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ORIGINAL INVESTIGATION

Physiological Determinants of Ultramarathon Trail-Running Performance

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Context: The physiological determinants of ultramarathon success have rarely been assessed and likely differ in their contributions to performance as race distance increases. ***Purpose:*** To examine predictors of performance in athletes who completed either a 50-, 80-, or 160-km trail race over a 20-km loop course on the same day. ***Methods:*** Measures of running history, aerobic fitness, running economy, body mass loss, hematocrit alterations, age, and cardiovascular health were examined in relation to race-day performance. Performance was defined as the percentage difference from the winning time at a given race distance, with 0% representing the fastest possible time. ***Results:*** In the 50-km race, training volumes, cardiovascular health, aerobic fitness, and a greater loss of body mass during the race were all related to better performance (all $P < .05$). Using multiple linear regression, peak velocity achieved in the maximal oxygen uptake test ($\beta = -11.7$, $P = .002$) and baseline blood pressure ($\beta = 3.1$, $P = .007$) were the best performance predictors for the men's 50-km race ($r = .98$, $r^2 = .96$, $P < .001$), while peak velocity achieved in the maximal oxygen uptake test ($\beta = -13.6$, $P = .001$) and loss of body mass ($\beta = 12.8$, $P = .03$) were the best predictors for women ($r = .94$, $r^2 = .87$, $P = .001$). In the 80-km race, only peak velocity achieved in the maximal oxygen uptake test predicted performance ($\beta = -20.3$, $r = .88$, $r^2 = .78$, $P < .001$). In the 160-km race, there were no significant performance determinants. ***Conclusions:*** While classic determinants of running performance, including cardiovascular health and running fitness, predict 50-km trail-running success, performance in longer-distance races appears to be less influenced by such physiological parameters.

Keywords: prolonged exercise, performance predictors, dehydration, running economy, fitness

Predicting ultramarathon running performance is a unique challenge, as ultramarathon races can vary greatly in distance, duration, and physiological demand. Ultramarathon running races range from any race exceeding the marathon distance (>42.2 km) to multiday events and commonly include diverse terrains and environmental conditions.[1,2] This results in vastly different physiological requirements between races and can make comparison across races challenging. The demographic of athletes racing ultramarathons is typically older than those who run shorter distances and is composed primarily of masters and recreational participants, rather than elite athletes.[1] Proposed contributors to successful ultramarathon performance include high aerobic fitness,[3,4] an ability to mitigate injuries,[5] avoidance of gastrointestinal issues,[6] delays of fatigue,[2] and psychological fortitude.[3]

The physiological determinants of running performance in standard distances from 5000 m to the marathon have been highly investigated and primarily include measures of aerobic fitness such as maximal oxygen uptake (VO_2max), lactate threshold or the percentage of sustainable VO_2max, and running economy.[7] Aerobic fitness seems likely to be a determinant of ultramarathon performance as well, as lactate threshold and VO_2max are related to distance covered in a 24-hour treadmill run,[4] and peak treadmill running velocity achieved during an incremental test is the best laboratory predictor of performance for races ≤90 km.[8] Lower body mass index (BMI) and body fat percentage are typically related to improved endurance running performance[9,10]; however, the correlation of BMI and ultramarathon performance is equivocal,[6,9,11,12] and performance is more strongly related to training volumes than BMI.[9,12] Excessive dehydration has been shown to negatively alter endurance exercise performance,[13] yet faster marathon runners typically lose more weight over the course of a race than slower runners, and a loss of upwards of 3% of body mass has been demonstrated in runners who completed marathons in <3 hours.[14] Loss of body mass following 161-km races is similar to that of marathons (~2%)[15]; however, there is only a weak relationship to faster racing times.[16] Furthermore, in contrast to shorter distance running, body mass loss cannot be solely attributed to dehydration in ultramarathon,[17] which may complicate the relationship between body mass loss and performance. Finally, while peak performance in the marathon is typically achieved around the age of 30 years, the age of the fastest 160-km runners worldwide is approximately 37 years for men and 39 years for women,[18] with experience being a greater determinant of success than age.[18] This may further suggest a shift in the importance of certain physiological parameters, such as aerobic fitness, which decreases with age.

To date, a comparison of the physiological determinants of performance across increasing ultramarathon race distances, and within similar racing conditions, has not been performed. The objective of this study was to examine whether common indicators of running performance could be used to predict performance in athletes who raced either a 50-, 80-, or 160-km ultramarathon, on the same day and over a common course.

