

## A multistage field test of wheelchair users for evaluation of fitness and prediction of peak oxygen consumption

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**Abstract**—An incremental multistage field test (MFT) for wheelchair users was developed to evaluate physical fitness and predict peak oxygen consumption ( $\text{VO}_2$ ). Using auditory feedback, the participants ( $n = 37$ ) were directed to wheel around an octagonal course, increasing their velocity every minute until exhaustion. Wheelchair velocity and metabolic parameters were recorded with the use of a speedometer and a portable spirometer system. The average number of exercise levels performed (MFT score) was  $9.17 \pm 5.81$ , resulting in a peak heart rate (HR) of  $99.0 \pm 13.9\%$  of the theoretical maximum. A test-retest analysis ( $n = 10$ ) showed that the MFT was reliable regarding MFT score, peak  $\text{VO}_2$ , and peak HR reached. Stepwise multiple regression based on individual, wheelchair, propulsion technique, and physiological parameters revealed that the MFT score was the best and only predictor of peak  $\text{VO}_2$  ( $\text{mL}/\text{min}/\text{kg}$ ) ( $= 18.03 + 0.78$  MFT score,  $r^2 = 0.59$ ). The MFT assesses wheelchair mobility and estimates peak  $\text{VO}_2$  encountered during the test.

**Key words:** *aerobic fitness field test, cardiorespiratory fitness, exercise testing, lower-limb disabled, wheelchair mobility.*

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### INTRODUCTION

Persons with lower-limb disability who have to rely on a manually propelled wheelchair for locomotion have a limited mobility and social range of action compared to able-bodied individuals. Wheelchair mobility can be optimized through improving the vehicle mechanics of the wheelchair, adjusting the wheelchair design to the user (wheelchair-user interface), as well as improving the individual's functional capacity [1]. In this respect, the assessment of cardiorespiratory fitness of wheelchair users has emerged as an important area of interest in rehabilitation and in the field of sports performance evaluation [2–5]. A common approach has been to use laboratory tests evaluating maximal cardiorespiratory adaptations during wheelchair exercise [4–7]. However, such tests require many resources in terms of qualified personnel and sophisticated instrumentation, which are not always available.

Depending on the use of the test results, field tests can serve as an alternative when the cardiorespiratory fitness of wheelchair users is being evaluated. Franklin et al. found that a modified 12 min Cooper test for distance was well correlated ( $r = 0.84$ ) with the peak oxygen consumption ( $\text{VO}_2$ ) determined by a laboratory arm-crank test [8]. However, the disadvantage of such a nonprogressive field test is that the subjects need to pace themselves to cover the greatest distance possible, which requires

some experience and a high degree of motivation. Vandewijck et al. developed a 25 m indoor “shuttle run” test with an auditory feedback signal to evaluate aerobic capacity of experienced wheelchair basketball players [9]. They validated their test with respect to maximal heart rate (HR), recorded both during the field test and during an arm-crank laboratory test, and reported a correlation of  $r = 0.78$ . Vinet et al. compared maximal cardiorespiratory variables recorded during an incremental field test on a 400 m tartan track and during a laboratory test [10]. They found a moderate correlation of  $r = 0.65$  between the peak  $\text{VO}_2$  values recorded during the two trials. However, the prediction of peak  $\text{VO}_2$  based on maximal speed reached in their field test was poor and the authors suggested that other variables than only those related to maximal field test performance should be considered to improve the prediction of peak  $\text{VO}_2$ .

The aims of the present investigation were to (1) develop a simple indoor multistage field test (MFT), applicable to a heterogeneous group of wheelchair users; (2) assess the reliability of this MFT; and (3) establish an equation to predict peak  $\text{VO}_2$  encountered during the test. In this respect, variables related to individual characteristics, wheelchair mechanics, wheelchair propulsion technique, and physiological performance were considered.

