Field Evaluation of Paralympic Athletes in Selected Sports: Implications for Training

MARCO BERNARDI[1,2], EMANUELE GUERRA[2,3], BARBARA DI GIACINTO[3], ANNALISA DI CESARE[1], VINCENZO CASTELLANO[4], and YAGESH BHAMBHANI[5]

[1]School of Specialty and Sports Medicine, Department of Physiology and Pharmacology - "V. Erspamer", "Sapienza", University of Rome, Rome, ITALY; [2]Italian Paralympic Committee, Rome, ITALY; [3]Institute of Sports Medicine and Science, Italian Olympic Committee, Rome, ITALY; [4]Scientific Direction, Santa Lucia Foundation, Rome, ITALY; and [5]Faculty of Rehabilitation Medicine, University of Alberta, Edmonton, CANADA

ABSTRACT

BERNARDI, M., E. GUERRA, B. DI GIACINTO, A. DI CESARE, V. CASTELLANO, and Y. BHAMBHANI. Field Evaluation of Paralympic Athletes in Selected Sports: Implications for Training. *Med. Sci. Sports Exerc.*, Vol. 42, No. 6, pp. 1200–1208, 2010. **Purpose**: The purpose of this study was 1) to describe the acute cardiorespiratory and metabolic responses of Paralympic athletes participating in the following five sports: Nordic sit skiing (NS, n = 5), wheelchair distance racing (WR, n = 6), wheelchair basketball (WB, n = 13), wheelchair fencing (WF, n = 6), and wheelchair tennis (WT, n = 4); and 2) to examine the relationship between field test performance and laboratory measures of aerobic fitness of these Paralympic athletes. **Methods**: Each athlete completed an incremental arm cranking exercise test to determine ventilatory threshold (VT) and peak oxygen uptake ($\dot{V}O_{2peak}$). Subsequently, field assessments were carried out using a telemetric system to measure the cardiorespiratory responses in their respective sport. **Results**: VT and $\dot{V}O_{2peak}$ (both expressed in milliliters per kilogram per minute) of athletes competing in NS (38.3 ± 5.76 and 51.0 ± 6.92 mL·kg^{-1}·min^{-1}) and WR (35.5 ± 5.96 and 48.1 ± 6.35 mL·kg^{-1}·min^{-1}) were significantly higher ($P < 0.05$) than those competing in WB (26.0 ± 2.13 and 36.9 ± 3.70 mL·kg^{-1}·min^{-1}), WF (23.2 ± 3.96 and 34.4 ± 5.81 mL·kg^{-1}·min^{-1}), and WT (24.0 ± 2.30 and 33.1 ± 2.85 mL·kg^{-1}·min^{-1}). In the field tests, the average $\dot{V}O_2$, higher in NS and WR than in WB, WF, and WT, during NS, WR, WB, WF, and WT was 79.4% ± 3.30%, 84.4% ± 2.10%, 72.1% ± 5.72%, 73.0% ± 3.10%, and 73.0% ± 1.91%, respectively, of $\dot{V}O_{2peak}$. There was a strong linear relationship between $\dot{V}O_2$ measured during the field tests and VT and $\dot{V}O_{2peak}$ (R^2 = 0.92 in each case). **Conclusions**: Athletes regulated their average work intensity during the field tests in the five Paralympic sports to approximate their individualized VT measured during incremental arm cranking exercise test, and this intensity was within the range recommended by the American College of Sports Medicine to improve cardiorespiratory fitness in well-trained subjects. In addition, performance of Paralympic athletes in these sports was highly dependent upon athletes' aerobic fitness. **Key Words:** DISABILITY SPORT, CARDIORESPIRATORY RESPONSES, EXERCISE INTENSITY, INTERMITTENT AND CONTINUOUS SPORTS, AEROBIC FITNESS

The International Paralympic Games is the platform for elite sport competition for individuals with disabilities (www.paralympic.org). During the last two decades, there has been very rapid growth in the Paralympic movement, with an increasing number of countries and athletes participating in these games. The first official games were held in Stoke Mandeville (Great Britain) in 1952, and since the games held in Seoul, Korea, in 1988 (3053 athletes from 61 countries), they have been hosted by the same city, in the same year, and at the same venues as the Olympic competitions. At the 2008 summer Paralympic games in Beijing, 3951 athletes from 147 countries competed in the following five impairment groups: spinal cord injury, cerebral palsy, amputees, visual impairment, and "Les Autres" (other impairments determining motor disabilities). These athletes competed in 20 summer sports that included athletics, wheelchair basketball (WB), wheelchair tennis (WT), and wheelchair fencing (WF). At the 2006 winter Paralympics in Turin, 474 athletes from 39 countries (compared with 365 athletes from 24 countries at the 1992 Tignes-Albertville Paralympics) competed in Nordic skiing (including biathlon), alpine skiing, ice sledge hockey, and wheelchair curling.

