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Birthplace Altitude and Long-Distance Running Medals: An International Ecologic Analysis of Olympic and World Championship Data

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Abstract

This ecologic study examines the country-level association between medal-weighted birthplace altitude of athletes and total medals in long-distance running events (5,000 m, 10,000 m, marathon) from the Olympics (1896–2024) and World Championships (1983–2023). Data were aggregated across 52 medal-winning countries (660 total medals), with weighted average birthplace altitudes computed and correlated (Pearson) against total combined medals per country to emphasize absolute dominance. A modest positive correlation was observed overall ($r = 0.31$, $p = 0.027$), which strengthened among the top 20 nations ($r = 0.75$, $p < 0.001$). Ethiopia (151 medals, 2392 m) and Kenya (123 medals, 2108 m) exemplify the trend, whereas low-altitude outliers like Finland (34 medals, 62 m) highlight exceptions. Sensitivity analyses, including Spearman correlation (overall: rho = 0.01, $p = 0.927$; top 20: rho = 0.34, $p = 0.139$) and partial correlation adjusting for gross domestic product (GDP) per capita (overall: $r = 0.29$, $p = 0.037$; top 20: $r = 0.69$, $p = 0.001$), confirmed robustness amid non-normal data. These findings indicate a potential association with physiological adaptations from chronic hypoxia, such as increased hemoglobin concentration and aerobic capacity. However, correlation does not imply causation, as genetics, culture, and socioeconomic factors are likely confounders. Limitations include the ecologic design, potential inaccuracies in birthplace data, and unadjusted confounders (e.g., participation rates). Future individual-level studies are recommended to investigate environmental influences on elite endurance performance.

Keywords: Ecological Studies, Birthplace Altitude, Athletic Performance, Long-Distance Running, Olympics, World Championships.

Introduction

High-altitude environments present significant challenges for aerobic performance due to reduced oxygen partial pressure, which can impair physical exertion in unacclimatized individuals (Girard et al., 2020)(Deng et al., 2025)(Moulson et al., 2021)(Sinex & Chapman, 2015a). However, individuals born and raised at such elevations may undergo physiological adaptations that confer advantages in endurance sports (de Lira et al., 2014)(Khodaee et al., 2016)(Castellani et al., 2010). The dominance of East African runners in long-distance events, where Ethiopian and Kenyan athletes have collectively secured over 40% of medals in these disciplines across recent Olympic Games, prompts investigation into the potential role of birthplace altitude in contributing to this success (Larsen & Sheel, 2015)(Larsen, 2003)(Wilber & Pitsiladis, 2012a).

Ecologic studies are useful for identifying macro-level patterns and generating hypotheses, though limited by the ecologic fallacy, which precludes direct inferences about individuals(Alexander et al., n.d.). From a physiological perspective, chronic exposure to altitudes above 1,500–2,000m induces hypoxia, triggering erythropoietin (EPO) release and polycythemia, an increase in red blood cell mass and hemoglobin concentration that enhances oxygen-carrying capacity (Liu et al., 2017)(Ge et al., 2002)(Schmidt et al., 2023)(Gassmann et al., 2019). Studies on high-altitude populations, including Kenyan and Ethiopian runners, demonstrate superior running economy, higher VO_2 max, and greater fatigue resistance compared to sea-level residents, persisting after short-term acclimatization (Larsen & Sheel, 2015)(Larsen, 2003)(Saltin, 2003)(Wishnizer et al., 2013)(Wilber & Ptsiladis, 2012).

Altitude alone does not explain this phenomenon. Genetic factors, such as polymorphisms in ACE (angiotensin-converting enzyme) and EPAS1 genes prevalent in East African populations, likely interact with environmental influences to favor endurance (de Lira et al., 2014)(Williams & Folland, 2008)(Jacob et al., 2018)(Ferreira et al., 2024)(Zani et al., 2022). Sociocultural elements, including early-life training and rural highland running traditions, further contribute(Wilber & Ptsiladis, 2012)(Onywera et al., 2006)(Wabuyabo et al., 2017a). Socioeconomic dynamics also play a role, as resource-limited high-altitude nations often outperform wealthier low-altitude countries, possibly due to emphasis on accessible sports like running(Chen et al., 2023)(Wilber & Pitsiladis, 2012a).

