A New Short Track Test to Estimate the $\dot{V}O_2$max and Maximal Aerobic Speed in Well-Trained Runners

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Abstract

Pallarés, JG, Cerezuela-Espejo, V, Morán-Navarro, R, Martínez-Cava, A, Conesa, E, and Courel-Ibáñez, J. A new short track test to estimate the $\dot{V}$O2max and maximal aerobic speed in well-trained runners. *J Strength Cond Res* XX(X): 000–000, 2019—This study was designed to validate a new short track test (Track$_{(1:1)}$) to estimate running performance parameters maximal oxygen uptake ($\dot{V}O_2$max) and maximal aerobic speed (MAS), based on a laboratory treadmill protocol and gas exchange data analysis (Lab$_{(1:1)}$). In addition, we compared the results with the University of Montreal Track Test (UMTT). Twenty-two well-trained male athletes ($\dot{V}O_2$max 60.3 ± 5.9 ml·kg^{-1}·min^{-1}; MAS ranged from 17.0 to 20.3 km·h^{-1}) performed 4 testing protocols: 2 in laboratory (Lab$_{(1:1)\text{-pre}}$ and Lab$_{(1:1)}$) and 2 in the field (UMTT and Track$_{(1:1)}$). The Lab$_{(1:1)\text{-pre}}$ was designed to determine individuals' Vpeak and set initial speeds for the subsequent Lab$_{(1:1)}$ short ramp graded exercise testing protocol, starting at 13 km·h^{-1} less than each athlete's Vpeak, with 1 km·h^{-1} increments per minute until exhaustion. The Track$_{(1:1)}$ was a reproduction of the Lab$_{(1:1)}$ protocol in the field. A novel equation was yielded to estimate the $\dot{V}O_2$max from the Vpeak achieved in the Track$_{(1:1)}$. Results revealed that the UMTT significantly underestimated the Vpeak (−4.2%; bias = −0.8 km·h^{-1}; $p < 0.05$), which notably altered the estimations (MAS: −2.6%, bias = −0.5 km·h^{-1}; $\dot{V}O_2$max: 4.7%, bias = 2.9 ml·kg^{-1}·min^{-1}). In turn, data from Track$_{(1:1)}$ were very similar to the laboratory test and gas exchange methods (Vpeak: −0.6%, bias = <0.1 km·h^{-1}; MAS: 0.3%, bias = <0.1 km·h^{-1}; $\dot{V}O_2$max: 0.4%, bias = 0.2 ml·kg^{-1}·min^{-1}, $p > 0.05$). Thus, the current Track$_{(1:1)}$ test emerges as a better alternative than the UMTT to estimate maximal running performance parameters in well-trained and highly trained athletes on the field.

Key Words: testing protocol, validity, running testing, evaluation, noninvasive methods

Introduction

Endurance training based on individual physiological events is effective to enhance training responsiveness and maximize cardiorespiratory, neuromuscular, and functional adaptations (40). This training method requires determining individualized intensities corresponding to physiological milestones, such as the maximal oxygen uptake ($\dot{V}O_2$max) and the lactate/aerobic-anaerobic thresholds (13,16,34,36,37). An accurate identification of these individual milestones will depend on the testing procedures (4,18,19). Therefore, variations in the testing protocol configuration (e.g., warm-up, workload increments, and total test duration) are decisive in the assessment of endurance performance (11,33).

It is well known that graded exercise testing (GXT), using metabolic systems under laboratory conditions, is the most accurate method to assess physiological responses to exercise in endurance sports (3). In particular, ramp protocols, in which the speed increases in a continuous fashion rather than in bouts (e.g., multistage protocols), are especially recommended for maximal cardiovascular testing and predicting the metabolic cost at individual workload (31,32). Numerous studies confirm that short ramp GXT, lasting 10–14 minutes, are the most appropriate assessment to identify individual physiological events in cyclists (14,24,25,28,33) and runners (11,31,32). The main reason for this choice is that longer protocols (lasting 20–30 minutes) or multistage tests (i.e., speed increments every 2–3 minutes) would prevent athletes from achieving their maximal potential because of accumulative fatigue, dehydration, muscle acidosis, and cardiovascular drift (4,18,32). However, the use of laboratory testing procedures is limited by the requirement of sophisticated equipment that most coaches and athletes are not equipped with or cannot afford. Furthermore, treadmill testing with a metabolic cart is impractical for routine athlete assessment and load adjustment compared with field-based and outdoor assessment using portable technologies. Unfortunately, the technology available for quantifying and monitoring running performance in outdoor conditions such as running power output is still limited (2). Thus, indirect estimations from track tests are, to date, the best alternative for determining individual training intensities in running, when laboratory equipment is not available.

There are 2 main running intensities that coaches can analyze using track tests: the peak velocity (Vpeak) and the maximal aerobic speed (MAS). The Vpeak is the highest speed attained during a test, whereas the MAS is the lowest speed that elicits the $\dot{V}O_2$max (20). The MAS is a reference value to determine training intensity and workload distribution in endurance sports based on the aerobic performance limits (39). Given the similarity between Vpeak and MAS intensities (11), running track tests use the Vpeak to estimate the $\dot{V}O_2$max and the corresponding MAS (5,6,21), if no metabolic system is available. Hence, bringing athletes to their maximal aerobic performance (i.e., $\dot{V}O_2$max) is an essential requirement when designing running track tests to measure athletes' endurance performance in the field (18).

