EFFECT OF ALTITUDE ON 100-M SPRINT TIMES: AN ANALYSIS OF RACE TIMES FROM THE FINALS AT MAJOR CHAMPIONSHIPS

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The aim of this study was to determine the effect of altitude on 100-m sprint times. A nonlinear regression analysis was conducted using competition data from the finals at major championships. The results indicate that the time advantage of competing at an altitude of 2250 m is about 0.19 ± 0.10 s for men and 0.23 ± 0.13 s for women. This is a substantial performance advantage and so the altitude of the competition venue should be taken into consideration when recognizing record performances.

KEY WORDS: aerodynamic drag, altitude, nonlinear regression, sprint.

INTRODUCTION: A fair system of recognizing record performances in athletics should consider the influence of environmental conditions. The International Association of Athletic Federations (IAAF) has a limit of 2 m/s for the allowable assisting wind in the 100 m; however, there is no limit on the altitude of the competition venue even though there is strong empirical evidence that race times are substantially improved at high-altitude venues. Unfortunately, previous studies of the effect of altitude on 100-m sprint performance have produced inconsistent results. A common benchmark for the effect of altitude on 100-m sprint times is the time advantage due to an altitude of 2250 m (the altitude of Mexico City, site of the 1968 Olympic Games). Mathematical modelling studies have produced values ranging from 0.05 to 0.18 s, and a statistical analysis of race times from the Olympic Games indicated the time advantage is about 0.19 s (Linthorne, 2016). In contrast, a statistical analysis of elite male and female athletes in major competitions using mixed linear modelling suggested that the time advantage is only about 0.10 s (Hollings, Hopkins, & Hume, 2012; Hamlin, Hopkins, & Hollings, 2015).

A high-altitude competition venue affects 100-m sprint performance mainly through the reduction in the aerodynamic drag force acting on the athlete. The difficulty when trying to empirically determine the effect of altitude on 100-m sprint time is that it is a small effect. Even at a high-altitude venue the reduction in sprint time is only about 1% and so the effect of altitude can easily be masked by other factors such as the wind, weather, air temperature, track surface, and the inevitable random variations in an athlete's performance. An empirical determination of the effect of altitude on 100-m sprint time will probably have a large uncertainty or might be inaccurate due to unseen systematic effects. Therefore, when attempting to empirically determine the effect of altitude on 100-m sprint time we should examine many varied data sets and use several methods of analysis.

The aim of the present study was to determine the effect of altitude on 100-m sprint times through an analysis of competition data. A nonlinear regression was used to analyse the race times from the finals at selected major championships.

METHODS: This study analysed data from major athletics championships that have competitions every one, two, or four years, but are held at different venues. The championships analysed were the Olympic Games, World Championships, European Championships, South American Championships, African Championships, Central American and Caribbean Championships, Pan American Games, and NCAA Championships. The electronic race times (to 0.01 s) and wind readings for the 100-m finals at each of the championships were obtained from *Wikipedia* pages for the international competitions, and from the *Track and Field News* website for the NCAA Championship. In some races, one or more of the athletes were disqualified or produced an unusually slow time (usually due to injury) and so these performances were not included in the analysis. The altitude of the competition venue (to an accuracy of a few metres) was obtained by using *Google Earth* (version 7.1.7.2606) to view the stadium in which the competition was held (Figure 1).

