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ORIGINAL RESEARCH

COMPARISON OF A DOUBLE POLING ERGOMETER AND FIELD TEST FOR ELITE CROSS COUNTRY SIT SKIERS

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ABSTRACT

Background. Sport specific ergometers are important for laboratory testing (i.e. peak oxygen consumption (VO_2)) and out of season training.

Objectives. The purpose of this study was to compare cardiorespiratory variables during exercise on a double poling ergometer to a field test in elite sit skiers.

Methods. Three male and four female athletes from the Canadian National / Developmental team (17-54 years of age, six with complete paraplegia and one with cerebral palsy) completed a field test and a double poling ergometer protocol separated by at least 24 hours. Both protocols consisted of three maximal trials of skiing of three minutes duration separated by 1.5 minutes of rest. A wireless metabolic system and heart rate monitor were used to measure cardiorespiratory responses [peak heart rate, peak VO_2, and peak respiratory exchange ratio (RER)] during each test. Arterialized blood lactate was measured before the beginning of exercise, after each trial and at 5, 10 and 15 minutes post exercise.

Results. No significant differences existed between the field and ergometer tests for peak oxygen consumption (VO_2) (field = 34.7 ± 5.5 $mL \cdot kg^{-1} \cdot min^{-1}$ vs. ergometer = 33.4 ± 6.9 $mL \cdot kg^{-1} \cdot min^{-1}$). Significantly higher peak heart rate and RER were found during the ergometer test. Significantly higher lactates were found during the ergometer test after trial 2 and trial 3.

Conclusion. The double poling ergometer is similar to a field test for evaluating peak VO_2 in elite cross country sit skiers; however, the ergometer test elicits a higher heart rate and anaerobic response.

Key Words: spinal cord injury, aerobic power, lactate.

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INTRODUCTION

Sit-skiing is an event at the Paralympics which involves the athlete sitting in a sled on skis and propelling with poles over race distances ranging from 2.5 to 15 km *(Figure 1)*. Physiological responses to sit skiing have never been evaluated.

Regular cross country skiing is characterized by repeated dynamic contractions over an extended period of time and requires a high level of sustained power output by both the upper and lower body.[1-4] One physiological trait that has been associated with cross country skiing success is maximal oxygen consumption (VO_2 max).[5-8,10,11] The VO_2 max is often measured in a laboratory setting on an ergometer, due to the technical problems related to testing in the field.[12] The most common ergometers used to evaluate all types of athletes include treadmills, cycle ergometers, and arm crank ergometers.[4,13] Testing for sports other than running or cycling lack specificity when using these ergometers;[4,14] therefore, a variety of sport specific ergometers is required. Recently, a double poling cross country ski ergometer has been modified to accommodate cross country skiers with disabilities (sit skiers) and is often used during training during seasons without snow. The purpose of this study was to compare the cardiorespiratory and metabolic responses in elite sit skiers during simulated skiing on this ergometer in a laboratory setting with the same responses during an outdoor field test. The hypothesis was that no significant differences would exist between the laboratory and field tests for the cardiorespiratory and metabolic repsonses evaluated in this study.

Figure 1. *A sit skier during the field test.*

METHODS

Subjects

Seven (three male and four female) subjects, aged 17 to 54 years, volunteered for this study. The subjects were recruited from the developmental and national Canadian Nordic ski teams. Subjects must have competed for a minimum of two years at an elite level which included national and international competitions. Four of the athletes were previously Paralympians, and one athlete was a multiple Paralympic medalist. Subject characteristics are shown in Table 1. The study was approved by the University of Saskatchewan Biomedical Research Ethics Board for research in human subjects. Written, informed consent was obtained prior to the start of the study.

