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Validation of an incremental field test for the direct assessment of peak oxygen uptake in wheelchair-dependent athletes

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The aim of this study was to validate an incremental field test performed by wheelchair-dependent (WD) athletes. Nine male paraplegic subjects (mean age: 28.9 ± 4.2 years) performed an incremental field test (FT) and a comparable laboratory test (LT) with their own usual wheelchairs. Both tests started with an initial speed of 4 $km.hr^{-1}$ and increased by increments of 1 $km.hr^{-1}$ every minute until volitional exhaustion. The FT was an adapted Léger and Boucher test (ALBT) and was conducted on a 400 m tartan field marked-off every 50 m with pylons. Ventilatory data were collected every 15 s using a portable telemetric system (Cosmed K2, JFB International, Italy). The LT was performed on an adapted treadmill (Sopur, Germany) and ventilatory data were collected every minute using a breath-by-breath automated system (CPX, Medical Graphics, MN, USA). The LT and the FT were not significantly different for duration (8 min 50 ± 1 min 24 *vs* 9 min 55 ± 29 s), percentage of maximal heart rate (HR, 86.2 ± 3.9 *vs* 89.7 ± 5.3%), maximal minute ventilation (VE, 101.6 ± 28.5 *vs* 96.8 ± 28.2 $l.min^{-1}$), and peak oxygen uptake (Vo_2 peak, $39.7 + 7.3$ *vs* $36.1 + 5.8$ $ml.kg^{-1}.min^{-1}$) assessed with the CPX and the K2, respectively. We concluded that the FT proposed in the present study is a valid test for direct Vo_2 peak assessment in wheelchair athletes using a portable Vo_2 telemetric system. Nonetheless, the Léger and Mercier model equation did not accurately predict Vo_2 max and further investigation is needed to determine a valid Vo_2 max prediction equation for these subjects during the FT.

Keywords: paraplegia; incremental field test; wheelchair exercise; peak oxygen uptake; Léger and Boucher test

Introduction

Aerobic fitness has been widely assessed in able-bodied (AB) and wheelchair-dependent (WD) subjects in laboratory tests.[1–3] Field tests (FT) to assess aerobic fitness have been carried out in AB individuals and are based on walking and running exercises that require use of both the lower and upper limbs. For WD subjects, who have only the use of their upper limbs, a specific FT is needed using wheelchair propulsion as the means of displacement. FTs are of great interest because they are similar, in terms of environment and activity, to competitive events. Moreover, nomograms or equations allow the accurate prediction of maximal oxygen uptake (Vo_2 max) from these tests and have been widely reported on for AB individuals.[4,5] In contrast, to our knowledge, only three studies have been reported about FTs in WD subjects, all with methodological difficulties and problems of data reliability. Rhodes *et al*[6] and Franklin *et al*[7] adapted the 12 min Cooper test, whereas Kofsky *et al*[8] validated a submaximal test on a portable arm-crank ergometer. Neither of these tests was both incremental and maximal, and thus they did not allow direct Vo_2 max assessment using a portable Vo_2 telemetric system. Indeed, such a system has recently been validated which enhances the interest of incremental FTs for direct Vo_2 max assessment.[9,10] The aim of the present study was to validate an incremental FT for the direct assessment of Vo_2 max using a portable telemetric system, in WD athletes, by comparing the maximal cardiorespiratory variables recorded during the incremental FT and a similar incremental laboratory test (LT).

Methods

Subjects

Nine male WD athletes, aged 28.9 ± 4.2 years (range: 24 to 35 years), provided informed written consent to participate in this study. Anthropometric data and general characteristics of these athletes are given in Table 1. The percentage of body fat was calculated according to the Durnin and Womersley equation.[12]

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All subjects had had lower-limb disabilities for at least 2 years prior to the study: seven were paraplegic due to traumatic spinal cord injury (SCI) with lesion levels from T4/T5 to L3, one subject was spina-bifida L5, and one subject was post-poliomyelitis with paralysis of the lower limbs. According to the International Stoke Mandeville Games (ISMG) functional classification, the paraplegic subjects were classified as II, III, IV and V corresponding with lesions in the areas T1-T5, T6-T10, T11-L3 and L4-S1, respectively. Non-paraplegic individuals were classified as class VI.[20] All subjects practiced their sport of wheelchair-racing or tennis an average of 6 h 20 min $\pm$ 3 h 12 min per week. They had all acquired good control of their wheelchairs, which was essential for the study.