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The University of Montreal Track Test (UMTT) is the most famous test to estimate essential running parameters in the field (21). The UMTT follows a multistage GXT protocol with 1 km·h^{-1} increments every 2 minutes (1:2 ratio) to estimate the $\dot{V}O_2$max and MAS from the Vpeak attained. The MAS is considered as the speed reached at the last wholly completed stage (e.g., if the last speed [Vpeak] is 18.5 km·h^{-1}, the MAS is 18 km·h^{-1}) (20). Using this simple speed-based calculation, a variety of authors have published their own UMTT modification, including slight variations on testing procedures such as distance between pylons, stage duration, initial speed, and warm-up (7,9,10).

Despite the fact that nowadays most coaches are designing their training plans based on the speed-based estimations derived from these track tests, some issues can question its validity. First, these tests follow long multistage protocols that require athletes to run for a notably long time until exhaustion, especially in well-trained and elite runners (e.g., for a given athlete with MAS = 20 km·h^{-1}, the UMTT will take 24 minutes). As previously noted, this long duration might raise some doubts on whether the Vpeak attained during the test reflects the athletes' true maximal physiological potential (8,18,26,28). Likewise, the laboratory protocols used to validate these track tests followed the same long multistage protocol; consequently, the measures obtained from both are equally limited (7,9,10). Finally, in all these tests, the speed increases in long bouts rather than progressively, which could impede the athletes reaching their real maximal cardiorespiratory performance (32). To overcome these issues, short ramp GXT protocols including 1 km·h^{-1} increments every 1 minute (1:1 ratio) seem to be a better alternative for running performance assessment in the field (11,31,32). Notwithstanding the aforementioned, although this protocol has been proven in the laboratory ($Lab_{(1:1)}$) (11), to the best of our knowledge, there is no alternative running track test available for runners.

Therefore, the aim of this study was to validate a new short track test with 1 km·h^{-1} increments every 1 minute ($Track_{(1:1)}$) to estimate running performance parameters ($\dot{V}O_2$max and MAS), based on a laboratory treadmill protocol and gas exchange data analysis ($Lab_{(1:1)}$). In addition, we compared the results with the UMTT, a multistage longer protocol with 1 km·h^{-1} increments every 2 minutes.

Methods

Experimental Approach to the Problem

Participants performed 4 testing protocols: 2 in the laboratory ($Lab_{(1:1)\text{-pre}}$ and $Lab_{(1:1)}$) and 2 in the field (UMTT and $Track_{(1:1)}$). Evaluations took place in 4 separate days with 48–72 hours rest in between. On the first day, participants performed a preliminary laboratory test using a treadmill and metabolic cart, following a short ramp GXT protocol with 1 km·h^{-1} increments every 1 minute ($Lab_{(1:1)\text{-pre}}$), as described elsewhere (11). Measures from the $Lab_{(1:1)\text{-pre}}$ were used to determine individuals' Vpeak. On the second day, participants visited the laboratory again to perform another GXT test following the same protocol ($Lab_{(1:1)}$) but setting the initial running speed according to each participant's Vpeak (i.e., starting at 13 km·h^{-1} less than each athlete's Vpeak), previously determined in the $Lab_{(1:1)\text{-pre}}$. Measures from the $Lab_{(1:1)}$ were considered as the gold standard for the validity analysis. On the third day, participants completed the multistage UMTT (21). On the fourth day, they completed the $Track_{(1:1)}$, a reproduction of the $Lab_{(1:1)}$ protocol in the field, following the same individual workload adjustment. Participants' heart rate (HR) was continuously monitored (V800; Polar, Kempele, Finland) in each test.

Subjects

Twenty-two trained male athletes (5,000–21,000 m) and triathletes (5,000 and 10,000 m) volunteered to participate in this study (mean ± *SD*: age 25.7 ± 7.9 years (all subjects 18 years or older), body mass 67.34 ± 6.5 kg, height 175.9 ± 5.0 cm, body fat 11.3 ± 1.8%, $\dot{V}O_2$max 60.3 ± 5.9 ml·kg^{-1}·min^{-1}, and endurance training experience 7.3 ± 4.0 years). All participants were competing at regional and national level races and following a regular training load of 4–6 days per week, 1–2 hours per day. Measurements were obtained during the precompetitive season. All participants were familiarized with the testing procedures used in this investigation. They underwent a complete medical examination (including ECG) that showed all were in good health. No physical limitations or musculoskeletal injuries that could affect testing procedures were reported. None of the subjects were taking drugs, medications, or dietary supplements known to influence physical performance. The Bioethics Commission of the University of Murcia approved the study, which was conducted according to the Declaration of Helsinki. Subjects were verbally informed about the experimental procedures and possible risks and benefits. Written informed consent was obtained from all subjects.

