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Statistical test of throwing events on the rotating Earth

Lack of correlations between range and geographic location

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Abstract. In a recent paper, Mizera and Horváth computed the effects of environmental factors on shot put and hammer throw ranges [J. Biomech. **35**, (2002) 785–796]. They found that the geographic location (latitude and altitude) influences throwing distances as strongly as meteorological conditions (wind and air density). Considering the small differences in record-breaking results, they proposed that normalization to a reference stadium should be introduced. Here we attempt to detect possible correlations between geographic location and throwing ranges by using all-time best result lists. Unfortunately the separation of the effects of different environmental factors is not possible, simply because they are not documented. Our tests failed to find the expected correlation. We conclude that the variance of human factors seems to dominate, thus any correction of measured results is probably unnecessary.

PACS. 01.80.+b Physics of sports – 02.50.-r Probability theory, stochastic processes, and statistics

1 Introduction

There is a well documented fact that record-breaking has slowed down in the last decades for many athletic disciplines. "Record-breakers face extinction" – comments the New Scientist [1] a recent analysis by Gembris *et al.* [2]. They point out that only a few disciplines have shown systematic improvements since 1985, thus most of the track and field records are being broken by chance. Whether this is a consequence of strict doping control measures [3], or athletes are getting closer to some physiological limits [4], is a subject of current discussion. Anyhow, shrinking differences of top results demand a high level of standardization and an ever improving measurement technology.

Fair determination of results is a central issue among the rigorous rules of the International Association of Athletics Federations (IAAF) [3]. It might seem surprising that the only environmental factor considered for official ratification of records is tail-wind at running and horizontal jumping events. Namely, results are not recognized when the average wind-speed (which is measured according to strict rules) exceeds 2 m/s during the time of actions. However, other environmental circumstances also strongly influence athletic performance: in long jump, *e.g.*, the sensational 8.90 m leap by Bob Beamon set in Mexico City, 1968, at an altitude of 2300 m, was finally surpassed by 5 cm after nearly 23 years by Mike Powell (1991, Tokyo). At the Mexico City Olympics, the high altitude led to world records in all of the men's races that were 400 m or shorter, including both relays and triple jump as well, but the thinner air (30% less oxygen than at sea level) proved disastrous to many athletes competing in endurance events.

Motivated by these facts, Mizera and Horváth performed detailed computer simulations to study the influence of various environmental factors on shot put and hammer throw ranges [5]. They solved numerically the equation of motion for a point mass in a rotating frame of reference by considering latitude, altitude, release direction, air drag at various meteorological parameters, head- and tail-wind, and ground obliquity. Aerodynamics is not involved (the wire and handle of a hammer is taken into account by an average form drag coefficient), thus the method is not adaptable directly for discus and javelin throw. Table 1 summarizes quantitative results for hammer throw [5]. The most important conclusion is that geographic location influences ranges so strongly as meteorological conditions. Mizera and Horváth developed correction maps permitting of an adjustment for measured distances to some reference conditions, and they proposed that future records should be ratified after proper normalization [5].

In this work we attempt to test possible correlations between top results and the latitude of events. Numerical results of Mizera and Horváth [5] predict that increasing vertical components for the centrifugal and Coriolis forces with decreasing latitudes promote large throwing

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Table 1. Maximal influence of environmental factors for hammer throw range [5]. Release parameters are optimized for the world record (86.74 m).

factor	effect	Δr [cm]
2 m/s head-wind	air drag	−66
2 m/s tail-wind	air drag	62
altitude (1000 m)	gravity + air density	55
latitude (50° decrease)	gravity + centrifugal force	34
air temperature (20 °C increase)	air density (drag)	34
air pressure (4 kPa increase)	air density (drag)	−16
release direction (180° East-West)	Coriolis force	3.4

distances closer to the equator with an eastward release. The main difficulty of such statistics is that the environmental factors at throwing events are not regularly recorded, especially considering subtle details (release direction, air pressure and temperature, etc.). Nevertheless our results indicate the lack of significant correlation, *i.e.* large throws have been succeeded at any latitude. The existing pitfalls of the analysis allows the only conclusion that human factors seem to dominate the statistics, thus the introduction of adjustments is probably not necessary in practice.