Protocol

The athletes performed two tests: (1) a FT that was an adaptation of the Léger and Boucher Test[4] (ALBT) for AB individuals, which is a continuous running multistage test that predicts $\dot{V}O_2$ max according to a validated equation, and (2) a continuous multistage LT. Both tests were performed by subjects with their own general purpose wheelchairs. Before testing, a medical examination was performed including clinical examination, blood pressure, heart rate (HR), cardiopulmonary auscultation and resting 12-lead EKG. All results were normal and did not contraindicate maximal exercise testing. The athletes were given verbal encouragement to reach maximal effort throughout the two tests. The order of the tests was randomized and both were performed by each subject within a one-month period. Between the two tests, the type and the intensity of each subject's training remained unchanged.

The FT 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 m.s^{-1}. The test protocol required each subject to propel his wheelchair as far as possible following the rhythm imposed by means of an audio-tape that provided feedback to the subjects. 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 s.min^{-1}.[14] The athlete adjusted his speed when crossing a pylon at the sound signal. The initial speed was 4 km.h^{-1} for 1 min; thereafter it was increased by 1 km.h^{-1} every min until exhaustion, which was defined as the inability to maintain the required speed with a 3 m distance behind the appropriate pylon at the sound signal and the inability to catch up at the next pylon. The number of executed laps, the number of crossed pylons and the duration of the test were noted. The last speed to be reached corresponded to the maximal aerobic speed defined as the speed necessary to attain $\dot{V}O_2$ max.[4,15] Throughout the test, the athlete was equipped with the Cosmed K2 (JFB International, Italy), a portable telemetric $\dot{V}O_2$ analyser.[9,10,16,17] 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 breathing frequency (f), tidal volume (VT) and minute ventilation ($\dot{V}E$), 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 miniatured polarographic electrode for the oxygen concentration measurement, FEO_2, is inside the microchamber. Ventilatory data ($\dot{V}E$, l.min^{-1}, $\dot{V}O_2$ l.min^{-1} and ml.kg^{-1}.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% (K2 instructions manual) before each test. The expired gases were sampled at the rate proportional to ventilation by means of a dynamic sampling pump. Since the K2 does not contain a CO_2 electrode, it is assumed that the individual is working at a respiratory exchange ratio (RER) of 1.00; therefore, the formula used to calculate $\dot{V}O_2$ is: $\dot{V}O_2 = \dot{V}E\ (FIO_2\text{-}FEO_2)$, where FIO_2 is assumed to be 20.9%. The criteria for $\dot{V}O_2$ peak were: (1) the stability of $\dot{V}O_2$ in spite of the speed

Table 1 General characteristics of WD athletes

Subjects (n=9)	*Age (yr)*	*Weight (kg)*	*Height (cm)*	*Body fat (%)*	*Lesion level (L-T)*	*Lesion classification (ISMG)*	*Lesion type* (I-C-S-F)*	*Sport** (R-T)*	*Training volume (h. week^{-1})*
1	28	72	180	22.9	L3	V	I/F	T	6
2	33	56	175	15.6	T4-T5	II	C/S	R	2
3	24	66	165	23.1	spina L5	VI	–	R	10
4	31	82	184	27.3	T10	III	C/S	R	10
5	33	50	161	17.7	polio	VI	–	R	10
6	24	67	175	24.3	T8-T9	III	C/S	T	4
7	25	60	170	22.5	T12	IV	I/–	T	4
8	27	62	180	12.6	T12-L1	IV	I/F	R	7
9	35	72	176	31.4	T8	III	C/S	T	5
M	28.9	65.2	174	27.9	–	–	–	–	6 h 20 min
SD	4.2	9.6	7.4	5.8	–	–	–	–	3 h 12 min

*I = incomplete, C = complete, S = spastic, F = flaccid, L = Lumbar, T = thoracic **T = tennis, R = racing increment, (2) an HR value near the theoretical maximal HR [210-(0.65 age)],[18] and (3) the inability of the athlete to maintain the required speed.

