## Original Article

# Prediction of $VO_{2peak}$ in wheelchair-dependent athletes from the adapted Léger and Boucher test

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**Purpose:**  The purpose of this study was to provide a predictive peak oxygen uptake ($\dot{V}O_2$ peak) equation in wheelchair-dependent athletes using the Adapted Léger and Boucher test.
**Subjects and protocol:**  Fifty-six wheelchair-dependent athletes, 47 males and nine females ($30.3 \pm 4$ years), underwent a clinical examination to assess their anthropometric characteristics: height, mass, body mass index (BMI), lean body mass, arm length, and muscular arm volume. They performed a deceleration field test to assess the subject-wheelchair resistance defined as a mechanical variable, and they then performed the Adapted Léger and Boucher test to assess physiological data at maximal exercise ($\dot{V}O_2$ peak, heart rate max) concomitantly with biomechanical (number of pushes) and performance variables (maximal aerobic velocity $Va_{max}$ and maximal distance). The $\dot{V}O_2$ peak was measured directly using a portable telemetric oxygen analyzer. Subjects were then randomly assigned to an experimental group ($n = 49$) to determine the predictive equation, and a validation group ($n = 7$) to check the external validity of the equation.
**Results:**  A stepwise multiple regression with $\dot{V}O_2$ peak (l min$^{-1}$) as the dependent variable led to the following equation: $\dot{V}O_2$ peak $= 0.22$ $Va_{max} - 0.63$ log(age) $+ 0.05$ BMI $0.25$ level $+ 0.52$, with $r^2 = 0.81$ and SEE $= 0.01$. Paraplegic subjects with high and low lesion level spinal injuries were attributed the coefficient of 1 and 0, respectively. The external validity of the equation was positive since the predicted $\dot{V}O_2$ peak values did not significantly differ from directly measured $\dot{V}O_2$ peak ($P > 0.05$).
**Conclusion:**   We concluded that $\dot{V}O_2$ peak in wheelchair-dependent athletes was predictable using the equation of the present study and the described incremental test.
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**Keywords:** paraplegics; incremental field test; peak oxygen uptake; predictive equation

## Introduction

Maximal oxygen uptake ($\dot{V}O_2$ max) has been described as an important parameter of aerobic performance.[1,2] Incremental exercise testing with direct laboratory measurement provides the most widely used and accurate $\dot{V}O_2$ max assessment. However, since equipment, expense, time and personal requirements make the laboratory procedure prohibitive for large populations, field tests have been developed for able-bodied subjects. One of the most commonly used is the Université de Montréal Track Test of Léger and Boucher.[3] Wheelchair-dependent subjects usually per-

form laboratory tests,[4,5,6] but the growing number who participate competitively in athletic activities need regular assessments of $\dot{V}O_2$ peak. Thus Di Carlo[7] used a sustained 12-min propulsion task to predict the examined changes in the $\dot{V}O_2$ peak of wheelchair-dependent subjects. This replacement of Cooper's 12 min run-walk test appeared to be a reliable tool in the assessment of wheelchair propulsion-endurance for individuals with spinal cord injury. Moreover, Rhodes et al.[8] and Franklin et al.[9] also used this Cooper 12 min test to predict the $\dot{V}O_2$ peak of wheelchair-dependent subjects. They established their predictive equation of $\dot{V}O_2$ peak in wheelchair-dependent subjects during rectangular field tests by using incremental laboratory assessment of $\dot{V}O_2$ peak as the dependent

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variable. One may suspect, however, that the use of two different test protocols in two different conditions would result in a methodological bias. In contrast, the present study assessed $\dot{V}O_2$ peak as the dependent variable in both an incremental protocol and field conditions, and thus eliminated this methodological bias. As previously reported,[9,10] we validated an adapted Léger and Boucher test (ALBT) for wheelchair-dependent athletes[9,10,11] which allowed the subjects to reach their $\dot{V}O_2$ peak. As expected, the predictive $\dot{V}O_2$ max equation of Léger and Boucher[3] for able-bodied subjects was inappropriate for the wheelchair-dependent athletes, as it included biomechanical and anthropometric variables that do not apply to wheelchair-dependent subjects, such as running cost and body surface area. In order to complement our previous work, this study was designed to provide a predictive $\dot{V}O_2$ peak equation in well-trained wheelchair-dependent athletes during the ALBT using a set of anthropometric, physiological, mechanical, bio-mechanical and performance variables.