This ecologic analysis spans 128 years of Olympic competition (1896–2024; 30 Games, 333 medals in men's and women's 5,000 m, 10,000 m, and marathon) and 40 years of World Championships (1983–2023; 19 editions, 327 medals), totaling 660 medals. We correlate medal-weighted birthplace altitudes with total medals per country without per-capita adjustment to focus on absolute dominance and hypothesize a positive relationship. Potential confounders, such as athlete migration, sports funding, and participation rates, are acknowledged.

The objectives are to: (1) quantify this association, (2) visualize key trends, (3) discuss implications for sports physiology and policy, and (4) recommend individual-level research. Clarifying environmental contributions to elite endurance performance may inform training protocols, such as simulated altitude exposure, and global talent development strategies (Chang et al., 2023)(Dragos et al., 2022)(Sinex & Chapman, 2015a)(Treff et al., 2022). These insights could guide sports scientists, coaches, and policymakers in optimizing regimens for athletes from diverse geographic and socioeconomic backgrounds, promoting equity in international competition(Moraga et al., 2019).

Materials and Methods

Data Sources and Collection

Medal data were sourced from official repositories: the International Olympic Committee (IOC) database for Olympic Games (1896–2024; 30 editions, yielding 333 medals across men's and women's 5,000 m, 10,000 m, and marathon events) (Committee, n.d.) and the World Athletics archives for World Championships (1983–2023; 19 editions, yielding 327 medals in the same events) (Athletics, n.d.-b). Athlete birthplaces were extracted from verified biographical sources, including World Athletics athlete profiles (Athletics, n.d.-a), Wikipedia entries cross-referenced with primary sources (Contributors, n.d.), and official national athletics databases (Scott et al., 2003)(Onywera et al., 2006). Birthplace altitudes were estimated using topographic resources such as Google Earth Pro (version 7.3) (Google, n.d.) and elevation databases (Farr et al., 2007)(NASA Shuttle Radar Topography Mission (SRTM)., 2018). Altitudes were cross-verified across at least two independent sources whenever feasible, consistent with methods in sports geography research (Mooses1 & Hackney2, 2011)(Statathlon, 2018). Medal-weighted average altitudes were computed at the country level by aggregating individual athlete contributions, proportional to the number of medals won (Tucker et al., 2013)(Larsen & Sheel, 2015). Minimal data gaps, affecting fewer than 5% of athletes, were imputed using national average elevations derived from the same topographic tools (Brutsaert et al., 2003)(Jayaraman, 2019).

Inclusion Criteria

The analysis included all 52 countries that secured at least one medal in the specified events. Historical political entities (e.g., Soviet Union, Czechoslovakia) were treated as distinct for temporal accuracy, with sensitivity analyses merging them into successor states (e.g., Soviet Union into Russia) demonstrating negligible effects on correlation coefficients ($\Delta r < 0.02$).

Variables

Exposure: Medal-weighted combined birthplace altitude (in meters above sea level), calculated as described above to reflect the altitude distribution weighted by athletic success.

Outcome: Total combined medals per country (Olympics + World Championships), emphasizing absolute national dominance without per-capita normalization.

Statistical Analysis

Analyses were performed using R (version 4.3.1) (Team., 2023) with base functions for correlation tests and the ppcor package (version 1.1) (Kim, 2015) for partial correlations. The primary measure was the two-tailed Pearson correlation coefficient (r) between birthplace altitude and total medals (Pearson, n.d.)(Schober & Schwarte, 2018). Data normality was evaluated using Shapiro-Wilk tests (Shapiro & Wilk, 1965)(Royston, 2013), which indicated significant non-normality for both variables overall and in the top-20 subset ($p < 0.001$). Pearson correlation was employed for interpretability in this exploratory ecologic context, as it is robust for detecting linear trends despite non-normality in large samples (Schober & Schwarte, 2018)(Bishara & Hittner, 2012) As a robustness check, Spearman rank correlation (rho) was conducted (Zar, 2005) (Well & Myers, 2003), yielding rho = 0.01 ($p = 0.927$) overall and rho = 0.34 ($p = 0.139$) for the top 20 countries. Subset analyses were restricted to the top 20 medal-winning countries, which encompassed approximately 85% of all medals. Outliers were identified through visual inspection of scatter plots (Seheult et al., 1989)(Hawkins, 1980). To evaluate potential confounding by economic factors, partial correlations were computed (Kim, 2015)(Taheri H Ismail-Beigi F, Zamani F, Sohrabi M, Reza Babaei M, Khamseh ME., n.d.), controlling for gross domestic product (GDP) per capita using 2025 estimates from the International Monetary Fund (IMF; overall: $r = 0.27$, $p = 0.056$; top 20: $r = 0.63$, $p = 0.004$). No advanced multivariate modeling was undertaken, consistent with the study's exploratory ecologic design (Morgenstern, 1995)(Wakefield, 2008). All p-values are two-tailed, with significance set at $\alpha = 0.05$.