Experimental Design

Throughout the study, all subjects were encouraged to undertake their normal training and diet. They were instructed to continue to be adequately hydrated, not eat two hours prior to the test, avoid strenuous exercise, and limit caffeine intake within six hours of testing. Prior to testing, body weight, height, and body composition were measured. Body weight was measured on a Toledo scale, accurate to the nearest 0.1 kilogram. Standing height was estimated based on arm span, age, and gender (Height = 0.75 *(arm span)* - 0.05 *(age)* + 4.04 *(gender)* + 40.91).[15] Body composition was estimated with bioelectrical impedance. Briefly, the electrical impedance measurements (RJL instruments, Quantum II, Lincoln, MI) were undertaken with the subject lying in a supine position on a plinth. Any metal objects (bracelets, watches) that were known to affect these measurements were removed from the patient.

Four sets of electrical impedance measurements were taken between the following combinations of limbs on each subject as previously described by Desport et al:[16] right upper and right lower limbs, right upper and left lower limbs, left upper and right lower limbs, and left upper and left lower limbs. For each hand-foot combination, the two receiving electrodes were placed at the level of the malleoli and proximal to the phalanges. The resistance and reactance for the four combinations were averaged and entered along with the patient's age, height, and weight into the Cypress software available with the instrument for the calculation of percent body fat. Bioelectrical impedance is reliable (r=0.96) and valid,

Table 1. *Subject characteristics.*

Subject	Injury	Age (Years)	Height (cm)	Weight (kg)	%Body Fat
M1	T10-complete	33	171	61.0	12
F2	T7-complete	45	173	51.0	14.4
F3	T7-complete	17	137	68.0	Data Missing*
M4	L1-complete	42	179	87.3	19.6
F5	CP	23	146	44.0	27
F6	L1-complete	45	165	63.2	37.5
M7	T11-complete	54	181	77.2	19
Mean		**37**	**165**	**64.5**	**21.6**
St. Dev.		**13**	**17**	**14.8**	**9.3**

St. Dev.= Standard deviation
M=Males
F=Females
T=Thoracic
L=Lumbar
CP=Cerebral Palsy
*Subject was unable to attend body composition analysis.

with good correlation to hydrostatic weighing (r = 0.95).[13]

Each subject then completed a field test *(Figure 1)* and a double poling ergometer protocol *(Figure 2)* in random order on separate days (separated by at least 24 hours). Each subject used their customized sit ski for both these test protocols. Both protocols consisted of three maximal trials lasting three minutes each, separated by 1.5 minutes of rest. A three-by-three minute repeat was deemed acceptable to achieve VO_2 peak based on previous research on able-bodied subjects.[17,18]

Following each exercise protocol, each subject passively recovered for 15 minutes. Temperature and wind conditions were monitored during the field test, and laboratory temperature was constant at 21 degrees Celsius. Wind conditions were minimal during the field tests (< 1m/sec) and temperature varied between -4°C to -15°C. The field-testing track was designed by the national team coaches to simulate an actual race. Blood lactate was monitored before beginning testing, after each trial, and after exercise at 5, 10, and 15 minutes. Heart rate was monitored during and after exercise with a Polar heart rate monitor (Polar, Levittown, United States). A wireless metabolic system (Sensormedic VmaxST, Conshohocken, United States, or Cosmed K4B[2], Rome, Italy) was used to monitor gas exchange variables (oxygen uptake, respiratory exchange ratio, breathing frequency, and minute ventilation) during exercise. Although two different metabolic systems were used, all but one subject used the same metabolic system for both the field and ergometer protocols. The instrument was calibrated using 16% oxygen and 4% carbon dioxide prior to and after each test to ensure accuracy of the data. The volume transducer was calibrated using a 3 L syringe. The breath-by-breath measurements were recorded on to the wireless metabolic system during the test, downloaded to a computer after the test, and subsequently averaged over 20-second intervals for analysis.