## METHODS

### Subjects and Protocol

The study was performed on a sample of 37 individuals (2 females and 35 males) who used a wheelchair for their daily living and/or sport activities. The study group included individuals with tetraplegia ( $n = 2$ ), paraplegia ( $n = 26$ ), postpolio ( $n = 5$ ), and lower-limb amputation ( $n = 4$ ). Inclusion and exclusion criteria for participation in the study were as follows: age between 18 and 60 years, a time-since-injury of at least 2 years, no acute infection or illness, no history of cardiovascular disease, and no counterindication for maximal exercise testing as indicated by a medical examination, including an electrocardiogram at rest. The Ethics Committee of the University of Liège approved the protocol, and all subjects provided written consent. The individuals' reported participation in physical activities was  $4.4 \pm 3.3$  h/wk. The sample was heterogeneous with respect to weekly involvement in physical activities, with values ranging from 0 h/wk ( $n = 7$ ) up to 16 h/wk ( $n = 1$ ). A subgroup of

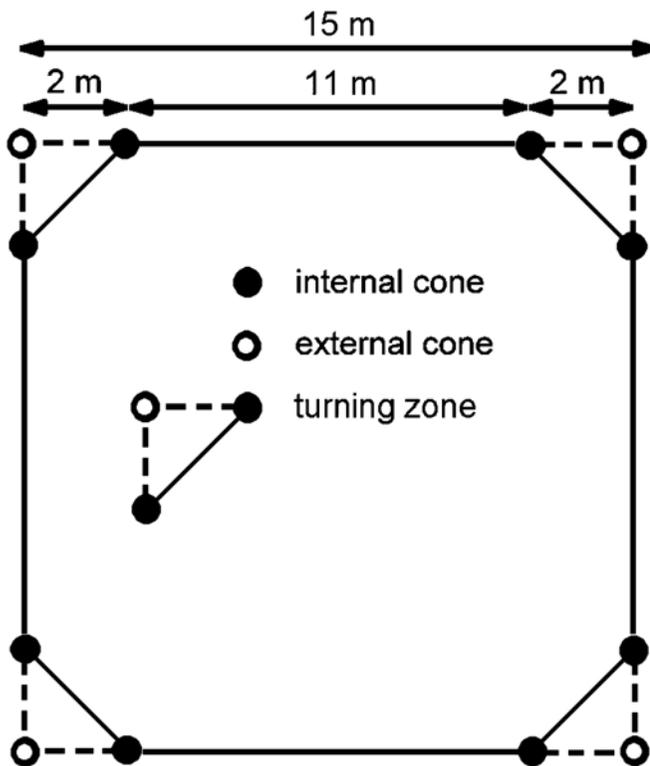
10 individuals chosen at random were asked to perform the MFT on two different occasions within 2 weeks to evaluate reliability. This subgroup comprised eight individuals with paraplegia and two with postpolio. The main characteristics of the whole subject group and the test-retest subgroup are shown in **Table 1**.

An MFT of progressively increasing intensity was developed, based on the incremental protocol described by Leger and Boucher [11]. The subjects were asked to wheel around an octagonal course delimited by cones. The course required a floor space of 15 m  $\times$  15 m (**Figure 1**). The four main sides of the octagon were 11 m long and the four short sides (angles) were 2.83 m long. The four turning zones through which the subjects wheeled were defined by two “internal” cones delimiting the angle of the octagon and one “external” cone placed on the corner of a 15 m  $\times$  15 m square. This arrangement avoided 180° changes of propulsion direction, as during the Leger and Boucher shuttle-run test, while at the same time, limiting the necessary space to perform the test. The velocity, and thus intensity of the MFT, was incremented in stages of 1 min duration, with the use of auditory feedback (“beep”-signal) from an audiotape [11]. On each beep-signal, the subject had to be within the turning zone. This resulted in an initial wheeling velocity of 6 km/h and increments of 0.37 km/h. The test was stopped if the subject was unable to reach the turning zone on three consecutive occasions, despite verbal encouragement. The test result was evaluated by the number of exercise levels performed (MFT score). This number was recorded to the nearest one-fourth exercise stage reached, discounting the three sides for which the turning zone was not reached in time. All tests were performed in the same sport hall, on a hardwood surface. The subjects used their own personal