Methods

Experimental Design

Fifty-one recreational runners who were registered in the Sulphur Springs trail races (Ancaster, Canada) for the 50-, 80-, or 160-km distances were recruited via e-mail for this cross-sectional study. The race was composed of 20-km hilly trail loops (~620 m of cumulative elevation gain per loop). Participants were all healthy

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and nonsmoking individuals between the ages of 18 and 60 years and provided written informed consent prior to testing. In the month prior to the race (mean 12 [7] d prior to race day), participants underwent baseline testing, including a training and racing history questionnaire, basic anthropometrics, resting blood pressure, heart rate (HR), and HR variability (HRV), a venous blood draw to assess hematocrit, and an incremental running test to exhaustion. Participants were asked to refrain from caffeine and heavy meals for ≥3 hours, drugs and alcohol for ≥24 hours, and intense exercise for ≥48 hours prior to baseline testing. On race morning, all athletes were weighed immediately prior to racing. Immediately following the race, postrace weight and hematocrit measurements were collected to assess dehydration status.

The study was carried out under approval of the University of Guelph ethics board and in accordance with the Declaration of Helsinki and was part of a larger study on ultramarathons and cardiovascular fatigue.[19,20]

Training and Racing History Questionnaire

In a written questionnaire, athletes were asked to report on their previous month of training, including how many hours and kilometers per week they ran, how many hours of strength or resistance training they underwent each week, and how many additional hours were spent on cross-training. They were also asked to report the kilometers per week completed on average in the past year. Finally, athletes reported the number of years of past endurance run training and how many marathons and ultramarathons they had previously completed.

Cardiovascular Health

Age, height, and body mass were recorded. Supine blood pressure was taken in triplicate using an automated oscillometric device (BpTRU, VSM Medical, Vancouver, BC, Canada) once the participant was relaxed (~1 to 2 min following positioning). The first recording was discarded, and the remaining 2 were averaged. Following a minimum of 5 minutes of quiet rest, a 4-minute recording of HRV using a SphygmoCor CPVH single-lead ECG (AtCor Medical Ltd, NSW, Australia) was collected during spontaneous breathing. Mean resting HR, the natural log of the square root of the mean of successive differences, and log of the square root of the mean of successive differences divided by HR were selected as the measures of interest, as they provide reliable measures of parasympathetic activity over a short time frame.[21]

Aerobic Fitness and Running Economy

Following resting measures, an incremental running test to volitional fatigue, with measures of indirect calorimetry, was performed (HP Cosmos Treadmill, Traunstein, Germany, and Cosmed Quark CPET metabolic cart, Rome, Italy) to determine VO_2max, ventilatory thresholds, and steady-state running economy. Participants completed three 3-minute submaximal stages at 1% grade to simulate outdoor running.[22] Paces were increased by 0.8 kph (0.5 mph) per stage from what was estimated to be a sustainable steady pace for the individual. The initial velocity was chosen after discussing the protocol with the participant and was often at a pace around or just below the individual's half-marathon pace (ranging from 8.0 to 15.3 kph). This ensured that by the end of the third stage, all participants had surpassed their first ventilatory threshold. Following the 3 submaximal stages, speed was increased each minute by 0.8 kph or 1% incline per the participant's choice, until volitional exhaustion. The choice to increase running speed or incline at the end of the test was designed so that those athletes unfamiliar with running at faster velocities could still achieve VO_2max. Athletes were not instructed to stop upon reaching a plateau in oxygen consumption, and the highest VO_2 value achieved using a 30-second rolling average was taken as maximal (VO_2max). Peak velocity was recorded as the highest velocity achieved during the maximal test if the treadmill incline was kept at 1% or was calculated as peak velocity = max velocity + (% grade × 0.2 kph).[23] Ventilatory thresholds were determined as previously described by Pallarés et al.[24]

Running economy was assessed as both oxygen cost (milliliter per kilogram) and caloric unit cost (kilocalorie per kilogram) per km in the last minute of the 3-minute running stage prior to the first ventilatory threshold[25] at a 1% treadmill grade. As such, while the velocities of running were not the same across participants, the relative intensity of running was, and, mathematically, running velocity was not included in the calculation.[25]

Fluid Alterations and Body Mass

Body mass was assessed directly prior to the race start on a standing scale positioned on a firm platform, and postrace mass was taken immediately following the races on the same scale. Brachial venipuncture was performed to collect a 10 mL sample for blood analysis in a related study,[19] with hematocrit assessed onsite by sampling from the vacutainer and using a microcapillary reader (Damon/IEC Division, Needham Heights, MA).