Procedures

Laboratory-Individualized Short Ramp Graded Exercise Testing Protocol. This protocol involved 2 laboratory tests using treadmills and metabolic carts ($Lab_{(1:1)\text{-pre}}$ and $Lab_{(1:1)}$), following a short ramp GXT with 1 km·h^{-1} increments every 1 minute, as described elsewhere (11). Both tests were performed on the same treadmill (HP Cosmos Pulsar; H Cosmos Sports & Medical GMBH, Nussdorf Traunstein, Germany) with an incline of 1.0% (17). Evaluations were performed under the similar environmental conditions (21–24° C and 45–55% relative humidity) at the same time of the day (16:00–19:00 hours) to minimize the circadian rhythm effects (30). Air ventilation was controlled with a fan positioned 1.5 m from the subject's chest at a wind velocity of 2.55 m·s^{-1}. Ventilatory performance ($\dot{V}O_2$, $\dot{V}O_2$max, and ventilation) was recorded on a breath-by-breath basis using a metabolic cart (MetaLyzer 3B-R3; Cortex Biophysik GmbH, Leipzig, Germany). A standardized warm-up was performed before each test. The preliminary test ($Lab_{(1:1)\text{-pre}}$) was made under medical supervision to discard cardiovascular diseases and determine the athletes' Vpeak. The second test ($Lab_{(1:1)}$) was individualized based on the Vpeak previously determined, as follows: the starting velocity was set at 13 km·h^{-1} slower than each athlete's Vpeak, after which the workload increased 1 km·h^{-1} per minute until exhaustion. Maximal effort criteria were considered to verify the outcomes (1). If verified, the MAS was determined as the first running velocity where $\dot{V}O_2$max was reached (20). The metabolic cart was calibrated before each test according to the manufacturer's instructions. The Vpeak was obtained automatically from the treadmill software using the formula proposed by Kuipers et al. (19):

$$V_{peak}\left(km\cdot h^{-1}\right) = V_{complete}\left(km\cdot h^{-1}\right) + Inc\cdot t/T,$$

in which $V_{complete}$ is the speed at the last completed stage, Inc is the speed increment (i.e., 1 km·h^{-1}), t is the time in seconds sustained during the incomplete stage, and T is the time in seconds required to complete a stage (i.e., 60 seconds).

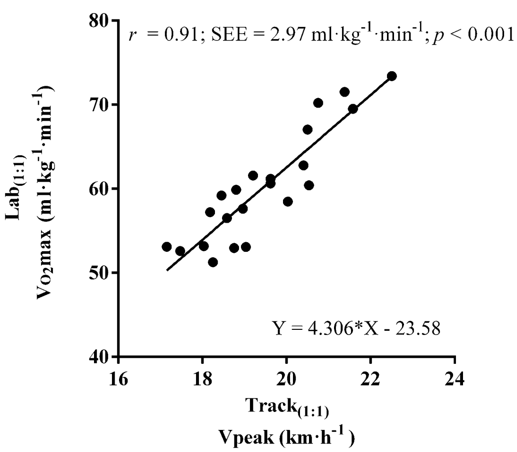

Figure 1. Linear regression relationship between the maximum oxygen uptake ($\dot{V}O_2$max) from the laboratory protocol ($Lab_{(1:1)}$, y-axis) and the peak velocity (Vpeak) during the field running test ($Track_{(1:1)}$, x-axis).

University of Montreal Track Test. The UMTT (21) was carried in a 400-m outdoor flat track. Running pace was controlled by audio beeps on a prerecorded file. Participants had to reach a pylon on each beep. Pylons were placed every 25 m along the track. The test ended when the athlete could not keep the imposed pace by the beeps and failed to reach the next pylon twice in a row. Initial speed was set at 8 km·h^{-1} and thereafter increased by 1 km·h^{-1} every 2 minutes until exhaustion. The Vpeak was obtained using the formula proposed by Kuipers et al. (19) considering 1 km·h^{-1} increments and the 120 seconds required to complete a stage. The speed at the last completed stage was taken as the MAS (e.g., if the last speed [Vpeak] is 18.5 km·h^{-1}, the MAS is 18 km·h^{-1}) (5,20). $\dot{V}O_2$max was calculated using the formula proposed by Léger and Mercier (22):

$$\dot{V}O_2max\left(ml{\cdot}kg^{-1}{\cdot}min^{-1}\right) = 3.5\ MAS.$$

Track-Individualized Short Ramp Graded Exercise Testing. The $Track_{(1:1)}$ was designed to follow the same ramp GXT protocol as the $Lab_{(1:1)}$ in outdoor conditions. The test was performed on a 400-m outdoor flat track on the basis of the UMTT (i.e., pace controlled by audio beeps and pylons each 25 m), but the velocity increased by 1 km·h^{-1} every 1 minute. After a standardized warm-up, the test started at 13 km·h^{-1} slower than each athlete's Vpeak (previously determined during the $Lab_{(1:1)}$) followed by progressive increments of 1 km·h^{-1} every 1 minute until exhaustion (11). Participants' running pace was individually set-up and controlled using automated sound beeps. The Vpeak was obtained using the same formula than the UMTT proposed by Kuipers et al. (19), considering 1 km·h^{-1} increments and the 60 seconds required to complete a stage. The MAS was estimated using the equation proposed by Cerezuela-Espejo et al. (11):

$$MAS\left(km{\cdot}h^{-1}\right) = Vpeak\left(km{\cdot}h^{-1}\right)\ 0.8348 + 2.308.$$