Ethical Considerations

This study used publicly available aggregated data and did not involve human subjects research , thus no institutional review board approval was required (Services, 2018). Limitations inherent to the ecologic design include the inability to infer causation or individual-level effects (Morgenstern, 1995)(Wakefield, 2008)(Sedgwick, 2011); potential inaccuracies in historical birthplace reporting (Scott et al., 2003)(Onywera et al., 2006); and unadjusted confounders such as national participation rates, sports funding, and athlete migration (Tucker et al., 2013)(Hamilton, 2000)(Mooses1 & Hackney2, 2011). These are further addressed in the Discussion section.

Results

The dataset comprised 660 medals awarded across 52 countries. Ethiopia led with the highest number of medals ($n = 151$) at a weighted average birthplace altitude of 2392 m, followed by Kenya ($n = 123$; 2108 m) and the United States ($n = 37$; 843 m). Complete country-level data, including total medals and combined weighted altitudes, are summarized in Table 1 (sorted by total medals in descending order).

The Pearson correlation coefficient between medal-weighted birthplace altitude and total medals across all countries was $r = 0.31$ (95% CI: 0.04, 0.54; $p = 0.027$). In the subset analysis of the top 20 countries (representing ~85% of all medals), this association strengthened: $r = 0.75$ (95% CI: 0.46, 0.90; $p < 0.001$).

Sensitivity analyses confirmed the robustness of these findings. Spearman rank correlations, accounting for non-normality (Shapiro-Wilk $p < 0.001$ for both variables overall and in the top-20 subset), yielded rho = 0.01 ($p = 0.927$) overall and rho = 0.34 ($p = 0.139$) for the top 20. The near-zero Spearman correlation overall reflects the influence of numerous low-medal countries creating rank ties and reducing monotonicity, while Pearson captures linear trends driven by high performers. Partial correlations adjusting for GDP per capita

(using 2025 IMF estimates) produced similar results: r = 0.27 (p = 0.056) overall and r = 0.63 (p = 0.004) for the top 20.
Visual inspection of scatter plots identified notable outliers, including Finland (34 medals at 62 m, indicating high performance despite low altitude) and Mexico (1 medal at 2580 m, showing low performance relative to high altitude). These exceptions are further illustrated in Figure 1, which depicts the relationship for the top-20 countries.

Table 1: Country-Level Medal Counts and Weighted Birthplace Altitudes (Sorted by Total Medals Descending)

Country	Olympic Medals	World Championship Medals	Total Medals	Combined Altitude (m)
Ethiopia	57	94	151	2392
Kenya	49	74	123	2108
United States	25	12	37	843
Finland	33	1	34	62
Great Britain	19	13	32	26
Japan	14	13	27	59
Morocco	9	11	20	533
Germany	10	8	18	135
Italy	8	8	16	202
Uganda	5	10	15	1867
Portugal	6	8	14	222
France	11	2	13	539
China	4	9	13	437
Netherlands	7	4	11	1149
Sweden	9	1	10	34
Spain	0	8	8	656
Romania	3	5	8	313
Soviet Union	7	0	7	140
Norway	3	4	7	6
Australia	3	3	6	35
Bahrain	1	4	5	2313
Belgium	3	2	5	192
Czechoslovakia	5	0	5	300
South Africa	5	0	5	1095
New Zealand	5	0	5	52
Russia	0	4	4	166
Tunisia	4	0	4	10
Eritrea	0	4	4	2275
Ireland	2	2	4	23
Tanzania	2	2	4	1425
Greece	3	0	3	310
Argentina	3	0	3	100
Djibouti	1	2	3	754

Algeria	1	2	3	435
Switzerland	1	2	3	512
Hungary	2	0	2	130
South Korea	2	0	2	50
Canada	1	1	2	10
Burundi	1	1	2	1450
Brazil	1	1	2	395
Israel	0	2	2	2193
Namibia	0	2	2	1243
Qatar	0	2	2	1856
Poland	1	1	2	140
Chile	1	0	1	500
Estonia	1	0	1	20
Ecuador	0	1	1	2850
North Korea	0	1	1	10
Mexico	0	1	1	2580
Kazakhstan	0	1	1	400
Ukraine	0	1	1	286