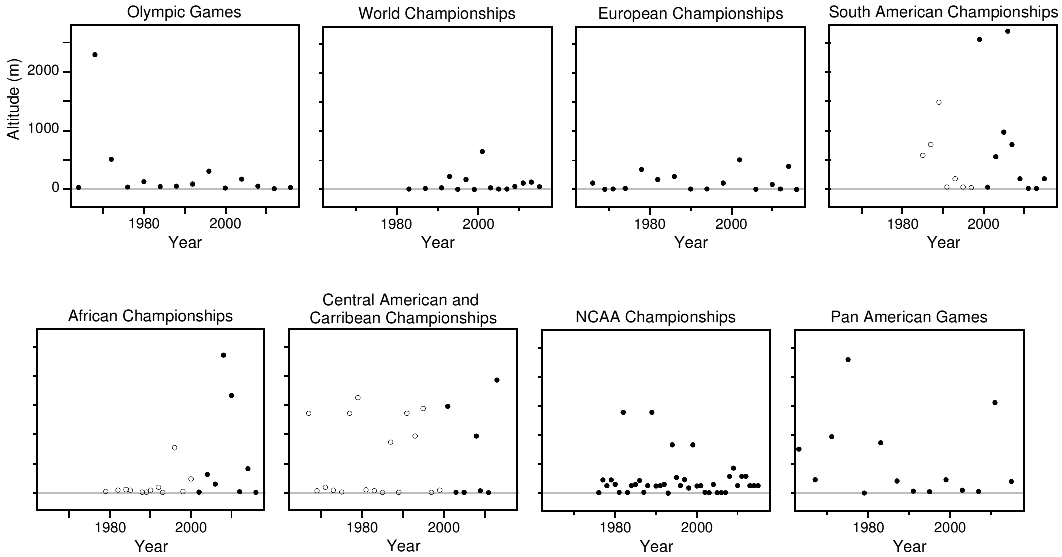

Figure 1: These plots show the altitudes of the competition venues for each of the selected major championships. Open circles = race data not available.

As well as altitude, the race times from the competitions were expected to be affected by the wind acting on the athletes during the race and by the historical improvement in 100-m performance over the years. The race times were corrected for wind using (Linthorne, 1994)

$$T_o = T + \alpha\,(V_w - \beta V_w^2)\ , \qquad (1)$$

where T_o is the performance in zero wind, T is the athlete's official race time, V_w is the wind reading, and α and β are constants with α = 0.050 s/m, β = 0.0556 s^2/m for men, and β = 0.0667 s^2/m for women. The global historical trend in 100-m performances is given by a four-parameter logistic curve (Linthorne, 2016);

$$T_{top20} = \frac{T_{max} - T_{min}}{1 + e^{-a\,(Y - Y_{inf})}} + T_{min}\ , \qquad (2)$$

where T_{top20} is the mean time of the top 20 athletes in the world rankings, Y is the year, T_{max} is the asymptotic maximum time, T_{min} is the asymptotic minimum time, Y_{inf} is the year at the inflection point of the curve, and a is a measure of the growth rate. The values of the coefficients are T_{max} = 11.37 s, T_{min} = 9.87 s, Y_{inf} = 1955 years, and a = –0.054 per year for men; and T_{max} = 12.58 s, T_{min} = 10.96 s, Y_{inf} = 1962 years, and a = –0.098 per year for women (Figure 2).

The effect of the altitude of the competition venue on the race time at a championship was obtained from a nonlinear regression analysis using *IBM SPSS Statistics* (version 20). The altitudes of the competition venues did not have a normal distribution and so a log transformation was applied to the altitude data. The relationship between the altitude the competition venue ($\log_{10}Alt$) and its associated time advantage (T_{adv}) was not expected to be linear. Results from the mathematical model developed by Arsac (2002) indicate the relationship can be expressed by a power relation;

$$T_{adv} = c\,(\log_{10}Alt)^{b}\ , \qquad (3)$$

where c is the scale factor and b (= 5.59) is the exponent. The equation that was fitted to the wind-corrected race times (T_o) at a championship was then

$$T_o = \frac{T_{max} - T_{min}}{1 + e^{-a\,(Y - Y_{inf})}} + T_{min} + Offset + T_{adv2250}\left(\frac{\log_{10}Alt}{\log_{10}2250}\right)^{b}\ , \qquad (4)$$

where the two fitted variables in the nonlinear regression are the time advantage of an altitude of 2250 m ($T_{adv2250}$) and the time offset of the championship from the global historical trend in 100-m performances (*Offset*).

RESULTS: The (wind-corrected) race times for all eight championships closely paralleled the global historical trend in 100-m performance (Figure 2). The calculated time advantage and offset for each of the championships are shown in Table 1. The offsets ranged from relatively small (0.01–0.06 s) for the global championships (i.e., Olympic Games, World Championships), to substantial (0.30–0.82 s) for the area championships in the less developed regions (i.e., South American Championships, African Championships, Central American and Caribbean Championships). Unfortunately, the calculated time advantage of an altitude of 2250 m showed substantial variation among from the eight championships, with some championships showing a large uncertainty (>0.20 s) in the calculated time advantage.