**Table 1.** Characteristics of total study sample ( $n = 37$ ) and of test-retest subgroup ( $n = 10$ ).

Variable	Total Study Sample ( $n = 37$ )		Test-Retest Subgroup ( $n = 10$ )	
	Mean	SD	Mean	SD
Age (yr)	36.5	11.5	38.2	13.0
Body Mass (kg)	77.7	19.5	75.3	13.2
Height (cm)	177.0	8.0	174.0	7.0
Time Since Injury (yr)	16.5	14.0	14.7	17.4
Time Since Wheelchair Use (yr)	11.0	7.5	9.7	8.0

SD = standard deviation



**Figure 1.** Illustration of octagonal track used for multistage field test (MFT).

wheelchair and were free to choose the direction of rotation for the test (clockwise or counterclockwise).

### Measurements

The wheelchair characteristics that were recorded were wheelchair mass, rear wheel camber, percentage of total mass (wheelchair and user) on the rear wheels, and total rolling resistance of the wheelchair-user system (see next paragraph). Wheelchair velocity during the MFT was measured with a custom-made speedometer. The device consisted of a probe based on the Hall principle, which produced an electrical current when exposed to an increasing magnetic field. The probe was positioned at the back of the wheelchair, just opposite the rim of the outside (with respect to the subject's direction around the track) rear wheel. Eighteen small steel magnets (9 g each) were installed at equal intervals on the circumference of the wheel, thus producing an electrical current at a frequency proportional to the velocity of the rear wheel. With a typical wheel circumference of 180 cm, for example, a velocity measurement was acquired every 10 cm of distance covered. The setup also comprised an electrical

interface (3.5 kg) installed at the back of the wheelchair, including a 12 V battery, signal conditioning circuitry, and a magnetic minidisk recorder with a numeric recording capacity of 74 min.

The average number of pushes necessary to cover one side of the octagon during the final exercise stage was determined from the acceleration phases of the instantaneous velocity record measured during the MFT. Furthermore, the percentage of speed loss during the turns was determined based on the average speed performed during the last exercise level and the average of the minimal velocity values recorded during the turns of that stage. The average number of pushes to cover one side and the speed loss during the turns in the last exercise stage were used to assess the efficacy of propulsion technique. Finally, the total rolling resistance of the wheelchair-user system was evaluated from a deceleration test [12], based on the slope of a linear regression calculated from the speed data recorded during a free deceleration of the wheelchair-user system from a given velocity to standstill. The deceleration test was performed three times along each of the four driving directions of the MFT. The force representing the total rolling resistance was taken as the average value obtained from the 12 trials.

We recorded  $\text{VO}_2$ , carbon dioxide rejection, and HR throughout the MFT using a K4b<sup>2</sup> system (Cosmed, Italy), consisting of a mask and portable unit worn by the subject. The mask contained a sampling tube and a turbine for measuring the expired air volume. The portable unit contained the  $\text{O}_2$  and  $\text{CO}_2$  sensors, sampling pump, signal transmitter, barometric pressure sensor, and electronics. The portable unit and a rechargeable battery were fixed to the back of the subject by a harness. The total mass of the portable system was approximately 800 g. The gas analyzers and flowmeter were calibrated before each exercise test. All data were stored in the portable unit and downloaded onto a computer hard disk after the test. The data were also monitored throughout the test with the K4b<sup>2</sup> telemetric data receiver unit. Breath-by-breath data were averaged over 10 s. Peak  $\text{VO}_2$ , peak HR, and peak respiratory exchange ratio (RER) were defined as the maximal values recorded during the last 30 s of the exercise test. Blood samples were taken from an ear lobe within the first minute of recovery from exercise and every 2 min thereafter. The samples were analyzed with respect to lactate concentrations with a YSI Model 1500 Sport lactate analyzer (Yellow

Springs Instrument, Ohio, U.S.). Peak lactate concentration was defined as the maximal value obtained within the first 10 min of recovery.