Figure 2. *Modified double poling cross country ski ergometer.*

The VO_2 peak was determined by the highest 20-second average from the three trials. Peak oxygen pulse was calculated as VO_2 peak (mL/min) divided by peak heart rate and was considered to be an indirect estimate of stroke volume.[19]

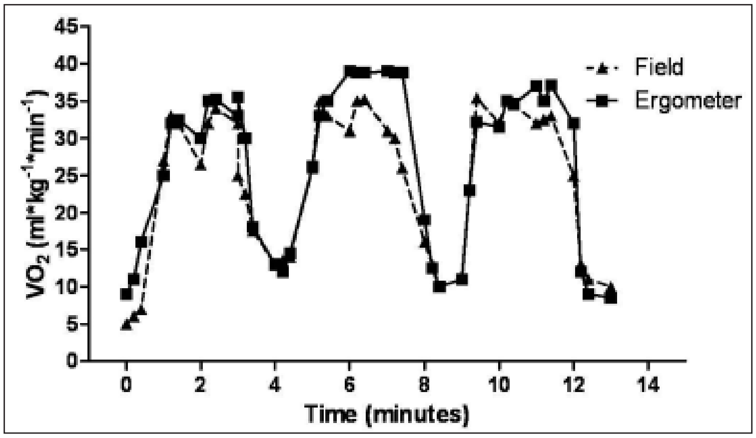

Figure 3. *Oxygen consumption (VO_2) measured in a representative individual during the field and double poling ergometer protocol (3 x 3 min).*

Statistical Analyses

Data are expressed as means ± standard deviations. Intraclass correlation coefficients were calculated between variables on the field and ergometer tests. A repeated-measures analysis of variance (ANOVA) was used to determine if differences existed between means for the double poling ergometer and field test protocols for VO_2 peak, peak heart rate, peak oxygen pulse, peak respiratory exchange ratio, peak minute ventilation, and peak respiratory rate. A 2 (field vs. ergometer) x 7 (baseline, after each repeat, and 5, 10, and 15 minutes post-exercise) repeated-measures ANOVA was used to assess differences between conditions for blood lactate concentrations. A Tukey's post-hoc test was used to determine differences between pairs of means on this last ANOVA. Statistical significance was set at $p \leq 0.05$. Statistical analyses were carried out using Statistica, version 5.0 (StatsSoft Inc., Chicago).

RESULTS

Typical VO_2 responses during the two tests are shown for a single subject in Figure 3. During the three maximal intervals, the subjects consistently achieved a high VO_2 response. No significant differences existed in the peak responses of the relative or absolute VO_2 *(Figures 4 and 5)*, oxygen pulse, respiratory rate, and minute ventilation between the double poling ergometer and the field test. However, the peak respiratory exchange ratio (field = 1.19 ± 0.14 vs. ergometer = 1.35 ± 0.11; P = 0.02) and peak heart rate (field = 173 ± 5 bpm vs. ergometer = 178 ± 4 bpm, P = 0.05) were significantly higher during the double poling ergometer protocol when compared to the field test *(Table 2)*. A significant protocol by time interaction occurred for blood lactate levels. The post-hoc analysis indicated significantly higher lactate levels for the ergometer protocol after trial 2 and trial 3, as shown in Figure 6. The intraclass correlation coefficients between protocols were 0.84 (p = 0.023) for relative peak VO_2, 0.86 (P = 0.015) for absolute peak VO_2 *(Figure 7)*, 0.95 (P = 0.005) for minute ventilation, 0.87 (P = 0.012) for oxygen pulse, and 0.85 (P = 0.019) for peak blood lactate. The intraclass correlation coefficients for peak heart rate (0.52; P = 0.197) and respiratory rate (0.70; P = 0.082) were not significant.

Table 2. *Peak respiratory and physiological characteristics.*

	Field	Ergometer	P-value
Peak VE (L/min)	103±33	94±24	0.103
Oxygen Pulse (VO_2/HR)	12.8±3.1	11.8±2.2	0.182
Respiratory Rate (breathes/min)	65.9±9.5	62.3±12.5	0.213
Peak HR (bpm)	173±5	178±4	0.046*
Peak RER (VCO_2/VO_2)	1.19±0.14	1.35±0.11	0.022*

*Denotes a significant (P<0.05) difference between protocols (Mean ± SD).