Statistical Analysis

Race performance was determined as percentage difference of winning time, accounting for race distance and sex ([subject time − winning time]/[winning time] × 100). Thus, the best performance would be noted as 0% different from winning time. Statistical analysis was performed using Statistical Package for the Social Sciences software (SPSS version 25; IBM Corp, Armonk, NY). Data were assessed for normality using the Shapiro–Wilk test. Between-race group analysis and finisher to nonfinisher analysis was assessed via 1-way analysis of variance with Bonferroni corrections for post hoc testing. Basic correlation matrix analyses were used to compare race distance performances with all outcome variables. Finally, stepwise multivariable linear regression was performed to determine predictors of performance for finishers of each race distance. To control for collinearity, the variable with the strongest relationship to performance was chosen from corelated variables. Sex-related differences were only examined in the 50-km race due to inadequate female representation in the other distances.

Results

Performance

Race times and percentage of winning time are presented in Figure 1. Mean finishing time for 50 km was 6.2 (2.3) hours for men and 6.4 (1.5) hours for women. The 80- and 160-km finishing times were 11.6 (1.8) and 25.2 (3.6) hours, respectively.

Subject Characteristics

All subjects were assessed postrace; therefore, data from all race starters (including nonfinishers) are presented in Table 1. The only

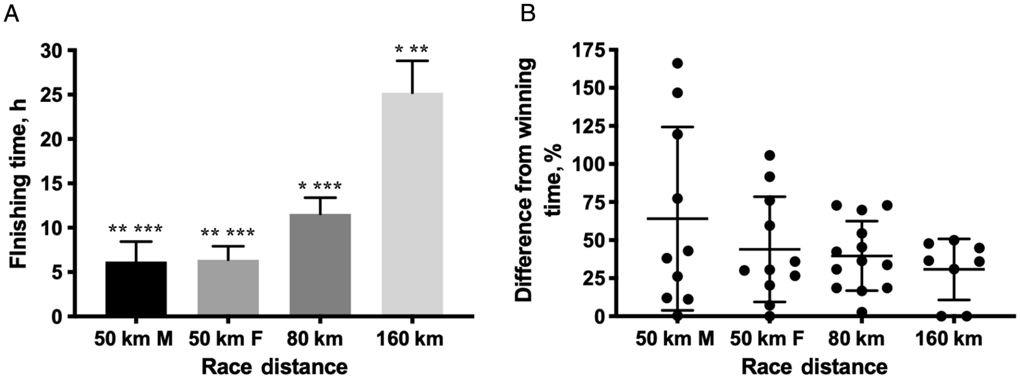

Figure 1 — Finishing time (A) and percentage difference from winning time (B) across 50-km male (M), female (F), 80-km mixed-sex and 160-km mixed-sex trail-running races. Brackets and horizontal bars in (B) represent mean (SD), with dots as individual data. **P* < .0001 from 50-km races. ***P* < .0001 from 80-km race. ****P* < .0001 from 160-km race.

Table 1 Baseline Subject Characteristics, Running Fitness, and Training History of 50-, 80-, and 160-km Ultramarathon Finishers and Nonfinishers of All Distances

