Performance determinants in tropical trail running: Race result analysis of the 5K and 10K Merapi Merbabu de Trail 2025

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ABSTRACT

Background: The limited research on the determinants of performance in short-distance trail running in tropical environments is a major problem in understanding the influence of environmental conditions on runners' performance and pacing strategies. **Objective:** This study aimed to examine the influence of race distance, sex, and age on trail running performance in the 5K and 10K categories of the Merapi Merbabu de Trail 2025. **Method:** A retrospective observational race result analysis was conducted using official race data from the Merapi Merbabu de Trail 2025. The study included 429 runners (5K: n = 144; 10K: n = 285), consisting of 275 male and 154 female participants. The primary outcome variable was finish time (in minutes), while the independent variables included race, distance, sex, and age. Statistical analyses were performed using SPSS version 26, including descriptive statistics, independent-samples t-tests, Cohen's d effect sizes, and multiple linear regression to evaluate predictors of performance. **Results:** Results showed a significant difference in performance between race distances. The mean finish time for the 5K category was 152.8 ± 44.3 minutes, while the 10K category averaged 306.1 ± 74.3 minutes ($t = -26.68$, $p < 0.001$, Cohen's $d = 2.50$). Male runners completed the 10K race faster than female runners (293 vs. 345 minutes). Regression analysis indicated that finish time increased by approximately 2–3 minutes per year of age, indicating a progressive decline in performance with increasing age. **Conclusion:** These findings indicate that race distance, sex, and age are significant determinants of trail running performance in tropical environments.

Keywords: age-related endurance decline, heat–humidity endurance stress, mountain trail running, sex differences in performance, short-distance trail race, tropical volcanic environment.

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INTRODUCTION

Endurance running in mountainous, hot environments imposes substantial physiological stress on athletes. Elevation gain increases the metabolic demand of running due to reduced oxygen availability and greater mechanical workload. At the same time, high ambient temperature and humidity elevate thermoregulatory strain, cardiovascular load, and the risk of dehydration. The interaction between altitude-related stress and heat exposure can significantly influence endurance capacity, pacing strategy, and overall race performance. Understanding these physiological responses is therefore important for optimizing performance and reducing the risk of heat-related illness during endurance events. Trail running is a rapidly growing endurance sport that combines long-distance running with technical terrain and environmental challenges. Compared with road running, trail races involve uneven surfaces, steep gradients, and variable terrain, which increase both biomechanical and metabolic demands during running. Previous studies have shown that uphill running increases oxygen consumption and muscular workload, while downhill running increases eccentric muscle loading and mechanical stress on the lower limbs (Millet et al., 2025; Millet et al., 2012; Vernillo et al., 2017). In addition, technical terrain may increase metabolic cost by approximately 10–20% compared with running on flat surfaces at the same speed (Gimenez et al., 2014). Recent studies have further demonstrated that terrain variability and pacing adjustments are important predictors of performance outcomes in trail running events (Gutiérrez et al., 2025). Compared with road running, trail races involve uneven surfaces, steep gradients, and variable terrain, which increase both biomechanical and metabolic demands during running. Previous studies have shown that uphill running increases oxygen consumption and muscular workload, while downhill running increases eccentric muscle loading and mechanical stress on the lower limbs (Millet et al., 2012; Vernillo et al., 2017). In addition, technical terrain may increase metabolic cost by approximately 10–20% compared with running on flat surfaces at the same speed (Gimenez et al., 2014).

Environmental conditions also play an important role in endurance performance. Exposure to high ambient temperature and humidity can increase cardiovascular strain, elevate core body temperature, and accelerate dehydration, which may impair endurance performance and increase the risk of heat-related illness (Périard et al., 2015; Racinais et al., 2015). Similarly, running at moderate elevation requires greater metabolic effort and may alter pacing strategies due to reduced oxygen availability and increased terrain difficulty (Millet et al., 2012). Recent research has also highlighted that physiological responses during trail running are influenced by terrain difficulty and external load demands, which may alter energy expenditure and running efficiency during competition (Barramuño-Medina et al., 2024; Gimenez et al., 2014; Martín-Rodríguez et al., 2024).