## Methods

### Subjects
Fifty-six wheelchair-dependent athletes (47 males and 9 females), aged $30.3 \pm 0.4$ years (range: 18 to 47 years) provided written informed consent to participate in this study, which had been approved by the institutional review board. All subjects had had lower-limb disability (39 paraplegics, 5 amputees and 12 post-polio) for at least 1 year prior to the study. The subjects were divided in two groups: high lesion level paraplegic subjects (HP) were attributed a coefficient of 1, and low lesion level paraplegic subjects (LP) were attributed 0. Amputees and post-poliomyelitic subjects were classed in the LP group. The difference between these two groups was the functionality or not of abdominal muscles. All subjects used their wheelchairs for everyday life and/or physical activities, and they were considered as having good control of their wheelchairs. All practiced sports (wheelchair-racing, tennis, fencing, swimming or basketball) for at least $6.25 \pm 4$ h per week and all competed at national level. All subjects performed the two tests, and after the tests, they were randomly assigned to one of two subgroups with the number of subjects in each group adapted to the following objectives: (1) an experimental group (EG) with 49 subjects (40 males and 9 females, 15 HP and 34 LP) to determine the predictive equation for $\dot{V}O_2$ peak, and (2) a validation group (VG) with 7 subjects (7 males, 1 HP and 6 LP) to verify the external validity of the predictive equation.

### Protocol
During a clinical examination, anthropometric variables were measured. During a deceleration field test, mechanical variables were recorded. During the ALBT,

**Table 1** Anthropometric variables included in the stepwise regression for the prediction of $\dot{V}O_2$ peak (EG) and the external validity (VG)

| Groups | | Age yr | H cm | MS kg | BMI kg m$^{-2}$ | LBM kg | MVA l | AL cm |
|---|---|---|---|---|---|---|---|---|
| | | | | | *Anthropometric* | | | |
| EG | x | 29.6 | 172.4 | 62.4 | 20.9 | 58.9 | 3.7 | 71.4 |
| (*n*=49) | SD | 1.29 | 13.2 | 10.3 | 2.4 | 10.1 | 0.9 | 4.8 |
| VG | x | 27.2 | 172.6 | 63.7 | 21.3 | 59.4 | 4.4 | 70.7 |
| (*n*=7) | SD | 1.32 | 7.9 | 8.3 | 1.0 | 7.9 | 0.07 | 4.4 |

No significant difference between EG and VG groups. H = height, MS = subject mass, BMI = body mass index, LBM = lean body mass, MVA = muscular volume of arm, AL = arm length

physiological, biomechanical and performance variables were assessed. These three steps were conducted the same day and in the same field conditions. The variables were chosen because of their relatively strong relationship with $\dot{V}O_2$ peak reported in the literature, and because they are easily measured.

The clinical examination, always made by the same examiner, assessed seven anthropometric variables. Height was measured with the subject in the supine position. The mass of the subject with the wheelchair was measured using a platform scale with a 5 kg wooden plank to allow wheelchair positioning. This process was repeated twice: once to weigh the subject + wheelchair first and then to weigh the wheelchair alone. The difference was the subject mass. Body mass index (BMI, kg m$^{-2}$) was calculated as the ratio of the subject mass by his squared height. Body fat was estimated by the sum of 4 skinfolds: triceps, biceps, subscapularis and suprailiac, measured twice on the left side of the body as recommended for use of the Durnin and Womersley equation.[12] Lean body mass was then calculated. Lastly, the muscular volume of the arm was assessed using skinfolds, circumferences and diameters according to Shephard *et al.*,[13] and arm length (AL, cm) was measured between the arm bend and the longest finger.