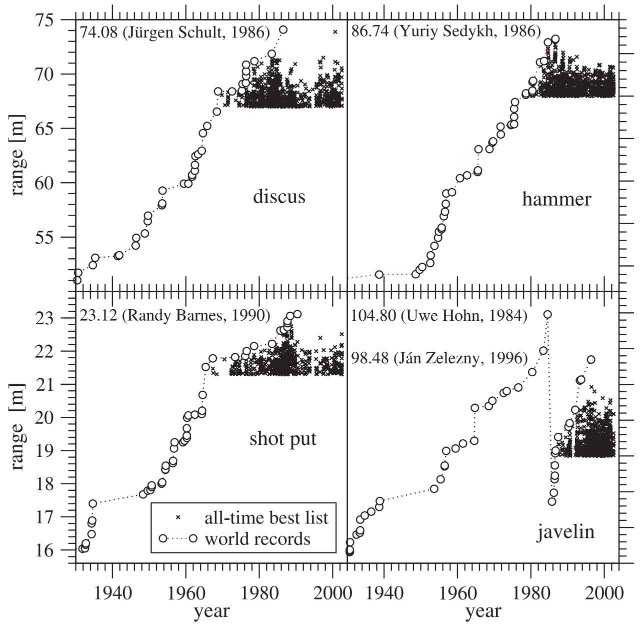

Fig. 1. Progression of world records for men's throwing events (empty circles). All-time best results since 1985 [6] are also indicated (crosses). Note that the technical specification of javelin changed in 1984 to ensure shorter flight times and point first landings (introduced also for women in 1999).

2 General statistics

The data we evaluated are the official records of IAAF [3] and the "unofficial" track and field all-time lists collected and maintained by Larsson [6]. We show here figures for men's results only, because women's data have very similar characteristics apart from numerical values. The time progression of world records together with the all-time best results are plotted in Figure 1. A clear hang of progress is obvious for the last years, a sole, almost record-breaking range was achieved only in discus throw (73.88 m by Virgilijus Alekna, Kaunas, 2000). The analysis of this observation is beyond the scope of the present work.

Figure 2 shows the histograms for the same data on semilogarithmic scales. All distributions seem to obey a smooth exponential shape with slightly different slopes when the maximal values are omitted from the fitting. Apparent outliers are the world records for discus and javelin throws, note however that technical specifications have changed meanwhile for the javelin in order to decrease peak ranges (endangering the audience on grandstands). The exponential shapes are consistent with a description based on extreme value statistics [2,7].

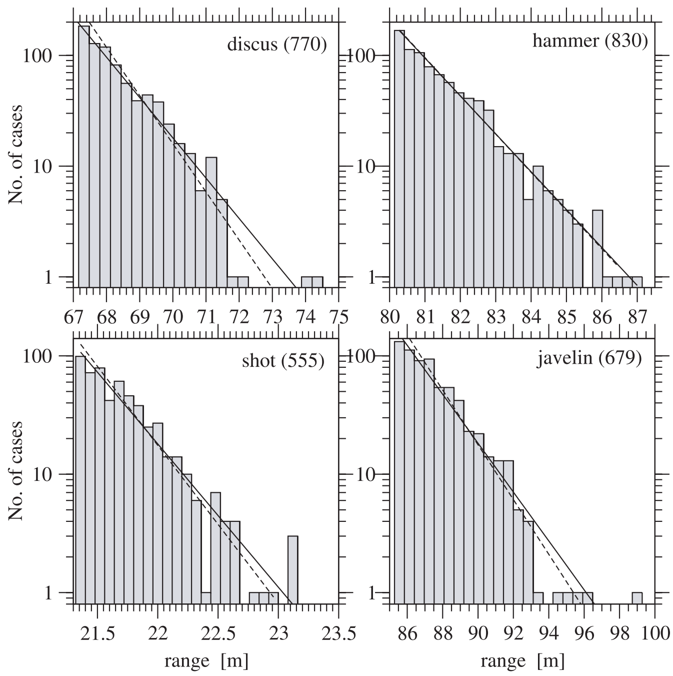

Fig. 2. Histogram for all-time best results since 1985 [6] on semilogarithmic scales. The total number of cases are indicated in parentheses. Solid lines denote exponential fits, dashed lines are the same excluding the largest values.