Statistical Analyses

Standard statistical methods were used for the calculation of means, *SD*s, and 95% confidence interval. Comparisons between $\dot{V}O_2$max, MAS, Vpeak, and HRmax measures obtained from the tests ($Lab_{(1:1)}$, UMTT, and $Track_{(1:1)}$) were conducted by analysis of variance with post hoc comparisons, intraclass correlation coefficient, and Bland-Altman bias analyses. The magnitude of agreement was examined through mean difference bias, *SD*, and 95% limits of agreement (LoA = bias ± 1.96 *SD*) calculations. Effect size (ES) was estimated using the Cohen's *d* index and interpreted as small (0.20), medium (0.50), and large (0.80). Analyses were performed using GraphPad Prism 6.0 (GraphPad Software, Inc., CA, USA) and SPSS software version 19.0 (IBM Corp., Armonk, NY, USA).

Results

A high linear relationship (r = 0.91) was observed between the Vpeak from the $Track_{(1:1)}$ and the $\dot{V}O_2$max obtained from the $Lab_{(1:1)}$ (Figure 1). Assuming a standard error of 2.97 ml·kg^{-1}·min^{-1}, the resulting equation was:

$$\dot{V}O_2max\ \left(ml{\cdot}kg^{-1}{\cdot}min^{-1}\right) = Vpeak\ \left(km{\cdot}h^{-1}\right)\ 4.306 - 23.58.$$

The total distances achieved at the end of each test were $Lab_{(1:1)}$ = 2,784 ± 281 m, $Lab_{(1:1)}$ = 2,827 ± 321 m, and UMTT = 4,877

Table 1

Validity results of running performance parameters from the laboratory and field test procedures.*†

	Protocol	$\dot{V}O_2$max (ml·kg^{-1}·min^{-1})	Vpeak (km·h^{-1})	MAS (km·h^{-1})	HRmax (b·min^{-1})	Time (s)
M ± *SD*	$Lab_{(1:1)}$	60.1 ± 6.6	19.3 ± 1.3‡	18.5 ± 1.1	191 ± 7	786 ± 44‡
	UMTT	63.0 ± 4.7§	18.5 ± 1.3‡	18.0 ± 1.3	190 ± 7	1,262 ± 160‡
	$Track_{(1:1)}$	60.4 ± 5.6‖	19.4 ± 1.4	18.5 ± 1.2¶	191 ± 6	794 ± 48
% Diff (95% LoA)	UMTT	4.7 (−2.1 to 11.0)	−4.2 (−9.1 to 0.8)	−2.6 (−7.4 to 2.6)	−0.7 (−3.0 to 1.6)	45.7 (19.6 to 71.8)
	$Track_{(1:1)}$	0.4 (−6.5 to 6.6)	−0.6 (−4.5 to 5.4)	0.3 (−4.7 to 5.5)	<0.1 (−2.1 to 2.2)	−1.0 (−3.4 to 5.4)
ICC	UMTT	0.889	0.944	0.916	0.950	0.180
	$Track_{(1:1)}$	0.900	0.963	0.964	0.958	0.964
Bias (95% LoA)	UMTT	−2.9 (3.5 to −9.2)	0.8 (1.7 to −0.1)	0.5 (1.5 to −0.5)	1.3 (5.6 to −3.0)	476 (137 to 815)
	$Track_{(1:1)}$	−0.2 (5.4 to −5.9)	<−0.1 (0.6 to −0.6)	<−0.1 (0.8 to −0.9)	<0.1 (4.0 to −4.1)	8 (−25 to 42)

*Vpeak = peak velocity achieved at the end of the test; MAS = maximal aerobic speed (i.e., speed at $\dot{V}O_2$max); HRmax = maximum heart rate attained during the GXT; GXT = graded exercise test; $Lab_{(1:1)}$ = laboratory ramp GXT protocol with 1 km·h^{-1} increments per minute (10); UMTT = University of Montreal Track Test multistage protocol with 1 km·h^{-1} increments every 2 minutes (19); $Track_{(1:1)}$ = new ramp GXT track protocol with 1 km^{-1} increments per minute; ICC = intraclass correlation coefficient; LoA = limits of agreement (LoA = bias ± 1.96 *SD*).

†Bias and % difference are calculated from a given track test minus the $Lab_{(1:1)}$.

‡Mean differences ($p < 0.05$).

§Estimated from the equation of Lacour et al.[20]

‖Estimated from the Vpeak using the equation proposed in Figure 1.

