Bring the Heat: Exploring the Relationship between Temperature and Short & Long-Distance Running Performance

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Background

Environmental conditions play a crucial role in athletic performance, particularly in outdoor running events. For instance, several studies indicate that increased temperature is associated with slower marathon completion times (Ely et al., 2007; Trubee et al., 2014; Vihma 2009). The impact of temperature is further exacerbated by high humidity, as humidity reduces evaporative heat loss and may lead to dehydration (Bongers et al., 2017). Wind speed, too, modulates temperature effects on running performance. Specifically, headwinds can accentuate performance decrements associated with elevated temperatures, while tailwinds might offer a performance advantage (Galloway et al., 1997).

While substantial research has been dedicated to the effects of temperature on long-distance running performance, there remains a knowledge gap regarding how temperature is differentially associated with short and long-distance running performance. Indeed, very few studies have examined temperature in relation to shorter running distances, such as the 5k or the mile. Further investigation into the associations between temperature and running performance, and how these relationships differ based on race distance, could provide valuable insights for athletes, coaches, and race organizers. Such knowledge may guide the formulation of more tailored training regimens to optimize performance while minimizing injury risk. Thus, this study aims to address the question: To what extent does the relationship between air temperature and running performance depend on race length for elite runners?

To explore this question, we use a dataset provided by Konstantinos Mantzios, Leonidas G. Ioannou, Andreas Flouris that details the finishing times and weather conditions during some of the world's largest running events from 1952-2019. Our analysis centers on data from 5ks and marathons, as these events enjoy widespread popularity, hold status as official Olympic disciplines, and are consistently conducted outdoors. Furthermore, the selected distances provide a meaningful contrast for evaluating the physiological demands of varied running lengths: 5Ks, on average, entail 84% aerobic and 16% anaerobic energy contributions, while marathons require approximately 97.5% aerobic and 2.5% anaerobic energy contributions ("Aerobic", n.d.). We hypothesize the existence of a statistically significant interaction between air temperature and race length in forecasting running performance. More specifically, we anticipate that higher air temperature will correlate with diminished running performances in marathon races as opposed to 5k events.

Methodology

To fairly analyze running performance across both 5k and marathon times, we established a metric termed 'world record deviation'. This is quantified as the difference between the first place time and the world record time, divided by the world record time (in minutes):

$$\text{world record deviation} = \frac{\text{world record time} - \text{first place time}}{\text{world record time}}$$

We designed 'world record deviation' such that an increase in this metric corresponds to enhancements in running performance, while a decrease corresponds to deteriorations in running performance. Employing this as our outcome variable, we fit a multiple linear regression model with an interaction term between air temperature and race type. Additionally, our model controlled for air temperature, wind speed, relative humidity, year, sex, race type, and competition.

Our selection of weather-based controls — namely air temperature, wind speed, and relative humidity — was informed by extant literature on ideal outdoor running conditions. Given our concerns about potential collinearity when adding weather variables, we opted against incorporating weather data such as solar radiation or time of day. Beyond meteorological parameters, we assessed an array of factors potentially influencing race times. Ultimately, our model accounted for variables such as sex, year, race type, and competition. We decided to control for competition since the proficiency and effort of the runners may change across the competition, sex since men often run faster than women, and year since running ability has improved over time.

We excluded race results that lacked first-place time data or failed to differentiate results based on gender. To test whether there was sufficient statistical evidence against the null hypothesis that regression slopes equaled 0, we used a t-test with 202 degrees of freedom set at a significance level of $\alpha = 0.05$.

Results

Our final sample comprised of 214 races after excluding 31 observations for missing first-place time data and 714 observations for results not disaggregated by gender. There were 148 5k race results and 66 marathon race results. The average air temperature across all analyzed races was 20.15°C, ranging from a high of 33.4°C to a low of 6.7°C. All linear model assumptions appear to be reasonably satisfied (**Appendix A**).

Table 1: Estimated regression coefficients for linear model

Model Term	**Estimate**	**Standard Error**	**P-Value**
Intercept	1.5238	0.2845	<0.0001
Sex			
Men	(Ref.)		
Women	0.0017	0.0029	0.5670
Year	-0.0008	0.0001	<0.0001
Temperature	-0.0001	0.0004	0.7297
Wind Speed	0.0011	0.0017	0.5228
Relative Humidity	-0.0001	0.0001	0.4725
Race Type			
5k	(Ref.)		
Marathon	0.0271	0.0126	0.0332
Competition			
Commonwealth	(Ref.)		

Diamond League	0.0321	0.0053	0.0000
Olympics	0.0173	0.0053	0.0013
World Championships	0.0153	0.0049	0.0019
World Cup	-0.0242	0.0081	0.0030
Temperature*Race Type *(Marathon)*	-0.0019	0.0006	0.0009

Given the p-value of 0.0009 for our interaction term, which falls below our established significance level of 0.05, there is sufficient evidence to suggest that the association between temperature and deviation from the world record depends on the race type.

For 5ks, for each 1°C increase in air temperature, the first-place percentage of the world record time is expected to decrease by 0.0001397%, controlling for all other variables in the model. To contextualize this, if the 5k world record was 12 minutes and 30 seconds, then each 1°C increase in air temperature would correspond to the first-place finisher being approximately 0.001 seconds slower than the world record.

On the other hand, for marathons, for each 1°C increase in air temperature, the first-place percentage of the world record time is expected to decrease by 0.002008%. Therefore, if the marathon world record was 2 hours and 10 minutes, then a temperature increase of 1°C would correlated with the first-place runner lagging by roughly 0.157 seconds compared to the world record.