### Statistics

The characteristics of the test-retest subgroup were compared to those of the total study sample with the use of independent t-tests. Reliability of the MFT was evaluated with the use of interclass correlations and Bland-Altman plots to graphically display the variability between the two measurements. The limits of agreement were calculated as the mean difference plus or minus coefficient of repeatability (two standard deviations of the differences between test-retest measurements) [13]. Variables concerning individual and wheelchair characteristics, as well as those assessed during the MFT, were subjected to correlation tests (Pearson product-moment correlations). We performed a stepwise forward linear regression to predict the peak  $\text{VO}_2$  obtained during the MFT. Statistical significance was considered at the  $p < 0.05$  level. All data are presented as mean plus or minus one standard deviation.

## RESULTS

**Table 2** gives an overview of the wheelchair characteristics and the peak performance parameters of the subject group during the MFT. The average number of exercise stages accomplished during the MFT was  $9.17 \pm 5.81$ , associated with a mean peak  $\text{VO}_2$  of  $25.2 \pm 5.9$  mL/min/kg. The

peak HR of  $172 \pm 26$  b/min represented  $99.0 \pm 13.9$  percent of the predicted maximum HR of  $220 \text{ b/min} - \text{age} - 10 \text{ b/min}$  for arm work [4]. The mean RER of  $1.19 \pm 0.13$  and peak blood lactate concentration of  $5.4 \pm 1.9$  mmol/L also indicate that the MFT represented a maximal effort.

The results from the first and the second reliability subgroup tests ( $n = 10$ ) were  $8.38 \pm 5.87$  and  $8.48 \pm 6.00$  for the MFT scores,  $24.8 \pm 4.4$  and  $24.9 \pm 4.9$  mL/min/kg for peak  $\text{VO}_2$ , and  $162 \pm 25$  and  $161 \pm 22$  b/min for peak HR. The average results for these variables were not significantly different from those of the whole study sample (independent t-test). Interclass correlations for the MFT score, peak  $\text{VO}_2$ , and peak HR were 0.99, 0.88, and 0.96, respectively. The variability of these parameters is illustrated in the Bland-Altman plots of **Figure 2**. The absolute differences for the MFT scores were  $\leq 1$  exercise stage, except for one subject who performed less well during the second test (difference of  $-1.75$  in MFT score). Following the second trial, this person declared to have had back pain, preventing the use of an efficient propulsion technique, although an HR of 171 b/min and an RER of 1.12 were attained at the end of the test. Maximal absolute differences between test-retest measurements were 3.6 mL/min/kg for  $\text{VO}_2$  and 14 b/min for HR. The limits of agreement were  $0.1 \pm 1.6$  exercise stages for the MFT score,  $0.1 \pm 4.6$  mL/min/kg for peak  $\text{VO}_2$ , and  $-1.3 \pm 15.4$  b/min for peak HR.

For the total study group, correlation tests were performed between the variables reflecting individual, wheelchair, and MFT performance characteristics. Those variables that were significantly correlated to peak  $\text{VO}_2$