Despite the growing popularity of trail running worldwide, most research on endurance running performance has been conducted in laboratory settings, road races, or ultra-distance mountain events. Relatively few studies have investigated performance patterns in real-world trail running competitions conducted in tropical environments. In particular, short- to intermediate-distance trail races such as 5K and 10K remain underexplored, even though these categories account for a large share of recreational and amateur trail running participation (Scheer et al., 2022).

Furthermore, demographic factors such as age and sex are known to influence endurance performance. Previous studies have reported that endurance performance typically declines with increasing age due to reductions in aerobic capacity and neuromuscular function (Lepers et al., 2018; Lepers & Stapley, 2016; Tanaka & Seals, 2008). Differences in performance between male and female runners have also been widely documented, often reflecting variations in physiological characteristics such as maximal oxygen uptake, body composition, and muscle mass distribution (Bassett et al., 2020; Hunter et al., 2024). However, limited empirical evidence exists on how these demographic factors interact with race distance in tropical trail-running environments.

The Merapi Merbabu de Trail 2025 event, held on the slopes of Mount Merapi and Mount Merbabu in Central Java, Indonesia, provides a unique opportunity to examine endurance performance in a tropical volcanic trail environment. The course includes steep gradients, volcanic terrain, and a tropical climate characterized by high temperatures and humidity, which may influence running performance and fatigue development. Therefore, the present study aims to analyze performance patterns in the Merapi Merbabu de Trail 2025 by examining: 1) Differences in performance between the 5K and 10K race categories, 2) Performance differences between male and female runners, 3) Age-related trends in performance decline, and 4) The combined influence of race distance, sex, and age on trail running performance. By using official race results from a real-world tropical trail running event, this study provides empirical evidence for the growing literature on endurance performance in challenging environmental conditions. It offers insights that support athlete preparation, race organization, and performance modeling in tropical mountain environments.

METHODS

Study Design and Participants

This study employed a retrospective observational design based on official race results from the Merapi Merbabu de Trail 2025 event. Race data were obtained from the race organizer's official results database. The dataset included 429 runners who completed the race, comprising 144 in the 5K category and 285 in the 10K category. The participants comprised 275 male and 154 female runners, aged 18 to 65 years. Participants were included in the analysis if they were officially recorded as finishers and had complete demographic information, including age and sex. Runners with incomplete race records or missing demographic data were excluded from the analysis to ensure data accuracy and statistical validity. All race result data were anonymized prior to analysis to protect participant confidentiality.

Ethical approval statement

This study was approved by the Ethics Committee (EC) Universitas Negeri Semarang (FIK UNNES) with approval number No. 421/KEPK/EC/2025. All procedures were conducted in accordance with the ethical standards for research involving human participants and complied with the principles of the Declaration of Helsinki. During the race registration process, all participants provided informed consent, which included permission for the use of anonymized race data for research purposes.

Research Instruments

The instrument used in this study is a secondary dataset obtained from the official results database of the 2025 Merapi Merbabu de Trail race, including finish time, race distance, age, and gender of participants. The primary outcome variable was finish time (minutes), an indicator of race performance. Independent variables included race distance (5K or 10K), sex (coded as male = 1 and female = 0), and age (years). In addition, an interaction term (distance × age) was included in the regression model to examine whether the effect of age on performance differed between race distances.

Data Analysis

Statistical analyses were performed using SPSS version 26. Descriptive statistics were calculated and reported as mean ± standard deviation (SD) (Hale, 2015; Lang & Altman, 2015). Differences in performance between the 5K and 10K categories were analyzed using an independent-samples t-test, and the magnitude of the difference was evaluated using Cohen's d. Furthermore, multiple linear regression analysis was conducted to assess the influence of age, sex, and race distance on finish time. Statistical significance was set at $p < 0.05$ (Cumming, 2013; Harriss et al., 2019).