	50 km	80 km	160 km	Nonfinishers (all distances)
Baseline characteristics				
Number of participants (sex)	21 (M:10, F:11)	13 (M:9, F:4)	8 (M:6, F:2)	9 (M:8, F:1)
Age, y	40 (10)	45 (9)	45 (10)	44 (11)
BMI, kg/m^2	24.1 (3.6)	24.0 (3.3)	24.1 (2.3)	24.3 (2.7)
Resting HR, beats/min	55 (8)	56 (7)	52 (8)	56 (8)
Mean arterial pressure, mm Hg	91 (9)	95 (8)	94 (5)	105 (18)***
RMSSD, ms	62.6 (39.0)	58.2 (39.1)	53.2 (23.5)	72.5 (54.9)
RMSSD/HR, a.u.	1.2 (0.9)	1.1 (0.9)	1.1 (0.6)	1.3 (1.5)
Aerobic fitness and running economy				
VO_2max, mL/kg/min	49.8 (10.3)	48.0 (3.8)	53.8 (8.3)	48.5 (8)
Peak velocity in GXT, kph	14.7 (2.9)	14.8 (1.0)	15.6 (2.2)	14.6 (1.6)
Oxygen cost, mL/kg/km	216.5 (21.6)	203.4 (11.0)	206.6 (14.1)	204.8 (28.6)
Caloric cost, kcal/kg/km	1.04 (0.12)	1.04 (0.16)	1.04 (0.13)	0.99 (0.16)
Training and racing history				
Running time in last month, h/wk	7.9 (3.4)	8.2 (1.9)	8.6 (1.9)	6.3 (3.5)
Running volume in last month, km/wk	66 (24)	87 (49)	88 (14)	51 (36)***
Running volume in last year, km/wk	54 (21)	56 (17)	72 (19)	36 (24)***
Estimated strength training, h/wk	1.4 (1.3)	1.4 (1.1)	1.3 (1.5)	0.7 (1.0)
Estimate total training hours, h/wk	11.7 (5.2)	10.2 (2.6)	12.6 (3.5)	8.5 (3.4)
Completed marathons/ultramarathons, n	7 (5)**	14 (10)*	20 (9)*	17 (22)
Years running, y	6 (4)	8 (9)	12 (6)	8 (6)

Abbreviations: a.u., arbitrary units; BMI, body mass index; F, female; GXT, graded exercise test; HR, heart rate; M, male; RMSSD, square root of the mean of successive difference; VO_2max, maximal oxygen uptake. Data are represented as mean (SD) except for number of participants.
**P* < .05 from 50-km group. ***P* < .05 from 160 km. ****P* < .05 from finishers.

between-group differences were that the 50-km race finishers had completed fewer marathons and ultramarathons than the 80- and 160-km finishers (all *P* < .05; Table 1). Of the 51 subjects tested at baseline, 42 (82%) completed their respective race distances (Table 1). Only 1 male and 1 female in the 50-km race and 1 male in the 80-km race did not finish, whereas 6 males did not finish in the 160-km race; therefore, finisher versus nonfinisher data were pooled across race distances. In the month prior to testing, nonfinishers completed fewer weekly training kilometers compared with finishers (51 [36] vs 77 [34] km/wk, *P* = .04) and reported a lower weekly running distance for the previous year (36 [24] vs 58 [20] km/wk, *P* = .006). Nonfinishers also had significantly higher resting mean arterial pressure (MAP) than finishers (105 [18] vs 92 [7.8], *P* = .002). No other baseline characteristics differentiated the 2 groups; however, nonfinishers were trending toward having a postrace increase in hematocrit (+2.3 [3] vs –0.3 [3.3], *P* = .051). Alterations in body mass and hematocrit following the race can be seen in Figure 2. All groups lost, on average, −1.6 (1.0) kg (*P* < .0001), but hematocrit was unchanged (Δ0.13% [3.4%], *P* = .15).

Training History and Performance

Among finishers in the 50-km race, running distance (kilometers per week) in the month preceding competition ($r = -.66$, $P = .001$) and average kilometers per week in the year preceding competition ($r = -.50$, $P = .02$) were associated with performance (percentage difference from winning time) when pooling across sex. For 50-km men, kilometers per week in the last month ($r = -.67$, $P = .04$), kilometers per week in the last year ($r = -.72$, $P = .02$), and years of run training ($r = -.77$, $P = .009$) were related to performance. For the 50-km women, total training hours per week ($r = -.78$, $P = .007$), and kilometers per week in the previous month ($r = -.84$, $P = .002$) were related to performance. No training variables were correlated with 80- or 160-km performance, although kilometers per week in the last year was trending in the 80-km race ($r = -.57$, $P = .06$).

Cardiovascular Indices and Performance

In the 50-km race with both sexes pooled, all baseline health measures were correlated with performance (Table 2). When separated by sex, BMI, and MAP were no longer significantly related to performance for women. No cardiovascular indices were related to performance in the 80- and 160-km races.

Aerobic Fitness and Performance

With both sexes pooled, peak running velocity achieved in the incremental test ($r = -.65$, $P = .001$) and VO_2max ($r = -.58$, $P = .006$) were related to 50-km performance, while the caloric cost of running ($r = .26$, $P = .25$) and oxygen cost ($r = -.33$, $P = .15$) per kilometers were not. When controlling for sex, the relationships became stronger for peak velocity (men: $r = -.93$, $P < .0001$; women: $r = -.87$, $P = .001$) and VO_2max (men: $r = -.82$, $P = .004$; women: $r = -.75$, $P = .007$). In the 80-km group, race performance was related to peak velocity achieved in the incremental exercise test ($r = -.88$, $P < .0001$) but no other variable. In the 160-km race, no correlations with aerobic fitness or running economy were linked to performance.