The LT was performed using a wheelchair mounted on an adapted treadmill (Sopur, Germany) and $\dot{V}O_2$ peak was assessed using a direct measurement method. The LT was a maximal continuous multistage exercise.[19–22] After a 2 min rest, the subject warmed up for 3 min at 4 $km.h^{-1}$; the speed was then increased by 1 $km.h^{-1}$ every min until exhaustion. Ventilatory data were collected using a breath-by-breath automated metabolic system (CPX, Medical Graphics, MN, USA). Briefly, expiratory airflow was measured with a pneumotachograph and expired gases were analyzed for O_2 with a zirconia solid electrolyte O_2 analyser and for CO_2 with an infrared analyser. Before each test, the volume was calibrated by five inspiratory strokes with a 3 litre pump; each gas analyser was calibrated with the room air (20.9% O_2, 0.03% CO_2) and a standard certified commercial gas preparation (12.0% O_2, 5.0% CO_2). $\dot{V}E$ ($l.min^{-1}$), $\dot{V}O_2$ ($ml.kg^{-1}.min^{-1}$), $\dot{V}CO_2$ production ($ml.min^{-1}$), f ($c.min^{-1}$) and V_T (ml) were collected every minute as an average of the last 20 s of every stage. A 12-lead EKG (Medical Graphics, MN, USA) was continuously monitored to collect HR ($b.min^{-1}$). The observation of at least three of the four following criteria was necessary to consider that the subjects had reached their $\dot{V}O_2$ peak: (1) the stability of $\dot{V}O_2$ in spite of the speed increment, (2) an HR value near the theoretical maximal HR, (3) a RER above 1.1, and (4) the inability for the athlete to maintain the imposed speed.

Statistical analysis

Differences between mean values of test duration, maximal HR, $\dot{V}E$ and $\dot{V}O_2$ peak values were statistically analysed using the Wilcoxon signed-rank test. The Spearman intra-class correlation test was used to assess the relationship between the $\dot{V}O_2$ peak measured throughout the LT and the FT, and to compare the differences between the individual $\dot{V}O_2$ peak values measured on the two tests. Moreover, the Bland and Altman method[23] was used to assess the agreement of individual $\dot{V}O_2$ peak values obtained throughout the LT and the FT. Significance was always fixed at $P<0.05$.

Results

The cardiorespiratory variables recorded throughout the LT satisfied the criteria for $\dot{V}O_2$ peak (Table 2). RER values above 1.1 (1.36 ± 0.13) and maximal HR near the maximal theoretical HR ($86.2 \pm 3.9\%$) indicated that the subjects performed a maximal exercise. The duration, percentage of theoretical maximal HR and $\dot{V}E$ during the LT were not significantly different from the values observed in the FT: 8 min 50 ± 1 min 24 *vs* 9 min 55 ± 29 s; $86.2 \pm 3.9\%$ *vs* $89.7 \pm 5.3\%$; and 101.6 ± 28.5 $l.min^{-1}$ *vs* 96.8 ± 28.2 $l.min^{-1}$, respectively. The $\dot{V}O_2$ kinetics throughout the FT reported in Figure 1 showed that the $\dot{V}O_2$ values progressively increased up to peak values. The results of the Wilcoxon signed-rank test revealed no significant difference between the $\dot{V}O_2$ peak assessed throughout the LT and the FT. The intra-class correlation ($r = 0.65$) indicated the significant relationship between the LT and the FT, as well as between individual $\dot{V}O_2$ peak values in the two test trials. Moreover, the Bland and Altman method showed the agreement between the individual $\dot{V}O_2$ peak values assessed throughout the two tests: the limits of agreement between the $\dot{V}O_2$ peak differences (mean $\pm$ 2 SD) were small enough to ensure similar $\dot{V}O_2$ peak was assessed throughout the two tests (Figure 2).

Discussion

Nine wheelchair athletes performed a field test, corresponding to an adaptation of the Léger and

Table 2 Comparison of maximal variable values during the LT and the FT.

Subjects	*Duration (min)*		*HR* ($b.min^{-1}$)		*HR* %		$\dot{V}O_2$ *peak* ($ml.kg^{-1}.min^{-1}$)		$\dot{V}E$ ($l.min^{-1}$)		*RER*
n=9	*LT*	*FT*	*LT*	*FT*	*LT*	*FT*	*LT*	*FT*	*LT*	*FT*	*LT*
1	7	9:41	182	185	90.2	91.7	33	37.6	89.2	92.2	1.45
2	9:47	9:27	173	180	87.1	90.7	32.3	28.5	78.6	73.7	1.46
3	8:32	9:27	163	163	79.4	79.4	45.8	41.6	106.1	77.3	1.34
4	11:05	11	166	173	83.1	86.6	42.8	34.1	167.9	160	1.22
5	7:30	9:55	168	176	84.6	88.6	54.4	43.7	82.3	81	1.16
6	9:36	9:41	179	182	87.6	89	37.4	28	115.9	99.4	1.48
7	8:07	9:55	183	184	89.8	90.3	34.4	36.1	79.8	82.4	1.46
8	10:11	10:08	168	183	83	90.4	42.9	42.7	84.4	81.4	1.31
9	7:38	9:55	180	195	91.3	98.8	34.7	32.6	109.8	123.8	1.38
x	8:50	9:55	173.6*	178.2	86.2	89.5	39.7	36.1	101.6	96.8	1.36
SD	1:24	0:29	7.6	13.3	3.9	5.3	7.3	5.8	28.5	28.2	0.13

