International Journal of Sports Physiology and Performance, **(Ahead of Print)**
https://doi.org/10.1123/ijspp.2025-0511

Human Kinetics
ORIGINAL INVESTIGATION

Time to Exhaustion at Traditional Physiological Indicators in Runners: Between-Subject and Between-Day Variability

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Background: The maximum oxygen uptake ($\dot{V}O_2$max), respiratory compensation point (RCP), and maximal lactate steady state (MLSS) are indicators used to assess athletes' performance. There is scarce information available on the tolerable duration of exercise (time to exhaustion [TTE]) while running at these physiological indicators. We aimed to analyze the TTE when running at these indicators, as well as to determine their between-subject variability and within-subject reliability. ***Methods:*** Thirteen male athletes volunteered to participate ($\dot{V}O_2$max = 60.2[4.2] mL·kg^{-1}·min^{-1}). Participants $\dot{V}O_2$max, RCP, and MLSS were assessed through treadmill testing, and they performed 2 TTE tests on different occasions at the speed corresponding to each indicator, during which blood lactate, heart rate, and perceptual responses were measured. ***Results***: TTEs were 03:38 (00:40), 10:58 (02:59), and 56:42 (13:02) mm:ss at the $\dot{V}O_2$max, RCP, and MLSS, respectively. A moderate between-subject variability was observed (coefficient of variation = 18.3%, 27.3%, and 23.0% for $\dot{V}O_2$max, RCP, and MLSS), but no significant associations were found between TTEs and other fitness indicators, such as the speed at which these intensities occurred, nor between TTEs and $\dot{V}O_2$max (all $r < .1$; $P > 0.2$). A high within-subject (ie, between-day) reliability was observed for the TTE at all indicators (coefficient of variation of 4.4%, 4.8%, and 6.4% for $\dot{V}O_2$max, RCP, and MLSS, respectively, and intraclass correlation coefficient of .94 and .97, and .90, respectively). ***Conclusions:*** Given their high within-subject reliability and their independence from other traditional physiological indicators of performance, TTE tests could be used for performance monitoring and for training prescription purposes.

Keywords: endurance training, maximal aerobic speed, respiratory compensation point, ventilatory threshold, maximal lactate steady state

Among other factors, such as exercise efficiency, endurance performance is highly conditioned by athletes' maximal aerobic capability, and by its fractional utilization which can be assessed during incremental laboratory testing through the analysis of maximum oxygen uptake ($\dot{V}O_2$max) and ventilatory thresholds (VT; eg, respiratory compensation point [RCP]), respectively.[1,2] For this reason, these indicators are commonly assessed to monitor runners' performance. Another physiological indicator related to endurance performance is the maximal lactate steady state (MLSS), defined as the highest workload at which blood lactate levels remain stable, which is assessed through several constant-load tests.[3] Theoretically, the MLSS corresponds to the highest oxidative metabolic rate that can be sustained during continuous exercise, thus representing the delineation between steady-state and nonsteady-state exercise.[4]

In addition to their usefulness for performance monitoring, these indicators can also be used to prescribe training loads by setting intensity relative to these physiological indicators (eg, instead of setting intensity relative to maximum heart rate [HR]). There is little information, however, on the tolerable duration of exercise (ie, time to exhaustion [TTE]) while running at the abovementioned physiological indicators. Of note, although different authors have assessed the TTE while running at the speed corresponding to the $\dot{V}O_2$max (known as maximal aerobic speed [MAS]).[5–9] There is scarce evidence on the TTE while running at the intensity corresponding to the MLSS [10,11] and particularly at the RCP, for which to the best of our knowledge there are no available studies in runners—as opposed to cycling.[12,13] With this metric, coaches could prescribe the duration of exercise bouts based on a percentage of the TTE at that intensity (eg, a bout representing 80% of the TTE for that workload); or, in reverse, they could estimate the time that is left out when running at a specific workload.

