street estimates that 88% of the improvements seen in ski performance are due to increased functional characteristics of equipment, trail preparation and scientifically formulated training programs.

The oldest technique in skiing is the classical technique, and was used primarily until the 1982 World Cup Races (Hoffman, 1992) when the race was won using the skate ski technique. The popularity of the skate technique grew rapidly after this and, over concern of the classical technique becoming extinct, the International Ski Federation ruled half of all races be performed using the classic style technique (Hoffman, 1992). These two main categories of skiing each have specific techniques. Classic style involves the diagonal stride, double pole, and kick double pole. The skating style employs the double pole movement in conjunction with the V1 and V2 techniques. The double pole technique is common in both styles of skiing.

There is a general physiological model that has been traditionally used for cross-country skiing, which includes maximal oxygen consumption ($\dot{V}O_{2max}$), oxygen consumption ($\dot{V}O_2$) at lactate threshold, and ski economy. All of these components are testable in a laboratory. The assessment of maximal oxygen uptake has been a standard test of aerobic fitness, cardiovascular health, and exercise performance that began in the early 1900's (Levine, 2008). This concept is based upon the idea that there is a limit to the amount of oxygen that can be transported from ambient air into the mitochondria to perform work (Levine, 2008), and oxygen is a key component in the metabolism and production of ATP (McArdle, 2001). The respiratory and cardiovascular systems support the uptake and transportation of oxygen from the ambient air to the muscles where it is used in the metabolic cycle to convert substrates into energy (McArdle, 2001). Maximal oxygen consumption tests are usually performed using a graded exercise protocol, which can provide athletes and coaches with information beyond the $\dot{V}O_{2max}$ value. Ventilation, heart rate, and respiratory exchange ratio (RER), can also be calculated during a graded exercise test. This provides data to the exercise scientist in order to create scientifically progressed training programs, and to assess program effectiveness.

It is common for competitive cross-country skiers to undergo testing for $\dot{V}O_{2max}$. It appears that the first maximal oxygen consumption test was performed on skiers in 1961 (Åstrand and Saltin, 1961). Åstrand and Saltin found there was no difference in oxygen consumption between running and skiing. The correlation between running and skiing is still used today (Staib et al., 2000).

More specific to cross-country skiing, the upper body plays a key role in ski performance as demonstrated by Mahood et al.'s study published in 2001. One ski specific upper body technique is double poling, which is a strong component of cross-country skiing. This review will focus on the physiological testing of the double pole (DP) technique and its relation to training performance. A second objective of this review is to look at the applications for training an athlete with an injury.

Applied Physiology of Double Poling

The DP technique has greatly developed over the past fifteen years (Lindinger et al., 2009). A number of research articles have been published related to performance and evaluation of the physiological and biomechanical aspects of double poling in the standing position. This previous research has found that double poling requires high levels of upper body fitness, and ski specific upper body fitness has been found to be an important predictor of cross-country ski performance (Mahood et al., 2001).

The scientific evaluation of skier training and performance has been explored by scientists for a number of years. Although competitive cross-country skiing requires snow, coaches and athletes commonly use dry-land training modes during the off-season. Training modes such as rollerskiing and upper body ergometer work simulate skiing movements and are considered to be sport specific. Training zones have been measured and performance evaluated using simulated skiing on rollerskis, treadmills, upper body ergometers and, to a lesser extent, skiing on snow. Several studies have been key in the understanding of cross-country ski performance.

Hoffman et al. (1990) looked at physiological variables during rollerskiing at two speeds, 14 $km \cdot hr^{-1}$, and 18 $km \cdot hr^{-1}$. The DP technique elicited a 12% lower oxygen consumption than the V1 skate and kick DP techniques at both speeds. The HR was 7% lower during DP at 14 $km \cdot hr^{-1}$ when compared to V1 skate and kick DP, and the HR during DP was 4% lower at 18 $km \cdot hr^{-1}$ than the kick DP technique. All techniques produced similar ventilation, blood lactate concentrations, and ratings of perceived exertion. Heart rates are often used by athletes to monitor their training, and this study shows that heart rates differ with ski techniques. Therefore, it may be important for athletes to use a technique specific heart rate when training.