As subjects used their own wheelchair, the deceleration field test[14] assessed the total wheelchair resistance (R Newton), i.e., the internal and external resistances of the subject + wheelchair system defined as a mechanical variable to standardize mechanical characteristics of wheelchairs. Briefly, the protocol required the subject to propel his wheelchair over a 20 m distance: the first 10 m in acceleration and the second 10 m maintaining a constant velocity. Once the subject passed the 20 m mark, he or she stopped propulsion and remained motionless in the wheelchair. The time needed to cover the 10 m at constant velocity (To, s) and the time for the wheelchair to decelerate and stop (Td, s) were measured using a chronometer with a precision of 1/100 s. As the velocity versus time slope was linear throughout the test, the deceleration was constant and R was a constant force calculated according to the following equation: R = 10m* (Mass

of subject+wheelchair)/(To*Td), with R in N, (Ms+w) in kg, and To and Td in s.

The incremental field test assessed physiological, biomechanical and performance variables. It was conducted on a 400 m tartan field marked-off every 50 m with pylons. The wind speed was measured with an anemometer prior to testing and had to be less than $2 \text{ m s}^{-1}$. The ALBT protocol has been described elsewhere.[10] Briefly, subjects propelled their wheelchairs as far as possible following the rhythm imposed by means of an audio-tape. The turning speed of the tape recorder was checked prior to the start of each test to ensure that any deviation was less than $1 \text{ s min}^{-1}$.[15] The athletes adjusted their velocity when crossing a pylon at the sound signal. The initial velocity was $4 \text{ km h}^{-1}$ for 1 min, thereafter it was increased by $1 \text{ km hr}^{-1}$ every minute until exhaustion, which was defined as the inability to maintain the required velocity with a 3-m distance behind the appropriate pylon at the sound signal and the inability to catch up at the next pylon. At the end of the ALBT, performance variables were noted: the maximal distance ($d_{max}$m) and the maximal velocity ($Va_{max}$, $\text{km h}^{-1}$) maintained in 1 min, defined as the velocity necessary to attain $\dot{V}O_2$ peak. A biomechanical variable was also noted, i.e., the number of pushes (NP) during the last 50 m of each 400 m lap were counted by an experimenter, which was used to assess the propulsion efficiency. Throughout the ALBT, the subjects were equipped with the Cosmed K2 (Rome, Italy), a portable telemetric oxygen uptake analyzer. This system is composed of a transmitting unit, battery, face mask, heart rate chest strip, and receiving unit. The face mask contains a photoelectric turbine for recording breathing frequency, tidal volume and minute ventilation, as well as a capillary gas sampling port within the turbine's housing. A sample of expired gas enters into a mixing microchamber with a capacity of 2 ml. A miniature polarographic electrode for the oxygen concentration measurement is inside the microchamber. The $\dot{V}O_2$, $\text{l min}^{-1}$ and $\text{ml kg}^{-1} \text{ min}^{-1}$ were collected every 15 s, after a 30-min warm-up for the K2 unit before every testing session. The K2 analysis system was calibrated with $O_2$ atmospheric air, which was assumed to be 20.9% before each test. The expired gases were sampled at the rate proportional to ventilation by means of a dynamic sampling pump. Despite the lack of a $CO_2$ electrode, the Cosmed K2 has been validated for direct $\dot{V}O_2$ assessment.[16,17] Heart rate (HR, $\text{beat min}^{-1}$) was measured with the Cosmed K2 every 15 s. The criteria for $\dot{V}O_2$ peak were HR within $15 \text{ beat min}^{-1}$ of age predicted maximal HR [220 - age], and the inability for the athlete to maintain the required velocity.