There is also a lack of evidence on the between-subject variability and test–retest reliability of the TTE when running at these indicators. A larger within-subject variability (ie, lower test–retest reliability) has been reported for TTE tests compared with fixed-duration or fixed-distance tests (ie, time trials),[14] although other authors suggest that TTE tests are at least as reliable as time trials.[15] This is of major relevance, as a high test–retest reliability is warranted if these TTE tests are used for longitudinal performance

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monitoring and training prescription. In addition, the degree of between-subject variability in TTE at different intensities remains largely unknown. In this regard, some studies suggest that the potential between-subject variability in TTE tests at the $\dot{V}O_2$max might be due to differences in performance (ie, inverse association between $\dot{V}O_2$max or MAS and the TTE at this indicator), but evidence remains scarce and limited to the $\dot{V}O_2$max.[6,16,17]

Under this context, the present study aimed to analyze the TTE when running at the intensity corresponding to the most relevant performance indicators (ie, $\dot{V}O_2$max, RCP, and MLSS). As a secondary goal, we aimed to determine the between- and within-subject (ie, between-day) variability of TTE, as well as to explore potential factors that could explain the degree of between-subject variability.

Methods

Participants

A convenience sample of 13 endurance-trained male athletes (runners and triathletes) participated in this study ($\dot{V}O_2$max = 60.2[4.2] $mL \cdot kg^{-1} \cdot min^{-1}$, height = 177 [4] cm, body mass = 71.0 [6.5] kg, age = 26.5 [8.8] y). All participants underwent a complete medical examination to ensure that they were in good health. None of the subjects were taking drugs or dietary supplements known to influence running performance. Participants were already familiarized with all tests (including the TTE tests), as they had previously undergone these tests as part of their performance monitoring. The Bioethics Commission of the University of Murcia approved the study, which complied with the latest version of the Declaration of Helsinki. Subjects were verbally informed about the experimental procedures and possible risks and benefits before written informed consent was obtained from them.

Experimental Design

A schematic representation of the study design is shown in Figure 1. On the first day, participants underwent a preliminary graded exercise test (GXTpre) with 12 lead Electrocardiogram monitoring to (a) confirm normal cardiac and pulmonary functioning, (b) familiarize subjects with testing equipment and with the GXT protocol, (c) discard participants with $\dot{V}O_2$max lower than 55.0 $mL \cdot kg^{-1} \cdot min^{-1}$, and (d) identify their preliminary MAS to allow a precise configuration of the subsequent experimental GXT protocol. During this preliminary GXT, athletes ran on a treadmill with 1% gradient, starting at a speed of 8.0 $km \cdot h^{-1}$ and increasing 1 $km \cdot h^{-1}$ every minute until exhaustion.

On a different day separated by at least 48 to 72 hours, subjects performed an experimental GXT to accurately establish the running speed associated with their $\dot{V}O_2$max and their RCP. One week later, participants visited the lab 2 to 3 more times to determine the speed associated with their MLSS. On subsequent visits, participants performed 2 TTE tests at the speeds associated with their $\dot{V}O_2$max, RCP, and MLSS, in a randomized order and with each TTE separated by 48 to 72 hours. All trials took place under constant laboratory environmental conditions (ie, 20–23 °C, 35%–50% relative humidity, wind cooled at 2.55 $m \cdot s^{-1}$) and were performed at the same time of day for each subject to avoid circadian rhythms effects.

To maintain steady training adaptations during the study (5 wk), participants followed an individual training protocol consisting of running sessions every 48 hours. These sessions consisted of running at their individually first ventilatory threshold (VT_1) for 20 minutes followed by running bouts of 5 to 7 minutes at 90% to 95% of RCP intensity until completing 70 minutes. All of them were asked to keep their eating habits constant following a similar type of high-carbohydrate diet during the days previous to testing, reaching at least 7 $g \cdot kg^{-1}$ during the previous 24 hours.[18]

