Published Online August 22, 2008

Updates on improvement of human athletic performance: focus on world records in athletics

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Introduction: Progression of world records (WRs) in athletics is a reliable mean to assess the potentiality of the human body, which also reflects how society has evolved over time and will continue to evolve. We conducted a quantitative analysis of WRs in measurable Olympic events from nine representative disciplines (100, 400, 1500, 10 000 m, marathon, long jump, high jump, shot put and javelin throw) in order to identify progression and trends.

Sources of data: Data were gathered for the years 1900–2007 from the database of the International Olympic Committee.

Areas of agreement: Overall, the relative improvement of athletic performance was higher in women than in men, being nearly doubled across the different specialities. The biggest increases were observed for javelin throw and shot put, in both men and women, respectively. Conversely, the improvement in race time was directly related to the race distance. We also observed a consistent significant linear model of WRs progression in time, although the improvement has substantially stopped or reached a plateau in several specialities.

Growing points: The observed trend might be explained by a variety of factors, including social and environmental changes, natural selection, advances in training and sport physiology, ergogenic aids and, possibly, doping.

Emerging areas for developing research: These results are discussed in a multifaceted approach, taking into account several biological, environmental and technological issues that might explain the trends observed.

Keywords: athletics/ergogenic aids/physiology/sports

Accepted: July 28, 2008

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Introduction

The study of the potentiality of the human body by monitoring sport performance is a method of investigating how society has evolved over time and will continue to evolve in the future millennium.[1,2] A serious competitive setting is where the consequences of performance are most important for an athlete – in principle, the essence of their being.

World records (WRs) in athletics (track and field) are ratified by the International Association of Athletics Federations (IAAF). Records are maintained for all events in the Olympic Games, and also for some other major competitions. The progression of WRs in athletics is traditionally considered a reliable mean to assess the improvement of athletic performances over time both from a physical,[3] and physiological perspective,[4] as WRs are measured in fairly standard external conditions.[1] Therefore, the identification of trends might provide useful insights that enable us to link the improvement of human athletic performances with biology, environment and sports technique.

Materials and methods

We conducted a quantitative analysis of WRs in measurable Olympic events from nine disciplines (100, 400, 1500, 10 000 m, marathon, long jump, high jump, shot put and javelin throw) to identify progression and trends. Data were gathered from the years 1900 to 2007 from the database of the International Olympic Committee.[5]

Results

Overall, the relative improvement of athletic performance was higher in women than in men, being nearly doubled across the different specialities (Figs 1 and 2). The biggest increases were observed for javelin throw and shot put, in both men (58.0% and 48.8%) and women (186.0% and 123.0%), respectively (Table 1). Conversely, the improvement in race time was directly related to the race distance. In fact, a highly significant, positive correlation was observed between percent improvement in race time (since the year 1900 for men and the year 1967 for women) and race distance, for both men ($r = 0.972$; $P < 0.001$) and women ($r = 0.969$; $P < 0.001$). The curve of progression for the male javelin throw records showed a substantial decay in the year 1984. This coincided with the period that the javelin (800 g) was redesigned because of the prodigious distances being thrown, and culminating in a WR throw of 104.80 m by the then East