¶Estimated from the $Lab_{(1:1)}$ values using the equation proposed by Cerezuela-Espejo et al.[11]

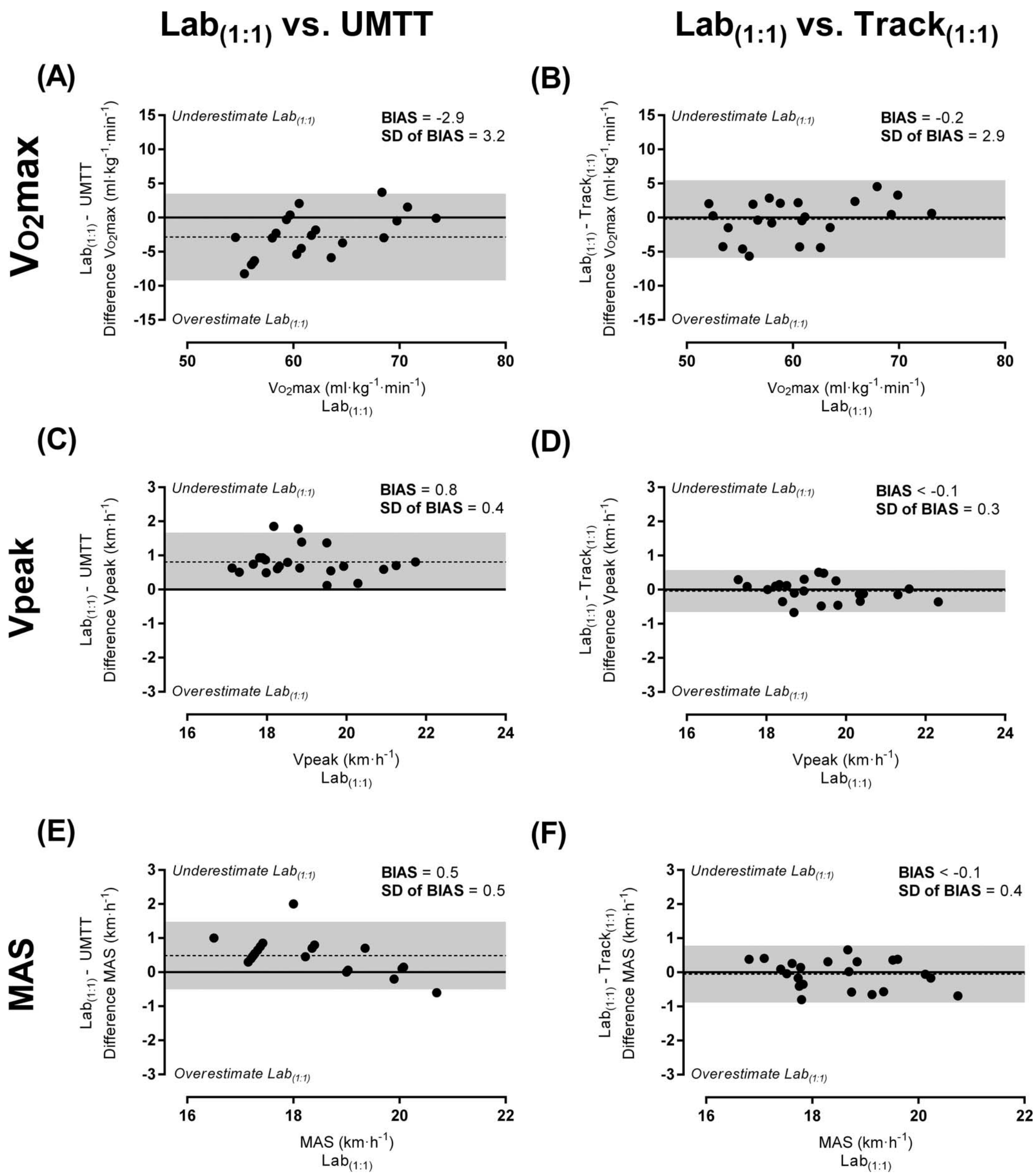

Figure 2. Bland-Altman plots indicating the agreement between the $Lab_{(1:1)}$ (gold standard) and the 2 running field tests: UMTT (A, C, and E) and $Track_{(1:1)}$ (B, D, and F). X-axis is the mean from the $Lab_{(1:1)}$; Y-axis is the mean difference between the $Lab_{(1:1)}$ and the given field test. Bias is shown as a dashed line. The gray area represents the 95% limits of agreement (LoA = bias ±1.96 *SD*). $\dot{V}O_2max$ = maximal oxygen uptake; Vpeak = peak velocity; MAS = maximal aerobic speed; UMTT = University of Montreal Track Test.

