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Effect of altitude on physiological performance: a statistical analysis using results of international football games

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Altitude and athletic performance: statistical analysis using football results

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ABSTRACT

Objective To assess the effect of altitude on match results and physiological performance of a large and diverse population of professional athletes.
Design Statistical analysis of international football (soccer) scores and results.
Data resources FIFA extensive database of 1460 football matches in 10 countries spanning over 100 years.
Results Altitude had a significant (P<0.001) negative impact on physiological performance as revealed through the overall underperformance of low altitude teams when playing against high altitude teams in South America. High altitude teams score more and concede fewer goals with increasing altitude difference. Each additional 1000 m of altitude difference increases the goal difference by about half of a goal. The probability of the home team winning for two teams from the same altitude is 0.537, whereas this rises to 0.825 for a home team with an altitude difference of 3695 m (such as Bolivia *v* Brazil) and falls to 0.213 when the altitude difference is −3695 m (such as Brazil *v* Bolivia).
Conclusions Altitude provides a significant advantage for high altitude teams when playing international football games at both low and high altitudes. Lowland teams are unable to acclimatise to high altitude, reducing physiological performance. As physiological performance does not protect against the effect of altitude, better predictors of individual susceptibility to altitude illness would facilitate team selection.

INTRODUCTION

In May 2007, football's governing body, the Federation of International Football Associations (FIFA), banned international matches from being played at more than 2500 m above sea level. International football games in South America often take place in high altitude cities—Bogotá, Colombia (2600 m); Quito, Ecuador (2800 m); and La Paz, Bolivia (3600 m) (see table on bmj.com)—presenting a serious challenge to players' acclimatisation mechanisms, particularly for teams playing away games at higher altitudes,[1] with the drop in air pressure making it difficult for the body to obtain sufficient oxygen.[2] At high altitude hypoxia, cold, and dehydration can lead to breathlessness, headaches, nausea, dizziness, and fatigue, and possibly altitude illness including syndromes such as acute mountain sickness, high altitude pulmonary oedema, and cerebral oedema.[3-8] Activities such as football can exacerbate symptoms,[9 10] preventing players from performing at full capacity.[11]

Ability to consume oxygen, which is reduced by acute exposure to high altitude, reflects players' physiological performance and correlates with football performance at a national level.[12 13] The Sport Medicine Commission of FIFA recommends that football matches above 3000 m should be played only after an acclimatisation period of 10 days because of the effects of acute exposure to altitude on performance.[1]

See extra table on bmj.com

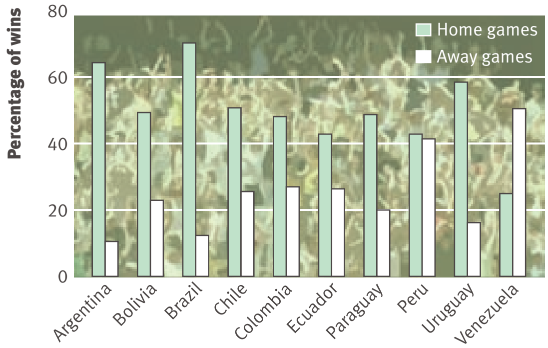

Fig 1 | Percentage of wins at home and away for each country in South America

Awareness of the most efficient means of acclimatising to altitude has important implications for all professional athletes.

Although it is recognised that teams acclimatised to high altitude benefit from favourable physiological conditions, the direct link with football performance at an international level has not been shown or quantified before. I investigated the effect of altitude on a large and diverse population of professional athletes. International football scores and results offer a direct measure of the performance of different teams at multiple altitudes, which can be linked to their ability to acclimatise. The primary hypothesis tested was whether and by how much altitude affects international football performance. By using a database covering a century of matches, I quantified the dependence of football results and scores on altitude and assessed how altitude can be a disadvantage or advantage for professional athletes.

METHODS

By the analysis of scores of international football games played in South America between 1900 and 2004, I directly assessed the influence of altitude on football. Only home and away games were included; I omitted all matches played in neutral venues. This dataset contained football scores for 10 national teams with a total of 1460 games. The well recognised advantage of playing at home as opposed to away is reported in detail elsewhere.[14]

Many factors influence the outcome of football games—including technique, strategy, management, and the players' physiological and psychological condition. I attempted to reduce the effect of these factors by investigating the results of football matches over more than a century. By analysing football results for the entire region of South America, I reduced the influence of any one country. I used dummy variables to code for each country, to control for the differing historical performances of the individual countries. The varying abilities of the different teams are shown by their performances (fig 1). The lowland teams—Brazil, Argentina, and Uruguay—are ranked first, second, and third by the percentage of home wins in our dataset and have won nine of the 17 World Cups (five, two, and two respectively). This high level of skill in the lowland teams serves to disguise the influence of altitude on football performance in South America.