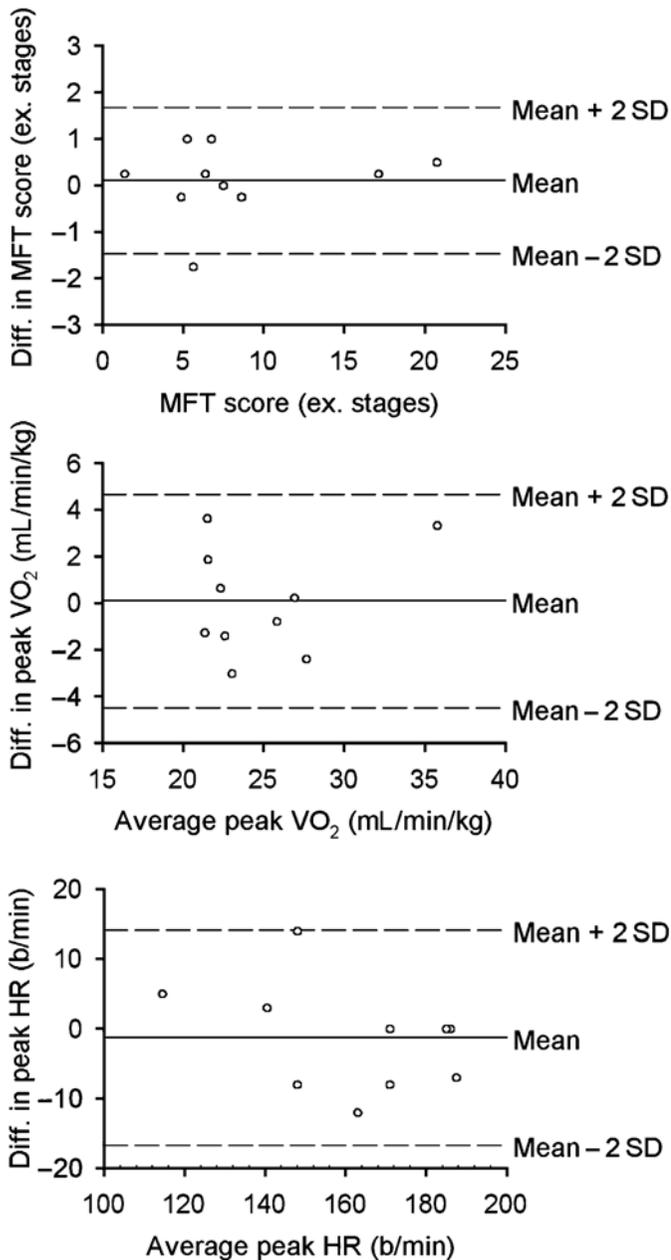
**Table 2.**

Characteristics of wheelchair and variables related to peak performance of subject group ( $n = 37$ ) during MFT.

	Parameter	Mean $\pm$ SD	Minimum	Maximum
<b>Wheelchair</b>	Mass (kg)	$14.2 \pm 4.6$	9.0	28.0
	Rear wheel camber ( $^\circ$ )	$7.0 \pm 5.0$	0.0	19.0
	Total rolling resistance (N)	$6.4 \pm 2.6$	2.5	15.0
	Mass on rear wheels (%)	$79.2 \pm 9.6$	51.8	93.5
<b>Peak Performance During MFT</b>	Peak $\text{VO}_2$ (mL/min/kg)	$25.2 \pm 5.9$	11.1	37.8
	Peak HR (b/min)	$172.0 \pm 26.0$	95.0	208.0
	Peak $[\text{La}^-]$ (mmol/L)	$5.4 \pm 1.9$	1.64	8.53
	Pushes/side last stage (n)	$6.1 \pm 1.7$	3.2	12.1
	Speed loss during last stage (%)	$24.7 \pm 8.8$	12.4	49.0
	MFT score (exercise stages)	$9.17 \pm 5.81$	1.25	23.00

MFT = multistage field test  
 $\text{VO}_2$  = oxygen consumption

HR = heart rate  
 $[\text{La}^-]$  = blood lactate concentration



**Figure 2.**

Bland-Altman plots illustrating test-retest variability of total number of exercise stages completed in multistage field test (MFT score), of peak oxygen consumption (peak  $\text{VO}_2$ ), and of peak heart rate (peak HR) encountered.

recorded during the MFT are shown in **Table 3**. The MFT score was best correlated to peak  $\text{VO}_2$  ( $r = 0.77$ ), but also variables concerning physiological performance (HR, blood lactate), propulsion technique (number of pushes required to cover one side), and wheelchair characteristics

(wheelchair mass, rear wheel camber, mass distribution over front and rear wheels) were associated with peak  $\text{VO}_2$ . Since most of these variables were correlated between themselves, a stepwise linear regression analysis was performed. This analysis revealed that no variable other than the MFT score added significantly to the predictive power of peak  $\text{VO}_2$ . The relationship between peak  $\text{VO}_2$  and the MFT score was as follows: peak  $\text{VO}_2$  ( $\text{mL}/\text{min}/\text{kg}$ ) =  $18.03 + 0.78$  MFT score (number of exercise stages);  $r^2 = 0.59$  (**Figure 3**).