± 984 m. Outcomes from each test are shown in Table 1. Analysis of variance was not able to detect mean difference in $\dot{V}O_2max$ ($F = 1.738$; $p = 0.184$), MAS ($F = 1.451$; $p = 0.242$), or HRmax ($F = 0.296$; $p = 0.745$) among the tests. In turn, Vpeak ($F = 3.181$; $p = 0.048$) was significantly lower in the UMTT compared with the $Lab_{(1:1)}$ (mean difference = -0.81 km·h^{-1}; ES = 0.62; $p = 0.04$) and the $Track_{(1:1)}$ (mean difference = -0.93 km·h^{-1}; ES = 0.67; $p = 0.03$). Correlation analysis revealed high and significant coefficients ($r > 0.889$) between both track tests (UMTT and $Track_{(1:1)}$) and the $Lab_{(1:1)}$. However, Bland-Altman analyses (bias and 95% LoA) confirmed a greater agreement in all the studied performance parameters in the $Track_{(1:1)}$ compared with the UMTT. Conversely, the UMTT overestimated the $\dot{V}O_2max$ ~2.9 ml·kg^{-1}·min^{-1}, underestimated the MAS ~0.5 km·h^{-1}, and importantly underestimated the Vpeak ~0.8 km·h^{-1} compared with the laboratory outcomes. Figure 2 depicts these results graphically using Bland-Altman plots.

Discussion

The current $Track_{(1:1)}$ test proposal (individualized, short ramp GXT on track with 1 km·h^{-1} increments per minute) was a better alternative than the UMTT to estimate maximal running performance parameters such as the $\dot{V}O_2max$ and MAS. The current findings provide further empirical evidence about the advantages of conducting individualized, short ramp protocols to assess maximal physiological parameters in endurance sports, particularly in running. Moreover, in light of the high agreement between the $Track_{(1:1)}$ test and the gas exchange laboratory conditions, this novel proposal emerges as a valid alternative to longer and multistage traditional track tests for a better evaluation of athletes' running performance.

Our findings revealed that the UMTT underestimated the Vpeak by 4.2% (~0.81 $km \cdot h^{-1}$) compared with the $Lab_{(1:1)}$, a validated maximal short treadmill GXT using gas exchange systems (11). Consequently, indirect estimations from the Vpeak attained at the end of the UMTT were notably altered and did not reflect the true maximal aerobic performance. These results confirm earlier findings suggesting that long (>20 minutes) and multistage tests avoid the athletes reaching their maximal running speed (8,18,26,28,32). According to this disclosure, the Vpeak attained in the $Track_{(1:1)}$ was higher than the UMTT (±1.0 $km \cdot h^{-1}$) and almost the same as the $Lab_{(1:1)}$ (bias = <0.1 $km \cdot h^{-1}$). Thus, the current short ramp $Track_{(1:1)}$ proposal is a more valid option than UMTT to make estimations derived from maximal running intensities such as the Vpeak using the same human and material resources.

A main advantage of the current $Track_{(1:1)}$ is the estimation of the MAS using a practical formula (11) based on the values obtained from the same protocol under laboratory conditions ($Lab_{(1:1)}$). The use of this formula allowed us to obtain a better estimation for the MAS (0.3% different) than using the UMTT methods (2.6% different) compared with gas exchange. This is critical, given the MAS is a helpful indicator to monitor training loads, assess changes in aerobic endurance, and individualize theoretical submaximal and maximal training intensities in runners (5,12,25,27,29). This high precision in the MAS estimation based on direct gas exchange measurements constitutes a powerful improvement of the $Track_{(1:1)}$ among available running track tests.

It is worth noting that the laboratory protocol used as a gold standard ($Lab_{(1:1)}$) has been proven as effective to estimate critical workloads, such as ventilatory thresholds (VT1 and VT2) and maximal lactate steady state (11). In this work, the authors provided a personal approach for exercise prescription (training zones). Given the $Track_{(1:1)}$ follows the same testing procedure as the $Lab_{(1:1)}$, these training zones can be determined from the MAS and Vpeak values obtained in this test.

The estimation of the $\dot{V}O_2max$ derived from the Vpeak attained during the $Track_{(1:1)}$ is a novel contribution of this study. This is possible due to the fact that the current short ramp GXT protocol guarantees that the Vpeak attained is likely to be the true individual fastest speed (11). Thus, we were able to yield an equation (Figure 1) to estimate $\dot{V}O_2max$, assuming an error of 2.97 $ml \cdot kg^{-1} \cdot min^{-1}$. This error could mainly come from the athletes' running economy (i.e., a different rate of energy consumption at a given speed), which has been shown to explain 7–12% of $\dot{V}O_2max$ variations in elite running athletes (38). Considering the current sample ($\dot{V}O_2max$ = 60 $ml \cdot kg^{-1} \cdot min^{-1}$), $\dot{V}O_2max$ might vary between 5.4 and 7.2 $ml \cdot kg^{-1} \cdot min^{-1}$ because of running economy, which could partially explain the error produced in our resulting equation (Figure 1). Future investigations are required to include running economy assessment during the $Track_{(1:1)}$ and $Lab_{(1:1)}$ testing procedures to refine the accuracy of the estimations.

Finally, although it is true that the UMTT showed high correlations, this coefficient may be limited because it indicates that a value changes when another changes but does not identify the presence of a high systematic error difference between measurements (23). Hence, for training and practical applications, the use of Bland-Altman agreement seems to be more relevant than correlations (15). In this sense, our findings revealed that, despite similar correlation, the $Track_{(1:1)}$ test exhibited higher agreement and lower bias with the laboratory than the UMTT. Therefore, the $Track_{(1:1)}$ should be a preferred option for testing athletes.