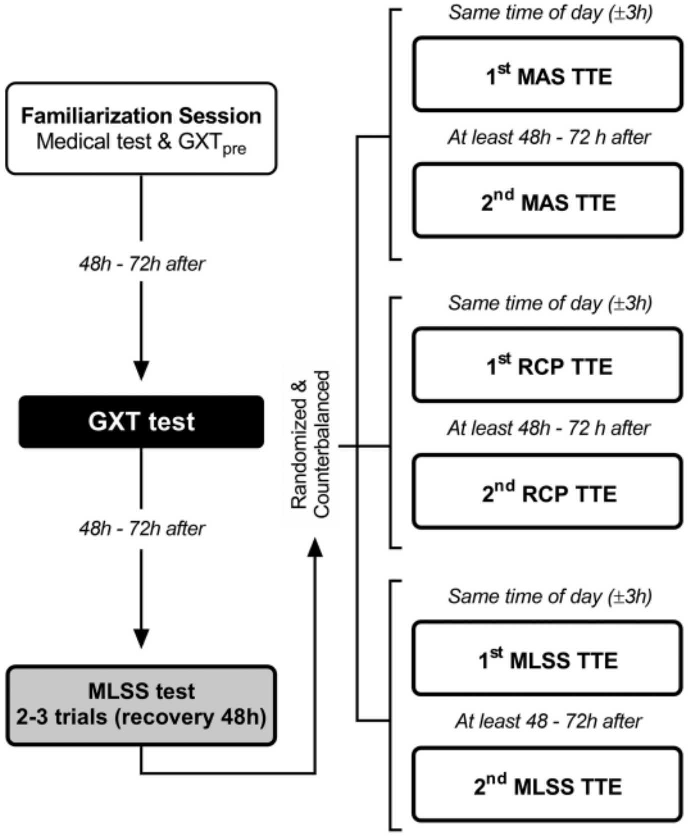

Figure 1 — Schematic representation of the study design. GXT indicates graded incremental test; MAS, maximal aerobic speed; MLSS, maximal lactate steady state; RCP, respiratory compensation point; TTE, time to exhaustion test.

Procedures

Graded Exercise Test

The experimental GXT consisted of an incremental ramp test on a treadmill (HP Cosmos Pulsar, HP Cosmos Sports & Medical GMBH), secured through a safety harness and set at a 1.0% slope to replicate the metabolic cost of outdoor running.[19] This ramp protocol started with a 5-minute warm-up at 8.0 $km \cdot h^{-1}$ and subsequent running speed increments were individualized between 0.8 and 1.1 $km \cdot h^{-1}$ every minute according to the previous preliminary GXT. This GXT protocol allows a clear detection of ventilatory thresholds (VT_1 and RCP),[20] is effective in determining a true $\dot{V}O_2$max[21] and is short enough (12–14 min) to avoid the local acidosis, fatigue, and cardiac drift that prevent maximal performance.[22,23]

During the GXT, oxygen consumption ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) were recorded using breath-by-breath indirect calorimetry (Cortex Metalyzer 3B) calibrated before each test. HR was continuously monitored (Polar Bluetooth H10). Capillary blood lactate samples from the finger were collected at the beginning (resting values) and at minutes 1, 3, 5, and 7 after the end of the GXT to assess peak lactate concentration ($[La+]_{peak}$) (Lactate Pro2, Arkray). This lactate analyzer has been previously shown to be reliable.[24]

VT_1 was determined when an increase in both ventilatory equivalent of oxygen ($\dot{V}E/\dot{V}O_2$) and end-tidal pressure of oxygen ($P_{ET}O_2$) occurred but with no concomitant increase in ventilatory equivalent of carbon dioxide ($\dot{V}E/\dot{V}CO_2$).[20] RCP was determined when both $\dot{V}E/\dot{V}O_2$ and $\dot{V}E/\dot{V}CO_2$ increased but $P_{ET}CO_2$ decreased.[20] MAS was determined as the first running velocity at which the highest $\dot{V}O_2$ value was reached. The VO_2peak was considered maximal ($\dot{V}O_2$max) when three of the following criteria were met: (i) failure of HR to increase with further increases in exercise intensity; (ii) a plateau in $\dot{V}O_2$ (or failure to increase $\dot{V}O_2$ by 150 $mL\cdot min^{-1}$) with increased workload; (iii) a respiratory exchange ratio ≥1.10; blood lactate > 8 $mmol\cdot L^{-1}$; and (iv) a rating of perceived exertion (RPE) >17 on the 6 to 20 scale.

Maximum Lactate Steady-State Test

Seven days after the GXT, participants attended the laboratory on at least 2 to 3 occasions (separated by 48 h) to perform 30-minute constant runs on the treadmill. Single capillary blood samples were collected for [La+] determination at baseline and on the minutes 10th and 30th of the test. The MLSS was considered as the highest speed at which [La+] increased less than 1 $mmol\cdot L^{-1}$ between the 10th and 30th minute of exercise.[20,25] The first trial to identify the MLSS was performed at the workload associated to 85% participants' RCP, based on previous studies.[26] Depending on the results of the first MLSS test, running speed was increased or decreased by 0.5 $km\cdot h^{-1}$ in the following trials, until MLSS criteria was fulfilled. MLSS was identified as the intermediate running speed between the last 2 intensities tested (ie, interpolation).[20,25]