*Significant difference ($P<0.05$)

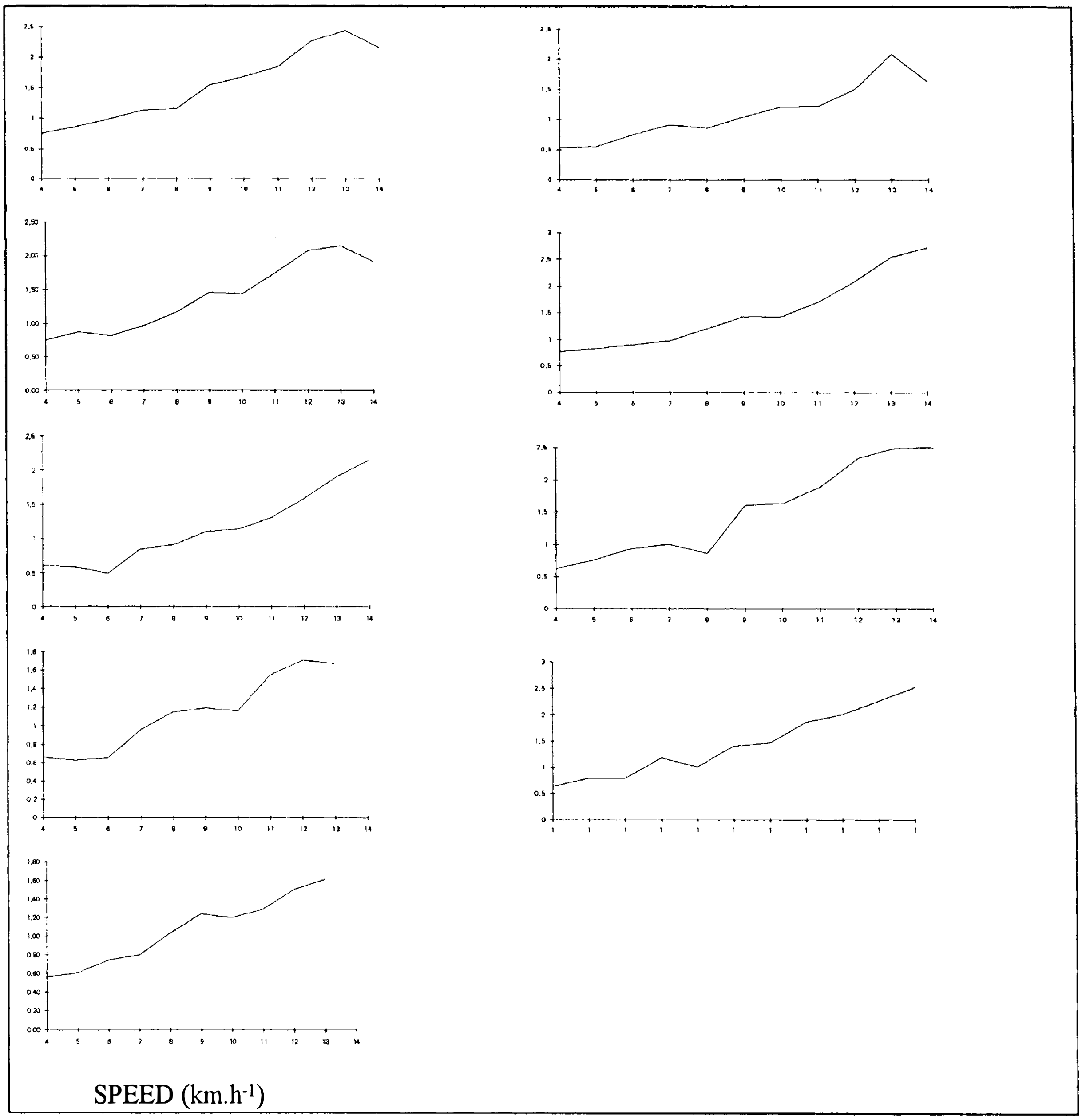

Figure 1 VO_2 (ℓ.min^{-1}) kinectics during the FT in the 9 WD athletes

Boucher test, during which direct VO_2 peak was similar to the VO_2 peak attained during a conventional graded laboratory test.

