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ORIGINAL ARTICLE

Assessment of maximal aerobic speed in runners with different performance levels: Interest of a new intermittent running test

Évaluation de la vitesse maximale aérobie chez des coureurs ayant différents niveaux de performance : intérêt d'un test de course à pied intermittent

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KEYWORDS
Intermittent exercise testing;
Maximal aerobic speed;
Test duration;
Reproducibility;
Comparative study

Summary
Objectives. — To compare performance and physiological responses derived from a new intermittent field test ($Test_{3L}$) with a standard continuous test ($Test_{VAM}$), and to examine its reproducibility.
Methods. — A first part ($n = 7$) allowed defining the maximal aerobic speed (MAS_{3L}) equations derived from $Test_{3L}$. A second part allowed validating MAS_{3L} in 43 runners, divided into three performance groups: G1 beginners ($n = 22$), G2 trained athletes ($n = 14$), and G3 elite ($n = 7$). The 43 runners performed the $Test_{3L}$ twice to measure its reproducibility.
Results. — The MAS values measured by the $Test_{VAM}$ (MAS_{VAM}) were not significantly different from MAS_{3L}, for each performance group taken individually or as a whole (3Gr). The difference between MAS_{VAM} and MAS_{3L} varied between 0.2 and 0.4 km.h on average. Similarly, no significant maximum heart rate (HRmax) differences were found between both tests. In contrast, blood lactate concentration (LA) was significantly higher in $Test_{VAM}$ compared to $Test_{3L}$. The total duration of $Test_{VAM}$ was 2.74, 3.02, 2.55, and 2.57 times longer for 3Gr, G1, G2, G3, respectively compared to $Test_{3L}$ ($P < 0{,}01$). There were no significant differences in MAS, HRmax and LA between the test—retest procedures for $Test_{3L}$.

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Conclusion. — Hence, it is suggested that the MAS and HRmax derived from Test_{3L} can be used when designing training programs. However, caution must be taken with regard to LA. Additionally, Test_{3L} is more or less 2.5 times shorter than Test_{VAM} and has a high reproducibility.

MOTS CLÉS
Test intermittent ;
Vitesse maximale aérobie ;
Durée du test ;
Reproductibilité ;
Étude comparative

Résumé
Objectifs. — Comparer la performance et les réponses physiologiques dérivées d'un nouveau test intermittent de terrain (Test_{3L}) avec celles mesurées par un test de piste progressif (Test_{VAM}), et examiner sa reproductibilité.
Méthodes. — Une première partie d'étude (*n* = 7) a permis la définition des équations de détermination de la vitesse maximale aérobie (VMA_{3L}) à partir de Test_{3L}. La seconde partie a comparé la VMA_{3L} obtenue chez 43 coureurs divisés en trois groupes en fonction de leur performance: G1 débutants (*n* = 22), G2 entraînés (*n* = 14), et G3 élite (*n* = 7). Ces athlètes ont effectué deux fois le Test_{3L} pour mesurer sa reproductibilité.
Résultats. — Les résultats ont montré que les valeurs de VMA mesurées par le Test_{VAM} (VMA_{VAM}) ne sont pas significativement différentes des valeurs de VMA_{3L} pour chaque groupe pris individuellement comme pour les coureurs considérés dans leur ensemble (3Gr). La différence entre VMA_{VAM} and VMA_{3L} varie entre 0,2 et 0,4 km.h^{-1} en moyenne. De même, aucune différence significative de fréquence cardiaque maximale (FCmax) n'a été observée entre les deux tests. En revanche, la concentration en lactates sanguins (LA) était significativement supérieure après Test_{VAM} par rapport à Test_{3L}. La durée totale du test Test_{VAM} était 2,74, 3,02, 2,55, et 2,57 fois plus longue par rapport au Test_{3L} pour 3Gr, G1, G2, G3, respectivement ($p < 0{,}01$). Aucune différence significative de VMA, FCmax et LA entre les deux répétitions de Test_{3L}.
Conclusion. — Ces résultats suggèrent que la VMA et la FCmax dérivées du Test_{3L} peuvent être utilisées pour la conception des programmes d'entraînement. Cependant, il faut être prudent quant à l'utilisation de LA. De plus, le Test_{3L}est environ 2,5 fois plus rapide à mettre en œuvre que Test_{VAM} et présente une reproductibilité élevée.

1. Introduction

Maximal aerobic speed (MAS) is tightly linked to running performance for distances ranging from 800 m to marathon [1—10]. Because it integrates maximal oxygen uptake (VO2max), energy cost and maximal aerobic power [10,11], the MAS is more strongly correlated with running performance than VO_2max alone [4,12]. This value, which can be used directly in the field, is of paramount use in setting training loads for physical activities which rely predominantly on aerobic energy expenditure [13—15].