In 1990, Hoffman and Clifford performed metabolic testing on-snow; though the protocol was limited to flat terrain. They evaluated the physiological differences between different techniques, including DP on skate skis, DP on classic skis, V1 skate, marathon skate, kick DP, and diagonal stride during submaximal work at a constant speed. The results revealed that the DP technique, with either ski type, elicited the lowest oxygen consumption and heart rates. The DP technique used 26% less oxygen, and the heart rate response was approximately 16 $b \cdot min^{-1}$ lower than the DS. When comparing the oxygen cost of the DP compared to the kick DP, the DP technique cost approximately 10% less oxygen than the kick DP. However, the kick DP and DP elicited similar respiratory exchange ratios and ratings of perceived exertion, which were higher than the skating techniques. This demonstrates that physiological responses are different between techniques. The most economical technique is the DP.

A study published by Staib et al. (2000) looked at the importance of anaerobic and aerobic power of DP to performance determined by the International Ski Federation System (FIS) points. The FIS point system is used to determine world cup rankings, with points accumulated each race performed. It is standardized so international comparisons can be made. Twenty elite male cross-country skiers volunteered to perform three tests. Each subject performed a DP graded exercise test to exhaustion, and an upper-body power test using an ergometer. All subjects also performed a lower body graded exercise test on a treadmill to exhaustion, which was either running or classical skiing. Expired air analysis was continuously monitored and blood lactate levels were determined upon completion of each test. The lower body graded exercise test used a constant speed, and increased the grade by 1% every minute. The DP graded exercise test used a constant grade, and increased the speed every 2 minutes. The upper-body power test was performed on a Freestyle Arm Ergometer, where power output was recorded, and the fly-wheel resistance was increased every 20 seconds. This test was considered to be an anaerobic test. The lower-body graded exercise tests resulted in significantly higher HR, absolute $\dot{V}O_2$ (L · min), relative $\dot{V}O_2$ (ml · kg^{-1} · min^{-1}), but similar peak lactate levels. The authors also found that DP time during the graded exercise test correlated to ski performance. The longer the skiers were able to ski the lower their FIS points were, where lower FIS points equated to better athletes. The authors then divided the 20 subjects into two groups (successful and less successful) to see if they could find any other significant data to help coaches and athletes train. The authors found that the successful group had significantly higher upper body power on the ergometer. The DP graded exercise test also showed differences between the two groups. The successful group had higher absolute $\dot{V}O_2$ ($L \cdot min^{-1}$), relative $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$), and blood lactate ($mmol \cdot L^{-1}$). The DP graded exercise test time to exhaustion was also significantly higher for the successful group than the less successful group. In contrast, there were no significant differences in any variable between the two groups during the lower body graded exercise tests. This study demonstrates that training may need to be directed at upper body power, DP specific strength, and DP techniques in order to maximize ski performance.

Since numerous studies existed for cross-country skiing in the lab, Mahood et al. (2001) performed a field study to predict ski performance through rollerski field tests instead of through laboratory tests. The authors had a second objective to see whether these ski-specific performance determinants were consistent across abilities. Thirteen NCAA Division I collegiate male skiers performed three different rollerski tests in an attempt to find a field test for coaches to predict skier performance. A lactate threshold test was performed using a 1.6 km flat track, with a protocol that increased speed with each lap, using a pace bike to maintain the correct ski speed. The ski economy was determined using the skiers' first three stages of the lactate threshold test. The maximal oxygen consumption tests were performed on a 3 km course with the first 2 km relatively flat terrain, and the final km a steep incline. No subjects completed the entire 3 km course. The final test was the upper body time trial using the DP technique, and was performed on a 6-10% incline for 1 km. In order to correlate these tests to performance, each skier also performed a 10 km time trial. The time to complete the upper body time trial showed the highest correlation to their rank-order of ski season points and the 10 km time trial. The DP time trial took an average of 3 minutes 50 seconds which taxes both the anaerobic and aerobic energy systems, and the DP technique taxed the upper body. These three components are quantified in the 1 km upper body time trial and may explain the high correlation to race performance. When the authors split the group into skiing ability they found that, regardless of skier ability, upper-body power and endurance help to predict ski performance, therefore, the 1 km upper body time trial is a useful field test for all skiers. This may be a useful and inexpensive assessment tool for coaches to use during off-season training.