*Statistical analysis*
The statistical analysis was done in three parts. In the first part, comparisons between anthropometric, physiological, mechanical, biomechanical and performance variables of the EG and VG groups were made using the Student unpaired *t*-test. The second part concerned

only the EG subjects and it allowed us to choose which independent variables (anthropometric, hours of training, physiologic, bio/mechanical) would enter into the stepwise regression. The first step consisted of determining the Gaussian distribution (using the Skewness, Kurtosis and the Shapiro Wilk W tests) and the availability of the linear model between each regressor and the explained variables. The second step consisted of searching for a statistical link between each regressor and the variable of interest; using a correlation matrix, the threshold value of *P* was 0.1. instead of 0.05, thereby ensuring a wide set of regressors. The third step consisted of submitting the selected regressors to two co-linearity tests according to Besley *et al*.[18] the first runs a condition index (square root of the highest Eigenvalue and each one of the variables) whose highest values make co-linearity a reliable hypothesis; the second indicates the consequence of such a supposed co-linearity on the variance inflation of estimates. The last step was a multiple stepwise regression to predict $\dot{V}O_2$ peak in the EG subjects. For this, the specified significance levels for entering and staying in the model were, respectively, 0.1 and 0.2, since the approach was an experimental one. In addition, a coefficient of variation was calculated, and regression tests were computed (residuals analysis, studentized residuals and Cook's D test) to assess the precision of the prediction. The third part concerned the VG subjects. The external validity of the equation was verified by comparing predicted $\dot{V}O_2$ peak and measured $\dot{V}O_2$ peak with a Student paired *t*-test. Statistical results were considered as significant when $P < 0.05$. All tests were performed using the S.A.S statistical software package of S.A.S. Institute, running on Vax/VMS.[19]

## Results

No significant difference between any of the variables was found between the EG and VG groups. Data on the anthropometric, physiological, mechanical, biomechanical and performance variables, for groups EG and VG, are reported in Tables 1 and 2. Values of $\dot{V}O_2$ peak in women and men were not significantly different that is why all results were reported as a whole group. According to the correlation matrix and the Gaussian distribution, the relevent variables (only age required transformation; log(age) successfully stabilized the variable) were $\dot{V}O_2$ peak, $Va_{max}$, HR max, log(age), BMI, AL and NP.

The stepwise regression model used these variables for the prediction of $\dot{V}O_2$ peak in $\text{l min}^{-1}$. This derived equation included $Va_{max}$ ($\text{km h}^{-1}$), log(age), BMI ($\text{kg m}^{-2}$), and lesion level (Table 3):

$$\dot{V}O_2 \text{ peak} = 0.22Va_{max} - 0.63\log(age) + 0.05BMI - 0.25\text{level} - 0.52,$$

with $r^2 = 0.81$ ($P = 0.01$) and SEE $= 0.097$. Figure 1 displays the measured $\dot{V}O_2$ peak and the predicted

**Table 2** Mechanical, physiological, biomechanical and performance variables included in the stepwise regression for the prediction of $\dot{V}O_2$ peak (EG) and the external validity (VG)

| Groups | | Physiological | | Mechanical | Biomechanical | Performance | |
| | | $\dot{V}O_{2\ peak}$ l min$^{-1}$ | HR max b min$^{-1}$ | R N | NP n | $d_{max}$ m | $Va_{max}$ km h$^{-1}$ |
|---|---|---|---|---|---|---|---|
| EG | x | 2.05 | 179.9 | 12.5 | 21.1 | 1327.1 | 12.22 |
| (n=49) | SD | 0.63 | 11.7 | 3.4 | 2.2 | 424.4 | 1.93 |
| VG | x | 2.32 | 181.4 | 13.3 | 20.9 | 1492.8 | 13.14 |
| (n=7) | SD | 0.34 | 14.6 | 5.2 | 5.8 | 329.7 | 1.58 |

No significant difference between EG and VG groups. R = total wheelchair resistance, NP = number (n) of pushes, $d_{max}$ = maximal distance, $Va_{max}$ = maximal aerobic velocity