Various tests were proposed to measure MAS, which can be grouped into two categories [14]. In the first one, the MAS corresponds to the speed reached at the end of a test primarily designed to determine VO_2max during laboratory events [16]. However, many runners and trainers, even at high-level, do not wish or do not have the possibility to carry out such a test regularly to optimise the training process. Indeed, the necessary equipment is expensive and allows the measurement of only one subject at a time, limiting its use on a daily practice of training, especially if one has to go to a specialised laboratory far from his/her training facilities [15,17]. In the second category, MAS is determined as the speed achieved during the last completed stage in a continuous incremental and maximum field test. It has been reported that field assessments have a better external validity and are considered more useful than laboratory evaluations [17—19]. In 1980, Léger and Boucher [20] published the first progressive test (GXT) called the University of Montreal track test (UM—TT). Thereafter, several protocols followed [21—23]. These tests are all based on the gradual increase in running speed using sound signals during a continuous run. One of the most frequently used tests for aerobic metabolism evaluation during running [24] is likely the ''VAM-EVAL'' test (Test_{VAM}) [22], from the French *vitesse aérobie maximale* (VAM), which means maximal aerobic speed, and EVALuation. It starts at 8.5 km.h^{-1} and the speed is then increased by 0.5 km.h^{-1} every minute. However, Test_{VAM} has some limits: the main one is the difficulty of adjusting the speed to the sound signals especially for people who are not used to running [25], as recently highlighted by Pallarés et al. [26]. These authors recommended the need for familiarisation with the sound signals when performing audio-guided running track tests to improve the validity of the test. In addition, many coaches and athletes do not always have the standard test soundtrack, as well as the environment necessary to carry it out [27]. Finally, a recent study has confirmed that the validity and reliability of GXT with 1-min stage protocols in runners needs to be fully verified [28].

Another important thing is that the total test duration is decisive in the assessment of endurance performance in runners [28]. It is well known that long ramp GXT, lasting 20-30 minutes (e.g., an athlete with MAS = 19 km.h^{-1}, the VAM-EVAL will take 22 minutes), would prevent athletes from achieving their maximal potential because of accumulative fatigue, dehydration, muscle acidosis, and cardiovascular

Table 1 Anthropometric measurements of the subjects.

	Part 1				Part 2			
	All (n = 7)	Beginners (n = 2)	Trained (n = 3)	Elite (n = 2)	All (n = 43)	Beginners (n = 22)	Trained (n = 14)	Elite (n = 7)
Age (yrs)	18.5 ± 2.4	16.0 ± 1.4	18.3 ± 1.1	21.5 ± 0.7	18.2 ± 2.2	17.0 ± 1.7	18.5 ± 0.6	21.7 ± 1.8
Weight (kg)	64.7 ± 8.4	60.5 ± 13.4	67.4 ± 9.2	69.0 ± 2.8	67.4 ± 6.8	68.7 ± 7.9	65.9 ± 6.1	66.5 ± 4.0
Height (cm)	172.4 ± 7.6	167.0 ± 8.4	171.6 ± 8.1	179.0 ± 1.4	172.7 ± 5.4	170.3 ± 5.3	173.5 ± 3.8	178.5 ± 3.4
BMI (kg/m^2)	21.6 ± 1.2	21.5 ± 2.6	21.8 ± 1.1	21.5 ± 0.5	22.6 ± 2.0	23.6 ± 2.0	21.8 ± 1.6	20.8 ± 0.7

Mean (± SD) values. BMI: body mass index.

drift. This limit is thus particularly true for well-trained and elite runners [26], for whom a very accurate MAS determination is of utmost importance. To solve these issues, a short duration of the test is, therefore, an important element to allow athletes achieving their true MAS [28]. Thus, short duration tests with inexpensive hardware should be preferred to favour a reliable measurement of MAS during the daily training process [18].

In this context, the aim of this study was to present a new intermittent field test to determine MAS, called three-level test (Test$_{3L}$). The main characteristics of this test are to be shorter than usual test, and adapted into three population groups: beginner, trained and elite runners. Test$_{3L}$ does not require any particular hardware, and is simple and fast to implement in the field. It also allows a large number of athletes to be tested at the same time. Thus, Test$_{3L}$ can be repeated regularly during the different cycles of a sports season in order to verify the training process and prescribe future training loads.

We compared the MAS and physiological variables obtained from Test$_{3L}$ with those of Test$_{VAM}$. We hypothesised that the MAS values obtained by Test$_{3L}$ (MAS$_{3L}$) would be comparable to those of Test$_{VAM}$ (MAS$_{VAM}$), but with a shorter running duration.