Numerous laboratory studies have documented the acute physiological responses to exercise in Paralympic athletes. The peak anaerobic (26,29,34) and aerobic (18,19,24,29, 35,39) responses under controlled laboratory conditions have received considerable attention in the scientific literature. Although much of the focus has been on athletes with spinal cord injury because of the physiological alterations that this

Address for correspondence: Marco Bernardi, M.D., School of Specialty in Sports Medicine, Department of Physiology and Pharmacology - "V. Erspamer", "Sapienza", University of Rome, P.le Aldo Moro 5, 00185 Rome, Italy; E-mail: marco.bernardi@uniroma1.it.
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type of injury induces, there is also limited research that has examined these responses in athletes with cerebral palsy (10,23) and amputation (15,17). It is generally accepted that measures of peak anaerobic power and capacity, peak aerobic power ($\dot{V}O_{2peak}$), and ventilatory threshold (VT) are significantly higher in Paralympic athletes compared with their sedentary counterparts (8). However, these descriptive studies have limited application in prescribing sport-specific training programs because there is a paucity of research that has evaluated the physiological responses of these athletes during actual or simulated sports competition. Studies conducted to date have evaluated the responses of recreational WB (14) and WT (4,30) players. As well, one investigation (21) compared the acute HR responses during WT, wheelchair racquetball, wheelchair volleyball, and WB. Currently, there is minimal research that has documented the physiological responses during actual or simulated competition in elite Paralympic athletes. Some investigators have evaluated these athletes during wheelchair racing (3,9) and WB (1,27,31,36–38).

Exercise prescription is routinely based on the acute cardiovascular and metabolic responses to standardized exercise tests conducted in the laboratory. Elite athletes are regularly monitored during different phases of their training cycle to maximize the benefits of training and prevent possible overtraining (7). However, to enhance the validity of their training programs, it is imperative that detailed information pertaining to the cardiovascular and metabolic responses be obtained in a field situation. During the last decade, the development of wireless metabolic systems has enabled sport scientists to conduct field assessments of athletes with minimal intrusion on performance (6). A recent investigation (1) that compared the oxygen uptake ($\dot{V}O_2$) during WB, WT, and wheelchair rugby during training in male recreational athletes concluded that individuals participating in WB and WT met the minimum energy expenditure requirements of the American College of Sports Medicine (ACSM) (2) for enhancing aerobic fitness in nondisabled individuals, whereas those involved in wheelchair rugby did not meet this criterion. A limitation of this study was that the relative exercise intensities (i.e., $\dot{V}O_2$ expressed as a percentage of $\dot{V}O_{2peak}$) of the three sports were not reported, thereby making it difficult to fully interpret the findings. Therefore, the purpose of this study was a) to describe the acute cardiorespiratory responses of Paralympic athletes during simulated competition in the following five sports: wheelchair long-distance racing events (WR), WB, WT, WF, and Nordic sit skiing (NS); and b) to examine the relationship between field test performance and aerobic fitness of these Paralympic athletes. It was hypothesized that a) the relative exercise intensity attained in all the five Paralympic sports would exceed the minimum ACSM requirements of 40%–50% of $\dot{V}O_{2peak}$ or 55%–65% of the peak HR for health benefits in physically active individuals and b) there would be a significant positive correlation between the oxygen uptake ($\dot{V}O_2$) measured during the field tests and the laboratory measures of aerobic fitness (i.e., VT and $\dot{V}O_{2peak}$).

METHODS AND PROCEDURES

Functional Classification of Athletes

A total of 34 male Italian Paralympic athletes with the following locomotor impairments participated in this study: paraplegia due to spinal cord injury (P, lesion levels ranging from the sixth thoracic segment of spinal cord, ASIA-A, to the third lumbar segment of spinal cord, ASIA-C; 5 athletes had incomplete lesions and 18 had complete lesions), lower extremity poliomyelitis (PM), transfemoral amputation (TFA), and transtibial amputation (TTA). In accordance with the Declaration of Helsinki, each athlete provided written informed consent for participation. All the testing procedures were approved by the Italian Institute of Sports Medicine and Science of the Italian Olympic Committee for athlete testing and by the Santa Lucia Foundation Ethical Committee. The specific information on impairment/disorder, classification, and pertinent anthropometric characteristics of these athletes in the five different sports is summarized in Table 1. Each athlete was classified at national and international levels according to the regulations governing their individual sport procedures, as required by the International

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TABLE 1. Anthropometric characteristics, impairment/disorder, and sport-specific classification of Paralympic athletes with locomotor disabilities (mean ± SD).

Sport	No. and Impairment/Disorder	Age (yr)	Height (m)[a]	Body Mass (kg)	Body Mass Index ($kg \cdot m^{-2}$)	IPC Sport Class
NS	3P, 2PM	39.6 ± 7.02[b,c]	1.72 ± 0.065[b,c]	64.6 ± 4.83[c]	21.9 ± 0.47[b]	LW 11.4 ± 0.65, WBC 2.8 ± 0.84
WR	5P, 1 double TF[a]	30.2 ± 6.97[d]	1.83 ± 0.032[d]	64 ± 7.2[c]	19.2 ± 1.75[c,d,e]	T5 3.5 ± 0.55, WBC 2.0 ± 0.77
WB	7P, 2PM, 2TTA, 2TFA	30.8 ± 7.2[d]	1.79 ± 0.094[d]	73.5 ± 9.26[b,d]	22.8 ± 2.03[b]	WBC 2.9 ± 1.33
WF	4P, 1PM, 1TTA	31.8 ± 5.42	1.79 ± 0.067	68.3 ± 6.98	21.3 ± 2.15	1.3 ± 0.52, WBC 2.2 ± 1.33
WT	4P	38.5 ± 10.25	1.75 ± 0.020	68.5 ± 8.43	22.3 ± 2.5[b]	All in open class, WBC 2.5 ± 0.71
All subjects (*N* = 34)	23P, 5PM, 3TTA, 3TFA	33.1 ± 7.75	1.78 ± 0.076	69.0 ± 8.40	21.7 ± 2.22	WBC 2.54 ± 1.13

Details for the classification procedures are available at www.paralympic.org.
[a] Height before the accident.
On the basis of ANOVA and Fisher least significant difference *post hoc test:* [b] the values are significantly different from WR; [c] the values are significantly different from WB; [d] the values are significantly different from NS; [e] the values are significantly different from WT.
M, men; P, paraplegia; PM, poliomyelitis; TFA, transfemoral amputee; TTA, transtibial amputee.
LW, locomotor winter games classification from LW 10 to LW 12; T5, wheelchair track classes from 1 to 4 (in the present study, no athlete in classes 1 and 2); WBC, International Wheelchair Basketball Federation functional classification: scores from 1 to 4.5; WF classes, B class (score 1) more severe than A class (score 2); WT, no athlete in the present study was in the 'Quad' class.