Body Mass, Hematocrit, and Performance

In the 50-km race, a decrease in body mass was related to better performance across both sexes ($r = .60$, $P = .004$), while changes in hematocrit were not ($r = -.13$, $P = .6$). For men independently, this relationship with body mass loss was even stronger (men: $r = .70$, $P = .02$; women: $r = .61$, $P = .047$). In the 80- and 160-km races, there were no relationships between body mass loss or hematocrit alterations with performance.

Performance Regression Models

Due to sex differences in bivariate correlations, and more participants in the 50-km race compared with the other distances, models were performed for 50-km male and female racers separately, but with pooled sexes for 80- and 160-km races. Full models are presented in Table 3. Due to collinearity in variables, only kilometers per week in the last month, age, BMI, MAP, HR, peak velocity achieved in the incremental test, and body mass loss were included as predictors. Individual predictors and their relationships to performance across each race distance are presented in Figure 3.

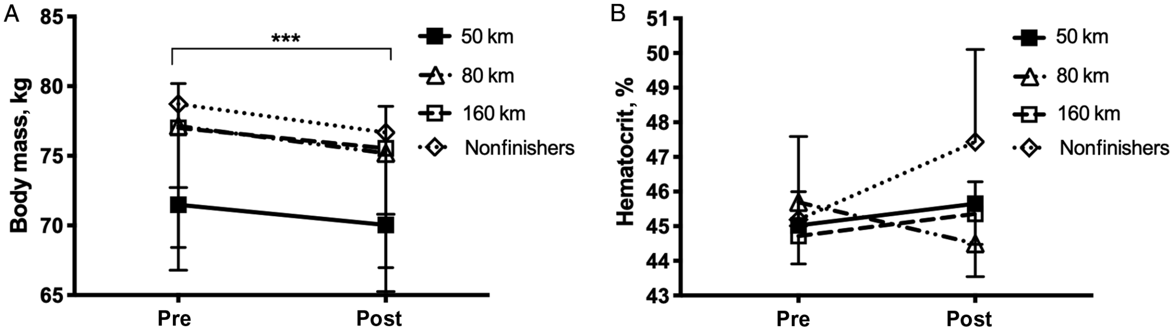

Figure 2 — Changes to body mass and hematocrit following 50-, 80-, or 160-km trail-running races. ***$P < .0001$, main effect of time. Baseline hematocrit was assessed during pretesting in the month prior to the race, whereas baseline body mass was assessed on race morning.

Table 2 Relationships Between Baseline Cardiovascular Measures and Ultramarathon Performance as Determined by Percentage Difference From Winning Time in the 50-, 80-, and 160-km Trail Race

Measure	50 km (*r*, *P*)	50 km men (*r*, *P*)	50 km women (*r*, *P*)	80 km (*r*, *P*)	160 km (*r*, *P*)
HR	.72, <.001	.68, .04	.82, .002	−.18, .55	.22, .60
lnRMSSD	−.63, .003	−.76, .02	−.69, .02	.09, .78	.15, .73
lnRMSSD/HR	−.67, .002	−.78, .01	−.73, .02	.08, .80	.07, .87
Age	.60, .005	.82, .004	.66, .04	.42, .16	.33, .43
MAP	.54, .01	.87, .001	−.31, .35	.21, .50	.33, .42
BMI	.67, .001	.75, .01	.40, .22	.50, .08	.18, .67

Abbreviations: BMI, body mass index; HR, heart rate; lnRMSSD, HR variability expressed as the natural log of the square root of the mean of successive differences; MAP, mean arterial pressure.