2. Materials and methods

2.1. Subjects

The study has been divided into two parts to validate Test$_{3L}$. This test is an intermittent test that consists in 1 min runs interspersed by 30 sec of recovery, the number of runs varying from 3 to 7 depending on the expected runner's performance (with 3 different performance levels; see Part 2 for further details). MAS is then calculated from an equation that consider the distance covered and a mathematical factor related to the chosen level (see Part 1 for further details). The purpose of Part 1 was to define the equation that will allow determining MAS as a function of the distance covered during the test, in accordance with the chosen performance level. This was achieved with a sample of 7 runners with various performance level. For sake of clarity, the results related to Part 1 is presented in the Method part. Part 2 was dedicated to the validation of the selected method on a wider sample of runners (n = 43). As this is the main study part, the associated results are presented in the specific Results section. All runners were in good health (no injury which could alter running performance and physiological response to exercise). They were advised to refrain from smoking, caffeinated and alcohol drinks, and high-intensity exercise during the 48 hours prior to testing. The study complied with the Helsinki declaration for human experimentation and the participants provided written consent to participate. Approval to conduct the study was obtained from the Ethics committee institute of sports and physical education at the University Abdelhamid Ibn Badis of Mostaganem, Algeria.

2.2. Design

2.2.1. Part 1

Seven male athletes (2 beginner athletes, 3 trained, and 2 elites; anthropometric characteristics presented in Table 1), first performed the Test$_{VAM}$ to determine their MAS (MAS$_{VAM}$), which has been used as the reference [22]. Seventy-two hours later, they performed Test$_{3L}$, adapted to their performance level (cf infra Part 2. Test$_{3L}$ Protocol). Beginners (G1) were defined as recreational runners (non-competitors) who started training (less than three months of regular training, trained 2—3 times a week). Trained (G2) were defined as runners that regularly compete at the national level, and who trained for more than 3 years of training on a regular basis (5 times/week). Elite (G3) were defined as runners that regularly compete at the international level, and who trained for more than 3 years of training on a regular basis (7—9 times/week).

As one of the Test$_{3L}$ characteristics is to be intermittent, recovery periods (30 sec) allow subjects to run longer distances than if the exercise had been carried out continuously. This means that the average run speed during Test$_{3L}$ overestimates the run speed that could be obtained during a continuous run of similar duration. We thus conducted Part 1 study to find 3 equations, which match the MAS of Test$_{3L}$ to that of the Test$_{VAM}$, for each performance level.

The average distances achieved at the end of Test$_{3L}$ were 862.5 ± 3.5 m, 1495.3 ± 53.3 m, 2547.5 ± 26.1 m for G1, G2, G3, respectively, whereas the MAS$_{VAM}$ obtained with the same athletes were 14.7 km.h^{-1} ± 0.2 for G1; 16.4 km.h^{-1} ± 0.3 for G2; 20.5 km.h^{-1} ± 0.4 for G3. The maximum heart rate (HRmax) measured at the end of Test$_{3L}$ and Test$_{VAM}$ were 195 ± 2 vs. 195 ± 0 bpm for G1; 191 ± 3 vs. 191 ± 0 bpm for G2; 191 ± 0 vs. 188 ± 1 bpm for G3. The homogeneity of the HRmax values at the end of both tests allowed confirming that maximal exertion was obtained at the end of the $Test_{3L.}$

Based on these results, a mathematical factor (F) to correct the mean speed obtained during $Test_{3L}$ was obtained as follows:

$$F = \frac{\text{Distance travelled (m)}}{\text{MASVAM}\left(\text{km.h}^{-1}\right)}$$

which corresponds to:

$$G1 \quad (Beginners) : F = \frac{862}{14.7} = 58$$

$$G2 \quad (Trained) : F = \frac{1495}{16.4} = 91$$

$$G3 \quad (Elite) : F = \frac{2547}{20.5} = 124$$

Hence, the equations to obtain MAS_{3L} correspond to:

$$G1 : MAS_{3L}\left(\text{km.h}^{-1}\right) = \frac{D}{58}$$

$$G2 : MAS_{3L}\left(\text{km.h}^{-1}\right) = \frac{D}{91}$$

$$G3 : MAS_{3L}\left(\text{km.h}^{-1}\right) = \frac{D}{124}$$

D is the total distance (in meters) travelled by the runner.

2.2.2. Part 2

Forty-three healthy male athletes of different levels (G1, $n = 22$; G2, $n = 14$; G3, $n = 7$) voluntarily participated in the second part of the study (anthropometric characteristics are presented in Table 1).