TTE Tests

Once the velocities associated with $\dot{V}O_2$max (MAS), RCP, and MLSS were identified, athletes completed 2 TTE tests at each of these intensities in different days (6 visits), in a random order and separated by 48 to 72 hours. All TTE tests started with a 10-minute warm-up (5 min at 80% and 5 min at 90% of the velocity corresponding to the VT_1) and ended when the participants were not able to maintain the speed. All experimental sessions were performed on the same treadmill, set at a 1.0% slope to replicate the metabolic cost of outdoor running.[19] Besides TTE at each speed, participants' HR and RPE were recorded every 5 minutes, while capillary blood samples were obtained at the beginning (baseline values) and at minutes 1, 3, 5, and 7 after the end of the TTE tests to assess $[La+]_{peak}$. During all trials subjects were kept blinded to elapsed time, lactate, and HR responses. All trials were repeated after 48 to 72 hours under identical conditions to assess within-subject (ie, between-day) reliability, whereas between-subject variability was assessed using the TTE tests of the first day.

Statistical Analysis

Data were screened for normality and homogeneity using a Shapiro–Wilk normality test and a Levene's test, respectively.

Between-subject variability in TTE at the speeds corresponding to $\dot{V}O_2$max, RCP, and MLSS (day 1) was quantified using the coefficient of variation (CV). Pearson correlation analyses were performed to assess relationships between the TTE at each physiological indicator, the subjects' $\dot{V}O_2$max, and the speeds associated with each TTE.

Between-day differences (day 1 vs day 2) in the TTE tests at each speed were assessed through a 2-way repeated-measures analysis of variance (intensity × day) with the Bonferroni test applied post hoc. Between-day reliability was assessed through the computation of CV and intraclass correlation coefficient (ICC, 2-way mixed effects model). ICC values less than .5 are indicative of poor reliability, values between .5 and .75 indicate moderate reliability, values between .75 and .9 indicate good reliability, and values greater than .90 indicate excellent reliability.[27] Bland–Altman plots were also used to assess between-day reliability. Statistics were performed using SPSS (version 27.0, IBM Corp).

Results

The running speed, TTE, and physiological responses associated to $\dot{V}O_2$max, RCP, and MLSS are shown in Table 1. Significant differences in the associated speed and the TTE were observed between physiological indicators ($P < .05$; Table 1). At the end of the TTE trials, peak values of RPE, HR, and [La+] were significantly lower as exercise intensity decreased ($P < .05$), except for HR_{peak} and $\%HR_{peak}$ that were not significantly different between $\dot{V}O_2$max and RCP ($P > .05$; Table 1).

A moderate between-subject variability was observed for the TTE at the $\dot{V}O_2$max (CV = 18.3%), RCP (CV = 27.3%), and MLSS (CV = 23.0%). No significant associations ($r < .061$; $P > .272$) were found between the TTE at each physiological indicator and the absolute speed at which these intensities occurred, nor between the TTE and $\dot{V}O_2$max (Figure 2).

Table 1 Main Physiological Data Obtained at Each Speed

	MAS	RCP	MLSS	Interaction (*P*)		
	Mean (SD)	Mean (SD)	Mean (SD)	MAS vs RCP	MAS vs MLSS	RCP vs MLSS
Speed, $km\cdot h^{-1}$	19.1 (1.3)	16.6 (1.4)	14.2 (1.4)	<.001	<.001	<.001
TTE, min:s	3:38 (0:40)	10:58 (2:59)	56:42 (13:02)	.042	<.001	<.001
RPE_{peak} (6–20)	19.6 (0.7)	18.4 (1.9)	15.4 (2.6)	.025	<.001	<.001
HR_{peak}, $beats\cdot min^{-1}$	187 (9)	187 (9)	181 (9)	.895	.048	.046
$\%HR_{max}$, %	98.3 (2.8)	98.3 (3.0)	95.2 (4.3)	.890	.034	.038
$[La+]_{peak}$, $mmol\cdot L^{-1}$	13.2 (3.1)	11.5 (3.2)	4.8 (1.5)	.281	<.001	<.001

Abbreviations: HR_{max}, heart rate achieved during the experimental graded exercise test; HR_{peak}, peak heart rate achieved during each TTE; $[La+]_{peak}$, peak capillary blood lactate concentration achieved during each TTE; MAS, maximal aerobic speed; MLSS, maximum lactate steady state; RCP, respiratory compensation point; RPE_{peak}, peak rating of perceived exhaustion achieved during each TTE; TTE, time to exhaustion. Note: Data are presented as mean (SD).