In order to investigate the dependence of performance on altitude, I defined four variables: (i) the probability of a win, (ii) the number of goals scored, (iii) the number of goals conceded, and (iv) the altitude difference between the home venue of a specific team and that of the opposition. The altitude difference variable, Δh, is zero when both home and away teams are from the same altitude, is positive when the home team is at high altitude and the away team has travelled up to altitude, and is negative when the away team has travelled down from altitude toward sea level. I considered three models resulting from different combinations of the above explanatory variables in order to quantify the relative contributions of the altitude and that of the difference in performance between individual countries. These models were intercept and Δh (model A); dummy variables for each country (model B); and Δh and dummy variables for each country (model C).

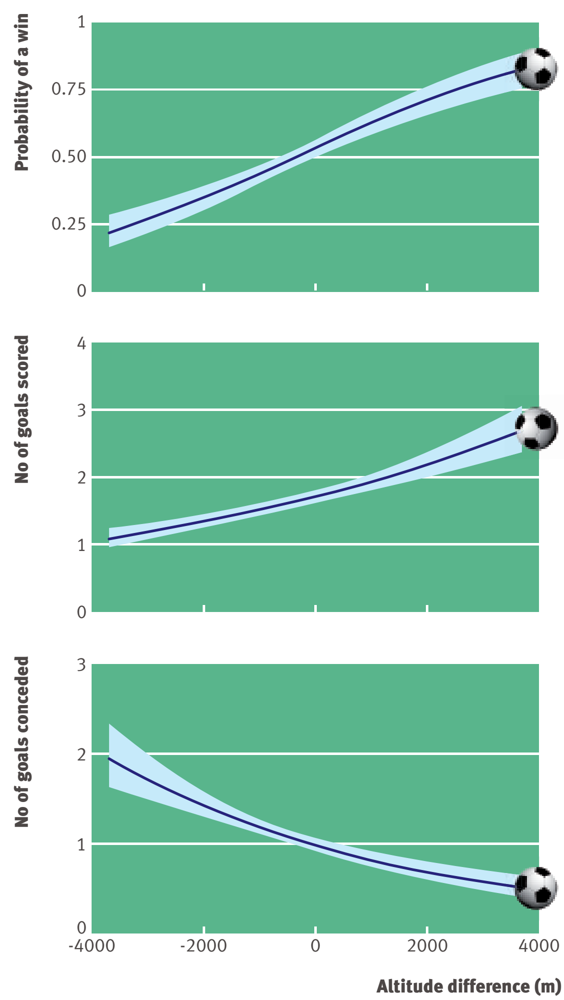

Fig 2 | Effect of altitude difference on the probability of winning (top panel) and on the number of goals scored (middle panel) and conceded (bottom panel). The shaded area indicates the 95% confidence interval.

Probability of a win

I investigated the probability of a win using the same explanatory variables as above and a generalised linear model with a binomial distribution and a logit relation. The set of explanatory variables consisted of dummy variables for each of the 10 countries and one variable for the altitude difference, Δh.

Goals scored and conceded

I used generalised linear models with a Poisson distribution to describe the variation in the number of goals scored and conceded as a function of Δh.

RESULTS

The home advantage for South American football teams was reflected in the significant difference ($P<0.001$) between the number of goals scored and conceded, with averages of 1.81 and 1.04 respectively. The percentage of home wins was 53.7%.

The table shows the parameters and diagnostics for the probability of a win with each of the three models. Altitude difference (model A) and country code (model B) are significant explanatory variables when used independently. The best fit is obtained when using both altitude difference and country code (model C). This result confirms that the inherent differences in performance between countries do not explain the altitude effect. Altitude difference was a significant ($P<0.001$) determinant of outcome for these international football games in both models A and C.

The average effect of altitude on the probability of winning was calculated from model C as shown in fig 2. The probability of a home win for two teams from the same altitude is 0.537, whereas this rises to 0.825 for Δh=3695 m (for example, Bolivia *v* Brazil) and falls to 0.213 when Δh=−3695 m (such as Brazil *v* Bolivia).