The MFT score represents a global indicator of the wheelchair user's mobility, which is related to individual characteristics, wheelchair properties, and the wheelchair-user interface. To identify which of the analyzed variables would adequately predict the MFT score, we performed another stepwise linear regression using the MFT score as the dependent variable. Eighty-two percent of the MFT score variability could be explained by the combined effects of the number of pushes required to cover one side of the octagonal course in the final exercise stage (X1), the percentage of total weight on the rear wheels (X2), peak  $\text{VO}_2$  expressed in milliliters per minute per kilogram (X3), and the percentage of speed loss during the turns in the final exercise stage (X4). MFT score =  $5.047 - 1.604 X1 + 0.116 X2 + 0.303 X3 - 0.121 X4$ ;  $r^2 = 0.82$ .

## DISCUSSION

Field tests have become an important component in rehabilitation and in sports science when evaluating the cardiorespiratory fitness of wheelchair users. They have some major advantages over laboratory tests: they are generally cost-effective and easy to administer, and they require few resources with respect to specialized equipment or qualified technicians (except for the compulsory emergency equipment and medical supervision in maximal exercise testing). To be useful, field tests must be reliable and valid, and they should be capable of evaluating a heterogeneous group of wheelchair users. Although some interesting approaches have been previously described in the scientific literature, these field tests either have been nonprogressive [8], were applied to a certain wheelchair sportsmen group [9], or were designed for outdoor facilities [10], which leads to standardization problems during routine testing. The indoor MFT developed here has the advantages of being progressive in nature and applicable

Table 3.

Pairwise correlations between all variables correlated ( $p < 0.05$ ) with peak  $\text{VO}_2$  measured during MFT ( $n = 37$ ).

	Peak $\text{VO}_2$	MFT Score	Peak HR	Peak $[\text{La}^-]$	Push n	WC Mass	Camber
<b>MFT Score</b>	+0.77*	—	—	—	—	—	—
<b>Peak HR</b>	+0.48*	+0.61*	—	—	—	—	—
<b>Peak <math>[\text{La}^-]</math></b>	+0.64*	+0.63*	+0.51*	—	—	—	—
<b>Push n</b>	-0.65*	-0.80*	-0.48*	-0.60*	—	—	—
<b>WC Mass</b>	-0.41*	-0.53*	-0.28	-0.50*	+0.60*	—	—
<b>Camber</b>	+0.40*	+0.64*	+0.23	+0.32	-0.53*	-0.59*	—
<b>% Mass</b>	+0.54*	+0.69*	+0.47*	+0.44*	-0.51*	-0.60*	+0.63*

\*Correlation is significant at 0.05 level.

 $\text{VO}_2$  = oxygen consumption

MFT score = number of exercise stages performed in multistage field test

HR = heart rate

 $[\text{La}^-]$  = blood lactate concentration

Push n = number of pushes necessary to cover one side of octagonal track during final exercise stage

WC = wheelchair

Camber = rear wheel camber

% mass = percentage of total mass (wheelchair and user) on rear wheels

to individuals with a wide range of physical capacity, using their own personal wheelchair. Additionally, the present study has investigated the influence of an extensive number of variables related to the user, the wheelchair, and the propulsion technique on the predictive power of peak  $\text{VO}_2$  encountered during the MFT.