This investigation has some limitations that should be noted. A familiarization with the sound signals is recommended for optimal running pace adjustment when performing audio-guided running track tests. No women were included in this test, so further investigations should confirm this validation. In addition, despite the near-perfect agreement, very good correlations, and minimum bias between the $Track_{(1:1)}$ and the laboratory, future studies should corroborate these findings by reproducing the $Track_{(1:1)}$ using a portable metabolic cart (35).

Practical Applications

This study demonstrates that the $Track_{(1:1)}$ is a valid, non-invasive, and individualized test to assess both external (Vpeak and MAS) and internal ($\dot{V}O_2max$ and HRmax) running performance parameters, while assuring that the athletes reach their maximal aerobic velocity. The use of the Vpeak to obtain high precision ventilatory estimations compared with laboratory exchange measurements constitutes a main practical application for daily training monitoring. The $Track_{(1:1)}$ intensity is individualized according to the athlete's maximum potential (i.e., Vpeak) to allow for completing the test within 14 minutes; in turn, longer or multistage track tests could lead to an early fatigue failure and underestimate the outcomes. Thanks to this short duration, measurements can be obtained from a single training session without compromising the training plan.

References

1. ACSM. Interpretation of Clinical Exercise Test Results. In: 9th, ed. *ACSM's Guidelines for Exercise Testing and Prescription*. Philadelphia, PA: Lippincott Williams and Wilkins, 2013. pp. 142–160.
2. Aubry RL, Power GA, and Burr JF. An assessment of running power as a training metric for elite and recreational runners. *J Strength Cond Res* 32: 1, 2018.
3. Beltz NM, Gibson AL, Janot JM, Kravitz L, Mermier CM, and Dalleck LC. Graded exercise testing protocols for the determination of vo_2max: Historical perspectives, progress, and future considerations. *J Sports Med* 2016: 1–12, 2016.
4. Bentley DJ, Newell J, and Bishop D. Incremental exercise test design and analysis: Implications for performance diagnostics in endurance athletes. *Sport Med* 37: 575–586, 2007.
5. Berthoin S, Gerbeaux M, Turpin E, Guerrin F, Lensel-Corbeil G, and Vandendorpe F. Comparison of two field tests to estimate maximum aerobic speed. *J Sports Sci* 12: 355–362, 1994.
6. Berthon P, Fellmann N, Bedu M, Beaune B, Dabonneville M, Coudert J, et al. A 5-min running field test as a measurement of maximal aerobic velocity. *Eur J Appl Physiol Occup Physiol* 75: 233–238, 1997.
7. Billat V, Hill DW, Pinoteau J, Petit B, and Koralsztein JP. Effect of protocol on determination of velocity at $\dot{V}O2max$ and on its time to exhaustion. *Arch Physiol Biochem* 104: 313–321, 1996.
8. Buchfuhrer MJ, Hansen JE, Robinson TE, Sue DY, Wasserman K, and Whipp BJ. Optimizing the exercise protocol for cardiopulmonary assessment. *J Appl Physiol* 55: 1558–1564, 1983.
9. Cazorla G. Field tests to Evaluate Aerobic Capacity and Maximum Aerobic Speed. In: *The Evaluation in Physical Activity and in Sport*. Cazorla G and Robert G, eds. Cestas, France: AREAPS, 1990. pp. 151–174.
10. Cazorla G and Leger L. *How to Evaluate and Develop Your Abilities Aerobics: The Progressive Test of the Shuttle Race, The Progressive Test of VAMEVAL Track Race*. Cestas, France: AREAPS Research and Evaluation Association in Physical Activity and Sport, 1993. p. 123.
11. Cerezuela-Espejo V, Courel-Ibáñez J, Morán-Navarro R, Martínez-Cava A, and Pallarés JG. The relationship between lactate and ventilatory