Paralympic Committee. Details for these procedures are available at www.paralympic.org. All the athletes met the minimum qualification standards established by the International Paralympic Committee for their respective sport. They were all evaluated while actively training during the precompetition phase of their sporting year. The breakdown of the athletes along with their sport-specific classification and disability was as follows:

- NS = 5: 1 = LW10.5 (P), 1 = LW11 (P), 1 = LW11.5 (P), and 2 = LW12 (both with PM)
- WR = 6: 3 = T53 (all with P) and 3 = T54 (1 with P, 1 with double TFA)
- WB = 13: 2 in class 1 (both with P); 4 in class 2 (3 with P and 1 with PM), 1 in class 2.5 (P), 1 with 3.5 (P), 2 with 4.0 (both with TFA), and 3 with 4.5 (1 with PM and 2 with TTA)
- WF = 6: 4 in class B (all with P) and 2 in class A (1 with PM and 1 with TTA)
- WT = 4: all in open class (all with P).

Incremental Arm Cranking Test

Each athlete completed an incremental arm cranking exercise (ACE) test on an isopower ergometer (ER-800; Ergoline, Bitz, Germany) to determine VT and $\dot{V}O_{2peak}$ under standardized laboratory conditions. This test was completed during the week preceding the field test. A continuous, multistage exercise test to volitional exhaustion was used for this purpose. The test consisted of a 3-min warm-up phase at a constant power of 50 W. This was followed by a ramp exercise phase with increments of 10 or 15 W every minute (1 W every 6 or 4 s), depending upon the functional classification and estimated aerobic fitness of the athlete. This protocol was designed to complete the effort phase of the ACE in about 10 min (35,40). The test was terminated when the athlete was unable to maintain the power despite constant encouragement or when at least two of the following criteria (2) were attained during the exercise phase of the test: a) an HR equivalent to 100% of their age predicted maximum (220 − age, years), b) a leveling off or a decline in $\dot{V}O_2$ with increasing work rate, and c) a respiratory exchange ratio ≥1.10.

Field Assessment of Five Different Sports

On a separate day after the ACE, each athlete completed a field test in their respective sport. During the test, the athlete was requested to provide his best effort to simulate an actual competition. The athlete was allowed to perform a sport-specific warm-up for several minutes without the portable metabolimeter before the actual field test. A brief description of the test procedures used during the field test measurements is provided in the succeeding sections.

Nordic sit skiing. Measurements were taken during a simulated 5-km race on an outdoor cross-country skiing track. The average environmental temperature was 0°C or below, and the relative humidity was 30%. Athletes were instructed to perform their races to the best of their abilities as they would in a competitive situation. On two occasions, a skier was tested during real competition. Average field test duration during the 5-km race was 17 ± 1.6 min.

Wheelchair racing. Measurements were taken during a simulated 5-km outdoor track event. The average environmental temperature was approximately 24°C, and the relative humidity was 40%. Typically, the athlete completed the field test within 15 min with an average speed ranging between 7 and 7.5 $m\cdot s^{-1}$ (corresponding to about 25 and 27 $km\cdot h^{-1}$). To simulate competitive WR performance, the athlete was encouraged to maximize speed during the final stages of the test.

Wheelchair fencing. Tests were carried out in pairs using actual fencing weapons. Each test included a range between 30 and 45 consecutive "attacks" to allow one of the fencers to effectively score 15 points ("hits") against his opponent during three intervals lasting 3 min each, interspersed with 1 min of recovery. The rest period between each test ranged between 5 min (to simulate a training condition) and 30 min (to simulate a competitive condition). To make the tests more fatiguing, the best fencer from the lower class (B) competed with one from the higher class (A). These tests were conducted indoors under controlled laboratory conditions. The average room temperature and humidity were 22.4°C ± 3.05°C and 43.5% ± 7.68%, respectively.

Wheelchair tennis. A typical two-set match lasting about 50–70 min was used as a simulation of this performance. The WT player was tested during either the first or the second set with a total monitoring time of at least 20 min. The matches were played on an indoor synthetic surface at an environmental temperature of approximately 22.3°C ± 0.51°C and relative humidity of 29% ± 1.4%.

Wheelchair basketball. Typical WB performance was evaluated in an indoor gymnasium. The average temperature and humidity were 24.1°C ± 2.91°C and 45.5% ± 6.61%, respectively. Each player was tested for at least two periods during either the first or the second half of the game. A rest interval of 15 min was provided between each half. The 10-min period of playing time corresponded to a real time of 12 ± 1.3 min.

