ORIGINAL ARTICLE

Functional fitness characteristics of ultramarathon runners specialized in 50 km and 100 km distances

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim Ultramarathon running represents a demanding form of endurance activity characterized by prolonged duration and substantial physiological load. Despite the application of various approaches to performance assessment, the relative contribution of different physiological characteristics to race performance across standard ultramarathon distances remains a subject of practical interest. The aim of this study was to identify and directly compare the functional fitness characteristics associated with race performance at 50 km and 100 km distances.

Material and Methods Thirty-one experienced ultramarathon runners performed an incremental treadmill test to volitional exhaustion to determine maximal oxygen uptake (VO_2max), aerobic threshold (AeT), anaerobic threshold (AnT), and the corresponding running speeds and respiratory exchange ratio (RER). Body mass index (BMI) was also assessed. Correlation and linear regression analyses were used to examine the relationships between physiological variables and race performance.

Results The relationships between physiological variables and race performance differed between the two distances. At 50 km, performance was primarily associated with aerobic power–related variables, including VO_2max ($r = 0.79$), running speed at VO_2max ($r = 0.82$), and body mass index ($r = -0.82$). At 100 km, stronger associations were observed for threshold-related variables, particularly running speeds at AeT ($r = 0.78$) and AnT ($r = 0.76$), while the association with BMI was weaker ($r = -0.52$). Average race speed corresponded to 71.7% of vVO_2max at 50 km and 62.5% at 100 km.

Conclusions The findings indicate a distance-dependent shift in physiological characteristics associated with ultramarathon performance. Shorter ultramarathon distances are more closely associated with aerobic power–related variables, whereas longer distances show stronger associations with threshold-related characteristics. These results support the concept of distance-specific physiological profiles in ultramarathon running. From a practical perspective, training approaches may benefit from accounting for these differences, with relatively greater emphasis on higher-intensity variables at shorter distances and threshold-related characteristics at longer distances.

Keywords: ultramarathon, VO_2max, aerobic threshold, anaerobic threshold, running performance, 50 km, 100 km

Introduction

Ultramarathon running represents one of the most demanding forms of endurance activity, characterized by prolonged duration and high physiological strain. Performance in such events depends on the interaction of multiple factors, including aerobic capacity, metabolic efficiency, and fatigue resistance. The complexity of these interactions, combined with variability in race distances and conditions, makes ultramarathon performance a multifaceted phenomenon requiring detailed analysis.

An ultramarathon is defined as a running event involving distances longer than 42195 m [1] or lasting more than 6 hours [2]. Ultramarathon competitions are gaining increasing popularity both in Ukraine and worldwide. The number of ultramarathon finishers has increased more than 14-fold, from 37.5 thousand to 535 thousand between 1992 and 2022 [3]. The official disciplines in which the International Association of Ultrarunners registers world records include 50 km, 50 miles, 100 km, 100 miles, 6 hours, 12 hours, 24 hours, 48 hours, and 6 days [4]. Among these, the 50 km and 100 km distances are of particular importance, as world records in these disciplines are also ratified by World Athletics, and they represent some of the most commonly contested ultramarathon events. Over the past decade (2012–2022), the number of 100 km competitions worldwide has doubled (from 259 to 529), while the number of finishers reached 46,313 in 2022, representing a 24.2% increase compared to 2012 [5]. In parallel, performance levels have improved, as reflected by decreasing finishing times [6]. For example, the average speed of the top 100 finishers at the World 100 km Championships increased from 13.23 km/h in 2012 to 13.85 km/h in 2022 [5].

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Previous studies have demonstrated relationships between ultramarathon performance and variables such as maximal oxygen consumption (VO_2max), velocity at VO_2max, anaerobic threshold, and oxygen consumption at race pace [7, 8, 9, 10, 11]. However, these findings are largely derived from studies conducted at different distances and under varying conditions. For example, Sabater-Pastor et al. [12] examined a 166 km cross-country race, O'Loughlin et al. [11] analyzed a 62 km event, and Howe et al. [10] investigated an 80.5 km treadmill ultramarathon.