RESULTS

The present study analyzed race performance data from 429 trail runners who completed the Merapi Merbabu de Trail 2025 event. The dataset included 144 runners in the 5K category and 285 runners in the 10K category. This section first presents the demographic characteristics of the participants, followed by analyses comparing race performance across distances and regression analyses examining predictors of finish time.

Table 1. Demographic Characteristics of Participants

Variable	Total (n=429)	5K (n=144)	10K (n=285)
Male (n, %)	275 (64.1%)	92 (63.9%)	183 (64.2%)
Female (n, %)	154 (35.9%)	52 (36.1%)	102 (35.8%)
Mean age (years)	38.7 ± 9.6	36.8 ± 9.1	39.6 ± 9.8
Age range (years)	18–65	18–62	19–65

As shown in Table 1, the study included 429 trail runners, comprising 275 male participants (64.1%) and 154 female participants (35.9%). Among these participants, 144 competed in the 5K and 285 in the 10 K. The mean age of all participants was 38.7 ± 9.6 years, with an age range between 18 and 65 years. Runners in the 10K category tended to be slightly older (39.6 ± 9.8 years) compared with those in the 5K category (36.8 ± 9.1 years).

Table 2. Comparison of Finish Time Between 5K and 10K Categories

Variable	5K (n = 144)	10K (n = 285)	Statistical Value
Mean finish time (min)	152.8	306.1	
Standard deviation (SD)	44.3	74.3	
95% Confidence Interval	145.5 – 160.1	297.5 – 314.7	
t-value			-26.68
p-value			< 0.001
Cohen's d (Effect Size)			2.50 (Extremely Large)

As shown in Table 2, the mean finish time for runners in the 5K category was 152.8 ± 44.3 minutes (95% CI: 145.5–160.1), whereas runners in the 10K category

recorded a substantially longer mean finish time of 306.1 ± 74.3 minutes (95% CI: 297.5–314.7). An independent samples t-test revealed a statistically significant difference between the two race distances ($t = -26.68$, $p < 0.001$). The magnitude of this difference was extremely large, as indicated by Cohen's $d = 2.50$, suggesting that race distance had a strong effect on performance outcomes among participants in the Merapi Merbabu de Trail event.

Table 3. Multiple Linear Regression Analysis Predicting Finish Time in Trail Runners

Predictor Variable	β Coefficient	Standard Error (SE)	p-value
Age (years)	2.3	0.41	< 0.001
Sex (Male = 1, Female = 0)	-48.2	8.6	< 0.001
Race Distance (10K vs 5K)	151.4	12.2	< 0.001

Table 4. Model Summary

Statistic	Value
R^2	0.41
Adjusted R^2	0.40
F-statistic	98.7
p-value	< 0.001

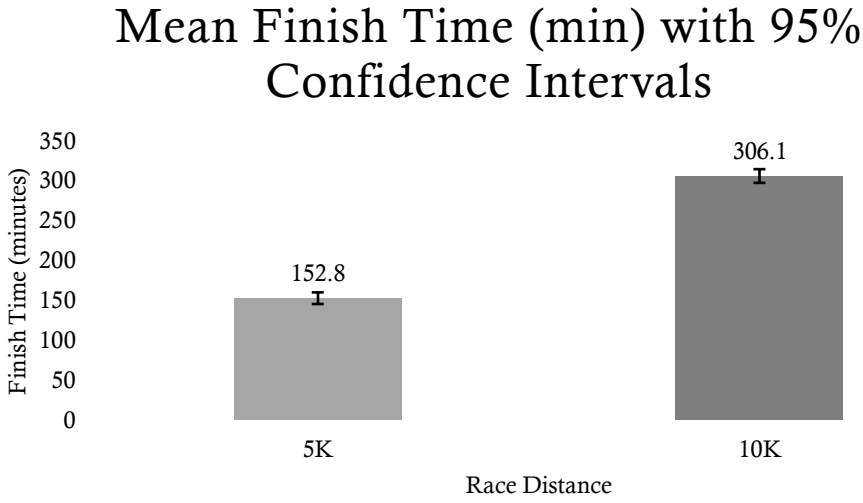

Figure 1. Mean finish time (minutes) for 5K and 10K race categories with 95% confidence intervals. The 10K category exhibited substantially longer finish times compared to the 5K category, with non-overlapping confidence intervals indicating a statistically significant difference between groups