Cardiorespiratory Measurements

For the ACE test conducted in the laboratory, the cardiorespiratory measurements were obtained using a breath-by-breath metabolimeter (Quark b^2; Cosmed, Rome, Italy). The athlete was also continuously monitored with an electrocardiogram (Delta 640, Cardioline, Italy). For the field assessments, these measurements were undertaken using two types of wireless metabolic systems. The initial measurements were obtained using the Cosmed K4RQ system (with a sampling rate of 15 s), and the latter measurements were obtained using the Cosmed K4b^2 system. All the metabolic instruments were calibrated according to the manufacturer's specifications. The oxygen and the carbon dioxide analyzers were calibrated using commercially available precision gases (15% oxygen and 4% carbon dioxide, balance nitrogen). The volume transducer was calibrated using a 3-L syringe. The calibration was verified following each test to ensure the accuracy of the data. The breath-by-breath data file for each athlete was initially examined to eliminate artifacts. Thereafter, the results were averaged every seven breath samples with a passing filter. For the field tests, the following $\dot{V}O_2$ values were calculated: a) mean for the entire assessment period and b) peak values averaged over 15-s intervals attained during the assessment period (peak field test). These values were also expressed as a percentage of the $\dot{V}O_{2peak}$ and VT values obtained during the incremental ACE test.

Blood Lactate Analysis

Capillary blood samples were taken from the earlobe at rest to assess basal lactate concentration and during each minute of the recovery phase of the ACE until the value began to decline. The peak value was used for subsequent analysis. Blood lactate concentration was also measured using the same procedures before and after each field test for comparative purposes. All blood samples were analyzed using a portable lactate analyzer (Lactate Pro, Arkray, Japan).

Determination of VT

VT was identified for each athlete from the incremental ACE data using the V-slope method (5): greater increase in carbon dioxide production with respect to oxygen consumption. Secondary criteria that were used to identify this point were systematic increase in the ventilatory equivalent for oxygen ($\dot{V}E/\dot{V}O_2$ ratio) without a concomitant increase in the ventilatory equivalent for carbon dioxide ($\dot{V}E/\dot{V}CO_2$) ratio (40). These identifications were done using the software available with the metabolic measurement instrument. These respiratory gas exchange criteria have been previously used to identify the VT in individuals with spinal cord injury (11,20,32) and in amputees (15). Once the time of occurrence of the VT was determined from the serial plots between exercise time and power output, $\dot{V}O_2$ and HR at this intensity were recorded and then expressed as a percentage of the peak $\dot{V}O_2$ and peak HR during the incremental ACE test.

Statistical Analysis

Descriptive statistics were calculated for each variable using standard procedures in each sport group and for all subjects. The laboratory and field test responses were compared using a one-way ANOVA followed by a Fisher *post hoc* test for least square differences, when appropriate, to analyze the differences among the five sport groups. Regression analysis was used in the overall group of athletes to establish the relationship between the field and the laboratory test measures of $\dot{V}O_2$. The results were considered to be significant at the 0.05 level of confidence. All statistical analyses were computed using the Statistical Package for the Social Sciences for Windows (Version 11.0; SPSS Inc., Chicago, IL).

RESULTS

Characteristics of athletes. It is evident from Table 1 that the NS athletes were significantly older than the WR and WB athletes, whereas there were no significant age differences among the other groups of athletes. With respect to the physical characteristics, the NS athletes were significantly shorter than the WR and WB athletes. The body mass of NS and WR athletes was significantly lower than that of WB players. The body mass index of the WR athletes was significantly lower than that of the NS, WT, and WB athletes.

VT and $\dot{V}O_{2peak}$. The values of the HR and $\dot{V}O_2$ at VT and peak exercise in the athletes who participated in the five sports are summarized in Table 2. It should be noted that the VT and the $\dot{V}O_{2peak}$ of the NS and WR athletes were significantly higher than the other three athlete groups when expressed in absolute and relative terms. The only exception to these findings was that there was no significant

TABLE 2. Oxygen uptake ($\dot{V}O_2$) and heart rate (HR) at the VT and peak exercise during incremental arm cranking exercise test for the Paralympic athletes participating in the five different sports (mean ± SD).

Sport	Variable	VT	Peak Exercise
NS (*n* = 5)	$\dot{V}O_2$ (L·min^{-1})	2.46 ± 0.299[a,b,c]	3.34 ± 0.324[a,b,c]
	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	38.3 ± 5.76[a,b,c]	51.9 ± 6.92[a,b,c]
	$\dot{V}O_2$ (% peak)	73.7 ± 3.2[b]	–
	HR (bpm)	158.6 ± 10.55[c]	186.2 ± 11.54
	HR (% peak)	85.2 ± 1.71[a,b,c]	–
WR (*n* = 6)	$\dot{V}O_2$ (L·min^{-1})	2.2 ± 0.22[a,b,c]	3.05 ± 0.27[a,b,c]
	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	35.5 ± 5.96[a,b,c]	48.1 ± 6.35[a,b,c]
	$\dot{V}O_2$ (% peak)	73.5 ± 3.50[b]	–
	HR (bpm)	159.8 ± 6.99[c]	187.0 ± 5.73
	HR (% peak)	85.5 ± 3.27[a,b,c]	–
WB (*n* = 13)	$\dot{V}O_2$ (L·min^{-1})	1.91 ± 0.317[d,e]	2.7 ± 0.45[d,e]
	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	26.0 ± 2.13[d,e]	36.9 ± 3.698[d,e]
	$\dot{V}O_2$ (% peak)	70.7 ± 3.51	–
	HR (bpm)	153.1 ± 12.99[c]	188.7 ± 10.13
	HR (% peak)	81.1 ± 3.81[c,d,e]	–
WF (*n* = 6)	$\dot{V}O_2$ (L·min^{-1})	1.6 ± 0.46[d,e]	2.4 ± 0.67[d,e]
	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	23.2 ± 3.96[d,e]	34.4 ± 5.81[d,e]
	$\dot{V}O_2$ (% peak)	67.6 ± 1.20[c,d,e]	–
	HR (bpm)	146.5 ± 9.79	182.0 ± 5.40
	HR (% peak)	80.4 ± 3.28[d,e]	–
WT (*n* = 4)	$\dot{V}O_2$ (L·min^{-1})	1.64 ± 0.258[d,e]	2.27 ± 0.300[d,e]
	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	24.0 ± 2.30[d,e]	33.1 ± 2.85[d,e]
	$\dot{V}O_2$ (% peak)	72.6 ± 2.69[b]	
	HR (bpm)	134.8 ± 20.29[a,d,e]	176.8 ± 19.74
	HR (% peak)	76.1 ± 5.48[a,d,e]	–
All subjects (*N* = 34)	$\dot{V}O_2$ (L·min^{-1})	1.97 ± 0.424	2.75 ± 0.543
	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	28.8 ± 6.87	40.2 ± 8.47
	$\dot{V}O_2$ (% peak)	71.3 ± 3.61	–
	HR (bpm)	151.8 ± 13.93	185.4 ± 10.69
	HR (% peak)	81.8 ± 4.50	–