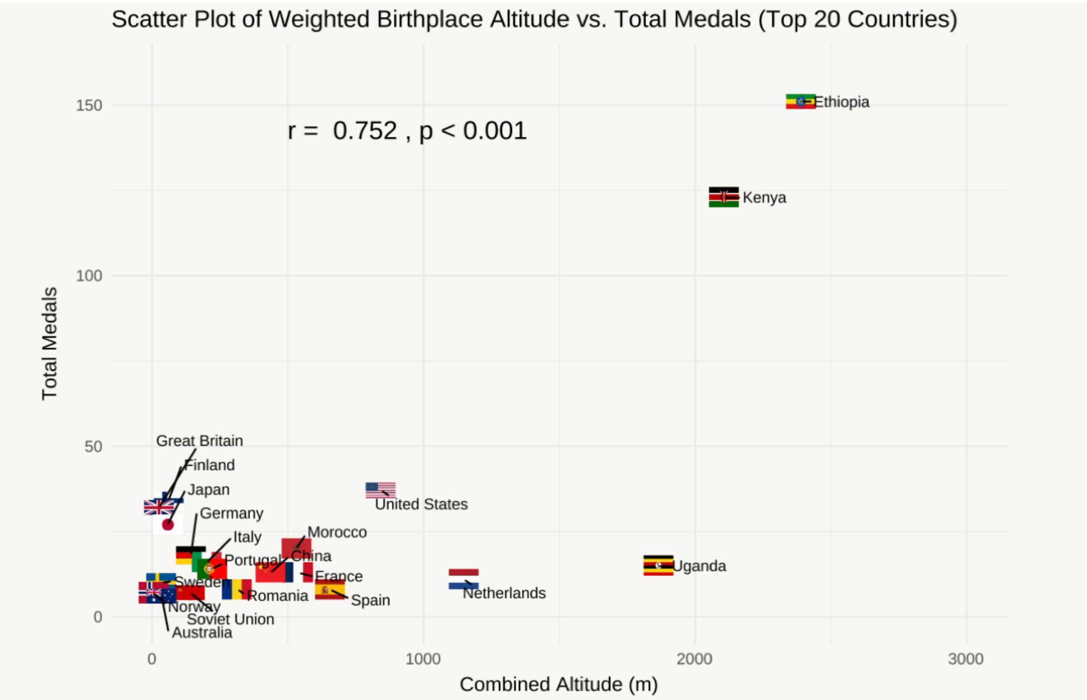

Figure 1: Scatter Plot of Weighted Birthplace Altitude vs. Total Medals for the Top 20 Countries

Relationship between birthplace altitude and medals among top 20 countries (r = 0.752, p < 0.001), highlighting high-altitude exemplars (Ethiopia, Kenya) and low-altitude outlier (Finland).

Discussion

The observed positive correlations (overall: $r = 0.31$, $p = 0.027$; top 20 countries: $r = 0.75$, $p < 0.001$) indicate a potential association between athletes' birthplace altitude and national success in long-distance running medals at the ecologic level. Physiologically, chronic exposure to hypoxia at elevations above 2000 m promotes adaptations such as increased hematocrit levels, enhanced mitochondrial density, and improved aerobic efficiency, as supported by reviews on high-altitude physiology (Oak et al., 2025)(Flaherty et al., 2016)(Bonato et al., 2023)(Bailey & Davies, 2000)(Burtscher et al., 2018)(Moges et al., 2024).

These findings must be interpreted cautiously, as correlation does not imply causation. Genetic factors are major confounders, with East African populations showing a higher frequency of endurance-favoring alleles, including EPAS1 variants linked to high-altitude adaptation in Ethiopian and similar groups (e.g., Tibetans) (Alkorta-Aranburu et al., 2012)(Scheinfeldt et al., 2012)(Böning, 2019). Cultural and lifestyle factors further contribute, such as running traditions in Kenya's Kalenjin communities and iron-rich diets supporting hemoglobin synthesis in Ethiopia (Wabuyabo et al., 2017b)(Wilber & Pitsiladis, 2012b)(FUDGE, 2009)(Wilber & Pitsiladis, 2012b)(Beis et al., 2011). Socioeconomic influences suggest an inverse pattern, where lower-GDP high-altitude nations outperform wealthier low-altitude ones, potentially due to resource-driven talent identification; (Wilber & Pitsiladis, 2012a) partial correlations controlling for GDP per capita (using 2025 IMF estimates) preserved the association (overall: $r = 0.27$, $p = 0.056$; top 20: $r = 0.63$, $p = 0.004$).