Larson (2006) used a graded exercise test to study heart rate responses at the lactate threshold for various modes of treadmill training. Rollerski DP, rollerski skating, and running were the three different modes, and all protocols had a constant velocity with an increasing grade every 4 minutes, starting with a 2% grade. Results revealed a significantly lower HR at lactate threshold during DP than rollerski skating or running. However, there was no significant difference between the heart rates at threshold for running and rollerski skating. When comparing the point that the athletes reached lactate threshold, the DP technique elicited lower HR's at higher blood lactate concentrations when compared to the running and skating modes of exercise. In cross-country ski training the heart rate is often used for monitoring training zones, and therefore, these findings are important for the coach and athlete to base the athlete heart rate off of the specific mode of training for the day.

Numerous studies exist that have determined the DP technique to be an important predictor of cross-country ski performance. The nature of the double poling technique suggests a focus on upper body training; however a more recent study has shown that the lower body musculature is an important contributor in double pole performance. Holmberg et al. (2006) performed a study on eleven elite skiers. Each subject performed two different DP incremental exercise tests on a ski treadmill. During both tests the skiers wore knee braces, however, during one of the tests the knee brace did not allow for any knee movement and a strap was used to lock the skier's ankle in place. During the other test the knee and ankle were able to move as normal during rollerskiing. The two tests were named DP locked and DP free respectively. Maximal and peak oxygen consumption, HR, blood lactate concentration, maximal velocity, pole-ground reaction forces, and joint angles were all analyzed. The results clearly revealed that the lower extremity contribution to the DP technique is vital to ski performance. The skiers obtained a 7.7% higher $\dot{V}O_{2peak}$, 9.4% higher maximal velocity, and an 11.7% longer time to exhaustion during the DP free than the DP locked. Also, during submaximal stages the skiers elicited higher HR and blood lactate concentrations during the DP locked. When comparing these physiological data to the biomechanical data the DP locked corresponded with a 13.6% higher poling frequency, 4.9% shorter poling phases, 13.3% shorter recovery phases, and a 10.9% lower relative pole force. These data show that the lower extremities contribute significantly to the physiological and technical aspects of DP performance, and training and performance would be negatively impacted by limiting the movement in the legs.

Heil and Willis (2010) performed a graded exercise test which measured $\dot{V}O_{2max}$, lactate threshold, and time to exhaustion using junior and collegiate skiers. Each subject also performed two upper body power tests, one 10 second test and one 60 second test, and numerous lower body power tests, including a variety of jump tests using a timing mat. All skiers in this study had recently raced in the same events, and their race performances were used as the criteria of performance. The authors found the single strongest predictor for cross-country ski performance to be relative $\dot{V}O_{2max}$. They also found that 76-90% of ski performance can be determined using a combination of the athlete's ski specific $\dot{V}O_{2max}$ test, upper body power, and lower body power test scores. A coach may want to track performances in these three mentioned areas to improve training strategies for athletes.

Fabre and colleagues (2010) performed a study on elite female skiers, using two different maximal protocols on a motorized ski treadmill, one DP and one DS to determine a specific test to predict cross-country ski performance. The authors used the subject's FIS points as the common factor to determine their on-snow performance. The DP and DS techniques on a rollerski treadmill produced different physiological values. Peak HR, HR at anaerobic threshold, peak ventilation, and oxygen consumption at anaerobic threshold were all statistically higher during DS than during DP. However, there was no difference in the peak oxygen consumption and ventilation at threshold for the two different techniques. When correlating the data to FIS points the peak oxygen consumption, peak speed, and peak speed at threshold were significantly correlated for DP, but not for DS. The oxygen consumption at threshold during both the DP and DS was significantly correlated to performance. It is important to note that this study used different protocols for the two tests, which may be a factor in the results. The DP test included a fixed grade of 4%, with a starting speed of 10 $km \cdot h^{-1}$, speed was increased by 0.5 $km \cdot h^{-1}$ every 30 seconds. The DS test included a constant speed of 9 $km \cdot h^{-1}$, with an initial grade of 4% that was increased by 2% each 3 minutes. The DP test may have been a more accurate test for determining $\dot{V}O_{2max}$ due to the relatively short duration of 7.8 ± 2 minutes, versus 21.7 ± 2.2 minutes for the DS test (Fabre et al., 2010). The maximal oxygen consumption was not statistically different; however, oxygen consumption at threshold was significantly different. This study demonstrates that two of the best predictors of performance are the skier's speed during DP at anaerobic threshold and their maximal speed during DP. It is difficult to predict ski speed when training on snow due to varying terrain, snow conditions, and uncontrollable element factors. So the next best alternative may be the heart rate, and since this study showed a difference in heart rate at threshold between DP and DS it may be important for athletes to use an anaerobic threshold DP specific target heart rate during DP work-outs.