**Table 3** Stepwise procedure for dependent $\dot{V}O_2$ peak (l min$^{-1}$) variable

| Step | Variable | Partial $R^2$ | Model $R^2$ | F | P |
|---|---|---|---|---|---|
| 1 | Vamax | – | 0.67 | 96.08 | 0.0001 |
| 2 | log(age) | 0.08 | 0.75 | 14.90 | 0.0004 |
| 3 | BMI | 0.027 | 0.78 | 5.56 | 0.0227 |
| 4 | lesion level | 0.027 | 0.81 | 6.32 | 0.0157 |
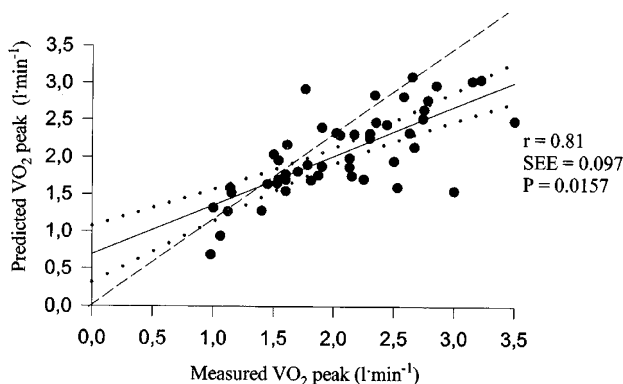


**Figure 1** Relationship between measured $\dot{V}O_2$ peak and predicted $\dot{V}O_2$ peak solid line = regression line, dashed line = identity line
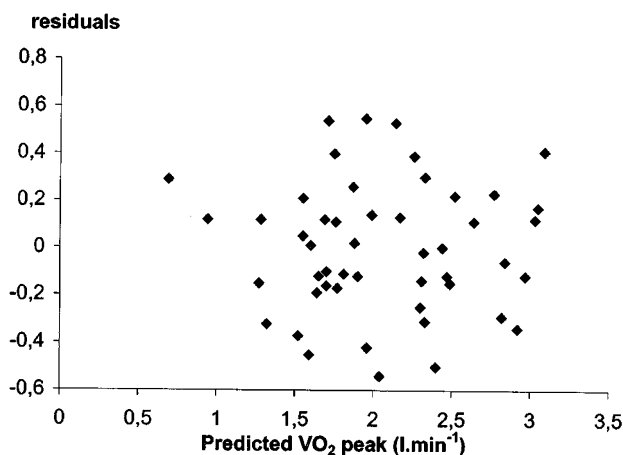


**Figure 2** Residuals analysis against predicted $\dot{V}O_2$ peak

$\dot{V}O_2$ peak. The coefficient of variation was calculated as equal to 15.3%. Figure 2 displays the linearity between residuals and predictors, and homoscedasticity was verified by graphical analysis of residuals, which showed the independency of residuals against predicted $\dot{V}O_2$ peak (horizontal distribution). Moreover, studentized residuals and Cook's D test did not detect any outliers in the model. The external validity showed that measured $\dot{V}O_2$ peak and predicted $\dot{V}O_2$ peak values in VG was not statistically different ($P = 0.65$).

## Discussion

The present study provided a predictive $\dot{V}O_2$ peak equation for wheelchair-dependent athletes from an incremental field test. The validity of this equation was checked on only seven subjects. The variables, anthropometric, mechanical, physiological, biomechanical and performance, were chosen very carefully.

The primary purpose of this investigation was to provide a predictive equation for $\dot{V}O_2$ peak in a field test which would be easy to use for both wheelchair-dependent athletes and their training staff. Anthropometric variables (height, mass, BMI, lean body mass, AL and muscular volume of the arm) were measured. The stepwise regression procedure needs non-correlated (and/or orthogonal) variables to avoid co-linearity and thus to ensure accurate estimates of regression parameters. Muscular volume of the arm and AL were highly correlated. Because of the above requirement and because accurate measurement of muscular volume of the arm is not always possible, we retained AL as the easier variable to measure. Similarly, lean body mass and BMI were correlated and we kept BMI.

