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Time Spent at $\dot{V}O_2max$: a Methodological Issue

Abstract

This study was designed to propose a standardised procedure to determine the time spent at $\dot{V}O_2max$ ($t\dot{V}O_2max$) based on the $\dot{V}O_2max$ of the day (i.e. the $\dot{V}O_2max$ value measured the day of the test). Ten male subjects first performed a graded field test, followed by a continuous running exercise to exhaustion, at the velocity of the Université de Montréal Track Test (V_{UMTT}) plus 1 km × h^{-1} (V_{UMTT}+ 1). The second test consisted of an exhaustive run at 100% of V_{UMTT}, followed by a V_{UMTT}+ 1 test. Different methods were used to compare time spent at $\dot{V}O_2max$, based on the $\dot{V}O_2max$ of the graded field test, and time spent at $\dot{V}O_2max$, based on the $\dot{V}O_2max$ of the day, during an exhaustive run at 100% of V_{UMTT}. Results have shown that V_{UMTT}+ 1 tests were of sufficient intensity and duration to identify the $\dot{V}O_2max$ of the day. Time spent at $\dot{V}O_2max$ ranged from 25 ± 53 s to 139 ± 76 s according to the method used. However, the $t\dot{V}O_2max$ method based on the sum of each value higher than 95% of $\dot{V}O_2max$ of the day appeared more robust than methods based on the time to exhaustion minus time to reach $\dot{V}O_2$ reference value, or the method based on the sum of values higher than $\dot{V}O_2max$ minus 2.1 ml × kg^{-1} × min^{-1}.

Key words
Field tests · maximal oxygen uptake · time to exhaustion

Introduction

Numerous studies have focused on the improvements in maximal oxygen uptake ($\dot{V}O_2max$) through training [7,17]. The improvements in $\dot{V}O_2max$ are generally explained by the fact that exercise allows subjects to reach and to maintain a high level of $\dot{V}O_2$. Wenger and Bell [18] suggested that the maximal gains in aerobic power were elicited by exercise intensities ranging from 90 to 100% of $\dot{V}O_2max$. Based on these studies, several authors [3–5] have characterised exercises to determine the velocity that allows $\dot{V}O_2max$ to be sustained for the longest time ($t\dot{V}O_2max$), hypothesising that the higher the stimulus of $\dot{V}O_2$, the greater the improvement. $t\dot{V}O_2max$ has been measured during continuous exercise [3,8,9] but also during intermittent exercise [4–6]. However, protocols for data collection to calculate $t\dot{V}O_2max$ differed between studies and the results are not comparable due to differences in protocols. For Billat et al. [3–5], the calculation of $t\dot{V}O_2max$ is equal to the sum of $\dot{V}O_2$ values superior or equal to the $\dot{V}O_2max$ measured during the graded test minus 2.1 ml × kg^{-1} × min^{-1}. This calculation seems inconsistent, as a 2.1 ml × kg^{-1} × min^{-1} value does not represent the same percentage of $\dot{V}O_2max$ in subjects with different maximal aerobic power (e.g. 5.3% of $\dot{V}O_2max$ for a subject with a $\dot{V}O_2max$ equal to 40 ml × kg^{-1} × min^{-1} versus 3% for a subject with a 70 ml × kg^{-1} × min^{-1} $\dot{V}O_2max$). To avoid this bias, both Hill and Rowell [8] and Hill et al. [9] proposed the calculation of $t\dot{V}O_2max$ by calculating time spent above 95% of $\dot{V}O_2max$. For these authors, $t\dot{V}O_2max$ represented the difference between the time to ex-

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haustion (TTE) and time to reach 95 % of $\dot{V}O_2$max (time at which $\dot{V}O_2$ started to plateau). For this calculation the authors hypothesised that when subjects reached $\dot{V}O_2$max, they maintained it until exhaustion. However, for highly trained males, Perrey et al. [16] observed a significant decrease in $\dot{V}O_2$ before exhaustion. This implies that some subjects would not maintain $\dot{V}O_2$max until exhaustion. It appears more consistent to assume that the t$\dot{V}O_2$max corresponds to the sum of $\dot{V}O_2$ values (not TTE minus time to reach $\dot{V}O_2$max) that are superior or equal to 95 % of the reference value for $\dot{V}O_2$max. In addition, in these studies [3–5,8,9], the t$\dot{V}O_2$max was calculated from $\dot{V}O_2$max values from the graded test performed previously. However, Katch et al. [11] reported ± 5.6 % day-to-day biological variations in $\dot{V}O_2$max. That could explain why Billat et al. [4] found that, for same exercise, certain subjects did not reach $\dot{V}O_2$max, while others maintained it for a long time. Therefore, it may be necessary to identify the $\dot{V}O_2$max of the day (i. e. the highest $\dot{V}O_2$ that a subject can reach the day of a test) to calculate the t$\dot{V}O_2$max more accurately. Our study was designed to propose a standardised procedure to calculate the t$\dot{V}O_2$max for an exercise to exhaustion at 100 % of the Université de Montréal Track Test velocity (V_{UMTT}). This test was chosen because it is the exercise form which has been studied the most. It was hypothesised that an exercise at V_{UMTT}+ 1 km × h^{-1} allows the $\dot{V}O_2$max to be elicited. The calculation of the t$\dot{V}O_2$max based on this procedure will be compared with the t$\dot{V}O_2$max calculated using the procedures provided by Billat et al. [3–5], Hill and Rowell [8] or Hill et al. [9], and a method based on the sum of each value included between $\dot{V}O_2$max and 95 % of $\dot{V}O_2$max. We hypothesised that t$\dot{V}O_2$max depends on the methods used. A standard procedure to calculate t$\dot{V}O_2$max will be proposed.