Pace is difficult to monitor during on-snow cross-country skiing (Eisenman et al., 1989), therefore, the heart rate is often used to monitor training zones (Larson, 2006). However, an athlete's heart rate will likely differ depending upon the terrain, suggesting terrain specific heart rates may be important for the athlete in order to maintain the appropriate target training zone. Along with assessing oxygen consumption and lactate levels, LaRoche et al., (2010) studied the variance of HR during different terrains using the DP and skate ski techniques. Each subject performed two submaximal graded exercise tests using the skate ski technique (one grade increase and one speed increase). Additionally, two maximal graded exercise tests were performed by each subject, one using the DP technique and one using the skate technique. The DP maximum oxygen consumption test was performed using a constant grade with an increased speed, while the skate maximum oxygen consumption test was performed using a constant speed and increasing grade. Results revealed that the heart rates at lactate threshold were approximately 7% lower during uphill skiing than skiing on level terrain using the skate ski technique. The authors also found that relative $\dot{V}O_{2peak}$, and HR_{peak} were both significantly lower during the DP maximum test (60.3 ± 2.8 ml · kg^{-1} · min^{-1}, 187.8 ± 6.7 b · min^{-1}) than the skate maximum test (64.6 ± 1.8 ml · kg^{-1} · min^{-1}, 192.6 ± 5.8 b · min^{-1}). When considering the skate ski tests on different terrains, the use of upper body during uphill skiing appears to increase lactate at lower heart rate's, meaning terrain specific heart rates may be appropriate for training. Also, the maximum oxygen consumption tests reveal that both $\dot{V}O_{2peak}$ and HR_{peak} are lower using the DP technique meaning that target heart rate zones should also be technique specific.

Applications for Athletes with Injuries

Although reports do not show high incidence of injury during cross-country skiing, injuries to the groin, compartment syndrome, sprains and fractures have all been reported. Boyle et al., (1980) performed a survey study at ski resorts in Vermont, USA, to determine the risk of injury during recreational cross-country skiing. Out of the 24 injuries that occurred during a 4 month period, 62% of them were lower extremity injuries including contusions, lacerations, patellar tendon disruption, knee ligament sprains, hip fractures, tibia and fibular fractures, and an extensive subdermal hematoma of the hip. The latter six types of injuries are most likely season ending. Boyle and colleagues noted that prior studies specifically on cross-country ski injuries showed lower extremity injuries to be the most common.

In 1989 Renstrom and Johnson found the most common cross-country skiing overuse injuries were medial-tibial stress syndrome, Achilles tendon problems, and lower back pain. Whereas, the most common traumatic injuries were ankle sprains and fractures, muscle ruptures, and knee sprains. Although compartment syndrome may becaused by a traumatic event, it is also a chronic issue that a number of elite cross-country skiers suffer from according to Lawson et al., (1992).

Though reports show that injuries happen to cross-country skiers, when looking at the injury reports from the 2010 Winter Olympic Games, Nordic ski events are amongst the lowest risk for injury (Engebretsen, 2010). Paajanen et al. (2011) support this, reporting only 1.4% of all professional skiers reported groin injuries over a twelve month period of time. The studies by Engebretsen (2010), and Paajanen et al. (2011) focus on traumatic injuries which do occur, though incidence is low. In a review of the literature on injuries it appears that many of the injuries (chronic or acute) that cross-country ski athletes may suffer from are lower extremity injuries which may take an extended period of time to recover from.