A multiple linear regression analysis was conducted to examine the influence of age, sex, and race distance on finish time among trail runners. As presented in Table 3, all predictor variables were statistically significant contributors to performance outcomes. Age showed a positive association with finish time ($\beta = 2.3$, $SE = 0.41$, $p < 0.001$), indicating that each additional year of age was associated with an increase of approximately 2.3 minutes in race completion time. Sex was also a significant predictor ($\beta = -48.2$, $SE = 8.6$, $p < 0.001$), suggesting that male runners completed the race approximately 48 minutes faster than female runners on average. Race distance demonstrated the strongest influence on finish time ($\beta = 151.4$, $SE = 12.2$, $p < 0.001$), indicating that participation in the 10K category was associated with an increase of approximately 151 minutes in completion time compared with the 5K category. The regression model was statistically significant ($F = 98.7$, $p < 0.001$) and

explained 41% of the variance in finish time ($R^2 = 0.41$; adjusted $R^2 = 0.40$), as shown in Table 4. These findings indicate that race distance, age, and sex collectively play an important role in determining trail running performance in the Merapi Merbabu de Trail event.

The comparison of mean finish times between race categories revealed a substantial difference between 5K and 10K runners. Participants in the 10K category had markedly longer completion times (306.1 minutes) than those in the 5K category (152.8 minutes) (Figure 1). The 95% confidence intervals for both groups did not overlap, reinforcing the statistical significance of this difference. This finding is consistent with the inferential analysis ($p < 0.001$). It is further supported by an extremely large effect size (Cohen's $d = 2.50$), indicating that race distance is a dominant factor influencing trail running performance.

DISCUSSION

The present study investigated the influence of race distance, sex, and age on trail running performance using official race results from the Merapi Merbabu de Trail 2025 event. The results showed a substantial difference in finish time between the 5K and 10K categories. Runners in the 10K category required significantly longer completion times compared with those in the 5K category, with an extremely large effect size (Cohen's $d = 2.50$). In addition, the regression analysis demonstrated that race distance, sex, and age were significant predictors of performance outcomes, collectively explaining approximately 41% of the variance in finish time. Specifically, the regression results indicated that increasing age was associated with slower performance, with finish time increasing by approximately 2.3 minutes per year. Sex was also a significant predictor, with male runners completing the race on average 48 minutes faster than female runners. Race distance showed the strongest influence on performance, indicating that the transition from 5K to 10K substantially increased race completion time. These findings highlight the importance of demographic and race characteristics in determining performance outcomes in trail running events conducted in tropical mountainous environments.

The significant difference in finish time between the 5K and 10K categories observed in this study is consistent with previous research on endurance running performance. Previous studies reported that elevation changes and uneven terrain significantly increase the metabolic cost of running compared with flat road running (Coratella et al., 2024; Vernillo et al., 2017). Similarly, it has been demonstrated that trail running places greater neuromuscular and metabolic demands on the body due to the combination of uphill and downhill segments (Gutiérrez et al., 2025; Mousavi et al., 2021). The influence of sex on performance observed in this study aligns with previous research on endurance sports. Male runners generally achieve faster finish times than female runners in endurance competitions, primarily due to differences in physiological characteristics such as maximal oxygen uptake (VO_2max), hemoglobin concentration, and muscle mass distribution (DeSio et al., 2025; Joyner et al., 2025; McClelland & Weyand, 2022; Senefeld & Hunter, 2024; Tiller et al., 2021). In addition, the positive association between age and finish time identified in this study is consistent with previous studies examining age-related performance decline in endurance sports. Together, these findings support the broader literature indicating

that race distance, sex, and age are key determinants of endurance performance across different running environments.