Material and Methods

Subjects

Ten physical education students volunteered to participate in this study and gave their written informed consent in accordance with the guidelines of the Lille (France) consultative committee for the protection of individuals in biomedical research. Their age, body mass and height were 20.8 ± 2.1 years, 74.4 ± 8.9 kg and 1.81 ± 0.08 m, respectively.

Overview

Subjects performed 4 field tests. First they performed a graded field test to determine maximal oxygen uptake ($\dot{V}O_2$max) and the Université de Montréal Track Test velocity (V_{UMTT}; [13]). The second test, performed twenty one minutes after the graded field test, consisted in running for as long as possible at a velocity equal to V_{UMTT} plus 1 km × h^{-1} (V_{UMTT}+ 1_{GRAD}). After resting for at least 48 h, and 1 week at most, subjects performed a 3rd test consisting of a continuous run until exhaustion at a velocity corresponding to 100 % of V_{UMTT} (TTE_{100}). Twenty-one minutes after the TTE_{100}, a continuous test at V_{UMTT} plus 1 km × h^{-1} (V_{UMTT}+ 1_{TTE}) was performed. Before entering the study, the subjects were familiarised with the exercise procedures and the analysers. All the tests were carried out in an indoor-stadium on a 200-m track marked with red cones every 25 m (inside the first lane), while green cones were set 2 m behind the red ones. For all tests the velocity was imposed with a tape recording, which indicated, by means of a brief sound, the moment when the subjects had to pass a red cone to maintain a constant speed. At each sound, the subjects had to be within 2 m of the red cones. The speed of the sound track was checked before each test. During all tests, subjects were verbally encouraged to run until exhaustion. The test ended with the volitional exhaustion of the subject or when he was unable to run at the selected velocity, i. e. when he was behind a green cone three consecutive times.

Graded test and continuous tests

The V_{UMTT} was determined from a graded field test [13]. The velocity at the first stage was set at 10 km × h^{-1} and was increased by 1 km × h^{-1} per stage of 2 min. The velocity at the last completed stage, increased by 0.5 km × h^{-1} if the subject was able to run a half stage, was retained as the V_{UMTT}. This method is in agreement with previous publications [1,2,12] demonstrating that increments of 1 km × h^{-1} every 2 min (or 0.5 km × h^{-1} every minute or 1.5 km × h^{-1} every 3 min) provide an accurate estimation of the velocity associated with $\dot{V}O_2$max (v$\dot{V}O_2$max).

The TTE_{100} consisted of a continuous run until exhaustion at a velocity corresponding to 100 % of V_{UMTT}. This test was preceded by a standardised warm-up, which consisted of running at 10 km × h^{-1} for 10 min and performing stretching exercises for 4 min. For this test, the TTE was measured at the nearest second.

The V_{UMTT}+ 1 tests consisted of a continuous run until exhaustion at a velocity corresponding to V_{UMTT}+ 1 km × h^{-1}. For these tests, the subjects were asked to run as long as possible and to maintain the imposed velocity for at least 2 min. The V_{UMTT}+ 1_{GRAD} and V_{UMTT}+ 1_{TTE} were carried out 21min after the graded field test and TTE_{100}, respectively. During the 21-min period, the subjects recovered passively for 15 min, warmed up for 5 min by running at 10 km × h^{-1}, and recovered for 1 min before the V_{UMTT}+ 1 began. The V_{UMTT}+ 1_{GRAD} was expected to be of sufficient intensity and duration to allow subjects to reach $\dot{V}O_2$max (in comparison with $\dot{V}O_2$max measured during the graded field test). The V_{UMTT} + 1_{TTE} was carried out in order to determine the $\dot{V}O_2$max the day of the TTE_{100}.