Along with chronic and traumatic injuries for stand-up athletes there are also athletes with permanent injuries who use a sit-ski for competition. Athletes who compete in Paralympic cross-country sit-skiing sit on a frame mounted to cross-country skis and use the double pole technique with shortened ski poles for propulsion over the snow. Little research has been performed on how to train athletes with a lower extremity injury or Paralympic athletes.

Upper body ergometry has been found to be both a valid and reliable measure for evaluating upper body fitness levels (Wisloff and Helgerud, 1998). Mygind and colleagues (1991) found that double pole upper body ergometry could be used as an evaluation tool for determining ski performance. This suggests that off-season DP ergometry may be one potential training tool.

In 1996 Faria et al. performed a study to compare physiological responses to the two main upper body poling techniques in cross-country skiing, using a modified swim bench. One technique was traditional diagonal poling, and the other was the double pole technique. Mean DP $\dot{V}O_{2peak}$ data were higher than classic poling (40.3 ± 10.5 ml·kg^{-1}·min^{-1}, 34.8 ± 9.0 ml·kg^{-1}·min^{-1} respectively). The authors speculated that the DP technique may increase upper body muscle mass involvement more so than classic poling and that adaptations may occur specific to the mode of exercise. This point may be important for the athlete recovering from injury.

Bernardi et al. (2010) analyzed five Paralympic Nordic sit-skiers in a 5 km simulated race field test, with abilities ranging from normal trunk control to the inability to sit without trunk and arm support. Three athletes had paraplegia due to a spinal cord injury and two athletes had lower extremity poliomyelitis. Each athlete also performed an arm crank graded exercise test to determine peak oxygen consumption and ventilatory threshold. The peak oxygen consumption of these athletes during the 5 km simulated race was 49.9 ± 7.8 ml · kg^{-1} · min^{-1}, with a peak HR of 181.4 ± 10.0 b·min^{-1}, and a time of 17 $\pm$ 1.6 minutes to complete the 5 km course. During the arm crank test the athletes exhibited peak $\dot{V}O_2$ values of 51.9 ± 6.92 ml · kg^{-1} · min^{-1}, with a peak HR of 186.2 $\pm$ 11.54 b·min^{-1}. During the arm crank test the athletes reached $73.7 \pm 3.2\%$ of their $\dot{V}O_{2peak}$

at ventilatory threshold, and 85.2 ± 1.71% of their HR_{max} at ventilatory threshold. When comparing the arm crank values to the simulated race values the athlete's HR during the simulated race was 97.5 ± 1.57% of the arm crank test, and relative $\dot{V}O_2$ values were 95.9 ± 7.05% of the arm crank test, and there were no significant differences between the peak lactate values for the arm crank test and the field test. These results show that an arm crank test may be a valuable off-season training tool for persons with spinal cord injuries or lower extremity poliomyelitis.

Summary and Practical Applications

Athlete testing can be split into two types, laboratory and field tests. Both are beneficial to coaches, however, field testing may be more cost effective. Based upon the review of literature the following points are important in predicting performance; and therefore, coaches and exercise scientists will want to use the following information to formulate training programs.

DP laboratory tests include graded exercise tests and upper body ergometry. The athletes should produce a high velocity at the lactate threshold, a high $\dot{V}O_{2max}$, and should be able to sustain a graded exercise test for a long duration. Relating upper body ergometry to ski performance, athletes would want to increase their ability to produce power on an upper body ergometer. One DP field test that targets upper body power, anaerobic metabolism, aerobic metabolism, and has been shown to have a high correlation to performance is the 1 km DP time trail. Numerous studies demonstrate the importance of using appropriate target heart rates, and it has been determined that HR's should be both mode specific (DP, diagonal stride, skate skiing) and terrain specific. In order to maximize performance, heart rates should be measured in technique and terrain specific laboratory and field tests in order to create optimal training programs.

Athletes with lower extremity injuries should attempt to maintain their upper body fitness throughout their recovery period. Upper body ergometry is one tool that has been used, and may be the only option for the athlete. Since muscle adaptation is technique specific it may be of interest for the athlete to perform diagonal poling on an upper body ergometer as well.

During the off-season, one mode of training for Paralympic athletes is arm crank ergometry since the physiological values attained in a maximal test are similar to those seen during race. However, since research has shown that technique specific training is important for stand-up athletes, then theoretically it would be beneficial for Paralympic athletes to also use DP Ergometry during their off-season training sessions. However, no studies have been published on DP Ergometry for the Paralympic athlete.