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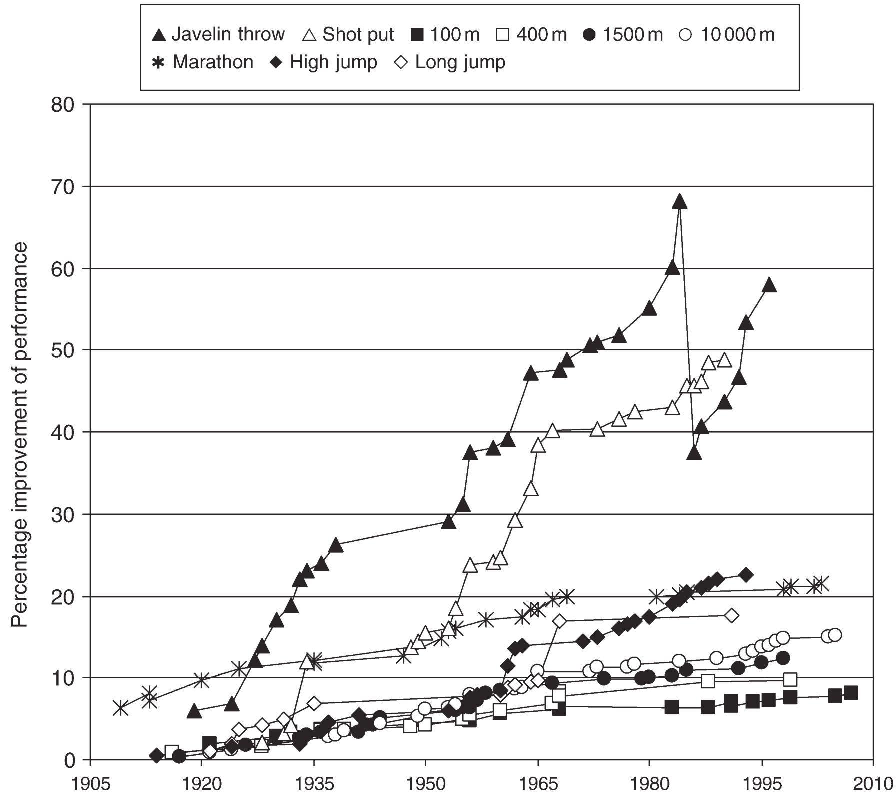

Fig. 1 Progression of male world athletic records in nine Olympic disciplines from 1900 to 2007.

German thrower, Uwe Hohn. In 1999, the women's javelin (600 g) was also redesigned, which explains a similar trend observed in the female curve of record progression. At variance with data on five different Olympic disciplines (10 000 m skating, weight-lifting, cycling, shots and 50 km walk),[2] we observed a consistent significant linear model of records progression in time, with correlation coefficients always greater than 0.839 (Table 2). In no case were the results of the exponential analysis of data superior to those of the linear regression (Table 2).

Discussion

There has been a dramatic improvement in athletic ability over the past century. This is reflected by the continuous progression of WRs in Track and Field Athletics from the early 1900s which was best fitted by a linear rather than an exponential model. However, such a

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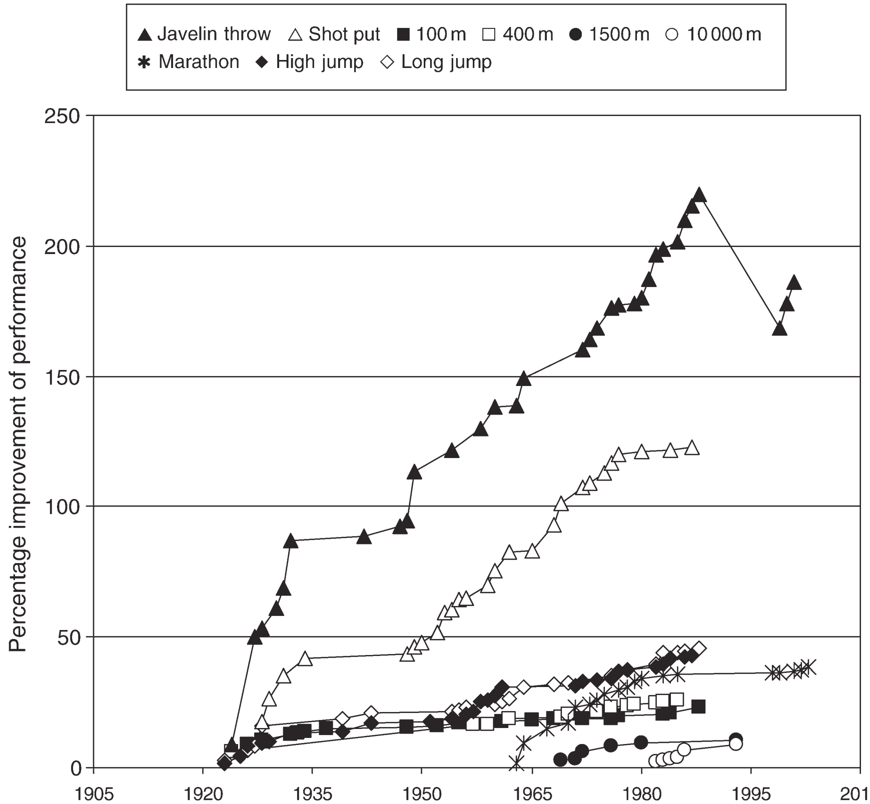