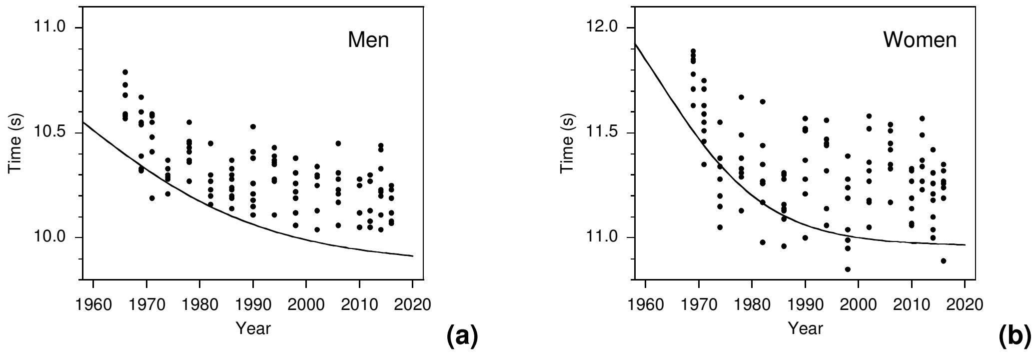

Figure 2: These plots show an example of a set of race times (corrected for wind) from the finalists at a major championship; (a) men and (b) women. Data is for the European Championships between 1966 and 2016. The solid line shows the historical improvement in 100-m performances obtained from the top 20 athletes in the annual world rankings (Linthorne, 2016).

Table 1
Time advantage of an altitude of 2250 m ($T_{adv2250}$) obtained from a nonlinear regression analysis of the wind-corrected 100-m race times by the finalists at selected major championships

Championship	Sex	$T_{adv2250}$ (s) (95% CI)	*Offset* (s) (95% CI)
Olympic Games	Men	0.22 (0.09)	0.03 (0.03)
	Women	0.17 (0.11)	0.02 (0.03)
World Championships	Men	0.18 (0.26)	0.06 (0.03)
	Women	0.00 (0.31)	0.01 (0.03)
European Championships	Men	–0.17 (0.24)	0.19 (0.02)
	Women	0.17 (0.35)	0.23 (0.05)
South American Championships	Men	0.12 (0.09)	0.60 (0.06)
	Women	0.06 (0.17)	0.82 (0.11)
African Championships	Men	–0.01 (0.12)	0.41 (0.06)
	Women	–0.23 (0.33)	0.35 (0.18)
Central American & Carribean Championships	Men	–0.06 (0.10)	0.32 (0.06)
	Women	–0.02 (0.15)	0.51 (0.08)
NCAA Championships	Men	0.12 (0.11)	0.28 (0.02)
	Women	0.25 (0.14)	0.40 (0.03)
Pan American Games	Men	0.22 (0.09)	0.32 (0.04)
	Women	0.26 (0.14)	0.43 (0.07)

DISCUSSION: The most reliable results for the effect of altitude on 100-m sprint times are probably those from the Olympic Games, Pan American Games, and NCAA Championships.

At these championships there were a greater number of competitions with race data, and several of the competitions were at high-altitude venues (>1000 m). Results from these three championships indicate that the time advantage due to an altitude of 2250 m is about 0.19 ± 0.10 s for men and 0.23 ± 0.13 s for women. At any given championship the women always had a larger uncertainty in the calculated time advantage. This is probably due to the greater range in race times at a competition arising from the lesser depth of competition in women's sprinting.

The time advantage obtained from the Olympic Games is similar to that obtained by Linthorne (2016), but has a greater uncertainty due to the present study analysing fewer athletes in each competition. The result from the Olympic Games is probably strongly influenced by the data from the Mexico City 1968 competition and so might be sensitive to systematic factors that affected the race times at this competition.

The results for the Pan American Games and NCAA Championships are based on many competitions, several of which were held at high-altitude sites. Although the calculated time advantage from these championships is probably reliable, we should be wary that the accuracy of the calculated effect of altitude could be influenced by systematic confounding factors at the high-altitude competitions or by a systematic deviation of performances at these championships from the global historical trend in sprint performance.

The World Championships and European Championships did not produce reliable values for the effect of altitude. Although these championships had data from many competitions, none of the competitions were held at venues above 1000 m. The calculated time advantage had a very large uncertainty which was probably due to variations in other factors that can systematically affect sprint performances at a competition. Although the South American Championships, African Championships, and Central American and Caribbean Championships had competitions at high-altitude venues, the calculated time advantage for these championships were based on relatively few competitions and so was not considered to be reliable. Also, some of these championships produced substantially different time advantages for the men and women, or had a large uncertainty in the calculated time advantage.

CONCLUSION: The results from this study indicate that 100-m sprinters derive a substantial performance advantage when competing at a high-altitude venue. The time advantage of an altitude of 2250 m is about 0.19 ± 0.10 s for men and 0.23 ± 0.13 s for women. Unfortunately, the uncertainty associated with this method of analysing competition data is relatively large. The effect of altitude on sprint performance is small and so is easily masked by other factors. Even so, the present study indicates that the performance advantage of altitude is sufficiently large that the altitude of the competition venue should be taken into consideration when recognizing record performances.

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