After learning of the experimental conditions, participants performed 3 testing protocols at least 72 hours apart (random order):

- a $Test_{VAM}$ in order to determine MAS_{VAM}, which will serve as the reference;
- a first $Test_{3L}$;
- a second $Test_{3L}$ to assess the reproducibility of the new test.

All tests were performed on a 400 m running track (synthetic surface) at the same hour of the day (16 h) 3 hours after eating and under the same experimental conditions (temperature between 17 and 21 °C and runway wind speed between 1.2 m/s and 1.5 m/s measured by a weather station: PCE-AM81, PCE Instruments®, Strasbourg, France). The HRmax was measured continuously using the heart rate monitor (Polar RS300x, Kempele, Finland) in order to determine the maximum heart rate (average during the final 15 seconds of the test). The theoretical maximum heart rate (220-age) was also calculated. Blood lactate was measured at rest (LT-1710, Lactate Pro, Kyoto, Japan), at the end of each test, at the 3 minutes of recovery.

2.3. $Test_{3L}$ Protocol

The test was carried out in a 400 m outdoor flat track, with a whistle and stopwatch. The $Test_{3L}$ is adapted to three categories of runners with different physical abilities: beginner, trained and elite. For beginners, it will be a matter of running the greatest possible distance in 3×1 minutes with 30 seconds of active recovery between repetitions in hopping on the spot or walking (recovery around the first-minute stopping point, which will later be the starting point of the second minute, and so forth); in the trained athlete, it will be a matter of running the greatest possible distance in 5×1 minutes with 30 seconds of active recovery between repetitions and; in the elite athlete, it will be a matter of running the greatest possible distance in 7×1 minutes with 30 seconds of active recovery between repetitions. MAS_{3L} was thus calculated for each population using equations previously determined (see Part 1).

2.4. $Test_{VAM}$

This test consists to follow race speed controlled by audio beeps on a pre-recorded file. Cones were placed every 20 m along the track as a reference. Participants had to reach cones on each beep and adjusted their running speed to the cones placed at 20-m intervals. The test ended when the subject could not keep the imposed pace by the audio beep and failed to reach the next pylon for 3 consecutive occasions. Initial speed was set at 8.5 km.h^{-1} and increases by 0.5 km.h^{-1} every minute until exhaustion. The MAS_{VAM} corresponds to the speed at the last completed stage [22].

2.5. Statistical analysis

Standard statistical methods were used for the calculation of mean ± SD, separately for each group as well as for all the runners grouped together ($3G_r$). Pearson product—moment correlations were used to assess the relationships between variables. Normality of data was checked using the Shapiro—Wilk test. Student's *t*-test for paired sample was used to compare the differences between both tests. Absolute agreement between tests was determined using limits of agreement analysis (Bland—Altman plot). The reproducibility was assessed using the coefficient of variation (CV) and the intraclass correlation coefficient (ICC). Statistical significance was set at $P < 0.05$. Statistical analyses were performed using SPSS version 20.0 for Windows (SPSS Inc., IBM, Chicago, USA).

3. Results

The total duration of $Test_{VAM}$ was 3.0 ± 0.7, 2.5 ± 1.7, and 2.5 ± 1.1 times longer for G1, G2, G3 than $Test_{3L}$ respectively ($P < 0.01$, Table 2). Figs. 1—4A show the linear regressions between MAS values obtained with both tests for 3Gr and

Table 2 Physiological characteristics and the performance realised during both tests (part 2).