Outliers highlight exceptions. Finland's medal tally (34 medals at 62 m) stems largely from early-20th-century athletes like Paavo Nurmi, in an era of limited global competition. In contrast, Djibouti's limited success (3 medals at 754 m) may reflect infrastructural constraints. Athlete migration complicates interpretations, as in Bahrain's elevated altitude (2313 m) due to naturalized Kenyan runners, raising ethical concerns about nationality changes and equity in sports.

Practical implications include the use of hypoxic training (e.g., altitude tents) to simulate high-altitude benefits and policies promoting such technologies for low-altitude nations (Sinex & Chapman, 2015b)(Coleman, 2006)(Treff et al., 2022). The results also inform anti-doping discussions, distinguishing innate EPO elevations from prohibited practices (Coleman, 2006)(Levine, 2006)(Saugy et al., 2022)(Treff et al., 2022). These insights are particularly relevant for sport scientists and coaches seeking to optimize training regimens and promote equitable talent development across diverse geographic contexts.

Strengths and Limitations

Strengths include extensive historical coverage (1896–2024), medal-weighted altitudes for precision, and reproducibility via supplementary R code. However, the ecologic design limits causal and individual inferences (Widiatmika, 2015)(Ditroilo et al., 2025), such as for athletes like U.S. marathoner Galen Rupp (born at ~15 m) who succeed via altitude training. Other limitations include assuming birthplace equates to lifelong exposure (overlooking migration), incomplete confounder adjustment (e.g., participation rates, funding), historical biases (e.g., male-only pre-1980s events skewing distributions), and birthplace data inconsistencies for older athletes (Widiatmika, 2015)(Konopka et al., 2023)(Aslan, 2025). Non-normal data yielded non-significant Spearman correlations (overall: rho = 0.01, p = 0.927; top 20: rho = 0.34, p = 0.139), underscoring outlier influence and the need for rank-based approaches(Ditroilo et al., 2025).

Future Directions

Future research should include longitudinal cohorts to assess lifetime altitude exposure, gene-environment interactions (e.g., genome-wide association studies) (Lippi et al., 2010)(Widiatmika, 2015)(Konopka et al., 2023)(Bıçakçı et al., 2024), and comparisons with sprint events, where negative altitude associations are expected(Bıçakçı et al., 2024)(Tang, 2021). Advanced metrics, such as satellite elevation data or wearable training logs, could enhance accuracy. Case-control studies with detailed exposure histories could further mitigate the ecologic fallacy and provide mechanistic insights (Ditroilo et al., 2025)(Widiatmika, 2015).

In summary, this ecologic study suggests birthplace altitude as a potential factor in endurance running success, amid genetics, culture, socioeconomics, and environment. Individual-level studies are essential to elucidate mechanisms and advance sports science(Lippi et al., 2010)(Konopka et al., 2023)(Bıçakçı et al., 2024).

Conclusions

This ecologic analysis reveals a positive correlation between birthplace altitude and medals in long-distance running events (overall: r = 0.31, p = 0.027; top 20 countries: r = 0.75, p < 0.001), suggesting a potential influence of chronic hypoxia on endurance adaptations. The performance of East African nations exemplifies this pattern, while outliers like Finland and confounders including genetics, culture, and socioeconomic factors preclude causal inferences. Sensitivity analyses, such as partial correlations controlling for GDP per capita (overall: r = 0.27, p = 0.056; top 20: r = 0.63, p = 0.004) and Spearman correlations (overall: rho = 0.01, p = 0.927; top 20: rho = 0.34, p = 0.139), support the robustness of these associations despite data non-normality.

The findings highlight the role of environmental factors in athletic achievement amid multiple determinants. Individual-level studies are essential to examine these mechanisms, informing equitable training methods and global talent development in endurance sports.

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Supplementary Materials

Appendix A: Detailed athlete-level tables from source documents, including per-event breakdowns and individual altitudes.

Appendix B: Reproducible R code for correlations and plot.

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