Determination of $\dot{V}O_2$max, $\dot{V}O_2$peak and $\dot{V}O_2$max of the day

During all the tests, respiratory gas exchanges were measured breath-by-breath using a portable system (Cosmed K4b^2, Rome, Italy) in order to determine ventilation (VE), oxygen uptake ($\dot{V}O_2$) and carbon dioxide production (VCO_2). This analyser has previously been validated over a wide range of exercise intensities [14]. Before each test, the O_2 and CO_2 analysis systems were calibrated using ambient air and a gas of known O_2 and CO_2 concentrations. The calibration of the K4b^2 turbine flowmeter was performed using a 3-l syringe (Quinton Instruments, Seattle, Wash., USA). The cardio-respiratory values were averaged on a 15-s period. Heart rate (HR) was continuously monitored (Polar Electro, Kempele, Finland).

The $\dot{V}O_2$max corresponded to the highest $\dot{V}O_2$ attained in two successive 15-s periods for the graded field test. It was judged that subjects had reached their $\dot{V}O_2$max when 3 or more of the following criteria were met: 1) a plateau in $\dot{V}O_2$ despite increasing running speed; 2) a final respiratory exchange ratio (RER) higher than 1.1; 3) visible subject exhaustion; 4) a HR within

Table **1** Methods used for the determination of time spent at $\dot{V}O_2$max for the running time to exhaustion at 100 % of the Université de Montréal Track Test velocity

	$\dot{V}O_2$max used as the reference point	***Measurement method***
Billat et al. [3 – 5]	$\dot{V}O_2$max in graded test	[1] $\dot{V}O_2$max minus 2.1 ml × kg^{-1} × min^{-1}
Hill and Rowell [8] or Hill et al. [9]	$\dot{V}O_2$max in graded test	[2] Time to exhaustion minus time to reach 100 % of $\dot{V}O_2$max [3] Time to exhaustion minus time to reach 95 % of $\dot{V}O_2$max
Present study	$\dot{V}O_2$max in graded test	[4] 95 % of $\dot{V}O_2$max
Present study	$\dot{V}O_2$peak in V_{UMTT}+ 1_{TTE} test	[5] $\dot{V}O_2$peak minus 2.1 ml × kg^{-1} × min^{-1} [6] Time to exhaustion minus time to reach 100 % of $\dot{V}O_2$peak [7] Time to exhaustion minus time to reach 95 % of $\dot{V}O_2$peak [8] 95 % of $\dot{V}O_2$peak

V_{UMTT}: Université de Montréal Track Test velocity; V_{UMTT}+ 1_{TTE}: continuous run at the Université de Montréal Track Test velocity plus 1 km × h^{-1}; $\dot{V}O_2$max: maximal oxygen uptake (graded field test); $\dot{V}O_2$peak: peak oxygen uptake (V_{UMTT}+ 1_{TTE}).

the 10 bpm of predicted maximum; 5) a lactate concentration higher than 9 mmol × l^{-1}.

For the continuous tests (V_{UMTT}+ 1_{GRAD}, TTE_{100} and V_{UMTT}+ 1_{TTE}), the $\dot{V}O_2$peak corresponded to the highest $\dot{V}O_2$ attained in two successive 15-s periods. Both V_{UMTT}+ 1 tests were performed in order to determine the $\dot{V}O_2$max of the day, independent of technological errors attributable to gas analysers and intra-individual chronobiological variations. It was assumed that the measured $\dot{V}O_2$peak corresponded to the $\dot{V}O_2$max of the day if the duration of these tests was longer than 2 min. According to Morgan et al. [15], an exercise at a velocity slightly higher than v$\dot{V}O_2$max was assumed to be of sufficient intensity to allow the subjects to reach $\dot{V}O_2$max if the duration of the test was at least 2 min. In addition, the $\dot{V}O_2$peak values of the V_{UMTT}+ 1_{GRAD} and V_{UMTT}+ 1_{TTE} were retained as the $\dot{V}O_2$max of day if they were higher than 94.4 % of the $\dot{V}O_2$max determined during the graded test. As reported by Katch et al. [11], the intra-individual day-to-day variability in $\dot{V}O_2$max was within ± 5.6 %.

Determination of lactate concentrations

Fingertip blood samples were obtained 3 min after each test. Lactate concentrations ([La]) were determined by a spectrophotometric method (Dr Lange, Berlin, Germany), which had previously been validated [10]. The accuracy of the analyser was checked before each test using standard solutions in lactate concentration.

Determination of time spent at $\dot{V}O_2$max

Time spent at $\dot{V}O_2$max (t$\dot{V}O_2$max) was measured for the TTE_{100} according to the 8 different methods described in Table **1**. The first four methods were based on the $\dot{V}O_2$max attained for the graded field test, and the four following methods were based on the $\dot{V}O_2$peak of the V_{UMTT}+ 1_{TTE}.