3 Geographic distribution

In order to detect any correlation between throwing performance and geographic location, we determined the coordinates (latitude and altitude) for track and field events

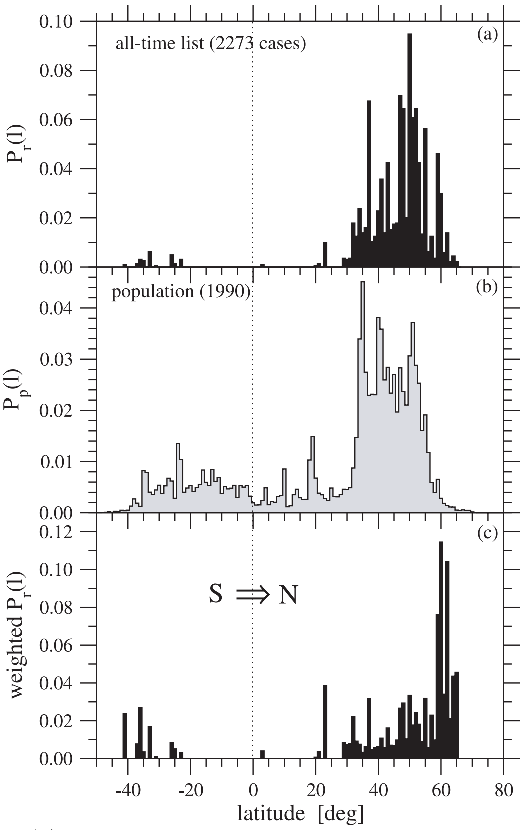

Fig. 3. (a) Normalized probability distribution for the latitude of all-time best throwing results [6] with a binning of 1°. (b) Normalized distribution of population in 1990 as a function of latitude for areas where considerable throwing athletics is present. (The total population in this statistics is approximately 2 billions of people.) (c) The same as (a) weighted with the empirical probability distribution of (b).

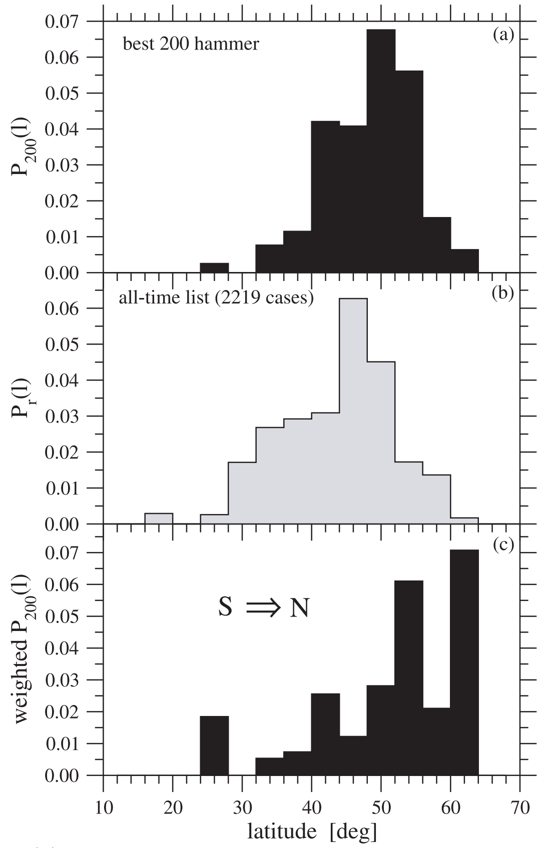

Fig. 4. (a) Normalized probability distribution for the latitude of the best 200 hammer throws [6] on the northern hemisphere with a binning of 4°. (b) Normalized probability distribution for the latitude of all-time best throwing results [6] on the northern hemisphere with a binning of 4°. (c) The same as (a) weighted with the empirical probability distribution of (b).

in the all-time lists [6], 2273 cases altogether [8]. At first, we did not separate different disciplines to have a better statistics.