On the basis of ANOVA and Fisher least significant difference *post hoc test:* [a] the values are significantly different from WB; [b] the values are significantly different from WF; [c] the values are significantly different from WT; [d] the values are significantly different from NS; [e] the values are significantly different from WR.

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TABLE 3. Heart rate (HR) and oxygen uptake ($\dot{V}O_2$) during the field assessments of the Paralympic athletes in the five different sports (mean ± SD).

Sport	Variable	Mean Field Test	Mean Field Test, % VT ACE	Mean Field Test, % Peak ACE	Peak Field Test	Peak Field Test, % VT ACE	Peak Field Test, % Peak ACE
NS (n = 5)	HR (bpm)	172 ± 11.3^{a,b,c}	108.4 ± 3.10^{a}	92.3 ± 1.02^{a,b,c}	181.4 ± 10.01	114.5 ± 2.36	97.5 ± 1.57
	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	41.3 ± 6.28^{a,b,c}	107.9 ± 6.46	79.4 ± 3.30^{a}	49.9 ± 7.80^{a,b,c}	130.7 ± 15.26	95.9 ± 7.05
WR (n = 6)	HR (bpm)	176 ± 4.6^{a,b,c}	110.3 ± 5.14^{a}	94.1 ± 2.09^{a,b,c}	186.8 ± 8.18^{c}	117.0 ± 4.89	99.9 ± 3.41
	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	40.5 ± 5.02^{a,b,c}	115.1 ± 6.75^{a,c}	84.4 ± 2.10^{a,b,c}	47.6 ± 6.72^{a,b,c}	134.6 ± 5.56	98.8 ± 1.31
WB (n = 13)	HR (bpm)	152 ± 12.5^{d,e}	99.6 ± 8.66^{d,e}	80.6 ± 6.18^{d,e}	174.4 ± 11.56	114.5 ± 11.09	92.6 ± 6.82
	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	26.5 ± 2.71^{c,d,e}	102.1 ± 8.66^{e}	72.1 ± 5.72^{d,e}	34.1 ± 4.16^{d,e}	131.3 ± 13.37	92.6 ± 7.75
WF (n = 6)	HR (bpm)	153 ± 9.8^{c,d,e}	104.9 ± 7.88	84.3 ± 5.03^{c,d,e}	172.2 ± 14.37	117.9 ± 11.75	94.6 ± 7.87
	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	25.0 ± 3.60^{d,e}	108.0 ± 5.03	73.0 ± 3.10^{e}	31.3 ± 3.90^{d,e}	136.1 ± 17.42	91.9 ± 11.06
WT (n = 4)	HR (bpm)	137 ± 17.9^{a,b,d,e}	102.0 ± 6.55	77.6 ± 2.90^{b,d,e}	158 ± 21.93^{e}	118.2 ± 14.94	89.4 ± 5.14
	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	24.2 ± 2.62^{d,e}	100.7 ± 5.27^{e}	73.0 ± 1.91^{e}	30.4 ± 4.26^{d,e}	126.3 ± 9.27	91.6 ± 5.44
All subjects (N = 34)	HR (bpm)	157.6 ± 16.64	104.0 ± 8.03	85.0 ± 7.55	175.3 ± 14.60	116.0 ± 9.63	94.5 ± 6.48
	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	30.6 ± 8.15	106.1 ± 8.43	75.6 ± 6.23	37.9 ± 9.15	132.0 ± 12.66	93.9 ± 7.51

Mean field test is the mean value obtained during the entire activity; peak field test is the highest value obtained during the activity (average of 10 s); % Peak ACE and % VT ACE are mean or peak field test values expressed as a percentage of the VT and peak value obtained during the ACE, respectively.

[a] The values are significantly different from WB.

[b] The values are significantly different from WF.

[c] The values are significantly different from WT.

[d] The values are significantly different from NS.

[e] The values are significantly different from WR.

ACE, arm cranking exercise test.

difference in absolute $\dot{V}O_{2peak}$ between the WR and the WB athletes. The WF athletes had a significantly lower value for VT expressed as a percentage of $\dot{V}O_{2peak}$ compared with the other four athlete groups. The HR response at VT, when expressed as percentage of peak HR was not significantly different between the NS and the WR athletes. However, both these groups attained significantly higher values than the other three athlete groups.