Statistical procedures

Data are presented for each subject. Means and standard deviations (mean ± SD) were calculated for each parameter analysed. Coefficients of variation (CV) were calculated for each method of t$\dot{V}O_2$max determination. A repeated analysis of variance (ANOVA) with Tukey's post-hoc test was used to compare the t$\dot{V}O_2$max calculated according to the different methods and the maximal values for $\dot{V}O_2$, HR, RER and VE between the different tests. The Student's *t*-test was used to compare the time to exhaustion between the two V_{UMTT}+ 1 tests. Regression analysis was used to examine the relationship between $\dot{V}O_2$max and $\dot{V}O_2$peak of the V_{UMTT}+ 1_{GRAD}, and between t$\dot{V}O_2$max based on the $\dot{V}O_2$max of the graded field-test and t$\dot{V}O_2$max based on $\dot{V}O_2$peak of V_{UMTT}+ 1_{TTE}. The $p < 0.05$ level was accepted as being significant for all tests.

Results

For the graded field test, all subjects satisfied the maximal criteria defined for the attainment of $\dot{V}O_2$max. The V_{UMTT}, TTE and maximal values for $\dot{V}O_2$ ($\dot{V}O_2$max and $\dot{V}O_2$peak) determined during the graded field test and TTE_{100} tests are presented in Table **2**. The ANOVA revealed no significant differences between $\dot{V}O_2$max and $\dot{V}O_2$peak measurements. The results of the ANOVA indicated no significant difference between maximal values for VE, RER, HR (Table **3**) measured for the 4 tests. Blood lactate concentration measured after the graded field test was not significantly different from that of the TTE_{100} (Table **3**). The correlation between the $\dot{V}O_2$peak measured for V_{UMTT}+ 1_{GRAD} and the $\dot{V}O_2$max measured for the graded field test was significant ($r = 0.99$, $p < 0.001$; Fig. **1**). The time to exhaustion was not significantly different between V_{UMTT}+ 1_{GRAD} and V_{UMTT}+ 1_{TTE}.

The t$\dot{V}O_2$max calculated according to the different methods is presented in Table **4**. The ANOVA detected significant differences ($p < 0.001$) among the 8 methods. The t$\dot{V}O_2$max values ranged between 24.5 ± 53.3 s for method [6] (Hill et al.'s method based on TTE minus time to reach 100 % of peak of V_{UMTT}+ 1_{TTE}) and 138.8 ± 76 s for method [3] (Hill et al.'s method based on TTE minus time to reach 95 % of $\dot{V}O_2$max of the graded field-test). For each method, the relationship between t$\dot{V}O_2$max based on $\dot{V}O_2$max of the graded field test and t$\dot{V}O_2$max based on $\dot{V}O_2$peak of the

Table **2** Performances, $\dot{V}O_2$max and $\dot{V}O_2$peak values for the 4 tests

Subjects	*Graded test*		*V_{UMTT}+ 1_{GRAD}*		*TTE_{100}*		*V_{UMTT}+ 1_{TTE}*	
	V_{UMTT} (km × h⁻¹)	*$\dot{V}O_2$max (ml × kg⁻¹ × min⁻¹)*	*TTE (s)*	*$\dot{V}O_2$peak (ml × kg⁻¹ × min⁻¹)*	*TTE (s)*	*$\dot{V}O_2$peak (ml × kg⁻¹ × min⁻¹)*	*TTE (s)*	*$\dot{V}O_2$peak (ml × kg⁻¹ × min⁻¹)*
1	17	60.0	185	59.8	450	56.0	234	57.3
2	16	55.3	165	55.8	355	55.4	170	57.4
3	18	59.8	138	59.1	306	58.6	200	59.8
4	16	52.7	270	51.7	360	52.1	180	52.2
5	17	64.9	240	64.4	302	63.8	208	64.4
6	17	59.0	165	57.5	365	58.5	122	56.8
7	19	56.3	149	58.0	333	57.7	181	59.2
8	18	61.5	188	62.2	335	60.6	212	61.6
9	18	51.6	152	52.7	232	54.2	130	54.3
10	19	72.0	180	72.3	465	73.2	208	72.9
Means	17.5	59.3	183.2	59.4	350.3	59.0	184.5	59.6
± SD	± 1.1	± 6.0	± 41.7	± 6.0	± 68.5	± 6.0	± 36.0	± 5.8

V_{UMTT}: Université de Montréal Track Test velocity; TTE_{100}: time to exhaustion at 100 % of V_{UMTT}; V_{UMTT}+ 1: continuous run at the Université de Montréal Track Test velocity plus 1 km × h⁻¹; $\dot{V}O_2$max: maximal oxygen uptake (graded field-test); $\dot{V}O_2$peak: peak oxygen uptake (V_{UMTT}+ 1).