The raw probability distribution for geographic latitude of large throws (Fig. 3a) has a highly peaked, irregular shape centered at about 50° N. If we accept that record-breaking is essentially a random process without a systematic trend [2,9], success rate at a given location should be proportional to the trial rate. Possible correlation between throw ranges and latitude should appear in a histogram weighted properly with the trial rate distribution. Big throws are well documented, but how to estimate trial rates for a given latitude?

An obvious idea would be to determine the geographic distribution of athletic competitions. It is clear, however, that the rank of events is not equal, best athletes concentrate on important championships, continental and world cups. The role of cities giving place to Olympics is prominent: facilities constructed during the preparation period attract major events for many years after the Games. However, a sampling restricted to Olympics (27 up to now) or IAAF World Championships (10 up to now) would result in a very poor statistics, furthermore many excellent results are achieved at relatively low rank events, such as national championships. The strength of a national competition depends on the spread and popularity of a given athletic discipline, but many other factors, such as the population size of a country, level of economic development, education, development of talents, etc., complicate the task of finding proper weight factors.

It is also a fact that, for many practical reasons, major international competitions drawing stars are organized in large cities or places not too far from highly populated areas. A given level of economic development is also necessary, but there is no strict correlation between GNP per capita and sporting activities (think of South-America, or the former "Soviet block" countries). As a first attempt to find a weighting function, we use the global population density [10] as a function of latitude, restricted to areas where any interest in *throwing* athletics is documented. Thus we don't consider Africa (apart from the southern part), Middle-Asia, India and China, but the whole American continent, Japan, Australia, Europe and Russia are involved (approximately 2 billions of people). The results are shown in Figure 3.

Before further discussion, we show our second attempt plotted in Figure 4. Here the best 200 hammer throw ranges on the northern hemisphere are separated, and the

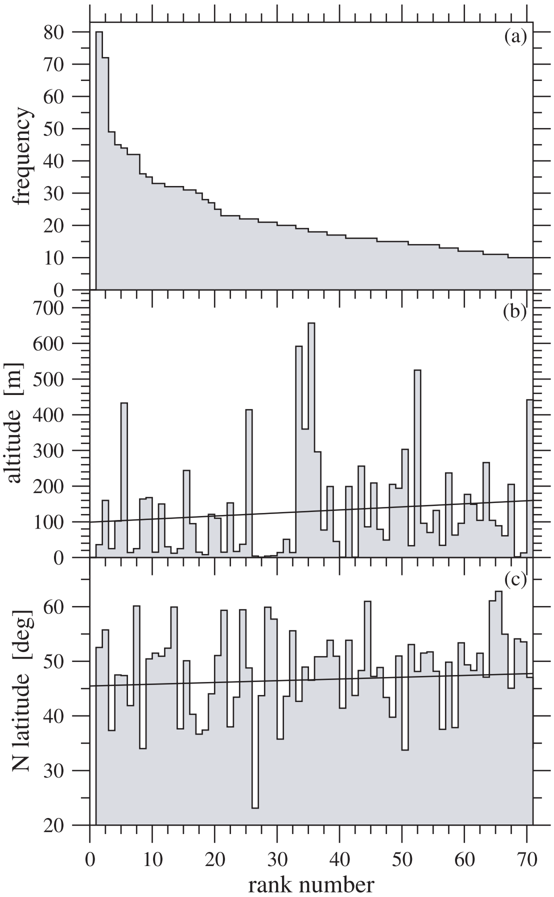

Fig. 5. (a) Rank statistics of locations appearing at least 10 times in the all-time lists of throwing events [6]. The first five cities are Berlin, Moscow, San Jose (CA), Budapest, and Zürich. (b) Altitude for the same places. (c) Latitude for the same places (all are on the northern hemisphere). Solid lines show linear fits.