Field test responses of five different sports. The mean and the peak values of HR and $\dot{V}O_2$ during the field tests of the five different sports are summarized in Table 3. It is evident that for both these variables, the values were significantly higher for the two sports that were continuous in nature, namely, NS and WR. In NS field tests, peak HR and $\dot{V}O_2$ values (98% of the laboratory ACE test) were reached at the end of both uphill slopes (typically every 2.5 km) and races. In the simulated WR events, the athletes increased their speed considerably toward the final stages, which resulted in HR and $\dot{V}O_2$ values reaching approximately 97% of the peak values recorded during incremental ACE. During the three intermittent sports, namely, WB, WF, and WT, there was a large variability in the HR and $\dot{V}O_2$ responses. The breath-by-breath measurements demonstrated a rapid increase in the $\dot{V}O_2$ measurements during the periods of intense physical activity with a fast recovery toward the resting level during periods of less intense activity. It is interesting to note that although the mean and the peak $\dot{V}O_2$ values were not significantly different among the three intermittent sports, the HR during WT was significantly lower than that recorded during the other two sports. Overall, the most intense of these three sports was WB, whereas the least intense was WT. When expressed as a percentage of the peak HR and $\dot{V}O_2$ during ACE, there were no significant differences in intensities between the continuous and the intermittent sports.

Blood lactate responses. A comparison of the peak blood lactate values during the ACE and the field tests is provided in Table 4. It is evident that during the ACE protocol, the values of the WF athletes were significantly lower than the other four athlete groups. During the field tests, the values were significantly higher in the NS athletes compared with the other four athletes groups. The WR athletes had significantly higher values than the WB, WF, and WT athletes. However, there were no significant differences in the peak lactate concentrations among the athletes in the three intermittent sports. Comparisons between the ACE and the field tests indicated no significant difference between the peak values for the NS and WR athletes. However, the peak lactate values during the three intermittent sports were significantly lower when compared with those obtained during the ACE test in these athletes.

Relationship between field and laboratory test measures. The scatterplots and the regression lines for $\dot{V}O_2$ measured during the field test and $\dot{V}O_2$ at the VT and peak ACE test for all athletes in the five sports are illustrated in Figures 1 and 2, respectively. The common variances (R^2) with VT and $\dot{V}O_{2peak}$ were 92% in each case (r = 0.958 and 0.961, respectively). For both these relationships, the data were best expressed by a linear model, with the majority of the data points for the five different sports regressing close to the 95% confidence interval. The regression equations for predicting $\dot{V}O_2$ during the field tests from VT and $\dot{V}O_{2peak}$ during incremental ACE test are given in equations 1 and 2. There was no significant

TABLE 4. Peak blood lactate values during the arm cranking exercise test and field assessments of the Paralympic athletes in the five different sports.

Sport	Peak Arm Cranking (mmol·L^{-1})	Peak Field Test (mmol·L^{-1})
NS (n = 5)	12.23 ± 1.47^{a}	12.43 ± 1.73^{a,b,c,d}
WR (n = 6)	11.4 ± 3.03^{a}	9.8 ± 2.37^{a,c,d,e}
WB (n = 13)	11.10 ± 1.92^{a}	3.93 ± 0.95^{b,e}
WF (n = 6)	8.5 ± 1.28	4.70 ± 1.38^{b,e}
WT (n = 4)	10.8 ± 3.10^{a}	3.75 ± 0.76^{b,e}

[a] The values are significantly different from WF.

[b] The values are significantly different from WR.

[c] The values are significantly different from WB.

[d] The values are significantly different from WT.

[e] The values are significantly different from NS.

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difference in the slope of the relationship between these two equations.

$$\text{field } \dot{V}O_2 = -2.09 + 1.137\dot{V}O_2 \text{ at VT; SEE} = 2.37 \quad [1]$$

$$\text{field } \dot{V}O_2 = -6.53 + 0.925\dot{V}O_{2\,peak}\text{; SEE} = 2.29 \quad [2]$$

DISCUSSION

To the best of our knowledge, this is the first investigation that has examined the acute cardiorespiratory responses during the laboratory and field settings of elite Paralympic athletes participating in the following five sports: NS, WR, WB, WF, and WT. The main findings were that a) the exercise intensities attained during all five sport exceeded the minimum criteria recommended by the ACSM (2) for enhancing and maintaining aerobic fitness and reached near maximal levels during NS and WR and b) the average exercise intensity during the field test was closely related to the VT and $\dot{V}O_{2peak}$ attained during the ACE test.

Field test responses during the five different sports. The average and the peak intensities attained by the five groups of athletes during the field tests were extremely high (Table 3). The mean HR response ranged from 79.0% in the WT players to 94.2% in the WR athletes. The mean $\dot{V}O_2$ ranged from 73.0% in the WF athletes to 84.4% in the WR athletes. In all these athletes, the exercise intensities attained were considerably higher than the minimum intensity recommended by ACSM for enhancing and maintaining aerobic fitness in healthy individuals (2). The current results demonstrated that the absolute values of HR and $\dot{V}O_2$ during these field tests were highest in the athletes who participated in NS and WR events (Table 3). As well, the HR and $\dot{V}O_2$ values were higher when expressed relative to the peak responses recorded during the incremental ACE test (Table 2). This is most likely because these athletes a) participated in sports that were continuous in nature, which placed a greater stress on the cardiorespiratory system, and b) performed high-intensity aerobic and anaerobic training on a regular basis. The three intermittent sports (WB, WT, and WF) demonstrated significantly lower absolute HR and $\dot{V}O_2$ values compared with the continuous sports, and there was no significant difference among these three sports for these two variables. These findings were consistent with those of a recent investigation (1), which compared the energy expenditure during WB, WT, and wheelchair rugby training and reported no significant difference between WB and WT, both of which were significantly higher than wheelchair rugby. The researchers attributed the lower energy expenditure during wheelchair rugby to the fact that this group included spinal cord–injured athletes with tetraplegia who tend to have a lower muscle mass, which would theoretically result in lower energy expenditure during the sport.