DISCUSSION

This study is the first to evaluate the cardiorespiratory responses of skiers with disabilities during sit-skiing, an event at the Winter Paralympics. The major finding of this study was the similar VO_2 peak values on the modified double poling ergometer compared to the field test. Wisloff and Helgerud[4] performed research on able-bodied skiers and they also had similar VO_2 peak values on a field test compared to values on the double poling ergometer. In the current study peak heart rate was significantly higher during the ergometer protocol when compared to heart rate during the field test. Wisloff and Helgerud[4] found similar heart rate results in able-bodied skiers.

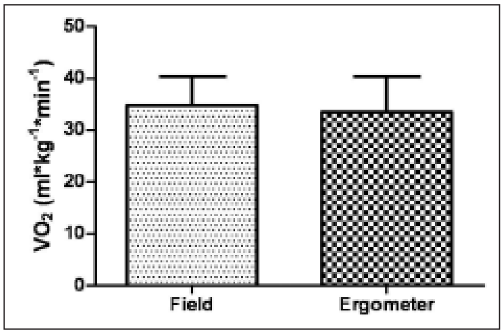

Figure 4. *Mean values for relative* VO_2 ± *standard deviations.*

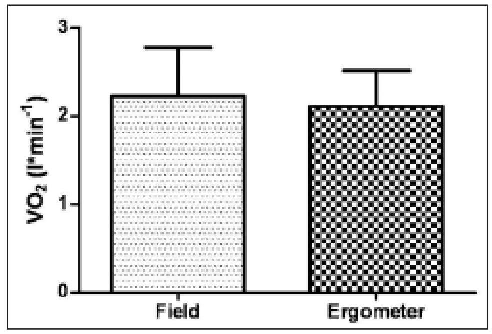

Figure 5. *Mean values for absolute* VO_2 ± *standard deviations.*

A potential mediating factor that may have affected the subjects' peak heart rate during the double poling ergometer protocol is the continuous resistance as compared to the varying speeds and tempos that occurred during the field test. The field testing course was designed to simulate an actual race with varying inclinations and turns, while the ergometer protocol maintained a constant resistance to the athlete. Therefore, the athletes may not have been able to reach their peak heart rate during the field tests due to short recovery periods (down hills and turns) throughout the testing course. There are two possible explanations for the similar VO_2 responses and a lower heart rate response during the field test. There may be a difference in oxygen extraction at the muscle (arterial-venous oxygen difference; (a-v)O_2 difference) or stroke volume responses between protocols. Oxygen pulse, which denotes the oxygen utilization per heart beat[20] is strongly correlated with stroke volume (r = 0.84) but not with (a-v)O_2 difference (r = 0.15).[19] The authors of the current study found no significant difference in peak oxygen pulse between protocols; therefore, it is likely that stroke volume was not significantly different between the two protocols. Therefore, a similar peak VO_2 accompanied by a lower peak heart rate during the field test compared to the ergometer test was most likely due to higher (a-v)O_2 difference during the field test. As mentioned above, the field test involves intermittent effort during the skiing course as one skis and then recovers during down hills and turns, whereas the ergometer test involves more continuous muscle contraction against the resistance of the ergometer. This may allow for greater blood flow to the muscles during the field test (as muscle recovers between contractions during down hills or turns), permitting a greater extraction of oxygen at the muscle from the blood, which would be reflected as a greater (a-v)O_2 difference. Future research is needed with direct measures of arterial and venous blood across the exercising muscle to test this hypothesis.