Reliability was assessed in a subgroup of 10 individuals who performed the MFT twice. The interclass correlations for MFT score, peak  $\text{VO}_2$ , and peak HR were high. However, a high correlation coefficient between the results of two measurements is not sufficient as an indicator of good agreement between the two measurements [13]. Therefore, we used Bland-Altman plots to graphically display the variability involved in these variables (Figure 2). In each case, the mean difference is close to zero and the coefficients of repeatability (2 SD of the difference between the test-retest measurements) are acceptable, comparing well to previously reported data [14]. Thus, one can conclude that the MFT is reliable with respect to the number of exercise stages accomplished (MFT score), peak  $\text{VO}_2$ , and peak HR encountered during the test. Since 95 percent of the differences between two tests are expected to be within the limits of agreement [13], an improvement (or a decline) of 1.6 in the MFT score can be considered significant.

Based on the peak values of HR ( $99.0 \pm 13.9\%$  of the theoretical maximum), RER ( $1.19 \pm 0.13$ ), and blood lactate concentrations ( $5.4 \pm 1.9$  mmol/L) recorded, the MFT can be considered a maximal exercise test. Therefore, the

peak  $\text{VO}_2$  measured during the MFT may provide a good estimation of peak aerobic capacity of the individuals tested. The values found in this study agree with previously reported data [8,15]. Franklin et al. evaluated a group of 30 wheelchair users who compare well to our

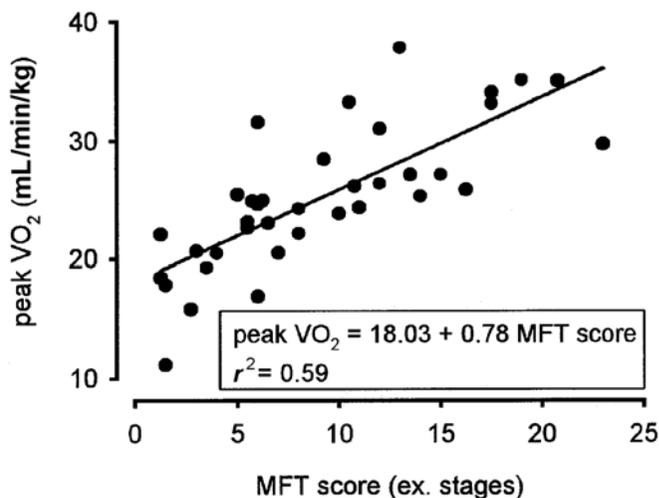


Figure 3.

Relationship between peak oxygen consumption (peak  $\text{VO}_2$ ) measured during multistage field test (MFT) and total number of exercise stages completed (MFT score) (results are from a linear regression analysis, stepwise multiple regression analysis having rejected several additional variables related to peak physiological performance, wheelchair propulsion, and wheelchair mechanics characteristics).

participants in terms of individual characteristics and disability groups [8]. They found a peak  $\text{VO}_2$  of  $22.0 \pm 5.9$  mL/min/kg and a peak HR of  $175 \pm 19$  b/min based on an arm-crank laboratory test. These are values similar to the present results of  $25.2 \pm 5.9$  mL/min/kg and  $172 \pm 26$  b/min, respectively. Pare et al. also reported peak  $\text{VO}_2$  values of the same magnitude ( $23.9 \pm 4.6$  mL/min/kg) in a group of 46 sedentary to moderately active wheelchair users [15].

The MFT probably reflects many components of the overall physical performance of an individual using his wheelchair, besides the mere aerobic capacity of the test participant. This is a feature already noted by other investigators. Vanlandewijck et al. found a fair correlation of  $r = 0.64$  between the performance in their 25 m shuttle run test and peak  $\text{VO}_2$  measured during a maximal arm-crank test [9]. Based on the results from a series of other field tests, Vanlandewijck et al. suggested that their shuttle run test was not only related to peak  $\text{VO}_2$  but also to anaerobic performance, muscle contraction velocity, and maneuverability with the wheelchair. According to these authors, the  $180^\circ$  turns after each 25 m and the resulting cumulative decelerations and accelerations of the wheelchair-user system probably solicited anaerobic energy sources to some extent. This was less critical with the present approach, where the participants wheeled around an octagonal track. The changes in direction were less abrupt, thus avoiding high decelerations and energy losses during the turns. Indeed, during the final exercise stage, the subjects lost only about 25 percent of their average velocity maintained during that level (see **Table 2**).