Tests and variables	$3G_r$ ($n = 43$)	Beginners ($n = 22$)	Trained ($n = 14$)	Elite ($n = 7$)
MAS ($km.h^{-1}$)				
$Test_{3L}$	15.8 ± 2.7	13.8 ± 0.6	16.5 ± 0.5	21.1 ± 0.8
$Test_{VAM}$	16.1 ± 2.5	14.0 ± 0.3	16.9 ± 0.8	20.9 ± 0.5
CC	0.93	0.27	−0.68	0.28
P	0.098	0.056	0.205	0.422
$Retest_{3L}$	15.9 ± 2.6	13.8 ± 0.6	16.5 ± 0.4	21.0 ± 0.7
CC test—retest reliability	0.99	0.97	0.87	0.99
ICC test—retest reliability	0.99	0.96	0.85	0.98
CI 95%	(0.995—0.999)	(0.92—0.98)	(0.61—0.95)	(0.85—0.99)
CV (%) test—retest reliability	16.9	5.0	2.6	3.7
HRmax (bpm)				
$Test_{3L}$	192.4 ± 3,3	193.9 ± 3.8	191.0 ± 2.2	190.7 ± 1.3
$Test_{VAM}$	193.0 ± 3.4	194.3 ± 3.7	191.8 ± 2.7	191.4 ± 1.7
Theoretical HRmax	201.7 ± 2.2	202.9 ± 1.7	201.5 ± 0.6	198.2 ± 1.8
CC	0.82	0.79	0.83	0.48
P	0.054	0.389	0.068	0.283
$Retest_{3L}$	192.6 ± 3.6	193.9 ± 3.8	191.8 ± 2.5	190.2 ± 3.4
CC test—retest reliability	0.85	0.86	0.81	0.80
ICC test—retest reliability	0.84	0.86	0.80	0.55
CI 95%	(0.73—0.91)	(0.70—0.94)	(0.49—0.93)	(−0.24—0.90)
CV (%) test—retest reliability	1.8	2.0	1.2	0.7
LA ($mmol.L^{-1}$)				
$Test_{3L}$	10.7 ± 1.5	9.4 ± 0.6	11.7 ± 0.3	13.1 ± 0.2
$Test_{VAM}$	11.1[a] ± 1.5	9.7[a] ± 0.8	11.9[a] ± 0.3	13.4[a] ± 0.3
CC	0.97	0.80	0.87	0.64
P	$P < 0.01$	0.001	$P < 0.01$	0.020
$Retest_{3L}$	10.8 ± 1.5	9.5 ± 0.7	11.7 ± 0.5	13.1 ± 0.2
CC test—retest reliability	0.97	0.80	0.91	0.89
ICC test—retest reliability	096	0.79	0.88	0.85
CI 95%	(0.95—0.98)	(0.57—0.91)	(0.68—0.96)	(0.38—0.97)
CV (%) test—retest reliability	14.2	6.7	3.3	1.7
Total duration (min)				
$Test_{3L}$	–	4.0 ± 0.0	7.0 ± 0.0	10.0 ± 0.0
$Test_{VAM}$	–	12.1[b] ± 0.7	17.9[b] ± 1.7	25.7[b] ± 1.1

P: *P* value; CV (%): coefficient of variation; CC: correlation coefficient; ICC: intraclass correlation coefficient; CI 95%: the 95% confidence interval; MAS: maximal aerobic speed; HRmax: maximum heart rate; LA: blood lactate concentration; $Test_{3L}$: three-level test; $Test_{VAM}$: VAM-EVAL test.

[a] Significant difference ($P < 0.05$).

[b] Significant difference ($P < 0.01$).

for each group separately. No significant MAS differences were found between the two tests for 3Gr or for each group taken individually. The high value of the correlation coefficient calculated from MAS_{3L} and MAS_{VAM} for 3Gr ($r = 0.93$; $P < 0.05$) shows that these two MAS were linked to each other, despite slightly lower correlations for groups 1 and 3 (Table 2). Similarly, systematic biases (0.24 $km.h^{-1}$ for 3Gr; 0.27 $km.h^{-1}$ for G1; 0.45 $km.h^{-1}$ for G2; −0.28 $km.h^{-1}$ for G3) and limits of agreement (−2.08—2.08 $km.h^{-1}$ for 3Gr; −0.96—1.51 $km.h^{-1}$ for G1; −2.05—2.96 $km.h^{-1}$ for G2; −2.01—1.43 $km.h^{-1}$ for G3) are low.

No significant HRmax differences were found between $Test_{3L}$ and $Test_{VAM}$. HRmax corresponded to 95%, 94%, 96%, 95% of the theoretical HRmax for 3Gr, G1, G2, G3 during $Test_{3L}$ (Table 2). However, blood lactate concentrations at the end of $Test_{VAM}$ were significantly higher than that measured at the end of $Test_{3L}$ (Table 2).

No significant difference was found when comparing the two $Test_{3L}$. Whatever the group, MAS, HRmax and LA were very close with low coefficients of variation (Table 2). Thus, the intraclass correlation coefficient calculated for 3Gr illustrates a high level of test—retest reliability. The reliability for the 3 groups was also excellent (Table 2).

4. Discussion

The main objective of the present study was to evaluate the reliability and reproducibility of MAS obtained with a new intermittent running test ($Test_{3L}$) compared to a traditional test ($Test_{VAM}$) [22], in three populations of runners with different training and performance characteristics. To our knowledge, no previously reported MAS test explicitly took into account the a priori performance level of the