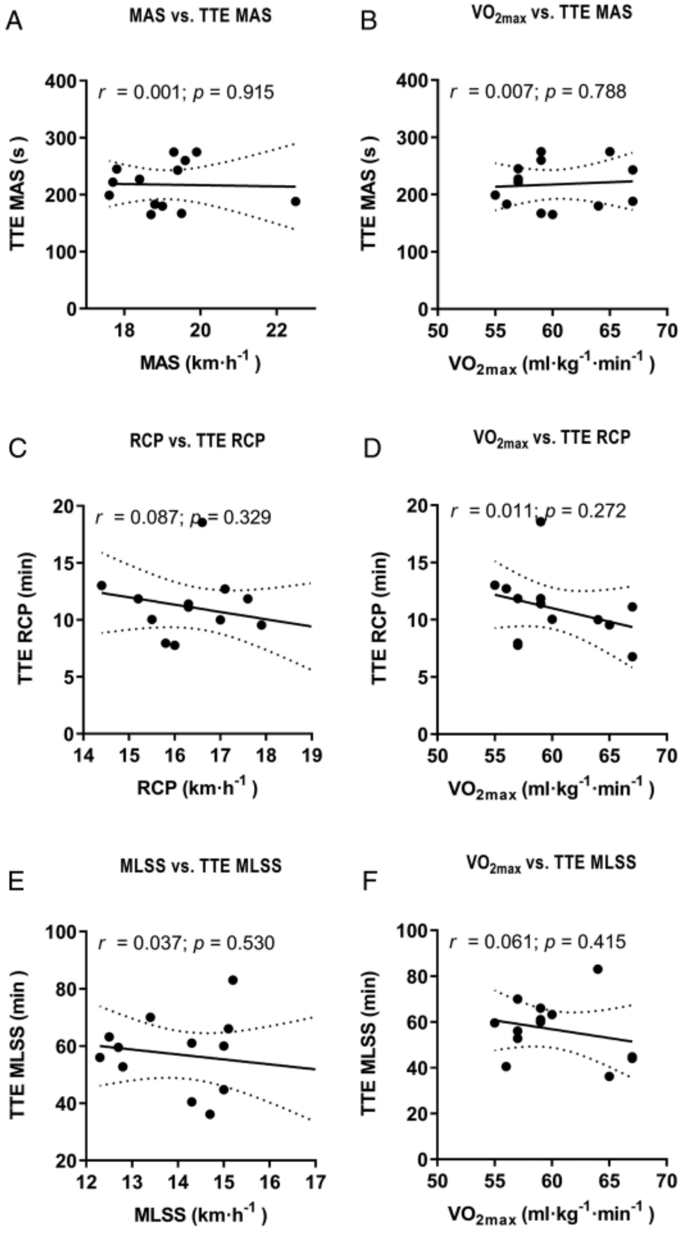

Figure 2 — Association between the TTE at the speed associated with the maximum oxygen uptake (MAS), the RCP and the MLSS, and the absolute speed at which these indicators occurred and with the maximum oxygen uptake. No significant associations were found. MAS indicates maximal aerobic speed; $\dot{V}O_2$max, maximum oxygen uptake; MLSS, maximal lactate steady state; RCP, respiratory compensation point; TTE, time to exhaustion test.

No significant differences ($P > .7$) were found between day 1 and day 2 for the TTE at any measured intensity. Bland–Altman plots showed a mean bias (± 95% limits of agreement) of −11 (29), 28 (88), and 11 (734) seconds for MAS, RCP, and MLSS, respectively (Figure 3).

An excellent between-day reliability was observed for the TTE at both MAS and RCP (CV of 4.4% and 4.8%, respectively, and ICC of .95 [95% CI, .85–.98] and .97 [95% CI, .92–.99], respectively), whereas a slightly lower but still excellent reliability was observed for the TTE at the MLSS (CV = 6.4%; ICC = .91 [95% CI, .74–.97]) (Figure 4).

Discussion

The present study describes the TTE of trained athletes when running at the intensity corresponding to traditional physiological indicators (ie, $\dot{V}O_2$max, RCP, and MLSS). We observed a moderate between-subject variability (CV = 18%–27%) for the TTE at all intensities. However, this variability was not associated with differences in the absolute speed associated with each physiological indicator nor with differences in participants' fitness (ie, $\dot{V}O_2$max). Despite this between-subject variability, the TTE tests showed high within-subject reliability, which might support their implementation for fitness monitoring and training prescription.