Table **3** Maximal values for lactate concentrations, ventilation, respiratory exchange ratio and heart rate measured during the different tests

Subjects	*Graded field-test*				*V_{UMTT}+ 1_{GRAD}*			*TTE_{100}*				*V_{UMTT}+ 1_{TTE}*		
	[La] (mmol × l⁻¹)	*VE (l × min⁻¹)*	*RER*	*HR (bpm)*	*VE (l × min⁻¹)*	*RER*	*HR (bpm)*	*[La] (mmol × l⁻¹)*	*VE (l × min⁻¹)*	*RER*	*HR (bpm)*	*VE (l × min⁻¹)*	*RER*	*HR (bpm)*
1	12.5	114	1.19	205	110	1.14	196	11.9	110	1.12	196	114	1.12	198
2	10.6	128	1.11	188	122	1.14	189	10.7	121	1.17	190	118	1.12	189
3	15.7	151	1.18	195	149	1.10	193	13.3	156	1.13	193	164	1.14	191
4	13.8	136	1.15	186	125	1.13	185	13.7	131	1.12	184	128	1.10	185
5	14.0	166	1.17	189	174	1.18	185	17.5	158	1.19	187	164	1.16	186
6	10.4	119	1.09	186	153	1.13	185	10.3	157	1.13	185	160	1.10	185
7	10.9	147	1.14	179	140	1.12	177	10.6	130	1.14	176	139	1.12	172
8	12.7	127	1.16	189	128	1.13	188	14.0	123	1.17	187	122	1.13	187
9	12.1	142	1.18	179	132	1.21	177	10.6	130	1.16	174	126	1.13	172
10	9.3	131	1.19	178	129	1.18	178	9.9	136	1.13	186	133	1.20	183
Means	12.2	136	1.16	187.4	136	1.15	185.3	12.4	135	1.15	185.8	137	1.13	184.8
±SD	± 2.0	± 16	± 0.03	± 8.2	± 18	± 0.03	± 6.6	± 2.5^{ns}	± 17	± 0.02	± 6.8	± 19^{ns}	± 0.03^{ns}	± 7.9^{ns}

^{ns}: no significant differences from other tests ($p > 0.05$).
V_{UMTT}+ 1: continuous run at the Université de Montréal Track Test velocity plus 1 km × h⁻¹; TTE_{100}: time to exhaustion at 100 % of V_{UMTT}; ([La]) : lactate concentration; VE: maximal ventilation; RER: maximal respiratory exchange ratio; HR: maximal heart rate.

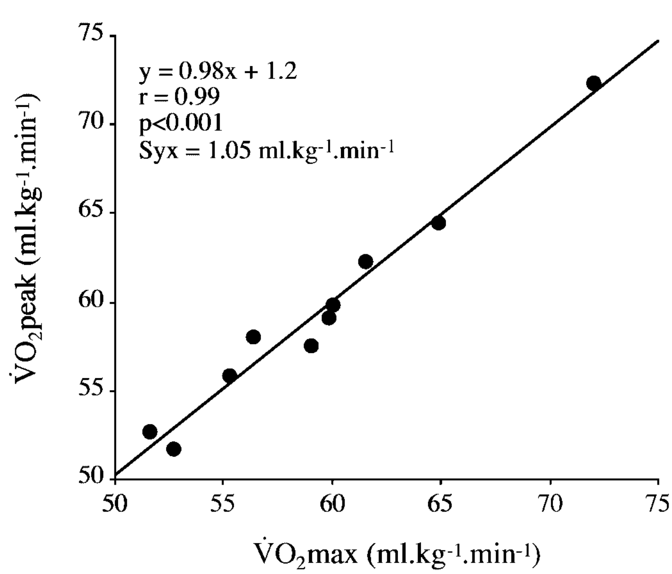

Fig. **1** Relationship between $\dot{V}O_2$max measured for the graded field test and $\dot{V}O_2$peak measured for the V_{UMTT}+ 1_{GRAD}.

V_{UMTT}+ 1_{TTE} is presented in Fig. **2**. Significant correlations were found for Hill et al.'s method ([3], [7] , method based on TTE minus 95 % of $\dot{V}O_2$max) and for the method proposed in the present study ([4], [8] , method based on the sum of each value higher than 95 % of $\dot{V}O_2$max).

Fig. **3** shows the $\dot{V}O_2$ plot of one subject for the graded fieldtest, V_{UMTT}+ 1_{GRAD}, TTE_{100} and V_{UMTT}+ 1_{TTE} tests.

Discussion

This study was designed to propose a standardised procedure to calculate t$\dot{V}O_2$max using the $\dot{V}O_2$max value of the day as a reference point. The first hypothesis was that a test performed until exhaustion at V_{UMTT}+ 1 km × h⁻¹ was of sufficient intensity and duration to elicit $\dot{V}O_2$max. This point was verified as the $\dot{V}O_2$peak measured at the end of this V_{UMTT}+ 1_{GRAD} test was not significantly different from the $\dot{V}O_2$max measured during the graded test. This point was also verified when the $\dot{V}O_2$peak was measured