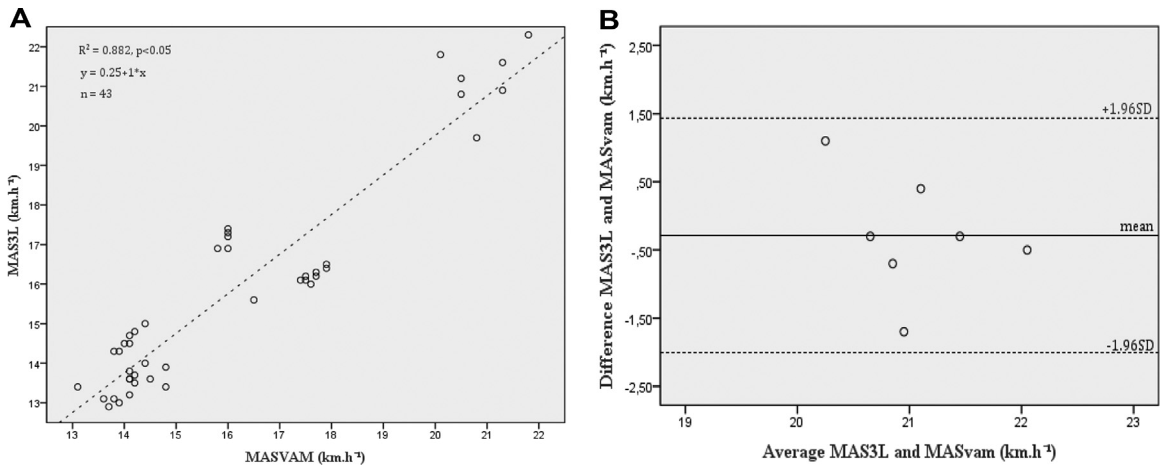

Figure 1 A. Linear regression between MAS_{3L} and MAS_{VAM} ($3G_r$). B. Analysis of Bland—Altman plot of MAS obtained with $Test_{3L}$ and $Test_{VAM}$. The dashed lines indicate 95% limits of agreement ($3G_r$).

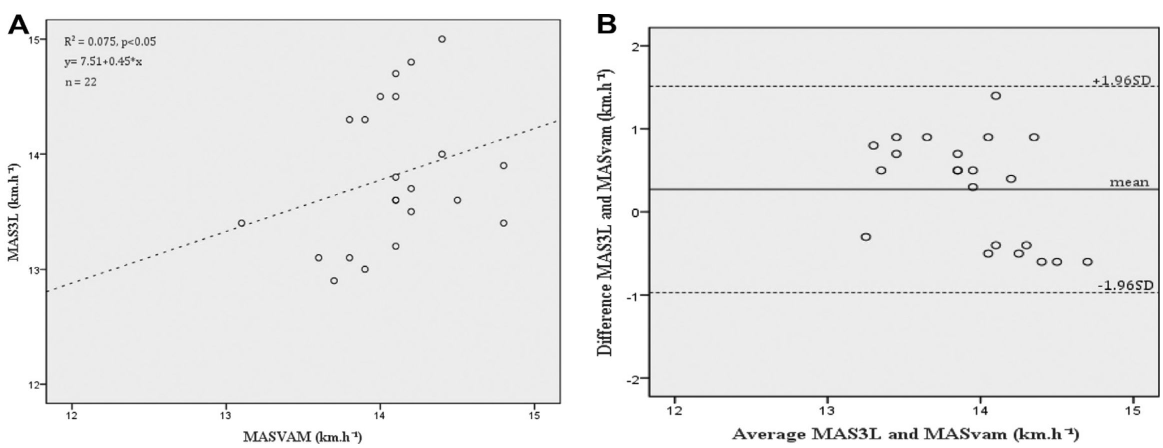

Figure 2 A. Linear regression between MAS_{3L} and MAS_{VAM} (G1). B. Analysis of Bland—Altman plot of MAS obtained in $Test_{3L}$ and $Test_{VAM}$. The dashed lines indicate 95% limits of agreement (G1).

tested runner. Yet, this represents a concept often overlooked by coaches: the adaptation of a testing procedure to the tested participant. The results showed that the MAS values obtained were not significantly different for each group taken individually or as a whole. Similarly, no differences in HRmax were observed, despite the significantly lower end of effort lactatemia with $Test_{3L}$.

In our study, the difference between MAS_{3L} and MAS_{VAM} varied from 0.2 km.h^{-1} to 0.4 km.h^{-1} on average. The MASs were very similar, given that 28 out of 43 athletes (or 2/3) have a gap of less than 1 km.h^{-1}, with a risk of overall error that never exceeded 1.7 km.h^{-1}. Similar to our observations, Berthon et al. [7] showed that the mean MAS obtained from a 5-min running field test (14.8 km.h^{-1}) was not significantly different from the UM—TT (14.6 km.h^{-1}). Carminatti et al. [24] have found similar MAS values by comparing an intermittent progressive test (Carminatti test) and the VAM-EVAL test, with a very high correlation (r = 0.98). Similarly, Bellenger et al. [18] compared the MAS obtained in the UM—TT and MAS through set distance time-trials between 1.600 and 2.200 m. The authors found no significant difference between the two tests. Furthermore, in our study, Bland—Altman's analysis showed an acceptable concordance in training process between MAS_{3L} and MAS_{VAM} (Figs. 1—4B), with 95% of the differences found to be within the limits of agreement of ±2 km.h^{-1}. These limits are greater than those reported by Carminatti et al. [24] which showed that the individual variation was about ±0.5 km.h^{-1} of the reference value.