Discussion

Our analysis suggests that the associations between temperature and running performance differ between marathon and 5K runners. Specifically, our results indicate that increasing air temperature correlate with more pronounced decreases in running performance (quantified by 'world record deviation') for marathon runners compared to 5K runners. While the observed disparities in performance might seem marginal at a glance, their real-world implications are substantial. Since world records in both race categories are frequently surpassed by mere milliseconds, a 1°C uptick in temperature could indeed be the decisive factor in setting or missing a world record.

This finding contributes to evidence that longer distance runners are vulnerable to the negative effects of high temperatures through providing a comparison point against shorter distance running. Furthermore, this analysis introduces a novel statistic based on individual performance relative to race-specific record benchmarks. This metric allows researchers to directly compare running performance across different types of race lengths.

Our results suggest that race organizers and coaches should pay close attention to the weather conditions and provide appropriate cooling strategies for long-distance runners to prevent excessive heat stress and improve performance. Moreover, the findings of this study advance our understanding of the complex relationship between environmental factors and athletic performance. They also highlight the need for continued research on developing evidence-driven guidelines for athletes competing in a range of weather conditions.

Limitations

One major limitation in our methodology is that the dataset does not identify first place finishers, making it possible that the independence assumption is betrayed. Specifically, if a runner won first place across multiple races, that data would no longer be independent. However, considering our relatively large sample size and the low probability that a single individual won first-place across multiple events, we posit that this assumption is reasonably satisfied.

Another limitation in our methodology is the use of a complete case analysis to address missing data. Given the administrative reasons for removing observations, we believe that missingness completely at random is reasonable to assume, leading only to a loss of power without biasing our regression results. An additional limitation of this research is its observational nature, precluding us from drawing a causal relationship between hotter temperatures and race outcomes. Future studies using randomized control trials would be useful to establish causality.

Conclusion

This analysis, encompassing 214 elite 5k and marathon races held between 1952 and 2019, demonstrates that the relationship between temperature and running performance varies based on race length. Our data suggest that rising temperatures more adversely impact performance in long-distance races than in their shorter counterparts. Given these findings, race organizer and coaches must be cognizant of environmental conditions and prepare runners accordingly with race-specific heat-mitigation strategies.

Works Cited

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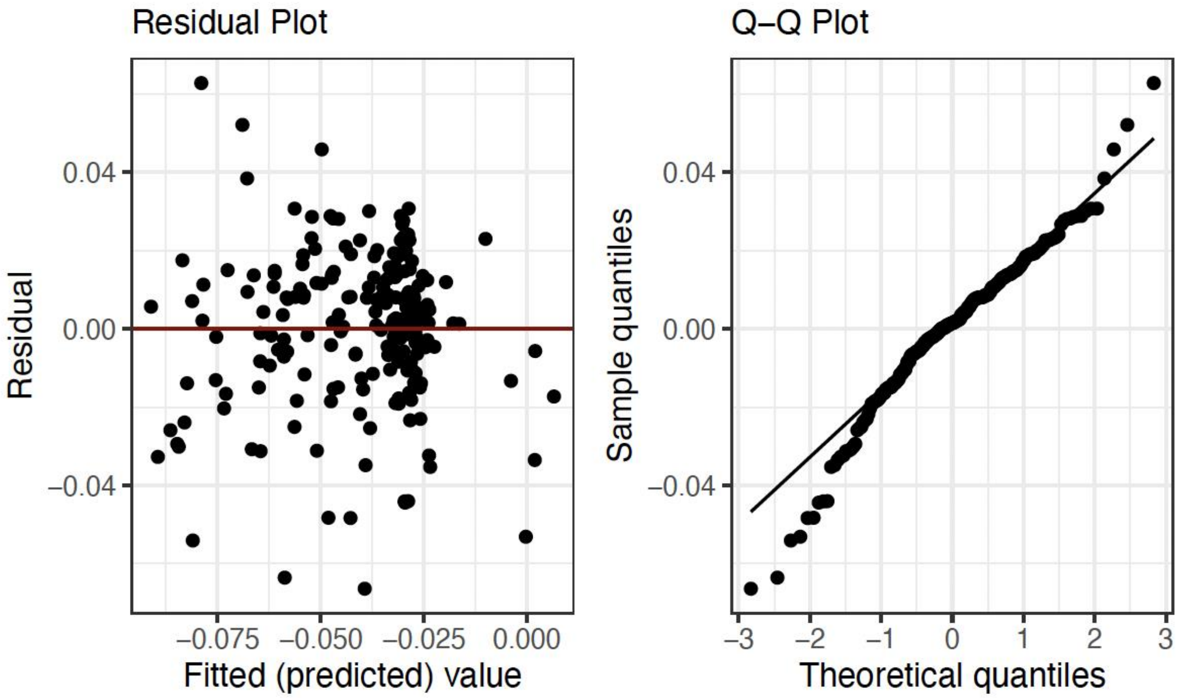
Appendix A. Linear Model Assumptions

Figure A1. Residual and Q-Q Plot for Linear Model



Independence: *satisfied*

- The assumption of independence in this study was met as each race in the dataset were not related to one another. However, see the limitations section for potential violations of this assumption.

Linearity: *satisfied*

- In our residual plot, the observations are symmetrically distributed around the horizontal axis. Thus, we find that this regression model is linear in the parameters.

Constant Variance: *satisfied*

- To satisfy the constant variance condition, the observations should be evenly spaced along the y-axis in our residual plot. There is a clump of observations around fitted values -0.025 and a slight fan out shape. However, the plot is relatively consistent otherwise. Thus, we find that the variance of the errors is constant.

Normality: *satisfied*

- There is minimal deviation in our Q-Q plot. Thus, we conclude that the normality condition is satisfied.