Ultramarathon disciplines encompass a wide range of distances and competition formats, which may require different physiological profiles for optimal performance. This is supported by the findings of Berger et al. [13], who demonstrated that oxygen consumption at competitive speed varies substantially depending on race duration and distance (e.g., 65–70% of VO_2max for 60 km versus approximately 40% for 24-hour events). These differences suggest that treating ultramarathons as a homogeneous category may obscure important distance-specific physiological characteristics.

Analysis of research findings has shown that ultramarathon performance is associated with a range of physiological variables, including aerobic capacity, threshold characteristics, and running economy. Researchers emphasize that the contribution of these factors may vary depending on race conditions, duration, and distance, reflecting the complex and multifactorial nature of ultramarathon performance. At the same time, the variability of studied distances and methodological approaches complicates the interpretation and direct comparison of existing results. This lack of consistency in the assessment of performance determinants continues to limit the identification of distance-specific physiological profiles in ultramarathon running.

Thus, despite the popularity of 50 km and 100 km races, existing studies typically examine ultramarathon performance determinants either across heterogeneous distances or within a single race format, without directly comparing standard ultramarathon distances under the same experimental conditions. As a result, it remains unclear whether the relative contribution of key physiological variables differs systematically between commonly practiced distances such as 50 km and 100 km.

It is hypothesized that performance determinants differ systematically between distances, such that 50 km performance is primarily influenced by aerobic power (VO_2max-related variables), whereas 100 km performance is more strongly associated with aerobic threshold characteristics and metabolic efficiency.

The aim of this study was to identify and directly compare the functional fitness characteristics associated with race performance at 50 km and 100 km distances.

Materials and Methods

Participants

A cross-sectional study involved 31 experienced ultramarathon runners who competed at distances of 50 km and 100 km. Participants were recruited through targeted invitations distributed via coaching networks and running communities. Eligibility was verified based on self-reported training history and confirmed participation in ultramarathon events (50 km and/or 100 km) within previous competitive seasons. Additional inclusion criteria included more than 3 years of regular endurance training and absence of acute injury at the time of testing.

The term "experienced" reflects a wide spectrum of performance levels, which was necessary for reliable correlation analysis. The data of 19 athletes (men, age 37 ± 4 years, body mass index 23 ± 2, VO_2max 57.0 ± 6.5 $ml \cdot min^{-1}$) were used to analyze performance at the 50 km distance, whereas the data of 21 athletes (men, age 38 ± 6 years, body mass index 23 ± 2, maximum oxygen consumption 57.3 ± 6.0 $ml \cdot min^{-1}$) were used for the 100 km distance.

The 50 km (n = 19) and 100 km (n = 21) groups partially overlapped, as some athletes participated in both distances. This reflects real competition participation patterns; therefore, datasets were analyzed separately for each distance to identify distance-specific performance determinants rather than to perform direct between-group comparisons.

The study procedures were approved by the Scientific Council of the National University of Ukraine on Physical Education and Sport (Registration No. 0121U108193) and conducted in accordance with the Declaration of Helsinki. All participants provided written informed consent prior to testing.

Research Design

Participants performed an incremental step test using an ergospirometric system (VIASYS LE 300 CE treadmill, Oxycon Pro JAEGER analyzer, Polar H10 chest pulse monitor, Lactate Plus lactate meter). Prior to each test, the gas analysis system was calibrated according to the manufacturer's guidelines using standard calibration gases, and the accuracy of treadmill speed was verified before each testing session. All tests were conducted under standardized laboratory conditions (temperature 20–22°C, relative humidity 40–60%). Standardized pre-test conditions included 48 hours of rest (no heavy exercise), 3 hours of fasting, and abstinence from stimulants (caffeine). The test protocol started at 8 km/h with increments of 1 km/h every 2 minutes until volitional exhaustion. Gas exchange variables were recorded continuously throughout the test.