Fig. 2 Progression of female world athletic records in nine Olympic disciplines from 1900 to 2007.

progression was non-homogenously distributed across the various disciplines of Track and Field Athletics, being higher in javelin throw and shot put and lower in short-distance races, such as 100 and 400 m. Moreover, the rate of improvement for women has been extraordinary, and overall greater than that observed for men over an identical period of time, especially for javelin throw, shot put, marathon and 10 000 m. This is in agreement with a previous hypothesis that male physiology is more suited to anaerobic strength events.[6] Carbone *et al.*[1] have previously demonstrated that the sequence of records in the history of athletics is not distributed in a random fashion, but that a distinct regularity exists. From a statistical viewpoint, this is indicative of a possible correlation, evidently unknown *a priori*, between a given event and the next one, and potentially related to cyclical training or to a regularity in the discovery of elite athletes in consecutive human generations. However, the results of our analysis, which was extended to embrace nine disciplines of Track and Field Athletics, raises a critical question: Is such

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Table 1 Progression of word records in athletics from 1900 to 2007

	Men			Women		
	First record	Actual record	Improvement (%)	First record	Actual record	Improvement (%)
100 m, time (date)	00:10:06 (1912)	00:09:74 (2007)	8.1	00:13:06 (1922)	00:10:49 (1988)	22.9
400 m, time (date)	00:47:08 (1900)	00:43:18 (1999)	9.7	01:04:04 (1922)	00:47:60 (1985)	25.7
1500 m, time (date)	03:55:08 (1912)	03:26:00 (1998)	12.4	04:17:03 (1967)	03:50:46 (1993)	10.3
10 000 m, time (date)	30:58:08 (1911)	26:17:53 (2005)	15.1	32:17:20 (1981)	29:31:78 (1993)	8.5
Marathon, time (date)	02:55:19 (1908)	02:04:55 (2003)	21.5	03:40:22 (1926)	02:15:25 (2003)	38.6
Long jump, distance (date)	7.61 m (1901)	8.95 m (1991)	17.6	5.16 m (1922)	7.52 m (1988)	45.7
High jump, distance (date)	2.00 m (1912)	2.45 m (1993)	22.5	1.46 m (1922)	2.09 m (1987)	43.2
Javelin throw, distance (date)	62.32 m (1912)	98.48 m (1996)	58.0	25.01 m (1922)	71.54 m (2001)	186.0
Shot put, distance (date)	15.54 m (1909)	23.12 m (1990)	48.8	10.15 m (1924)	22.63 m (1987)	123.0

Time has been represented as h:min:s.