In the present study, we found a TTE of 3 to 4 minutes when running at $\dot{V}O_2$max-associated speed (ie, MAS), as assessed through a ramp protocol with increases of ~1 km/h every minute. This result is in line with a previous study that assessed the TTE when running, cycling, rowing, or swimming at the $\dot{V}O_2$max with a similar protocol.[5] However, longer TTEs (5–7 min) at this speed have been reported in other running-based studies.[6,9] These longer durations may stem from methodological differences in the identification of $\dot{V}O_2$max. Specifically, if $\dot{V}O_2$max is underestimated due to the use of longer stages during the incremental test (eg, increases of 1 km/h every 3 min), the resulting TTE may be artificially prolonged.[25] Therefore, our shorter TTE is consistent with a protocol that likely elicited a true $\dot{V}O_2$max and reflects the expected physiological limit for sustained maximal aerobic effort. Indeed, 1-minute stages are recommended for the measurement of maximal aerobic capacity in athletes,[28] and we confirmed the maximality of the GXT with a plateau in HR/$\dot{V}O_2$max. Of note, a previous study by our research group using the same measurement equipment and similar experimental protocols in cyclists confirm this hypothesis, as we detected a very similar TTE (3–4 min) at the power output associated with the $\dot{V}O_2$max.[12] Notwithstanding, the observed TTE at MAS is protocol dependent, and longer stages can result in lower MAS despite similar $\dot{V}O_2$max, which would be associated with longer TTE.

Although previous studies had already analyzed the TTE when exercising at the $\dot{V}O_2$max during running, cycling, rowing, or swimming,[5,6] a whole picture of the TTE when running at the wide range of intensities at which athletes habitually train and compete was lacking. To the best of our knowledge, the TTE when running at the RCP remained, to date, unknown. In the present study we found a TTE at the RCP ~11 minutes, which is overall in line with previous studies in cyclists. Specifically, our group and others have reported a TTE when pedaling at the RCP of ~11 to 20 minutes.[12,13,29] Regarding the MLSS, in the present study, we found a TTE of ~56. Other studies in runners have found a TTE at the MLSS ranging from ~35 min[10] to 70 to 80 minutes.[30–32] Of note, when comparing the present study in runners with the previous one by our research group in cyclists, conducted with the same experimental protocol, a slightly lower (4%) TTE can be observed when running compared with cycling at the RCP. This difference is amplified when running compared with cycling at the MLSS (57 vs 74 min). The reasons behind the reduced TTE when running compared with cycling particularly at the MLSS could be due to an increased metabolic, cardiovascular, and/or neuromuscular stress with the former.[33] However, a study by Faude et al[34] reported a TTE when cycling at the MLSS of ~50 minutes, which is similar to that observed in the present study for running; therefore, further research is warranted to elucidate the individual or methodological factors influencing TTE at a given intensity. It is also worth noting that, in line with previous studies in cycling,[12,30] we observed that RPE at the end of the TTE

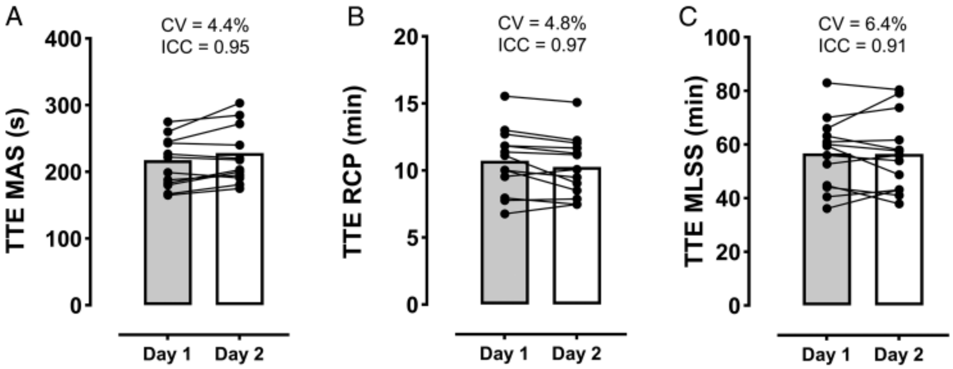

Figure 3 — Between-day differences in the TTE at the speed associated with the maximum oxygen uptake (MAS—Panel A), the RCP (Panel B), and the MLSS (Panel C). No significant differences were found. MAS indicates maximal aerobic speed; MLSS, maximal lactate steady state; RCP, respiratory compensation point; TTE, time to exhaustion test.