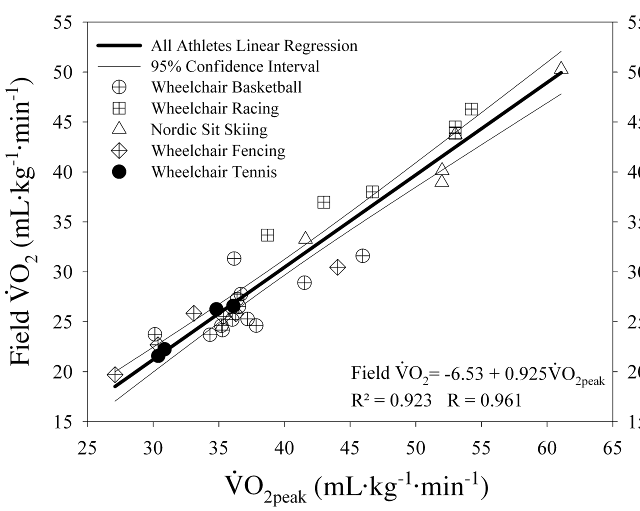

FIGURE 1—Relationship between the oxygen uptake during the field test (field $\dot{V}O_2$) and peak oxygen uptake during incremental arm cranking ($\dot{V}O_{2peak}$) in the athletes participating in the five Paralympic sports (*N* = 34).

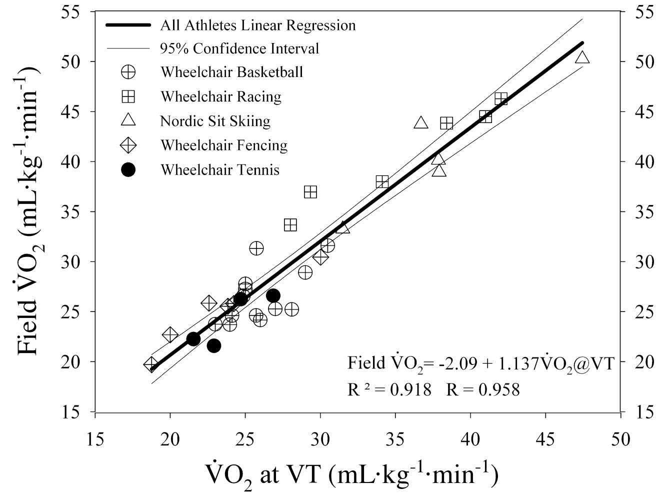

FIGURE 2—Relationship between the oxygen uptake during the field test (field $\dot{V}O_2$) and the oxygen uptake at VT during incremental arm cranking exercise ($\dot{V}O_2$ at VT) in the athletes participating in the five Paralympic sports (*N* = 34).

Relationship between field and laboratory test measures. The current results indicated a close relationship between the field test performance and the aerobic fitness parameters (VT and $\dot{V}O_{2peak}$) measured in the laboratory (Figs. 1 and 2). It is interesting to note that the athletes who participated in the three intermittent sports, namely, WB, WT, and WF, frequently exercised at intensities well above VT, and in some instances the peak values approached their $\dot{V}O_{2peak}$ measured in the laboratory during ACE. During each of these sports, peak HR and $\dot{V}O_2$ values expressed as percentage of ACE were approximately 10%–20% higher than the mean values demonstrating large variations in the intensity of these simulated events. However, the fact that their average work intensity was very close to VT suggested that these athletes tended to pace themselves so that they did not rely

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extensively on anaerobic metabolism, thereby delaying the onset of fatigue. The significantly lower levels of blood lactate tend to support this hypothesis. The results (Table 4) indicated that the NS and WR athletes accumulated the largest concentrations of lactate during the field tests compared with those participating in the three intermittent sports. This was because these athletes performed continuously at an intensity that was well above their VT (Table 2) and that they accelerated their performance during some phases of the race. Blood lactate concentrations obtained during WB, WF, and WT field tests were considerably lower when compared with NS and WR field tests, although the average $\dot{V}O_2$ during these three events was also above the VT for these athletes (Table 2). This can be attributed to the fact that these three sports were intermittent in nature, and despite the short periods of intense physical activity that frequently approached the peak values, the lactate could be metabolized (oxidized) during the rest intervals and periods of less intense physical activity (33). It should be noted that the blood lactate concentrations observed for these three intermittent sports were 50%–60% higher than the values recently reported (1) for WB, WT, and WR athletes during sport-specific training sessions. This could be because the current study evaluated highly trained Paralympic athletes, whereas the study cited evaluated recreational athletes.