Although this study did not directly measure physiological variables, the observed differences in performance across race distances may be explained by the greater physical demands of longer trail running distances. Trail races often involve significant elevation changes, technical terrain, and environmental stressors, all of which can increase the energetic cost of running. Previous studies have shown that uphill running increases oxygen consumption and muscular effort, while downhill running increases eccentric muscle loading and mechanical stress on the lower limbs (Coratella et al., 2024; Vernillo et al., 2017). These biomechanical demands may contribute to greater fatigue accumulation during longer races. Recent biomechanical research has shown that uphill and downhill running significantly modify mechanical loading patterns and muscular activation, which may influence fatigue development and running efficiency during trail competitions (Gimenez et al., 2014; Lu et al., 2025; Minetti et al., 2002; Vernillo et al., 2017). In addition, environmental conditions such as high ambient temperatures and humidity, characteristic of tropical trail running events, may further influence endurance performance. Heat exposure has been shown to increase cardiovascular strain and thermoregulatory stress during prolonged exercise, potentially affecting pacing strategy and overall performance (Mallett et al., 2025; Nybo et al., 2014; Périard et al., 2015; Sawka et al., 2011). However, because the present study used race results rather than physiological measurements, these interpretations should be considered in the context of the existing literature rather than as direct experimental evidence.

The findings of this study have several practical implications for athletes, coaches, and race organizers involved in trail running events conducted in tropical environments. First, the strong influence of race distance on performance underscores the importance of appropriate pacing strategies across race categories. Runners running longer distances may need to adopt more conservative pacing strategies to manage fatigue and environmental stress. Second, the influence of age on performance suggests that training programs should consider age-related physiological changes. Older runners may benefit from training strategies that emphasize endurance capacity, strength maintenance, and recovery. Third, race organizers may use performance data from events such as the Merapi Merbabu de Trail to develop evidence-based race management strategies. These may include determining realistic cut-off times, optimizing hydration station placement, and improving safety measures for participants competing in challenging environmental conditions.

Limitations of the study

Several limitations of the present study should be acknowledged. First, the study relied on race result data rather than direct physiological measurements. As a result, variables such as VO_2max, lactate concentration, hydration status, and markers of muscle damage were unavailable for analysis. Second, the dataset did not include information about participants' training background, running experience, or pacing strategies, which may also influence race performance. Third, environmental conditions such as temperature, humidity, and elevation gain were not directly incorporated into the statistical analysis, even though these factors may influence trail running performance.

Future studies should integrate race performance data with physiological measurements in order to better understand the mechanisms underlying endurance performance in trail running. The use of wearable sensors and portable metabolic devices may allow researchers to monitor variables such as heart rate, energy expenditure, and thermoregulatory responses during trail races. In addition, further research is needed to examine the influence of environmental factors such as heat stress, altitude exposure, and terrain characteristics on endurance performance in tropical trail running events. Such studies would contribute to the development of more comprehensive performance models for trail running competitions conducted in challenging environmental conditions.

CONCLUSION

This study demonstrates that trail running performance in tropical environments is significantly influenced by race distance, sex, and age. Finish times increased substantially from the 5K to the 10K, indicating greater performance demands in technical trail terrain. Male runners completed faster than female runners, and age was associated with a progressive decline in performance. These findings contribute to the development of performance models for trail running events conducted in tropical environments.

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AI DISCLOSURE STATEMENT

During the preparation of this manuscript, the authors used DeepL Translate and Grammarly to support translation, grammar checking, and language refinement. All generated outputs were carefully reviewed and edited by the authors to ensure accuracy, clarity, and adherence to academic standards. The authors take full responsibility for the content of this manuscript.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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CONFLICT OF INTEREST

The author declares no conflict of interest.

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