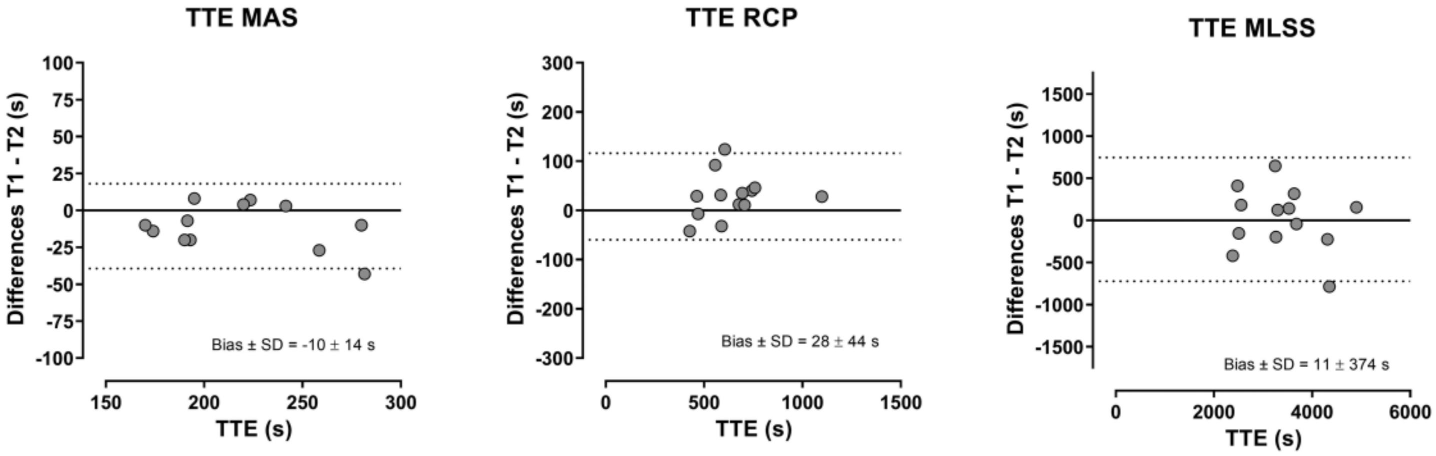

Figure 4 — Bland–Altman of the within-subject (ie, between-day) differences in the TTE at the speed associated with the maximum oxygen uptake (MAS, the RCP, and the MLSS. MAS indicates maximal aerobic speed; MLSS, maximal lactate steady state; RCP, respiratory compensation point; TTE, time to exhaustion test.

test at the MLSS was not maximal (~15 out of 20), as compared with the TTE tests at MAS and RCP, in which maximal values were observed (18–20 out of 20). It has been proposed that, whereas performance at intensities above the aerobic/anaerobic transition is conditioned by alterations at the physiological level (eg, acidosis), exhaustion at the MLSS occurs while physiological reserve capacity still exists.[30] Given that RPE is not maximal at the end of the test, further research is warranted to elucidate the determinants of fatigue when exercising at this intensity.

Our results also highlight a moderate between-subject variability (CV = 18%–27%) in the TTE when running at all physiological indicators. In the same line, previous studies in cyclists have also reported a large between-subject variability in the TTE for other indicators such as the RCP (eg, 28% for the RCP[13]), but the factors influencing this between-subject variability remain largely unknown. Billat et al[6] and Midgley et al[17] reported an inverse association between $\dot{V}O_2$max or MAS and the TTE at this indicator. In turn, in the present study, no association was found between the TTE at each physiological indicator and the speed at which these indicators were found, nor between the TTE and the $\dot{V}O_2$max. Thus, our results suggest that runners with a higher overall fitness (ie, higher $\dot{V}O_2$max, or higher speed associated with the $\dot{V}O_2$max, RCP or MLSS) do not necessarily have a higher or lower TTE, at least in the present sample—which was quite homogenous This suggests that classical physiological thresholds do represent the same degree of physiological stress (hormonal, metabolic, neuromuscular, and cardiovascular) during running. Therefore, despite these thresholds occurring at different running velocities among a group of trained athletes, the time that each runner can maintain that velocity is surprisingly similar. In the same line, a previous study[13] observed no associations between the TTE at the RCP and different fitness indicators in cyclists (eg, power output at RCP, $\dot{V}O_2$max). Further evidence is therefore warranted to confirm whether the tolerable exercise duration at a given relative intensity is dependent on other physiological indicators, or whether it can be considered as a separate indicator of fitness.