The following variables were determined: maximal oxygen consumption (VO_2max), oxygen consumption at aerobic threshold (VO_2 at AeT), oxygen consumption at anaerobic threshold (VO_2 at AnT), running speed and respiratory exchange ratio (RER) at VO_2max, aerobic threshold, and anaerobic threshold. Data processing was performed using Labmanager v5.3.0 software. Body composition was assessed using a Tanita BC 545N analyzer, and body mass index was calculated. Metabolic thresholds were identified using standard ventilatory criteria. The aerobic threshold (AeT) was defined as the point at which the ventilatory equivalent for oxygen (VE/VO2) began to increase without a concurrent rise in VE/VCO2. The anaerobic threshold (AnT) was defined as the point of a secondary non-linear increase in ventilation (VE) accompanied by a consistent rise in VE/VCO2 (respiratory compensation point). Threshold determination was performed by experienced investigators. In cases of ambiguity, threshold values were verified through repeated inspection of ventilatory curves to ensure consistency.

Statistical analysis

All statistical analyses were performed using Microsoft Excel and Statistics Kingdom software. Data are presented as mean ± standard deviation. The normality of data distribution was assessed using the Shapiro–Wilk test. Depending on distribution characteristics, Pearson's or Spearman's correlation coefficients were used to evaluate relationships between functional fitness variables and race performance at 50 km and 100 km distances.

To assess the contribution of physiological predictors, linear regression analyses were conducted. Initially, univariate regression models were applied to examine the independent association of each variable with race performance. Subsequently, multivariate regression models were constructed to identify the most relevant predictors while accounting for interrelationships between variables. Predictor selection for multivariate models was based on statistical significance in univariate analysis and physiological relevance. Multicollinearity was assessed using correlation matrices, and highly correlated variables were not included simultaneously in the same model. Model assumptions, including linearity, normality of residuals, and homoscedasticity, were evaluated using residual diagnostics. The coefficient of determination (R^2) was used to estimate the explanatory power of each model. Statistical significance was set at $p < 0.05$.

Given the number of tested variables, the analysis was considered exploratory. Therefore, no formal correction for multiple comparisons was applied; however, the results were interpreted with caution, taking into account the increased risk of Type I error. Outliers were identified based on residual analysis and excluded only when clearly deviating from model assumptions. The number of excluded observations, if any, was minimal and did not affect the overall trends.

A partial overlap between the 50 km and 100 km datasets was present, as some participants contributed data to both distances. To address this, all analyses were conducted separately for each distance, and no direct statistical comparisons between groups were performed. Each dataset was treated as an independent observational subset in accordance with the exploratory design of the study.

Results

The main functional fitness indices of the athletes, obtained from the incremental test and body composition analysis, as well as race performance and competitive speed for the 50 km and 100 km distances, are presented in Table 1.

As shown in Table 1, athletes competing at 50 km demonstrated higher average running speed compared to those competing at 100 km, despite similar values of VO_2max and body mass index. At the 50 km distance, faster athletes (finishing time < 4 h) maintained running speeds exceeding their aerobic threshold, whereas slower athletes performed below this level. In contrast, at the 100 km distance, competitive speed remained below the aerobic threshold regardless of performance level. On average, the difference between aerobic threshold speed and race speed at 100 km was 12.7% (1.6 km·h^{-1}). Competitive speed corresponded to 62.5% of vVO_2max for the 100 km distance and 71.7% for the 50 km distance.

Correlation analysis revealed differences in the relationships between functional fitness characteristics and race performance at the 50 km and 100 km distances (Table 2).