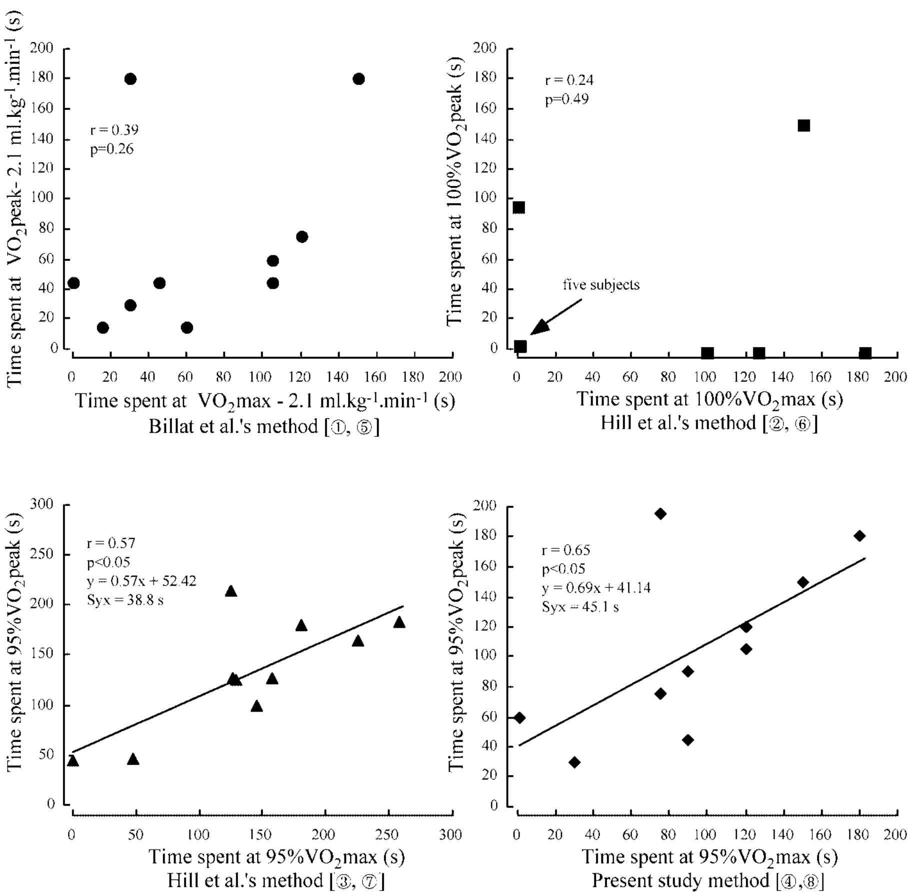

Fig. **2** Relationship for each method between t$\dot{V}O_2$max based on $\dot{V}O_2$max of the graded field test and t$\dot{V}O_2$max based on $\dot{V}O_2$peak measured for the V_{UMTT}+ 1_{TTE}.

Table **4** Time spent at $\dot{V}O_2$max according to the 8 methods for the time to exhaustion at 100 % of the Université de Montréal Track Test velocity (V_{UMTT})

Subjects	***Methods based on $\dot{V}O_2$max of graded field-test***				***Methods based on $\dot{V}O_2$peak of V_{UMTT}+ 1_{TTE}***			
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***
	(s)	***(s)***	***(s)***	***(s)***	***(s)***	***(s)***	***(s)***	***(s)***
1	0	0	0	0	45	0	105	60
2	60	100	145	90	15	0	100	45
3	15	0	126	120	15	0	126	120
4	150	0	180	180	180	0	180	180
5	30	0	47	30	30	0	47	30
6	30	0	125	75	180	95	215	195
7	105	183	258	75	60	0	183	75
8	45	0	125	90	45	0	125	90
9	120	127	157	120	75	0	127	105
10	105	150	225	150	45	150	165	150
Means ± SD	66.0 ± 50.6	56.0 ± 75.1	138.8 ± 76.0	93.0 ± 53.3	69.0 ± 61.3	24.5 ± 53.3	137.3 ± 49.1	105.0 ± 56.1
CV (%)	76.6	134.1	54.7	57.3	88.9	217.4	35.8	53.4
Different from:	3*; 7*	3**;7**	1*;2**; 5*; 6***	6*	3*; 7*	3***; 4*; 7***; 8**	1*;2**; 5*; 6***	6**

1, 5: Billat et al.'s method (values higher than $\dot{V}O_2$max minus 2.1 ml × kg^{-1} × min^{-1}); 2, 6: Hill et al.'s method (TTE minus time to reach 100 % of $\dot{V}O_2$max); 3, 7: Hill et al.'s method (TTE minus time to reach 95 % of $\dot{V}O_2$max); 4, 8: method of the present study (values higher than 95 % of $\dot{V}O_2$max).
*: significantly different with $p < 0.05$; **: significantly different with $p < 0.01$; ***: significantly different with $p < 0.001$.

during the V_{UMTT}+ 1_{TTE}. Thus, the V_{UMTT}+ 1 test allowed the $\dot{V}O_2$max of the day to be determined (i.e. the value for $\dot{V}O_2$ used as a reference to calculate t$\dot{V}O_2$max). The second hypothesis was that t$\dot{V}O_2$max depends on the method used. Our results confirm this hypothesis as significant differences between t$\dot{V}O_2$max calculation methods were found.