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Table 2 Analysis of the progression in world records from 1900 to 2007

Discipline	Men		Women	
	Linear regression analysis	Exponential analysis	Linear regression analysis	Exponential analysis
100 m	$y = 0.06x - 120$, $r = 0.970$; $P < 0.01$	$y = (9^{-12})^{0.014x}$, $r = 0.932$; $P < 0.01$	$y = 0.17x - 321$, $r = 0.966$; $P < 0.01$	$y = (5^{-9})^{0.011x}$, $r = 0.933$; $P < 0.01$
400 m	$y = 0.12x - 221$, $r = 0.977$; $P < 0.01$	$y = (2^{-22})^{0.026x}$, $r = 0.923$; $P < 0.01$	$y = 0.324x - 617$, $r = 0.995$; $P < 0.01$	$y = (9^{-19})^{0.023x}$, $r = 0.981$; $P < 0.01$
1500 m	$y = 0.15x - 289$, $r = 0.987$; $P < 0.01$	$y = (5^{-26})^{0.031x}$, $r = 0.895$; $P < 0.01$	$y = 0.310x - 606$, $r = 0.841$; $P = 0.036$	$y = (1^{-43})^{0.051x}$, $r = 0.779$; $P = 0.082$
10 000 m	$y = 0.18x - 340$, $r = 0.988$; $P < 0.01$	$y = (4^{-23})^{0.027x}$, $r = 0.921$; $P < 0.01$	$y = 0.597x - 1181$, $r = 0.947$; $P < 0.01$	$y = (2^{-105})^{0.122x}$, $r = 0.901$; $P < 0.01$
Marathon	$y = 0.16x - 298$, $r = 0.968$; $P < 0.01$	$y = (2^{-9})^{0.012x}$, $r = 0.938$; $P < 0.01$	$y = 0.666x - 1292$, $R^2 = 0.705$, $r = 0.839$; $P < 0.01$	$y = (2^{-31})^{0.037x}$, $r = 0.642$; $P = 0.128$
Long jump	$y = 0.21x - 399$, $r = 0.919$; $P < 0.01$	$y = (7^{-27})^{0.032x}$, $r = 0.883$; $P < 0.01$	$y = 0.583x - 1116$, $r = 0.977$; $P < 0.01$	$y = (1^{-24})^{0.03x}$, $r = 0.898$; $P < 0.01$
High jump	$y = 0.32x - 608$, $r = 0.977$; $P < 0.01$	$y = (3^{-35})^{0.042x}$, $r = 0.958$; $P < 0.01$	$y = 0.586x - 1123$, $r = 0.987$; $P < 0.01$	$y = (2^{-27})^{0.033x}$, $r = 0.904$; $P < 0.01$
Shot put	$y = 0.79x - 1526$, $r = 0.975$; $P < 0.01$	$y = (5^{-35})^{0.042x}$, $r = 0.914$; $P < 0.01$	$y = 1.915x - 3675$, $r = 0.973$; $P < 0.01$	$y = (4^{-24})^{0.03x}$, $r = 0.967$; $P < 0.01$
Javelin throw	$y = 0.62x - 1187$, $r = 0.908$; $P < 0.01$	$y = (3^{-18})^{0.022x}$, $r = 0.879$; $P < 0.01$	$y = 2.134x - 4049$, $r = 0.941$; $P < 0.01$	$y = 63.4^{0.042x}$, $r = 0.904$; $P < 0.01$

improvement over time only due to cyclical training and discovery of elite athletes in consecutive human generations, or can alternative explanations be proposed? Our findings could arise through a broad range of mechanisms, although evidence is currently lacking as to which of these potential mechanisms might be dominant.

First, economical advances and broader coverage of sports by media has contributed to enhance the base number of athletes, including those competing at higher levels. Statistically speaking, this has contextually increased the chance that 'extreme outliers' will occur in a normal distribution of athletes, and may partly account for an improvement in records. Secondly, genetics might be involved: several genes influence athletic performance, which can thus be considered a polygenic trait.[7] A high degree of natural selection will have occurred over time, and the best athletes might be increasingly characterized by a prevalence of genetic alleles that enhance performance as generations pass by. This may also account for the lower improvement of athletic performance in sprints (e.g. 200 and 400 m) when compared with middle- and long-distance events (1500 and 10 000 m and marathon). Performances of sprint athletes are mostly dependent upon two variables, which are basically reaction time and fast muscle fibres, while in endurance athletes performance is regulated by slow muscle fibres, and by aerobic capacity; the latter can be substantially increased by either