As shown in Table 2, the pattern of relationships between physiological variables and race performance differed between the 50 km and 100 km distances. At the 50 km distance, performance was primarily associated with aerobic power and threshold-related variables, including VO_2max ($r = 0.79$), vVO_2max ($r = 0.82$), and velocities at anaerobic and aerobic thresholds ($r \approx 0.69–0.75$). Body mass index showed a strong negative association with performance ($r = -0.82$), while no meaningful relationships were observed for respiratory exchange ratio variables. At the 100 km distance, the pattern shifted toward a greater role of threshold-related variables, particularly velocities at aerobic and anaerobic thresholds ($r \approx 0.76–0.78$). Running velocity at VO_2max remained significantly associated with performance ($r = 0.72$), whereas VO_2max itself was not. In addition, respiratory exchange ratio at VO_2max showed a moderate positive relationship ($r = 0.57$). Body mass index

Table 1. Functional fitness indices of experienced ultramarathon runners

Variable	50 km (n = 19, age 37 ± 4 years)	100 km (n = 21, age 38 ± 6 years)
Race performance (h:min:s)	3:59:15 ± 00:46:33	09:23:12 ± 01:19:29
Average speed ($km \cdot h^{-1}$)	12.9 ± 2.0	10.9 ± 1.5
Body mass index	23 ± 2	23 ± 2
VO_2max ($ml \cdot min^{-1}$)	57.0 ± 6.5	57.3 ± 6.0
vVO_2max ($km \cdot h^{-1}$)	17.6 ± 1.6	17.7 ± 1.4
RER at VO_2max	1.08 ± 0.05	1.06 ± 0.09
VO_2 at AnT ($ml \cdot min^{-1}$)	50.0 ± 5.9	50.0 ± 6.0
vAnT ($km \cdot h^{-1}$)	14.9 ± 1.5	14.8 ± 1.5
RER at AnT	0.98 ± 0.05	0.94 ± 0.08
VO_2 at AeT ($ml \cdot min^{-1}$)	43.1 ± 5.0	41.7 ± 4.8
vAeT ($km \cdot h^{-1}$)	12.8 ± 1.4	12.6 ± 1.8
RER at AeT	0.91 ± 0.06	0.88 ± 0.08

Note: VO_2max – maximal oxygen consumption; vVO_2max – running speed at VO_2max; AnT – anaerobic threshold; AeT – aerobic threshold; RER – respiratory exchange ratio. Values are presented as mean ± standard deviation.

Table 2. Correlation between functional fitness characteristics and race performance at 50 km and 100 km distances

Variable	50 km (n = 19) r (p-value)	Interpretation	100 km (n = 21) r (p-value)	Interpretation
Age	0.079 ($p = 0.749$)	No significant relationship	-0.403 ($p = 0.070$)	No significant relationship
Body mass index	0.817 ($p < 0.001$)	Significant	-0.516 ($p = 0.017$)	Moderate
VO_2max	0.793 ($p < 0.001$)	Significant	0.414 ($p = 0.070$)	No significant relationship
vVO_2max	0.819 ($p < 0.001$)	Significant	0.720 ($p < 0.001$)	Significant
RER at VO_2max	0.065 ($p = 0.792$)	No significant relationship	0.567 ($p = 0.014$)	Significant
VO_2 at AnT	0.732 ($p < 0.001$)	Significant	0.432 ($p = 0.057$)	No significant relationship
RER at AnT	0.111 ($p = 0.650$)	No significant relationship	0.370 ($p = 0.131$)	No significant relationship
vAnT	0.749 ($p < 0.001$)	Significant	0.757 ($p < 0.001$)	Significant
VO_2 at AeT	0.672 ($p = 0.002$)	Significant	0.717 ($p < 0.001$)	Significant
RER at AeT	0.000 ($p = 0.999$)	No significant relationship	0.310 ($p = 0.210$)	No significant relationship
vAeT	0.690 ($p = 0.001$)	Significant	0.781 ($p < 0.001$)	Significant

Note: VO_2max – maximal oxygen consumption; vVO_2max – running speed at VO_2max; AnT – anaerobic threshold; AeT – aerobic threshold; RER – respiratory exchange ratio. r – correlation coefficient. Interpretation is based on statistical significance ($p < 0.05$).

demonstrated a moderate negative association ($r = -0.52$). The results indicate a distance-dependent shift from aerobic power–related variables at 50 km toward greater importance of threshold and efficiency-related characteristics at 100 km.