Table 3 Multivariate Models Comparing Performance Predictor Variables of Training History, Cardiovascular Health, Running Fitness, and In-Race Dehydration to Percentage Difference From Winning Time in 50-, 80-, and 160-km Trail Races

Group	Variables	*B* (SE)	Standardized *B* (a)	*R*	R^2(adjusted R^2)
50 km men	Peak velocity	−11.7 (2.2)	−0.60 (0.002)	.98	.96 (.95)
	Mean arterial pressure	3.1 (0.8)	0.46 (0.007)		
50 km women	Peak velocity	−13.6 (2.7)	−0.73 (0.001)	.94	.87 (.84)
	Δbody mass	12.8 (4.9)	0.38 (0.03)		
80 km	Peak velocity	−20.3 (3.3)	−0.88 (<0.0001)	.88	.78 (.76)
160 km	—	—	—	—	—

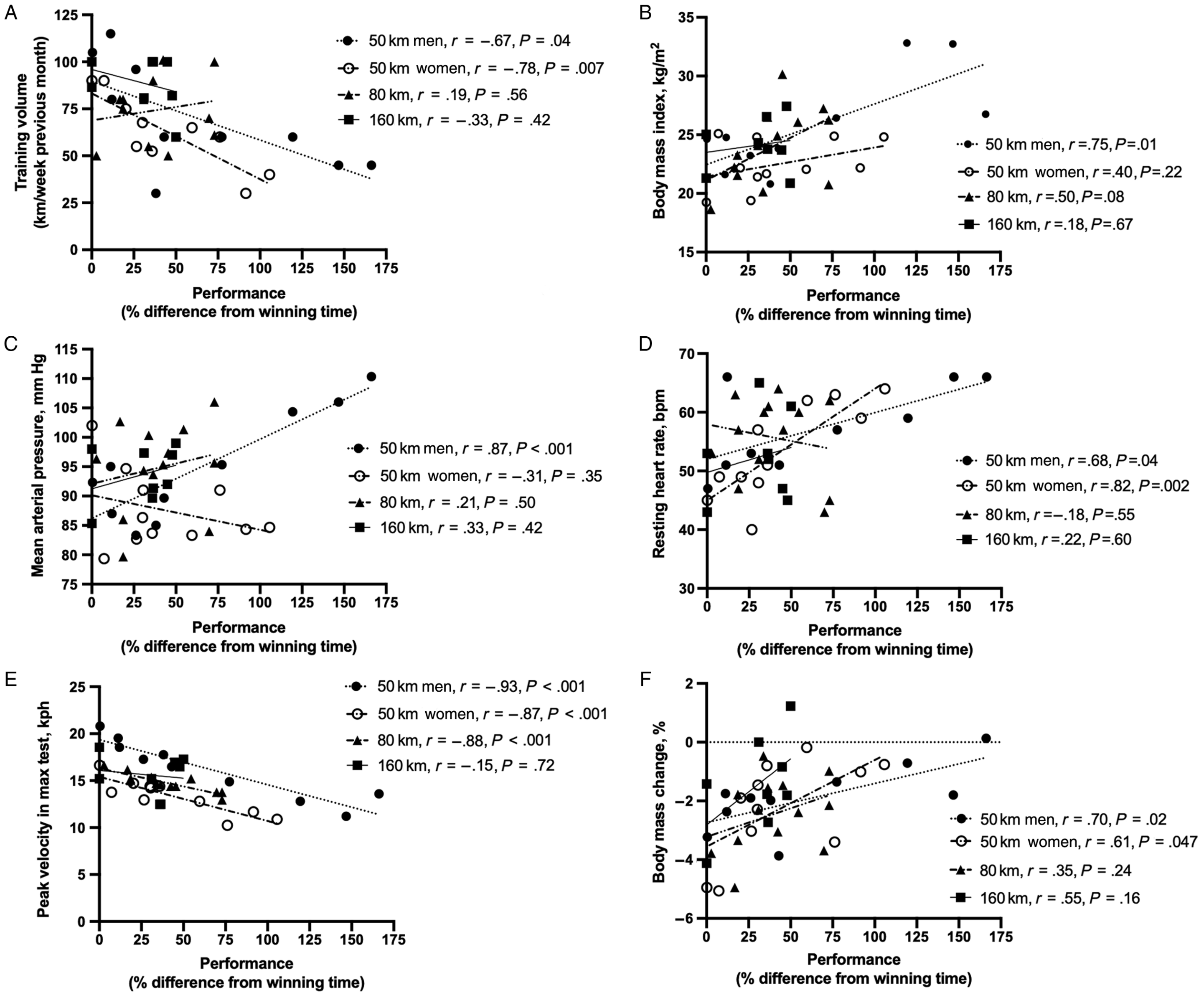

Figure 3 — Relationships between performance expressed as the percentage difference from winning time and training volume (A), body mass index (B), mean arterial pressure (C), resting heart rate (D), peak velocity in the maximal-oxygen-uptake test (E), and body mass change following the race (F) in 50-, 80-, and 160-km ultramarathon races. bpm indicates beats per minute.