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regular training or manipulation (e.g. blood doping). Conversely, reaction time, which is strongly dependent on the neurovegetative system, has a limited margin of improvement when compared with muscular power and aerobic capacity.[4] Alternatively, jumping events are limited by tendon stress limits, which cannot be overcome past a certain natural limit and this might explain why the curve of WRs progression for these specialities is now almost flat. Certainly, whether and/or how much genetic selection has helped the progression of WRs may soon be known, given that high throughput microarray-based epigenetic technology (e.g. ChIP-on-chip and ChIP-seq) will soon be widely available.

Thirdly, the introduction of professional coaching, improvements in training/racing techniques and introduction of ergogenic aids in the form of nutritional supplements and unfair practices have also profoundly changed sports performance. For examples, running economy has greatly improved long distance running, and the Fosbury flop has improved high jump performance. If this is true, then limits will be approached, and a point will be reached, perhaps soon, where performance becomes essentially static, with only the occasional, once-every-generation 'super-athlete' able to set new records. Indeed, we can hypothesize that this situation may have already been reached in some events, such as long jump and short distance runs, as progression of WRs in these events has nearly stopped or has substantially slowed. Among ergogenic aids, doping practices might have played a definitive role in WRs progression. In Figure 1, the curves slowed down in the 1970s in both men and women, at the time that antidoping testing was initially introduced by the International Olympic Committee.[5]

Also, the greater the role that equipment and technology plays a part in a sport, the greater the likely ongoing improvement. Thus, better padding has favoured the improvement in jumping events, the use of fibreglass poles and softer landings have made a huge difference in the development curve of javelin and pole vault, and ergonomics/wind resistant clothes and better running shoes have enabled runners to optimize energy consumption. Finally, it should also be noted that improved accuracy in electronic equipment (compared with past use of stopwatches and measuring tapes) would have played a role in the more accurate measurement of performance. Over the past century, foot races (in particular sprints) were measured to the nearest decimal of a second. Currently, the measurement precision has progressed to a hundredth of a second and, in the very near future, it may be necessary to measure improvements to the nearest thousandth of a second or even less to enable the identification of a new record. Similarly, we might be forced to measure high or long jumps to the nearest millimetre to record new goals.

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Conclusions

The performances of athletes are the product of genetic endowment, hard work and, increasingly, the contribution of science. The latter began many years ago, when scientists, physiologists, kinesiologists, nutritionists, biomechanists and physicists began applying their knowledge to the benefit of athletic performance. As a result, ongoing practicing of a sport for hours is no longer enough to enable an athlete to win. Future limits to athletic performance will be determined less and less by the innate physiology of the athlete, and more and more by scientific and technological advances and by the still evolving judgment on where to draw the line between what is 'natural' and what is artificially enhanced. A previous study determined that by the year 2007, WR would have reached 99% of their asymptotic value.[2] Our analysis in basically in agreement with this hypothesis. Although WRs initially progressed according to a linear model in the nine Olympic disciplines of Track and Field Athletics included in our analysis, as already reported by Mognoni *et al.*,[4] in most instances the progression curve has flattened-out over the past 20 years (e.g. run and jumps), while in other circumstances (e.g. shot put) no improvement has been recorded since the mid-1900s. Hence, if the present conditions prevail for the next 20 years, this will support the hypothesis that most of the male WRs will probably no longer be substantially improved,[2,8] although some female WRs can still be expected to be broken, given increased access and participation.[6] Nevertheless, if gene doping is enacted, we may never be able to predict what the limits of human performance might be. The probability is that further improvements will be mostly due to chance (occurrence of 'extreme outliers' in the normal distribution of top-class athletes), the use of mechanical aids,[9] the introduction of genetic or other forms of doping and, finally, environmental and ecosystem revolutions (e.g. pollution). These would probably make any current mathematical model unreliable for forecasting progression of WRs in athletics.

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