The results of the regression analysis, including coefficients of determination (R^2), demonstrated differences in the strength of associations between functional fitness characteristics and race performance depending on the competitive distance (Table 3).

As shown in Table 3, the strength of associations between functional fitness variables and race performance differed between the 50 km and 100 km distances. At the 50 km distance, performance was primarily associated with aerobic power–related variables, particularly running velocity at VO_2max and body mass index (both $R^2 \approx 0.67$). Threshold-related variables also showed consistent but slightly weaker associations. At the 100 km distance, the pattern shifted toward a greater role of threshold-related characteristics, with the strongest associations observed for running velocities at aerobic and anaerobic thresholds ($R^2 \approx 0.57–0.61$). Additional variables demonstrated moderate associations, while aerobic power (VO_2max) was not associated with performance.

The results indicate a distance-dependent shift from aerobic power–related characteristics at 50 km toward greater importance of threshold-

Table 3. Association between functional fitness characteristics and race performance at 50 km and 100 km distances (regression analysis)

Variable	50 km R^2	p-value	100 km R^2	p-value
Body mass index	0.67	< 0.001	0.27	0.017
VO_2max	0.63	< 0.001	–	–
vVO_2max	0.67	< 0.001	0.52	< 0.001
RER at VO_2max	–	–	0.32	0.014
VO_2 at AnT	0.54	< 0.001	–	–
vAnT	0.56	< 0.001	0.57	< 0.001
VO_2 at AeT	0.45	0.002	0.44	0.001
vAeT	0.48	0.001	0.61	< 0.001

Note: VO_2max – maximal oxygen consumption; vVO_2max – running speed at VO_2max; AnT – anaerobic threshold; AeT – aerobic threshold; RER – respiratory exchange ratio. R^2 – coefficient of determination. Values represent results of univariate linear regression models. "–" indicates no statistically significant association.

related variables at 100 km. These findings highlight the importance of considering distance-specific physiological profiles when analyzing ultramarathon performance.

Discussion

The present study provides a direct comparison of physiological performance-related variables between two standard ultramarathon distances within a single cohort using a unified testing protocol. In contrast to previous studies that examined isolated distances or heterogeneous race formats [9, 10, 14, 15], the findings indicate that the relative contribution of aerobic power and threshold-related variables differs depending on race distance.

The results show that functional fitness characteristics associated with race performance differ between the 50 km and 100 km distances. In particular, VO_2max was associated with performance at the 50 km distance but not at 100 km, whereas running velocity at VO_2max was associated with performance at both distances. These findings are consistent with previous research. A systematic review by Garbisu-Hualde [14] reported associations between VO_2max, vVO_2max, and ultramarathon performance across distances ranging from 42.2 km to 101 km; however, distance-specific differences in the contribution of these variables were not addressed. Fornasiero et al. [9] demonstrated a relationship between VO_2max and performance in a 65 km mountain race, while Balducci et al. [15] reported a significant association between vVO_2max and performance in a 75 km mountain ultramarathon. In contrast, Howe et al. [10], in a study of 80.5 km treadmill running, reported that VO_2max was not associated with performance, and highlighted running economy as a relevant factor.

In contrast to these studies [9, 10, 14, 15], the present results indicate that the role of VO_2max decreases with increasing race distance, while velocity-based variables remain consistently associated with performance. This suggests that treating ultramarathons as a homogeneous category may obscure distance-specific physiological differences. The observed associations between body mass index and race performance at both 50 km and 100 km distances are consistent with previous findings. Anthropometric characteristics, including body mass index, have been reported as relevant factors influencing endurance performance. In ultramarathon running, lower body mass and favorable body composition are associated with improved performance, likely due to reduced energy cost of locomotion and enhanced metabolic efficiency during prolonged exercise [16].