Discussion

The aim of this investigation was to examine the strength of association between ultramarathon performance of increasing distance and a comprehensive battery of physiological predictors. It was found that 50-km trail racing performance is associated with physiological determinants similar to that of the marathon,[8] with the primary influence being peak velocity in an incremental test and VO_2max, followed by measures of cardiovascular health (MAP) in men and body mass loss throughout the race[14] for women. In the 80-km race, only peak velocity in the incremental test was predictive of performance, and in the 160-km race, no variables were associated with performance suggesting that typical physiological variables become less important as the race length increases. Notably, training volume (in kilometers per week) and baseline blood pressure separated finishers from nonfinishers, and this occurred primarily in the 160-km race.

Running Fitness

To date, VO_2max, lactate threshold, and running economy have been considered the main predictors of long-distance running performance.[7] Noakes et al[8] previously reported that peak velocity achieved in a maximal treadmill test was the best laboratory test predictor of performance up to 90 km, followed by running velocity at the lactate turn point, VO_2max at 16 kph, and VO_2max itself. Furthermore, Millet et al[4] found that 24-hour treadmill running performance (~149 km) was related to VO_2max and velocity at VO_2max. However, it is also understood that ultramarathon racers use a smaller percentage of their VO_2max with increasing race duration,[26] and that the association between VO_2max and performance is attenuated progressively as event distances are extended from 5- to 85-km races.[27] In this investigation, we support the finding that peak running velocity achieved during the maximal test was predictive of performance up to the 80-km distance,[8,27] but this relationship was not maintained for the 160-km race. This is a similar finding to a recent study, which demonstrated laboratory fitness tests predicted performance in a 68-km, but not a 121-km, mountain ultramarathon.[28] It is likely that the low-intensity effort required to complete double 80-km distances, combined with all of the other physiological and behavioral determinants of outdoor ultramarathon success, make running fitness of lesser importance in the longest duration events.

Running economy, which is often considered a better predictor of long-distance running performance than VO_2max,[26] was not found to predict performance across any race distance in this investigation. This is perhaps understandable as treadmill running form is not representative of trail running form on an undulating course, and the lower intensities sustained for ultramarathon running may reduce the importance of running economy on performance.[3] Millet et al[3] have argued that factors that decrease running economy, including increased leg mass, stride frequency, shoe mass, and flexibility, may in fact improve ultramarathon performance through mitigation of fatigue and injury. As such, laboratory-based running economy is an inadequate predictor of trail and ultramarathon running performance, despite its utility in road and track running.

Training volumes and previous experience appear to play a large role in ultramarathon performance. It has been demonstrated that training volume is more important than training pace for predicting 100-km performance,[9] but that this relationship is reversed for marathon success.[9] Furthermore, those athletes that performed longer training runs prior to a 24-hour race completed the most distance in the race,[12] and in a survey of 500 participants in the Western States 100-Mile Endurance Run, faster finishing times were associated with greater training volumes.[6] Finally, the fastest ultramarathon runners in the world demonstrated improvements in their race times year to year, despite older age (~37 to 39 y), suggesting that experience may play a role in subsequent ultramarathon performance.[18] As such, it was hypothesized that in the longer duration events (80 and 160 km), racing experience and training history would have a greater association with performance than other physiological variables. Unexpectedly, we found that training volumes were related only to performance in the 50-km race, and more experience was not correlated with performance across any racing distance. However, when comparing finishers to nonfinishers, the nonfinishers ran fewer kilometers per week. While we cannot conclude that training volumes and previous experience aided 80- or 160-km performance, insufficient mileage prior to the race certainly played a role in participant withdrawal.

Health and Anthropometry

While it is understood that ultramarathon runners are typically older and less aerobically fit than shorter distance runners,[29] previous investigations have rarely examined baseline cardiovascular health correlates to performance. In a high-elevation trail marathon, lower resting HR and BMI, but not HRV, were correlated with performance.[30] The HRV was found to be inversely correlated with finishing time in a 118-km mountain ultramarathon, and the authors suggested greater baseline parasympathetic modulation allowed for greater autonomic resources during the race.[31] In this investigation, it was found that all baseline health measures were independently predictive of performance in only the 50-km race. This may relate to the larger sample size and heterogeneity in the 50-km race but could also suggest that the higher intensity sustained during 50-km races, as compared with 80- or 160-km races, required a greater cardiovascular and autonomic reserve.