thresholds in runners: Validity and reliability of exercise test performance parameters. *Front Physiol* 9: 1320, 2018.
12. Esfarjani F and Laursen PB. Manipulating high-intensity interval training: Effects on VO2max, the lactate threshold and 3000 m running performance in moderately trained males. *J Sci Med Sport* 10: 27–35, 2007.
13. García-Pallarés J, García-Fernández M, Sánchez-Medina L, and Izquierdo M. Performance changes in world-class kayakers following two different training periodization models. *Eur J Appl Physiol* 110: 99–107, 2010.
14. Gaskill SE, Ruby BC, Walker AJ, Sanchez OA, Serfass RC, and Leon AS. Validity and reliability of combining three methods to determine ventilatory threshold. *Med Sci Sports Exerc* 33: 1841–1848, 2001.
15. Giavarina D. Understanding Bland Altman analysis. *Biochem Med* 25: 141–151, 2015.
16. Helgerud J, Høydal K, Wang E, Karlsen T, Berg P, Bjerkaas M, et al. Aerobic high-intensity intervals improve VO2max more than moderate training. *Med Sci Sport Exerc* 39: 665–671, 2007.
17. Jones AM and Doust JH. A 1% treadmill grade most accurately reflects the energetic cost of outdoor running. *J Sports Sci* 14: 321–327, 1996.
18. Julio UF, Panissa VLG, Shiroma SA, and Franchini E. Effect of protocol manipulation for determining maximal aerobic power on a treadmill and cycle ergometer: A brief review. *Strength Cond J* 5: 58–71, 2017.
19. Kuipers H, Rietjens G, Verstappen F, Schoenmakers H, and Hofman G. Effects of stage duration in incremental running tests on physiological variables. *Int J Sports Med* 24: 486–491, 2003.
20. Lacour JR, Padilla-Magunacelaya S, Chatard JC, Arsac L, and Barthélémy JC. Assessment of running velocity at maximal oxygen uptake. *Eur J Appl Physiol Occup Physiol* 62: 77–82, 1991.
21. Léger L and Boucher R. An indirect continuous running multistage field test: The Universite de Montreal Track Test. *Can J Appl Physiol* 5: 77–84, 1980.
22. Léger L and Mercier D. Gross energy cost of horizontal treadmill and track running. *Sport Med* 1: 270–277, 1984.
23. Lin L, Hedayat AS, Sinha B, and Yang M. Statistical methods in assessing agreement. *J Am Stat Assoc* 97: 257–270, 2002.
24. Lucía A, Hoyos J, Pérez M, and Chicharro JL. Heart rate and performance parameters in elite cyclists: A longitudinal study. *Med Sci Sports Exerc* 32: 1777–1782, 2000.
25. Lucía A, Sánchez O, Carvajal A, and Chicharro JL. Analysis of the aerobic-anaerobic transition in elite cyclists during incremental exercise with the use of electromyography. *Br J Sports Med* 33: 178–185, 1999.
26. Lukaski HC, Bolonchuk WW, and Klevay LM. Comparison of metabolic responses and oxygen cost during maximal exercise using three treadmill protocols. *J Sports Med Phys Fitness* 29: 223–229, 1989.
27. McLaughlin JE, Howley ET, Bassett DR, Thompson DL, and Fitzhugh EC. Test of the classic model for predicting endurance running performance. *Med Sci Sports Exerc* 42: 991–997, 2010.
28. Midgley AW, McNaughton LR, and Carroll S. Time at VO2max during intermittent treadmill running: Test protocol dependent or methodological artefact? *Int J Sports Med* 28: 934–939, 2007.
29. Millet GP, Candau R, Fattori P, Bignet F, and Varray A. VO2 responses to different intermittent runs at velocity associated with VO2max. *Can J Appl Physiol* 28: 410–423, 2003.
30. Mora-Rodríguez R, Pallarés JG, López-Gullón JM, López-Samanes Á, Fernández-Elías VE, and Ortega JF. Improvements on neuromuscular performance with caffeine ingestion depend on the time-of-day. *J Sci Med Sport* 18: 338–342, 2015.
31. Myers J and Bellin D. Ramp exercise protocols for clinical and cardiopulmonary exercise testing. *Sport Med* 30: 23–29, 2000.
32. Myers J, Buchanan N, Walsh D, Kraemer M, McAuley P, Hamilton-Wessler M, et al. Comparison of the ramp versus standard exercise protocols. *J Am Coll Cardiol* 17: 1334–1342, 1991.
33. Pallarés JG, Morán-Navarro R, Ortega JF, Fernández-Elías VE, and Mora-Rodriguez R. Validity and reliability of ventilatory and blood lactate thresholds in well-trained cyclists. *PLoS One* 11: e0163389, 2016.
34. Pallarés JG, Sánchez-Medina L, Carrasco L, Díaz A, and Izquierdo M. Endurance and neuromuscular changes in world-class level kayakers during a periodized training cycle. *Eur J Appl Physiol* 106: 629–638, 2009.
35. Perez-Suarez I, Martin-Rincon M, Gonzalez-Henriquez JJ, Fezzardi C, Perez-Regalado S, Galvan-Alvarez V, et al. Accuracy and precision of the cosmed k5 portable analyser. *Front Physiol* 9: 1764, 2018.
36. Scharhag-Rosenberger F, Walitzek S, Kindermann W, and Meyer T. Differences in adaptations to 1 year of aerobic endurance training: Individual patterns of nonresponse. *Scand J Med Sci Sports* 22: 113–118, 2012.
37. Seiler S and Tønnessen E. Intervals, thresholds, and long slow distance: The role of intensity and duration in endurance training. *Sportscience* 13: 32–53, 2009.
38. Shaw AJ, Ingham SA, Atkinson G, and Folland JP. The correlation between running economy and maximal oxygen uptake: Cross-sectional and longitudinal relationships in highly trained distance runners. *PLoS One* 10: e0123101, 2015.
39. Stöggl T and Sperlich B. The training intensity distribution among well-trained and elite endurance athletes. *Front Physiol* 6: 295, 2015.
40. Wolpern AE, Burgos DJ, Janot JM, and Dalleck LC. Is a threshold-based model a superior method to the relative percent concept for establishing individual exercise intensity? A randomized controlled trial. *BMC Sports Sci Med Rehabil* 7: 16, 2015.