In the present study, HRmax obtained during $Test_{3L}$ was not significantly different from HRmax obtained during $Test_{VAM}$. These values were significantly related (Table 2), and were close to the maximal theoretical value, in accordance with the fact that such a test should be near maximal [29,30]. This result was in line with those of Berthon et al. [7] who found that the HRmax obtained in a 5-min running field test (191.8 ± 8.1 bpm) was similar to that obtained from the UM—TT (192.6 ± 7.7 bpm), and of Dupont et al. [31] who found similar values comparing the UM—TT (192.3 ± 8.0 bpm) and Yo-Yo intermittent recovery test (191.4 ± 7.8 bpm). All correlations presented in Table 2 confirm that $Test_{3L}$ can be used to determine the HRmax.

Blood lactate is also a commonly used indicator to find out if exercise was carried maximally [30]. The results of

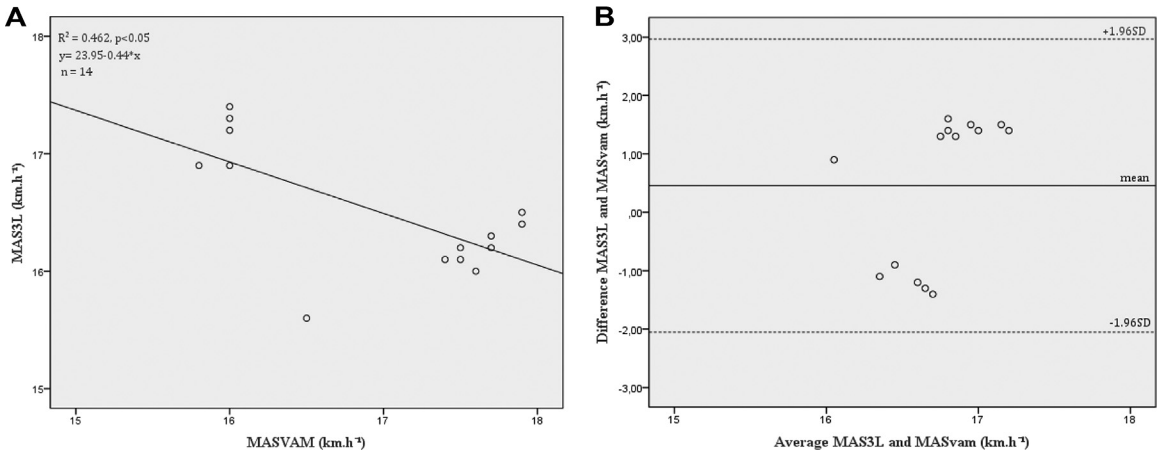

Figure 3 A. Linear regression between MAS_{3L} and MAS_{VAM} (G2). B. Analysis of Bland—Altman plot of MAS obtained in $Test_{3L}$ and $Test_{VAM}$. The dashed lines indicate 95% limits of agreement (G2).

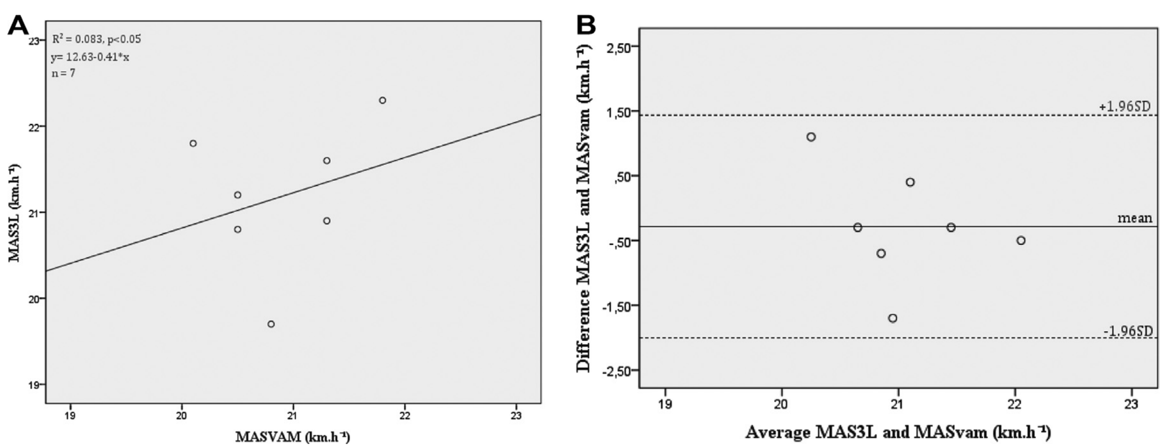

Figure 4 A. Linear regression between MAS_{3L} and MAS_{VAM} (G3). B. Analysis of Bland—Altman plot of MAS obtained in $Test_{3L}$ and $Test_{VAM}$. The dashed lines indicate 95% limits of agreement (G3).