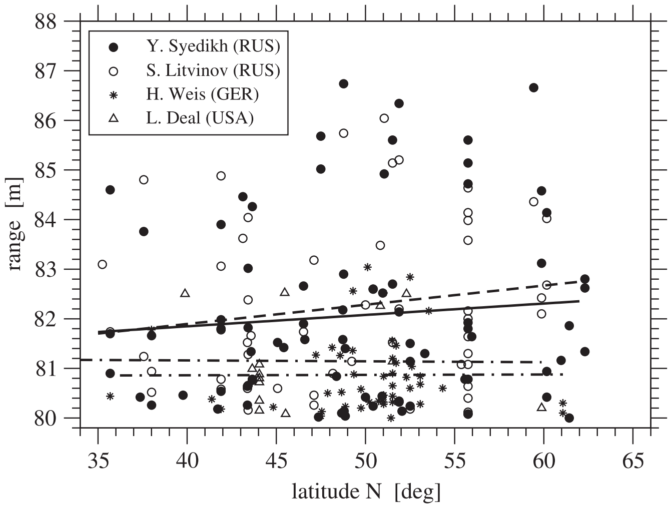

Fig. 6. All-time best results of four excellent athletes in hammer throw as a function of latitude of the events. Lines indicate linear fits. (The legend box does not hide data.)

histogram is determined with a binning of 4° (1° bins give essentially separated peaks). For normalization, the whole all-time list is used with the same binning. Here the underlying assumption is that the frequency of locations listed for large throws in any discipline characterizes the overall trial rate.

Both Figures 3c and 4c indicate just the opposite of what we expect from considering the physical effects on the rotating Earth. Nevertheless we can not conclude that such correlation exists because of several problems. First of all, many factors influence simultaneously throw ranges (see Tab. 1), and we cannot separate them for lack of documentation. The proper weighting of the raw distribution functions is problematic, too. We could check, however, the possible effect of altitude, the results are plotted in Figure 5. 71 places appearing at least 10 times in the all-time lists [6] are collected and ranked according to the number of big throws there. Figures 5b and c show the altitude and latitude for the same places. Linear fits of negligible slopes indicate the lack of correlations.

Another pitfall of the statistics above is that it reflects the contribution of many athletes in a rather wide time period. A convincing measurement in a physical sense would be throwing statistics for many-many trials at different locations of a given test person, with accurate records of all environmental parameters. The best that we could do is to test individual best performances, representative examples being shown in Figure 6. Fitted lines have very small slopes again, cases for negative values (not shown here) can also be found. There is no sign of significant correlations.

Up to now we did not mention an additional parameter contributing significantly to the variance of throw ranges: the human factor. Athletes are not machines, therefore the reproduction of optimal actions can not be perfect in spite of intensive training. Actually, this is the gist of sport competitions. Figure 6 indicates that even the best individual results scatter widely, not to mention the performance during one throwing series.

The crucial role of human factors is reflected in the histograms shown in Figure 7, where the statistics of men's final in hammer and javelin throws for two IAAF World Championships is plotted. Throws were performed during a couple of hours in the same stadium, thus latitude, altitude, release direction and meteorological conditions were the same for all finalists. Unfortunately each athlete has usually 3 or 4 ratified trials during a final, thus a separated treatment is less quantitative. Nevertheless, individual results (see Fig. 8) are almost so widely distributed as the range of the cumulative histogram. It never happens in a major competition that the winner performs the three largest throws. The data presented here indicate that the uncertainty in human factors can be estimated in the range of several meters.