The decision to use two different systems for measuring VO_2 during the LT and the FT was based on the results in numerous publications of similar VO_2 max with the K2 *versus* conventional methods comparable to the CPX, ie. with similar pneumotachographs (breath-by-breath system)[16] and gas analysers (Beckman, USA[9] and NEC, Japan[10]), throughout the incremental exercise tests. Moreover, the results were confirmed by the significant intra-class correlation and the Bland and Altman method (Figure 2) which indicated a good relationship and agreement respectively between the individual VO_2 peak values assessed throughout the two measurement methods.

The variables measured during the LT satisfied the criteria for VO_2 peak. The durations of the LT and FT were not significantly different, and were within the time span recommended by Buchfuhrer *et al*,[24] ie 8 to 12 min to reach VO_2 max; thus both tests were assumed to be valid to assess this parameter. The percentage of theoretical maximal HR reached in FT was not significantly different from that of the LT. This demonstrated the high demand placed on the cardiovascular system throughout both tests, and

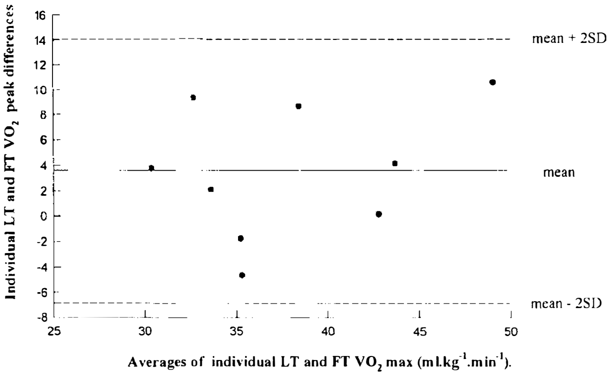

Figure 2 Bland and Altman graphic for LT-Vo_2 peak and FT-Vo_2 peak agreement

confirmed that they are maximal. Moreover, the Vo_2 peak recorded during the LT was not significantly different from that recorded during FT. Thus, the direct assessment of Vo_2 peak using a portable Vo_2 telemetric system during the FT was validated. The progressive intensity of the FT protocol was an important element of its overall quality; this was indirectly indicated by the Vo_2-speed plot slope (Figure 1).

The FT in the present study, moreover, seemed to elicit a greater involvement of the WD athletes than the LT, as has been noted in other studies. This could explain the significantly higher maximal HR values recorded throughout the FT *versus* the LT. This finding may be explained by a higher motivation on the field, a more familiar environment, and a higher rolling resistance of the wheelchair on the field. In fact, in the FT, the wheel friction on the ground, the gravitational force and the air resistance[27] were increased. The speed displacement and, consequently, the air resistance were also enhanced, allowing a better thermoregulation by better conduction, convection and evaporation effects. Moreover, the propelling technique on the field, characterized by more pronounced forward flexion of the trunk,[28] led to higher power output but implied greater muscular work, involving a higher HR.[29]

The Léger and Mercier equation for Vo_2 prediction in AB individuals using lower limbs (Vo_2 max $= 1.353 + 3.163$ s $+ 0.0122$ s^2 with Vo_2 max in ml.kg^{-1}.min^{-1} and speed -s- in km.h^{-1}) was inappropriate. Indeed, this equation includes parameters for AB subjects which do not apply to WD subjects. In order to improve the predictive quality of the equation, we developed a version using the same model (Vo_2 max $= a + bs + cs^2$ where a,b,c were specific constant values and s, maximal speed (km.h^{-1}). This version gave a very low predictive value, ie $r^2 = 0.18$. This result suggests that maximal speed (s) was not the only parameter to predict the Vo_2 peak in WD athletes throughout the FT. Other variables, such as mechanical (ie rolling resistances, weight of the wheelchair, etc), biomechanical (ie number of handrim pushes, etc), anthropometrical and/or physiological factors, may be involved. Therefore, a more comprehensive, better-adapted equation for the Vo_2 peak prediction in WD subjects throughout FT needs to be tested.

In conclusion, the field test proposed in the present study, an adaptation of the Léger and Boucher test, allowed the accurate direct measurement of Vo_2 peak, using a Vo_2 portable telemetric system, in wheelchair-dependent athletes. It can be considered as a valid and reliable FT for the assessment of aerobic fitness in these subjects. This test could also be proposed for WD sedentary subjects and WD patients in rehabilitation. Evaluation of a wide heterogeneous sample of WD subjects, with collection of direct Vo_2 peak and numerous other variables (physiological, mechanical, biomechanical, anthropometric and so on) throughout this field test, would allow the determination of a predictive Vo_2 peak equation.

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