Determination of the $\dot{V}O_2$max of the day

Repeated measurements of $\dot{V}O_2$max for the same subject are characterised by day-to-day variations. Katch et al. [11] reported a ± 5.6 % day-to-day intra-individual variation in $\dot{V}O_2$max, due to biological variations (more than 90 %) and technological errors (less than 10 %). When calculating t$\dot{V}O_2$max, a small difference

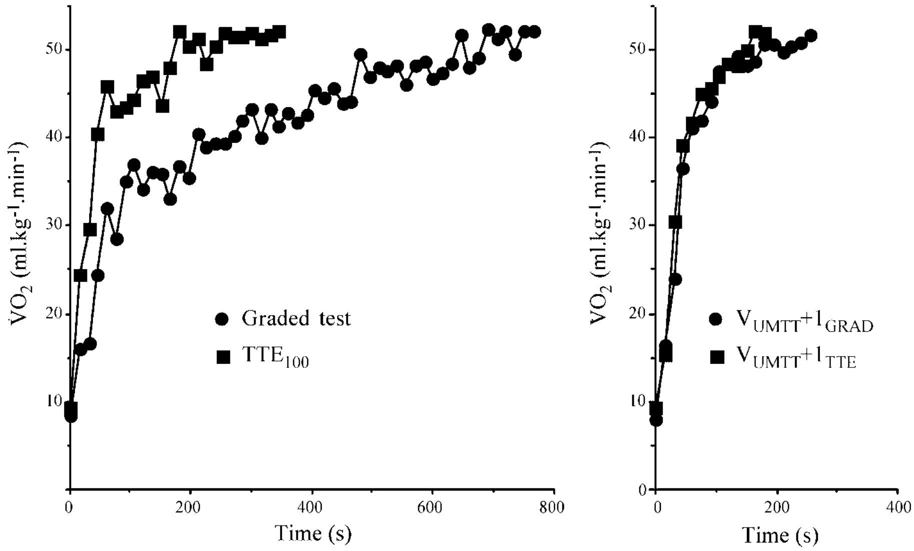

Fig. **3** An example of the $\dot{V}O_2$ versus time relationship for the graded field test, V_{UMTT}+ 1_{GRAD}, TTE_{100} and V_{UMTT}+ 1_{TTE} for the same subject.

in $\dot{V}O_2$max could induce a large variation in t$\dot{V}O_2$max. For example, consider a subject with a $\dot{V}O_2$max of 50 ml × kg^{-1} × min^{-1} measured during a graded test. If on the day of a TTE_{100}, for technical or biological reasons, the subject is only able to reach a $\dot{V}O_2$max of 48 ml × kg^{-1} × min^{-1} (i.e. a 4% error), the t$\dot{V}O_2$max would be nil. Conversely, if the measured maximal value is 52 ml × kg^{-1} × min^{-1}, a long t$\dot{V}O_2$max would be found. To avoid such errors, it appears necessary to identify the $\dot{V}O_2$max of the day, which has to serve as a reference value to accurately calculate the t$\dot{V}O_2$max. In the present study, a simplified procedure was proposed to determine $\dot{V}O_2$max of the day. To reach this goal, a test was proposed, following the graded field test. After a standardised recovery period, it consisted of running as long as possible at a velocity equal to V_{UMTT}+ 1 km × h^{-1}. This exercise was performed after the graded field test to verify that the V_{UMTT}+ 1 km × h^{-1} test allowed subjects to reach $\dot{V}O_2$max. The maximal values for $\dot{V}O_2$ obtained during the graded test (59.3 ± 6.0 ml × kg^{-1} × min^{-1}) were not significantly different from the $\dot{V}O_2$peak obtained during the V_{UMTT}+ 1_{GRAD} (59.4 ± 6.0 ml × kg^{-1} × min^{-1}) and were significantly correlated ($r^2 = 0.97$, $p < 0.001$). The mean duration of the V_{UMTT}+ 1_{GRAD} was 183.2 ± 41.7 s. According to Morgan et al. [15], this exercise duration (more than 2 min), at a velocity higher than v$\dot{V}O_2$max (V_{UMTT} in the present study), can allow subjects to reach $\dot{V}O_2$max. Consequently, the V_{UMTT}+ 1_{GRAD} appears to be an appropriate form of exercise to determine the $\dot{V}O_2$max of the day. This test could take into consideration the day-to-day variability of a subject's $\dot{V}O_2$max measurement.