this work showed that the mean lactate values are 0.2 to 0.4 mmoL higher with $Test_{VAM}$ than with $Test_{3L}$. This small significant difference can be explained by several factors. Indeed, an increase in the speed of 0.5 km.h^{-1} between two levels during $Test_{VAM}$ penalised athletes at the end of the race, in soliciting ''abruptly'' lactic glycolysis to face this sudden increase in race speed. In addition, $Test_{VAM}$ duration is longer than $Test_{3L}$, involving the anaerobic glycolysis at a higher level and favouring the accumulation of blood lactate. The most important factor may be the recovery between each minute of the race in $Test_{3L}$. It is known that integration of an active recovery during intermittent exercise decreases lactate dissemination and promotes aerobic glycolysis [32]. The fact that the same MAS values were reached with lower lacatemia during $Test_{3L}$ pointed out that this test may be less burdensome for the runner and that the latter can repeat the test more frequently during the training process.

Therefore, the results of our study showed that $Test_{3L}$ was reliable for measuring MAS. This new test appeared as a valid alternative to traditional track tests, which are generally longer. Indeed, with $Test_{VAM}$, a well-trained subject can run more than 25 min while a beginner runs less than 11 min, as observed in this study. The advantage of the $Test_{VAM}$ is that the first stages are used as a warm-up (time that must be added to our test). But, the distinct disadvantage is that the duration and intensity of the warm-up which corresponds to the first stages of the $Test_{VAM}$ vary with physical fitness. Indeed, the less trained a subject, the shorter and more intense the warm-up. The same observation has also been reported by Berthon et al. [7] while performing the UM-TT. Thus, compared to the $Test_{VAM}$, the differences in race time between the $Test_{3L}$ and $Test_{VAM}$ can be considerable. Based on our study, $Test_{3L}$ is more or less 2.5 times shorter than $Test_{VAM}$. It is thus easier to use it repeatedly during the training routine. It was well known that the test itself produces fatigue, and therefore must not overstep certain limits [7]. Another advantage of $Test_{3L}$ is that it is not based on the use of a beep sound and several runners could be tested at a time, creating emulation that faithfully reproduces the running competition.

The choice of the duration of each level in $Test_{3L}$ was proposed in reference to the time limit at MAS (Tlim at MAS) [33]. It is known that Tlim at MAS is correlated with the MAS [34], although there is wide inter-individual variability [6,35]. The running times (3 to 7 min) proposed in our study were consistent with the Tlim at MAS values reported by Billat and Koralsztein [6] (between 3 and 9 min) or Billat et al. [35] (between 2 min 30s and 10 min), and respect the inter-individual differences. Our three levels test creates a link between the athlete's potential and the measurement method of MAS, which makes it more individualised, unlike $Test_{VAM}$.

The second purpose was to check the reproducibility of $Test_{3L}$. Clinical studies have suggested that tests, with CV values of less than 10% and CCI above 0.75, should be considered as capable of determining practical acceptance of clinical variations [36]. In our study, the CV and ICC test—retest values for MAS showed that $Test_{3L}$ is sufficiently reproducible for all three levels. This reproducibility was similar to other studies (CV = 2.7—4.9%, ICC = 0.81—0.93) [23,37,38]. Another important result of this study is the good reproducibility of HRmax slightly smaller than that observed in the Carminatti test [37] (CV = 2.0—2.5%) for young players (U12 and U14). In addition, lactatemia has also a high reproducibility, with CV values lower than that observed for the 45—15 test [39] (CV = 22.7%).

5. Conclusions

In conclusion, the three-level test allowed obtaining a reproducible MAS comparable to a traditional test, such as VAM-EVAL. Hence, MAS, as well as maximum heart rate derived from $Test_{3L}$, could be used when designing training programs. However, caution must be taken with regard to lactatemia. In addition, $Test_{3L}$ had a high reproducibility. Although this study highlights the importance of $Test_{3L}$, it should be considered as preliminary and further studies are to be conducted in order to complete the validation of this test.

Disclosure of interest

The authors declare that they have no competing interest.

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