Table | **Parameters and diagnostics for each model of the probability of a win in international football matches between South American countries**

	Generalised linear models†		
Variable	Model A	Model B	Model C
Intercept	0.15**	—	—
Altitude (km)	0.21***	—	0.39***
Dummy variable for each country:			
Argentina	—	0.61***	0.48***
Bolivia	—	−0.02	1.21***
Brazil	—	0.87***	0.68
Chile	—	0.03	−0.04**
Colombia	—	−0.06	0.65
Ecuador	—	−0.29	0.47*
Paraguay	—	−0.06	−0.40***
Peru	—	−0.28	−0.66
Uruguay	—	0.34*	0.15***
Venezuela	—	−1.10***	−1.33***
Deviance	1972.12	1944.89	1882.25
Akaike information criteria (AIC)	1976.12	1964.89	1904.25
Bayesian information criteria (BIC)	1986.69	2017.76	1962.40
R2	2.20%	3.55%	6.66%
Adjusted R2	2.01%	2.56%	5.57%

†Model A = intercept and altitude difference. Model B = variables for each country. Model C = altitude difference and variables for each country. Significance: *(P<0.05), **(P<0.01), and ***(P<0.001).

WHAT IS ALREADY KNOWN ON THIS TOPIC

The ability to consume oxygen, which is reduced by acute exposure to altitude, reflects athletes' physiological performance

The better trained teams, on average, have higher mean consumption rates of oxygen

WHAT THIS STUDY ADDS

This study quantifies the effect of altitude on football games between the national teams of South American countries

Teams from high altitude countries have a significant advantage when playing football at both low and high altitudes

I also used altitude difference and country code to construct separate models for the number of goals scored and the number conceded. In each model, the coefficient for Δh was significant ($P<0.001$), but its impact was greatest on the number of goals scored. Teams score more (and concede fewer) goals with increasing Δh (fig 2), suggesting that altitude difference has a significant negative impact on performance. In the case of two teams from the same altitude the home team will, on average, win by 0.70 goals. For each 1000 m of altitude difference, the home team gains almost half of a goal. In the case of Bolivia, playing at home in La Paz, this represents on average a win by 2.18 goals and an advantage of 1.48 goals when competing against teams from sea level (Δh=3695 m). Of this increased home advantage, 1.00 goal is gained by increased goal scoring and 0.48 goal is gained by fewer goals being conceded.

DISCUSSION

The altitude difference between home and away teams in international football games in South America significantly affected the outcome of games. High altitude home teams scored more and conceded fewer goals when playing low altitude teams, and for each additional 1000 m of altitude difference the home team's score increased by about half a goal. In the case of Bolivia playing against a sea level opponent such as Brazil, the probability of a home win was effectively increased from 0.537 to 0.825 because of altitude. The advantage of high altitude teams over their low altitude opponents was greatest at high altitude, but it was also present at low altitude.

The advantage when playing at high altitude is to be expected given the differential in oxygen consumption between the two teams and the effect this has on physiological response and football performance. The surprising result is that the high altitude teams also had an advantage when playing at low altitude, benefiting from a significant advantage over their low altitude opponents at all locations. Although "living high and training high" is accepted as beneficial for athletes performing at high altitude, its effects on performance at sea level are less clear.[15] A growing body of evidence indicates that "living high and training low" is an effective training technique, leading to increased numbers of red blood cells, oxygen consumption, and running performance. It has also been shown to improve sea level performance in accomplished and elite runners.[16 17]

Strengths and weaknesses of study

The strength of the study is the novel approach of using a large football database, containing results of 1460 games played at multiple altitudes over a 100 year period. This is in contrast to previous studies on the effects of altitude, which are based on population sizes of the order of 10.[1] My statistical analysis of football scores provides a direct measure of the relation between physiological performance and altitude that is not susceptible to the effects of any one individual or team.

The weakness of the study is the difficulty in controlling for other factors that influence football outcome, such as the quality of the training and manager. With such a long record of data, however, the results are unlikely to be affected by any single manager. I used dummy variables for each country to control for the differing levels of ability of the teams. There are other effects of altitude such as air resistance which could affect performance. For example, the ball travels differently at high altitudes; it spins less, sails further, and moves faster.