The results indicated significantly higher lactate and RER values during the double poling ergometer protocol as compared to the field test, which suggest an increased anaerobic cost during the ergometer protocol. Although diet composition was not controlled before tests, this most

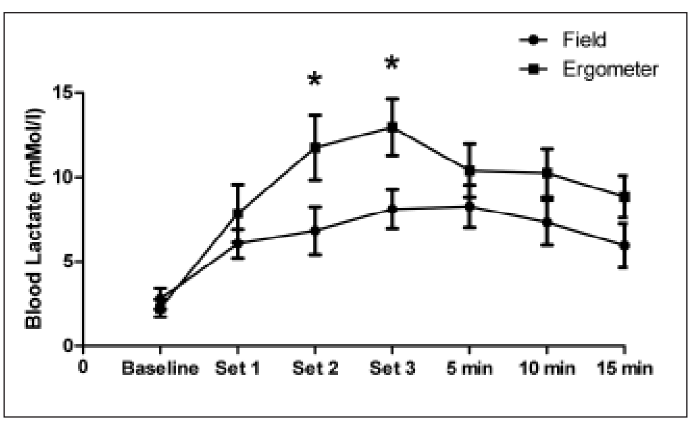

Figure 6. *Mean blood lactate values during various time points* ± *standard error. Ergometer test was significantly* ($P < 0.05$) *greater after trial 2 and trial 3 compared to field test.*

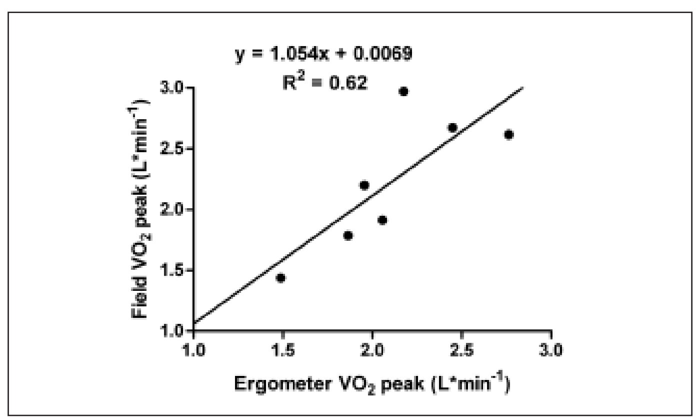

Figure 7. *Correlation for absolute peak* VO_2 *measured on the ergometer vs. field test.*

likely had minimal influence on RER or lactate because all subjects belonged to the same training center where nutrition and hydration of athletes were carefully managed. Athletes at camp were supplied with and ate a similar breakfast each morning before testing. As mentioned earlier, the field test allowed small recovery periods which may have affected lactate results, by allowing increased lactate clearance through increased blood flow which could account for the lower lactate and RER.

One mediating factor that may have had an effect on all metabolic and cardiovascular values measured is environmental temperature. The average temperature was 21°C during the laboratory test and -8°C during the field test. Previous studies have demonstrated an increase in venous return, stroke volume, VO_2, and a decreased heart rate in cold environments[21,22] while others have found contradictory results.[23,24] The present study found no significant difference between the two protocols for the peak VO_2 or oxygen pulse, suggesting little or no effect of the cold on these athletes.

The major limitation of the current study was the small sample size due to the uniqueness of this population. The small sample size increased the likelihood of a type II error (i.e. finding no difference between conditions when in fact there is a difference). Another limitation was the multiple comparisons which increased the likelihood of a type I error (i.e. finding a difference when in fact there is no difference). However, controlling for the type I error (i.e. use of a Bonferonni correction) was deemed too conservative with the lack of power from the small sample size.

CONCLUSION

In summary, the results suggest that a double poling ergometer protocol performed in the laboratory is comparable for measuring the peak VO_2 to a field test in elite cross country sit skiing athletes. However, the field test elicits a significantly lower peak heart rate and a lower blood lactate and RER. This difference is most likely due to the continuous nature of the ergometer test compared to the more intermittent nature of the field test where the athlete alternates between periods of skiing and gliding depending on the section of the course.

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