The observed between-subject differences in TTE at a given intensity might be in line with the concept of durability (ie, the ability to attenuate physiological distress when exercising at a given workload, or the ability to attenuate performance declines after a given work), which some authors have proposed could be a separate indicator of performance given it is not associated with other traditional indicators (eg, $\dot{V}O_2$max, RCP).[35,36] Although durability was not specifically assessed in the present study, the use of TTE at fixed relative intensities may relate to individual tolerance to sustained exercise.[37] In this regard, as recently discussed by Faude et al,[38] a lower durability (or physiological resilience) might result in an athlete starting a test at a given fixed intensity (eg, 100% MLSS), but finishing at a much higher relative intensity (eg, 120% MLSS), which would be likely associated with a lower TTE. Further research is therefore needed to confirm the association between durability/resilience and TTE at a given intensity.

Finally, it is worth noting that despite the moderate between-subject variability, we observed a high within-subject reliability (ie, low between-day variability) for the TTE when running at all physiological indicators. This is reflected by high ICC (≥.9), with the lowest values observed for the MLSS, which can be partly due to the greater length of the TTE (which might increase variability) and to potential sources of error during MLSS testing. This result might support the potential utility of TTE testing to monitor performance. With the help of a calibrated treadmill, or on the track using GPS and time signals a runner should be able to measure the TTE for a given running speed. This information could be useful for training prescription, allowing a deliberate control of what percentage of the TTE athletes are completing in their training routines when running at a given speed. Using a similar concept (ie, level of effort),[39] resistance training has evolved in recent years to an improved control and distribution of training loads. It is worth noting, however, that Faude et al[34] reported a much higher CV (24.6%) for the test–retest reliability of TTE when cycling at the MLSS and therefore the utility of this indicator to monitor performance should be confirmed in future studies.

Some limitations of the present study should be acknowledged. We analyzed a convenience sample of 13 well-trained athletes and therefore these findings should be confirmed in larger cohorts with varying performance levels. As mentioned above, the TTE observed here are protocol-dependent, and it is possible that different TTE are observed if MAS, RCP, or MLSS are determined using different procedures. Moreover, we did not assess TTE at other physiological indicators, such as the VT or critical power, which could have provided greater insights on the topic. However, this was largely unfeasible due to the numerous tests already included in the study. Finally, it would have been interesting to analyze the association of TTE at a given intensity and other markers of durability (eg, performance decline after a given work, or physiological decoupling at a given workload) or actual race performance.

Conclusions

We assessed the TTE at running speeds associated with the most common physiological thresholds used to predict endurance performance (ie, MLSS, RCP and $\dot{V}O_2$max). In this sample of well-trained runners, these TTE were highly reproducible, and although moderate between-subject variability was observed, this was not due to differences in traditional fitness indicators. These findings suggest that the TTE could be used by runners to monitor changes in performance, as well as to design training bouts at a given percentage of the TTE for that running speed.

Practical Applications

The present findings show that TTE at velocities corresponding to $\dot{V}O_2$max, RCP, and MLSS is a highly reproducible metric and a practical marker of exercise tolerance in trained runners. Practitioners can use TTE to track longitudinal changes in an athlete's capacity to sustain a given relative intensity, thereby complementing traditional physiological thresholds that do not predict TTE. Furthermore, TTE can directly inform training prescription by defining interval durations as a percentage of an individual's TTE at a target pace (eg, 60%–90% TTE) to optimize load management and specificity. Given the high within-subject reliability observed, small changes in TTE at a fixed speed are likely to represent meaningful adaptations (power–velocity profile) and can therefore guide training progression and recovery decisions.

Acknowledgments

Valenzuela is supported by a postdoctoral contract granted by Agencia Estatal de Investigación (RYC2024-048275-I) and University of Castilla-La Mancha and Fondo Social Europeo Plus (FSE+) (2024-UNIVERS-12850). Martínez-Cava is partially funded by CAR Region de Murcia (ID:39782/2024). Higueras-Liébana and Buendía-Romero received funding from Centro de Investigación Biomédica en Red sobre Fragilidad y Envejecimiento Saludable (CB16/10/00477), Plan Propio de Investigación of the University of Castilla-La Mancha and Fondo Europeo de Desarrollo Regional funds from the European Union (2025-GRIN-38408). Buendía-Romero is supported by a postdoctoral contract granted by Spanish Ministry of Science and Innovation (JDC2023-052593-I, funded by MCIU/AEI/10.13039/501100011033).

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