We used the functionality of abdominal muscles to divide our subjects after consideration of the results of Coutts *et al.*[4] These authors studied maximal exercise responses of paraplegic subjects of different classes. They reported a 'break' in the responses between class III (lesion level T5–T10 without active abdominal muscles) and class IV (lesion level T11–L3 with active abdominal muscles), and then divided their subjects into only two groups: HP and LP subjects. This classification has been used[5] and studies have shown that HP subjects

reach lower $\dot{V}O_2$ peak than LP subjects.[4,5] In the present study, HP subjects were attributed a coefficient of 1, thus the constant term in the predictive equation was 0.27 ($-0.25*1 + 0.52$). The LP subjects were attributed to 0, and the constant term was 0.52 ($-0.25*0 + 0.52$). This $\dot{V}O_2$ peak difference of 0.25 l min$^{-1}$ (0.52 – 0.27) between LP and HP groups was close to the $\dot{V}O_2$ peak difference reported by Flandrois et al.[5] in active LP and HP subjects (0.18 l min$^{-1}$), and was lower than that reported by Coutts et al.[4] in sedentary LP and HP subjects (0.77 l min$^{-1}$). The homogeneous training level of the subjects in the present study may have reduced the difference between the HP and LP athletes.

Va$_{max}$ and maximal distance have been reported to be highly correlated with $\dot{V}O_2$ peak by, respectively, Léger and Boucher[3] and Cooper et al.[20] Di Carlo[7] used maximal distance covered of 12 min as an indicator of functional endurance in subjects with spinal cord injury. Using the same rectangular test, Rhodes et al.[8] and Franlin et al.[9] estimated $\dot{V}O_2$ peak from maximal distance in wheelchair-dependent subjects. However, because of the incremental characteristic of the ALBT, Va$_{max}$ was retained instead of maximal distance, which is often used with rectangular tests. Moreover, Va$_{max}$ corresponded to the last minute of the ALBT and thus to the $\dot{V}O_2$ plateau reported at the final stages of the test. HR max was not entered into the regression model, both because it did not enhance the predictive equation and because a HR telemetric system with a chest strip would have been necessary, which would have limited the use of the equation.

Surprisingly, R did not enter into the predictive equation. One would expect to correlate Va$_{max}$ with R since every subject performed the ALBT with his own general purpose wheelchair but, in fact, Va$_{max}$ may already include R. Thus, R was not necessary to predict $\dot{V}O_2$ peak in wheelchair-dependent athletes. Similarly, NP was negatively correlated with $\dot{V}O_2$ peak ($-0.53$) and was not retained by the stepwise procedure. NP was measured during the last 50 m of each 400 m lap, therefore it was not always measured concomitantly with the attainment of Va$_{max}$ and thus was not predictive of $\dot{V}O_2$ peak.

The selected predictor variables, Va$_{max}$, log(age), BMI, and lesion level, were easily measured without special equipment, therefore no material was needed to predict $\dot{V}O_2$ peak throughout the ALBT. Moreover, the equation was highly predictive (0.80) with a small SEE (0.01) and a quite low coefficient of variation (15.3%). The residuals analysis showed the independence of these residuals against the predicted $\dot{V}O_2$ peak and the measured $\dot{V}O_2$ peak. The non-homogeneity of each variable between the groups, assessed by the standard-deviation dispersion, confirmed the extrapolation quality of the equation. The external validity was verified by comparing measured $\dot{V}O_2$ peak and predicted $\dot{V}O_2$ peak in the VG subjects. This result, in only seven randomly chosen subjects, will need to be verified. Nevertheless, it indicates that the

ALBT with this new equation may provide a good prediction of $\dot{V}O_2$ peak in these well-trained wheelchair-athletes, men and women, whose disability does not involve the upper extremities, and who are using their own general-purpose wheelchairs.

In conclusion, the ALBT allowed the determination of predictive $\dot{V}O_2$ peak equation in well-trained wheelchair-dependent athletes. Although the external validity of the equation was checked in only some subjects, it may have wide applicability in aerobic evaluation and during training sessions of wheelchair-dependent athletes. The assessment of a much larger and heterogeneous population, particularly in terms of age and training level, using the protocol of the present study could enhance the predictive $\dot{V}O_2$ peak equation for all wheelchair-dependent subjects.

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