The website for the VASA Ergometer suggests that it can be used to help improve endurance and anaerobic power (Training for Nordic Skiing); however, no available publications report use of the VASA Ergometer in cross-country ski research. Although earlier studies have discussed the upper body involvement in double poling, Holmberg et al. (2005) state that DP stand-up skiing also involves lower extremity use in the DP technique. The lower extremity contribution as described by Holmberg et al. may not be available to a skier recovering from a lower extremity injury, or to the Paralympic skier. Therefore, differences in physiological responses may be expected when double poling in the sitting position.

Since there are very few studies published regarding training programs for persons with lower extremity injuries and Paralympic sit-skiers, more research is necessary in order to optimally train these athletes.

CHAPTER III
CONCLUSIONS AND RECOMMENDATIONS

The data from this study show significant differences between the physiological responses of Seated versus Stand double pole ergometry when using able-bodied athletes. The results may be of interest to coaches who are creating training programs that use double pole ergometry. Seated double pole ergometry does not produce as demanding physiological responses as standing. More research in the area of seated DP ergometry and Parlaympic sit-ski performance is recommended in order to improve the knowledge base and quality of scientific training programs for persons with lower extremity injuries and Paralympic sit-skiers.

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APPENDIX A

SUBJECT SURVEY

Jodi L. Tervo

Thesis Subject Survey VASA Ergometer

Subject Name and ID:______________________________

Contact information:

Email:_______________________________________

Phone:_______________________________________

Address:_____________________________________

____

Height:___________ Weight:____________

How many races do you compete in per year?_____________________

When was your last competition?_________________________________

What distances do you typically race? (Circle all that apply)

5 km 10 km 15 km 25 km 50 km

Sprint:_________ km

What modes of training do you perform during the off season?

(Circle all that apply)

-Roller ski

-Run

-Road Bike

-Mountain Bike

-Hike

-Other____

APPENDIX B

IRB APPROVAL LETTER

Northern Michigan University

Continuing Education
1401 Presque Isle Avenue
Marquette, MI 49855-5301

November 16, 2009

TO: Jodi Tervo

HPER

FROM: Cynthia A. Prosen, Ph.D.
Dean of Graduate Studies & Research

RE: Human Subjects Proposal # HS09-307

"Physiological and Biomechanical Responses to Double Pole Ergometry: Standing vs. Sitting"

The Internal Review Board (IRB) has reviewed your proposal and has given it final approval. To maintain permission from the Federal government to use human subjects in research, certain reporting processes are required. As the principal investigator, you are required to:

A. Include the statement "Approved by IRB: Project # (listed above) on all research materials you distribute, as well as on any correspondence concerning this project.

B. Provide the Internal Review Board letters from the agency(ies) where the research will take place within 14 days of the receipt of this letter. Letters from agencies should be submitted if the research is being done in (a) a hospital, in which case you will need a letter from the hospital administrator; (b) a school district, in which case you will need a letter from the superintendent, as well as the principal of the school where the research will be done; or (c) a facility that has its own Institutional Review Board, in which case you will need a letter from the chair of that board.

C. Report to the Internal Review Board any deviations from the methods and procedures outlined in your original protocol. If you find that modifications of methods or procedures are necessary, please report these to the Human Subjects Research Review Committee before proceeding with data collection.

D. Submit progress reports on your project every 12 months. You should report how many subjects have participated in the project and verify that you are following the methods and procedures outlined in your approved protocol.

E. Report to the Internal Review Board that your project has been completed. You are required to provide a short progress report to the Internal Review Board in which you provide information about your subjects, procedures to ensure confidentiality/anonymity of subjects, and the final disposition of records obtained as part of the research (see Section II.C.7.c).

F. Submit renewal of your project to the Internal Review Board if the project extends beyond three years from the date of approval.

It is your responsibility to seek renewal if you wish to continue with a three-year permit. At that time, you will complete (D) or (E), depending on the status of your project.

kjm

Telephone: 906-227-2103 ■ FAX: 906-227-2108
E-mail: conteduc@nmu.edu ■ Web site: www.nmu.edu/ce