The $\dot{V}O_2$peaks measured during the V_{UMTT}+ 1_{TTE} were not significantly different from the $\dot{V}O_2$max measured during the graded field test, nor from $\dot{V}O_2$peak measured during the TTE_{100}. For each subject, the $\dot{V}O_2$peak measured during the V_{UMTT}+ 1_{TTE} was at least equal to 94.4% of $\dot{V}O_2$max. In addition, the mean time to exhaustion was 184.5 ± 36 s with no subject having a running time lower than 2 min. This result suggests that all the subjects reached their $\dot{V}O_2$max for the V_{UMTT}+ 1_{TTE}.

Time spent at $\dot{V}O_2$max

When t$\dot{V}O_2$max was calculated based on the $\dot{V}O_2$max value measured during the graded field test, our results were in agreement with previously published data. For a TTE_{100}, Hill and Rowell [8] found a t$\dot{V}O_2$max of 56 ± 48 s for the method based on 100% of $\dot{V}O_2$max of the graded test (56 ± 75 s in the present study) and 140 ± 46 s for the method based on 95% of $\dot{V}O_2$max of the graded test (139 ± 76 s in the present study). Conversely, despite similar TTE (333 ± 116 s for Billat et al. [3] and 350 ± 69 s in the present study), Billat et al. [3] found a t$\dot{V}O_2$max of 190 ± 87 s, which was longer than our results (66 ± 51s). The difference in a t$\dot{V}O_2$max may result from a difference in the warm-up procedure. In the present study, the TTE_{100} began after a 1-min rest period. In the study by Billat et al. [3], the TTE_{100} began immediately after a run at 60% of v$\dot{V}O_2$max that could reduce the time to reach $\dot{V}O_2$max, and increase t$\dot{V}O_2$max.

In the present study, t$\dot{V}O_2$max was calculated from the $\dot{V}O_2$max of the graded field test and from the $\dot{V}O_2$peak of the V_{UMTT}+ 1_{TTE}. To estimate the sensitivity of the method used to calculate t$\dot{V}O_2$max, the relationships between t$\dot{V}O_2$max based on $\dot{V}O_2$max (graded field-test) and t$\dot{V}O_2$max based on $\dot{V}O_2$max of the day ($\dot{V}O_2$peak of V_{UMTT}+ 1_{TTE}) were calculated. It was assumed that the stronger the relationship was, the lower the sensitivity of the method to variation in $\dot{V}O_2$max was. For the method based on $\dot{V}O_2$max minus 2.1 ml × kg^{-1} × min^{-1} (Table **1** [[1], [5]]) and 100% of $\dot{V}O_2$max [[2], [6]], no relationships were found (Fig. **2**). Significant correlations were found between t$\dot{V}O_2$max when the measurements were based on 95% of $\dot{V}O_2$max of the graded field test (Table **1** [[3] and [4]]) and 95% of the $\dot{V}O_2$max of the day (Table **1** [[7] and [8]]). These results indicate that these methodologies are more robust and attenuate the effects of small variations in $\dot{V}O_2$max measurement. Consequently, it seems preferable to use a range of $\dot{V}O_2$ (95% of $\dot{V}O_2$max) to measure t$\dot{V}O_2$max and obtain a more reproducible measurement.

Reference method to calculate t$\dot{V}O_2$max

Our results suggested measuring t$\dot{V}O_2$max based on 95% of $\dot{V}O_2$max. A consequence of this calculation is a reduction of the inter-individual variations in t$\dot{V}O_2$max (Table **4**). The coefficients of variation calculated according to these calculations were lower than those based on other methods. Moreover, inter-individual variations were further reduced when the calculation was based on the $\dot{V}O_2max$ of the day. This could be partly explained by the fact that, with such a calculation, the range of the subjects' $t\dot{V}O_2max$ was slightly diminished. Similar $t\dot{V}O_2max$ were obtained when calculated from values higher than 95% of $\dot{V}O_2max$ and TTE minus time to reach 95% of $\dot{V}O_2max$. However, it has been demonstrated that, at the end of an exhaustive continuous exercise, a decrease in $\dot{V}O_2$ was often observed [16]. In such conditions, the method based on the time to reach $\dot{V}O_2max$ could lead to an overestimation of $t\dot{V}O_2max$. Moreover, such methodology is not applicable when $t\dot{V}O_2max$ has to be calculated for short intermittent runs that are characterised by frequent variations in $\dot{V}O_2$ [3,5,6]. The method based on the sum of times spent above 95% of the $\dot{V}O_2max$ of the day was assumed to be the more accurate to calculate $t\dot{V}O_2max$.

Conclusion

This study has shown that the variability in $\dot{V}O_2max$ is a parameter to be taken into account in the calculation of $t\dot{V}O_2max$. In the present study, the determination of the $\dot{V}O_2max$ of the day was made from an exercise at V_{UMTT}+ 1 km × h^{-1}, which was of sufficient intensity and duration to elicit $\dot{V}O_2max$. This study also showed that the $t\dot{V}O_2max$ depends on the method used. The method based on the sum of each value higher than 95% of $\dot{V}O_2max$ of the day appears the most robust method to calculate $t\dot{V}O_2max$.

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