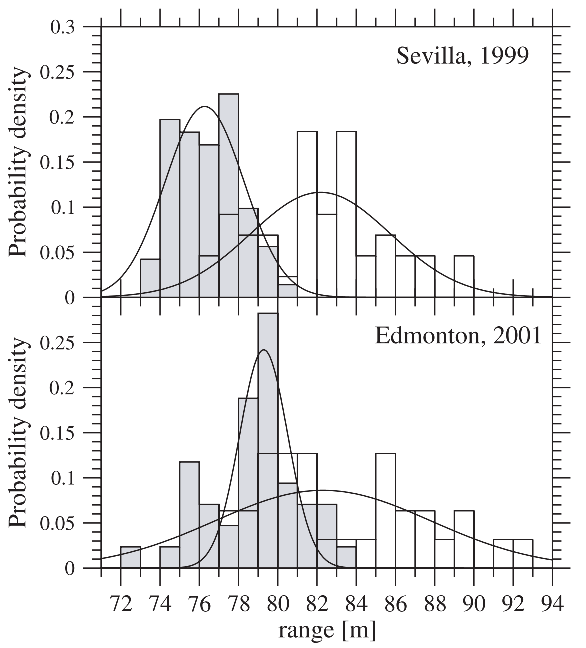

Fig. 7. Histograms of the finals for men's hammer (gray bars) and javelin (empty bars) throw in two recent world championships. Gaussian fits indicate very broad standard deviations.

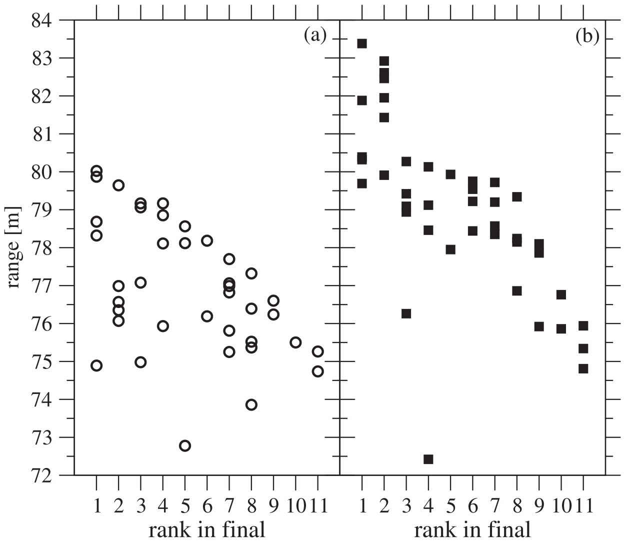

Fig. 8. Graphical representation for two finals of men's hammer throw. (a) Sydney Olympics 2000 (latitude 33° S, altitude 1 m), and (b) IAAF World Championships, Edmonton 2001 (53° N, 643 m). Both competitions were won by Ziolkowsky Szynon (POL). Note the wide scatter of individual performances.

4 Conclusions

We have shown four different tests for detecting possible correlations between large throw ranges and geographic locations, each of them failed. The main difficulty of such statistics is that there is no way to separate the effects of different environmental parameters from the available data. Considering the results of Figures 7 and 8, one can see that the apparent large unsteadiness of human factors easily masks any other environmental influences.

Physical effects are obviously present at throwing events, and each of them can be fully taken into account by means of a proper detectional and computational apparatus. It is a different question, whether the normalization procedure proposed by Mizera and Horváth [5] should be introduced or not, only because it is technically possible, and how far such corrections could be pushed. For example, throw ranges depend strongly on the release height determined primarily by the tallness of athletes (this parameter is not analyzed in Ref. [5]). Does it mean that a fair evaluation of throw ranges would require corrections involving body heights, too? We believe, not. First of all, time progression shows that all of the records set at extreme circumstances (such was the Mexico City Olympics) were broken later as a consequence of continuous development in training and sport science. Secondly, record-breaking is apparently not an end in itself for most of the athletes: they prefer to compete where many other stars are present, benefiting or suffering from the same environmental circumstances together, instead of seeking high mountains close to the equator and waiting for low pressure weather with an optimal tail-wind. Existing data suggest that human sport performance is far from being such uniform that record breakings in near future could be exclusively determined by environmental factors.

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