Similarly to the present study, Vinet et al. used a portable  $\text{VO}_2$  measurement system (K2, Cosmed, Italy) to validate an incremental field test with respect to a laboratory test on a wheelchair treadmill [10]. They found a correlation of  $r = 0.65$  between the peak  $\text{VO}_2$  values of both tests applied to a group of wheelchair athletes ( $n = 9$ ). However, the predictive power for peak  $\text{VO}_2$ , based on maximal speed reached during their field test, was poor, with a coefficient of determination of  $r^2 = 0.18$ . They argued that wheelchair-related factors such as rolling resistance or wheelchair mass, as well as propulsion technique parameters and physiological variables, might improve the prediction of peak  $\text{VO}_2$  when using a field test. However, in contrast to these considerations and our own expectations, the MFT score was the only variable maintained in the stepwise linear regression analysis. The MFT score accounted for 59 percent of the variability of

peak  $\text{VO}_2$  encountered (see **Figure 3**), a result, which may be attributed to the heterogeneity of the present study sample as compared to the more homogeneous wheelchair athletes tested by Vinet et al. [10].

None of the supplementary variables investigated here added significantly to the predictive power of peak  $\text{VO}_2$ . The reason is that most of these variables were correlated with each other (see **Table 3**) and were thus excluded from the regression model. Close inspection of **Table 3** also shows that all of these variables were highly correlated to the MFT score, which suggests again that the MFT probably represents a global evaluation of the wheelchair-user performance. Indeed, wheelchair mobility is not merely related to the cardiorespiratory fitness of the individual but also to his or her propulsion technique, the mechanical characteristics of the wheelchair, and the adjustments of these characteristics to the individual's functional capacities [1]. This finding was confirmed by the results of our second regression analysis using MFT score as the dependent variable, which could be explained by variables related to wheelchair propulsion efficacy, wheelchair adjustments, and peak  $\text{VO}_2$ . Therefore, an interesting feature of the MFT is that it provides an overall assessment of the "wheelchair-user system" in terms of mobility and peak velocity, important practical aspects of a wheelchair user's independence and social range of action.

A limitation of the present results, and thus related to the use of the MFT, is that variations in floor surface are likely to influence the MFT score and the MFT- $\text{VO}_2$  relationship, thus reducing the prediction accuracy of peak  $\text{VO}_2$  during the MFT. Comparisons between results obtained in different settings should therefore be made with caution, and the MFT should preferably be performed on a hard floor surface. The test results can be used for comparison between successive evaluations, if environmental conditions are similar. However, a laboratory exercise test is more appropriate in contexts where a precise measurement of peak  $\text{VO}_2$  is needed. The present results may have been influenced to some extent by the additional mass of the measurement equipment used. The electrical interface, speedometer, and K4b<sup>2</sup> system amounted to a total supplementary mass of  $\sim 4.5$  kg. This represents a mean of 4.9 percent of the total mass of the wheelchair-user combination.

The MFT is a convenient test that can be used routinely to follow the overall progression of a wheelchair patient or athlete over a short term. It allows for simultaneous testing

of four subjects, if they choose the same direction of rotation for the test. The MFT has the advantage of being a simple, low-cost test, requiring limited space (slightly more than the 15 m × 15 m surface required for the octagonal course), little material, and no specific prior experience by the test subject and the examiner. However, it should be noted that the MFT is a symptom limited (fatigue) exercise test that may stimulate the cardiovascular system to maximal levels if continued to exhaustion. Consequently, this test requires qualified medical supervision and appropriate emergency procedures, especially since the wheelchair-user population is at relatively high risk for secondary cardiovascular complications. In this respect, the MFT could be used more conservatively, by evaluating the MFT score for an individually determined submaximal HR. Further study should be directed toward the use of submaximal field tests.

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