Finally, while a lower body fat percentage and BMI are generally predictive of performance in ≤42.2-km running,[10] the relationship between BMI and ultramarathon running performance is equivocal. Unlike shorter distance running, it is possible that greater fat stores may aid in ultramarathon performance,[32] and greater leg muscle mass may have advantages in terms of strength and resistance to muscle damage.[3] The BMI and percentage body fat were not correlated with performance in a 24-hour race[12] or a 7-day ultramarathon[11] but were weakly correlated with 100-[9] and 161-km performance.[6] As a greater amount of exercise usually leads to a reduction in body mass and body fat, the weak associations between low BMI and performance may be largely driven by training volumes.[12] In accordance with the literature, our results suggest BMI is only correlated with 50-km performance in men and did not appreciably improve predictive models using multivariate analysis.

Body Mass Loss

It has been established that faster marathon runners typically lose more body mass than slower runners while racing[14]; however, it is also understood that excessive dehydration will impact performance through loss of thermoregulatory capacity and stroke volume.[13] As such, in shorter distance races, such as the marathon and up to the 50-km ultramarathon, a moderate loss of body mass (~2% to 3%) may be ergogenic due to a reduction in body mass to be propelled, with gains in body mass being unequivocally detrimental to performance.[14,16] In longer distance races, the relationship between loss of body mass and improved performance is less robust, with only a weak ($r = .092$) correlation between loss of body mass and improved performance following observation of 887 ultramarathon (161 km) performances.[16] Furthermore, while dehydration is one cause of body mass loss, in events over 1 hour, a given change in body mass does not equate to an equal change in body water due to body mass alterations from substrate use and metabolism.[17] As such, any loss in mass unrelated to a loss in body water would likely have a net positive effect on performance.[17] In the current investigation, similar to the marathon, one of the primary determinants of performance in the 50-km women's race was a decrease in body mass, and this was not a significant finding in the other race distances. Interestingly, it can be seen that while the 80-km racers lost body mass, there was also a reduction in hematocrit suggestive of increased plasma volume or decreased blood constituents. It is likely that hemolysis and/or plasma volume expansion occurred in this group,[33] although why this occurred primarily in the 80-km distance is unknown. Furthermore, nonfinishers were trending toward a significant increase in hematocrit compared with finishers, possibly indicating severe dehydration, although other blood markers of dehydration were not assessed in order to confirm these findings. As prerace hematocrit measures were taken during baseline testing in the month prior to the race under controlled conditions and postrace hematocrit measures were taken directly after the race, strong conclusions cannot be made regarding this variable. As it stands, a moderate (2%–3%) but not excessive loss of body mass is likely beneficial to performance, as is consistent with previous findings.[17]

Practical Applications

Previous studies examining ultramarathon performance have been restricted to single-distance races, or comparisons between different races performed on separate days and on different courses. The nature of this investigation, whereby athletes ran on the same course and experienced similar environmental exposures, make between-distance performance predictors easier to discern. From this, we can conclude that 50-km racing should be treated in similar fashion to a marathon in terms of preparation, with an emphasis on running and cardiovascular fitness. Furthermore, the 80-km race is dictated by running fitness, but performance is not easily predicted by other physiological determinants. Finally, the 160-km race requires a certain amount of training for completion, but performance is not predicted by typical physiological variables.

Limitations

Despite efforts, we were unable to reliably assess food, drink, or anti-inflammatory intake during the races, and, as such, we cannot determine the influence of these factors on performance. Furthermore, there were many more physiological, as well as psychological, determinants that could have been assessed. We did not assess participant motivation to ensure all subjects raced to the best of their abilities; however, there was no indication that any participant had entered the event without the intention to race it. Finally, due to the nature of this work, we had relatively small sample sizes of finishers in some race distances, which may make the current findings hard to generalize to other races or cohorts. Statistically, the low number of finishers and homogeneity in participant characteristics in the 160-km race may have resulted in null findings in the regression analysis; however, the significant findings in finisher versus nonfinisher data are mainly attributable to the 160-km race.

Conclusions

Ultramarathon trail running performance is dictated by different physiological determinants depending on the race distance. Performance at the 50-km distance is largely determined by running fitness. As the distances are increased, there are fewer physiological determinants, with only running velocity achieved in the incremental running test predicting 80-km performance and no physiological variables predicting 160-km performance. Future work should assess other potential determinants not examined here, including muscular/neuromuscular and psychological fatigue resistance, in order to better predict ultramarathon performance.

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