Hoffman et al. [17, 18] reported associations between body composition characteristics, including body mass index and fat mass, and ultramarathon performance. Similarly, Rüst et al. [19] demonstrated that body mass index and body fat were associated with performance in 100 km running. O'Loughlin et al. [11] found that body mass index was associated with finishing time in men, but not in women, during a 62 km ultramarathon. According to Denadai et al. [8], running speed during ultramarathon competitions typically corresponds to 50–70% of that at VO_2max, while oxygen consumption during competition ranges from 45% to 60% of VO_2max. These findings are consistent with the present results, where competitive speed corresponded to approximately 62.5% of vVO_2max at 100 km and 71.7% at 50 km.

The respiratory exchange ratio (RER) was also examined in relation to ultramarathon performance. This parameter reflects the ratio of carbon dioxide production to oxygen consumption and is commonly used as an indirect indicator of substrate utilization, with higher values associated with greater carbohydrate use and lower values with increased fat oxidation [20, 21].

Previous studies have suggested that RER may be related to metabolic characteristics relevant to endurance performance. For example, Tanji and Nabekura [22] reported smaller changes in RER with increasing speed in faster runners compared to slower ones. In addition, RER has been discussed in relation to aerobic and anaerobic metabolic responses in trained athletes [23].

In the present study, no association was observed between RER and performance at the 50 km distance, whereas a significant relationship was identified between RER at VO_2max and performance at 100 km. Higher RER values at VO_2max were associated with higher running speed at this distance. This observation appears inconsistent with the commonly emphasized role of fat oxidation in ultra-endurance performance. However, the interpretation of RER in this context remains complex, as it reflects multiple physiological processes, including substrate utilization and buffering capacity. Therefore, the role of RER in relation to performance at different ultramarathon distances requires further clarification.

The present results also indicate that oxygen consumption and running velocity at aerobic and anaerobic thresholds are associated with race performance at both 50 km and 100 km distances. These variables have received limited attention in previous ultramarathon studies, particularly in the context of direct comparison between standard distances. The observed relationships suggest that threshold-related characteristics may contribute to performance differentiation across ultramarathon distances and should be considered alongside aerobic power variables when analyzing performance profiles.

Limitations and Future Research

The findings of this study should be interpreted in light of several limitations. A partial overlap of participants between the 50 km and 100 km groups may introduce non-independence of observations. Although analyses were conducted separately for each distance, this factor should be considered when interpreting the results. In addition, the observational and exploratory design, the interrelated nature of physiological variables, and the absence of full multivariate control for potential confounders limit the strength of inferences. The lack of correction for multiple comparisons also increases the risk of Type I error. Future research may further examine sex-specific differences in performance determinants, the role of threshold-related variables across different ultramarathon formats, and the contribution of metabolic indicators such as RER to performance outcomes.

Practical Implications

The results suggest that training approaches in ultramarathon running may benefit from considering distance-specific physiological profiles. For shorter ultramarathon distances (e.g., 50 km), aerobic power–related variables, including running velocity at VO_2max, appear to be more strongly associated with performance. In contrast, for longer distances (e.g., 100 km), threshold-related variables, particularly running velocities at aerobic and anaerobic thresholds, show stronger associations. These findings may be taken into account when structuring training programs, with consideration given to the relative emphasis on high-intensity and submaximal training components depending on race distance.

Conclusions

The present study demonstrates that physiological characteristics associated with ultramarathon performance differ between standard distances, indicating that 50 km and 100 km events should not be considered as a single homogeneous category. The findings suggest a distance-dependent shift in the relative role of physiological variables, with greater relevance of aerobic power–related characteristics at shorter ultramarathon distances and increased importance of threshold-related variables at longer distances. These observations support the concept of distance-specific physiological profiles in ultramarathon running and highlight the need to consider these differences when analyzing performance. From an applied perspective, the results suggest that training approaches and monitoring strategies may benefit from accounting for distance-specific demands, with emphasis on aerobic power and higher-intensity variables for shorter distances and threshold-related characteristics for longer distances.

Conflict of Interest

The authors declare that they have no conflicts of interest.

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