Implications of results

Low altitude teams may adopt different strategies to cope with playing at high altitude. One approach is to arrive at high altitude only hours before the game, whereas another is to allow sufficient time for acclimatisation. The latter approach is often not feasible given the busy schedules of today's international football players. Furthermore, there is no agreed time for acclimatisation, apart from the knowledge that the longer the duration of the activity and the higher the altitude, the more time required for acclimatisation. When possible, the best approach for avoiding altitude illness is to ascend slowly, allowing sufficient time for acclimatisation.[6] Recommendations for above 3000 m include increasing sleeping altitude by only 300-600 m each day and taking a rest day for every additional 1000 m in altitude. Drug treatment may also provide some protection against altitude illness. *Ginkgo biloba* and aspirin have been shown to be more effective than placebo, but most evidence supports the prophylactic use of acetazolamide.[6 18]

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All references and another table are in the version on bmj.com

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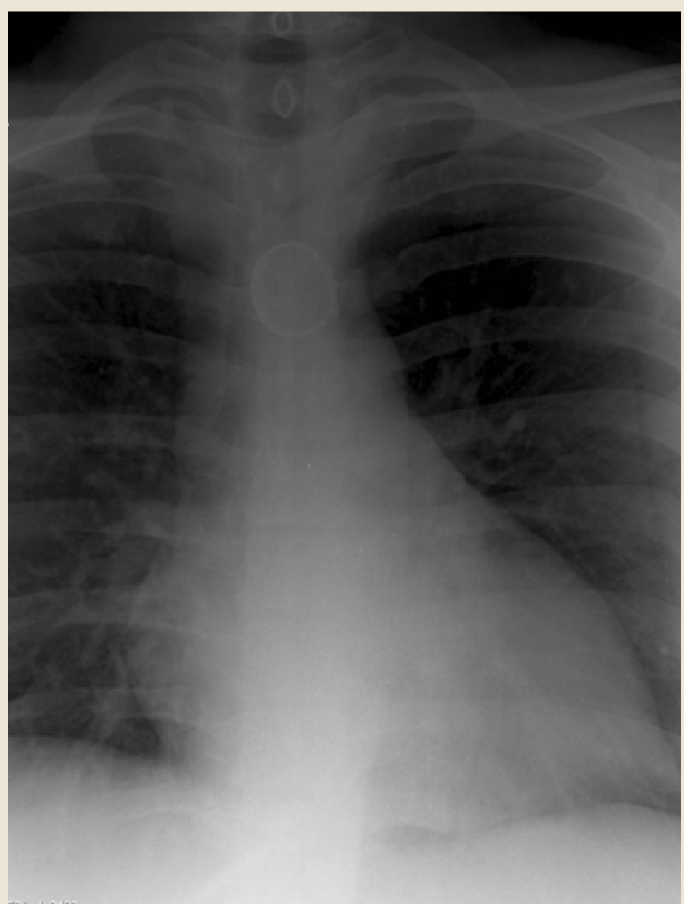
Champagne: the safer choice for celebrations



A 24 year old Australian rules football player presented to the emergency department complaining of a sensation of a foreign body stuck in his throat. The sensation was associated "with an inability to breathe properly." Earlier that day, when celebrating his team's victory in the premiership, he had downed the remaining beer in the premiership cup, inadvertently swallowing a beer bottle cap.

Physical examination, radiography, and fibreoptic examination of the neck and throat were unremarkable. An anteroposterior chest radiogram showed a round metallic foreign body with scalloped edges at the level of the aortic arch (figure). Blood ethanol level was 0.109 g/100 ml. A beer bottle cap was retrieved via endoscopy later that evening, without complications.

Excessive alcohol consumption as a celebratory consequence of high profile sporting victories is well known. Oesophageal obstruction from a bottle cap, however, is rarely seen in emergency departments.[1 2] In suspected cases, airways obstruction and injury should be rapidly excluded.

A comprehensive Medline search failed to elicit an example of oesophageal obstruction secondary to the ingestion of a champagne (or wine) cork. Since the 18th century, champagne has been the beverage of choice for celebrations[3] and on current evidence should remain so.

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1 Prakash K, Rosario PG, Kim S. Esophageal obstruction from a beerbottle cap. *N Engl J Med* 1989;321:121-2.
2 Rottman SJ, Lindsay KL, Kuritzkes R. Of college fads, bottle caps, and esophageal obstruction. *Ann Emerg Med* 1988;17:869.
3 Montagne P. *Larousse gastronomique*. London: Hamlyn Group, 2001:242.