Implications for sport performance and training. These findings have two important implications for evaluating the sport performance and training of athletes with disabilities who are involved in these five sports. First, equations 1 and 2 can be used to predict the average $\dot{V}O_2$ during these five sports on the basis of VT and $\dot{V}O_2$ determined during ACE. This information, in conjunction with the laboratory measures of VT and $\dot{V}O_{2peak}$, can be used by sport scientists to evaluate the performance of the athletes more comprehensively during their training cycle. Two important points should be noted when using these equations: a) VT and $\dot{V}O_{2peak}$ were measured during incremental ACE, whereas field tests were performed in the athletes' personal sport-specific wheelchairs or sledges (differences in the cardiorespiratory and metabolic responses between these two exercise modes could have some influence on the validity of these equations (8)); and b) there was considerable variation in the environmental testing conditions during the field tests. For example, the WR tests were conducted at a temperature of 24°C and at a relative humidity of 40%, whereas the NS tests were completed at a temperature of 0°C or below and at a relative humidity of 30%. Research that has examined the cardiovascular responses and metabolic efficiency of paraplegics exercising under hot and cool climates has demonstrated small but significant changes in these responses (12,22). Consequently, the regression equations derived for predicting the energy expenditure during the field tests could have some associated error. However, all the athletes in this study were experienced in participating in their respective sports under varying environmental conditions, and therefore the influence on their performance would most likely have been minimal. The SEE in equations 1 and 2 were 2.29 and 2.36 $mL \cdot kg^{-1} \cdot min^{-1}$ for predictions from the VT and $\dot{V}O_{2peak}$ values, respectively. This corresponds to a prediction error of approximately 5% of the $\dot{V}O_{2peak}$ attained during the ACE. The ability to accurately predict the energy expenditure during a game situation could be very useful to sport scientists because it is not always feasible to obtain field test measurements in athletes. Moreover, from a physiological perspective, the alterations in these two aerobic fitness parameters during the competitive year could reflect concomitant changes in field test performance.

Second, the fact that the athletes regulated their average work intensity during the field tests to approximate the VT and that these measurements were significantly correlated with both VT and $\dot{V}O_{2peak}$ implies that high levels of aerobic fitness are of considerable importance for these athletes. The ACSM (2) recommends training at the following minimum intensities for enhancing aerobic fitness in healthy nondisabled individuals: a) HR equivalent to 55%–65% of peak HR and b) $\dot{V}O_2$ that corresponds to 50% of the $\dot{V}O_{2peak}$ attained during an incremental exercise test. In well-trained subjects, the upper limit for the training intensity is 90% of peak HR and 85% of $\dot{V}O_{2peak}$. The current observations (Table 3) indicated that the average HR and $\dot{V}O_2$ values exceeded the minimum intensity requirements and were approaching the upper limits recommended for well-trained subjects. A previous investigation (25) that tested the ACSM equation for using target HR for training prescription in a group of female wheelchair athletes observed a strong correlation (0.973) between the $\%\dot{V}O_2$ and the %HR during incremental wheelchair propulsion. Although the HR values were slightly higher than those reported by the ACSM, the authors concluded that it was not necessary to modify the HR guidelines for enhancing aerobic fitness in women with low-level paraplegia (lesion below T6 level). From a biochemical standpoint, it has also been recommended that in nondisabled subjects and high-performance athletes (28,33), the training intensity should be at or above the anaerobic (lactate) threshold to induce significant improvements in this parameter and to increase the tolerance to high levels of lactate. As well, research (13) has demonstrated the effectiveness of high-intensity (all-out) training to increase oxidative capacity in skeletal muscles and to improve performance in exercises that rely mainly on aerobic energy metabolism. Although these recommendations for enhancing aerobic fitness in nondisabled individuals have been developed on the basis of sound research, there is limited research that has tested these techniques in individuals with disabilities. Chin et al. (16) demonstrated that an endurance training program prescribed on the basis of the anaerobic threshold was effective in improving both the anaerobic threshold and $\dot{V}O_{2peak}$ in single-leg amputees. Further research is needed to evaluate the efficacy of various training techniques to enhance fitness and sport performance in elite Paralympic athletes with different disabilities.

Limitations of the study. The current findings should be interpreted with caution because of the following limitations. First, with the exception of WB, the sample sizes in the remaining four sports that were evaluated were quite small. Hence, the descriptive data may not be representative of the overall population of elite competitors in that particular sport. It should be noted, however, that the number of athletes participating in some of these sports (e.g., NS, WT, and WF) at the Paralympic games is also quite low (www.paralympic.org). Therefore, the small sample sizes may be a reflection of the limited number of participants in these sports. Second, the majority of athletes who were evaluated were individuals with mid- to low-level paraplegia (23 athletes). The remaining 11 athletes were individuals with amputation (n = 6) and lower-extremity poliomyelitis (n = 5). Although the acute cardiorespiratory control mechanisms of these athletes were most likely unaffected by their impairment, it is possible that other unknown factors could have influenced their results. Third, the current study did not examine the relationship between measures of anaerobic fitness and field test performance. Because three of the five sports examined were intermittent in nature, it is possible that the anaerobic power and capacity of these athletes would also be related to performance. Future studies should investigate the relationship between field test performance and measures of both aerobic and anaerobic fitness so as to identify the best predictors of performance in Paralympic athletes. Finally, these observations can be generalized only to male athletes in their respective sports because no female athletes were evaluated in this study. Further research is necessary on a larger number of athletes in both genders to establish a strong data base for elite Paralympic sport.

CONCLUSIONS

The aerobic capacity of elite male NS and WR athletes was significantly higher than that of WB, WF, and WT players. This was attributed primarily to the greater aerobic demands of these two continuous sports and the high-intensity training performed by these athletes. During the field tests of their respective sports, the athletes regulated their average work intensity to approximate their individualized VT measured during incremental ACE in the laboratory. The relative HR and $\dot{V}O_2$ during the field tests in each of the five Paralympic sports were within the range recommended by the ACSM to improve cardiorespiratory health in well-trained subjects. There was a strong relationship between the $\dot{V}O_2$ measured during the field tests and the laboratory measures of aerobic fitness. It was concluded that performance in these continuous and intermittent sports in elite Paralympic athletes is highly dependent upon their aerobic fitness.

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