Longitudinal master track and field performance decline rates are lower and performance is better compared to athletes competing only once

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ABSTRACT

In master athletics research, cross-sectional data are easier to obtain than longitudinal data. While cross-sectional data give the age-related performance-decline for a population, longitudinal data show individual trajectories. It is not known whether athletes who repeatedly compete have 1) a better performance and 2) a slower age-related decline in performance than that obtained from cross-sectional data from athletes competing only once. To investigate this, we analyzed 33,254 results of 14,118 male athletes from 8 disciplines in the database of 'Swedish Veteran Athletics'. For each discipline and for the pooled data of all disciplines, quadratic models of the evolution of performance over time were analyzed by ANCOVA/ANOCOVA using MATLAB. The performance was higher in athletes with 2 or more data-points compared to those with only $n = 1$ ($p < 0.001$), with further increases in performance with an increasing number of data-points per athlete. The estimated performance decline was lower in people with 2 or more results (sprint, 10 km, jumps; $p < 0.001$). In conclusion, we showed that longitudinal data are associated with a higher performance and lower performance decline rate.

KEY WORDS: longevity, lifespan, big data, athletics, computational model

INTRODUCTION

Computational models of the trajectory of the age-related decline in athletic performance are of interest not only for the individual athlete, but also in the evaluation of the effects of lifestyle changes, diseases and orthopedic issues during ageing (1-4). The decline in physical performance with age can currently not be stopped, but may be mitigated by a variety of interventions (5). In the research of the efficacy of lifestyle factor countermeasures to attenuate the age-related decline in performance, often cross-sectional (CS) data are used, as they are easier to obtain than longitudinal (LN) data (1,6-12). It has been reported that CS data show in general a lower performance at any age than LN data, and it has been suggested that this is probably due to better-performing athletes continue in the sport longer (4,13-14). In addition, uninterrupted training seems to attenuate the rate of age-related decline compared to CS data in sprinting and middle-distance running (4). Stones & Kozma (15) even found CS declines to be approximately twice as steep as LN declines. This is, however, not unequivocal. For instance, it has been observed that some physiological characteristics of athletes who started late with athletics are as good as in those who had been active for longer (16), and we found that 80-year-old athletes who stopped competing performed as well as those continuing until the age of 85 (2). LN data is considered more appropriate than CS data for studying ageing. However, previous studies (14,15) were only based on small data sets to compare CS and LN data. To address this problem, we analyzed the Swedish master track and field database that includes a large amount of data from annual rankings of the last 120 years, from 35- to 96-year-old athletes. We used this database to assess 1) whether the trajectories of age-related declines differ between CS and LN data, 2) how this is affected by the number of years an athlete participates in competitions, 3) whether athletes who repeatedly compete perform better than those who compete only once and 4) whether the estimated performance trajectories differ between younger and older athletes.

MATERIALS AND METHODS

The Institutional Review Board of the Faculty of Medicine of Rheinisch-Westfälische Technische Hochschule Aachen (reference number EK 300/17) has approved the study. It was performed in accordance with the ethical standards of the 1964 Declaration of Helsinki and its later amendments.

Generation of data set

The publicly available database of 'Swedish Veteran Athletics'[1] was scraped and processed using Python-scripts (scraper, parser and combiner/formatter) to obtain a data set in 8 athletics disciplines (see 13 for details). In Sweden, master athletics starts at the age of 35 years. The data only includes each athlete's best performance in each year, so the term "number of results" used in this paper also reflects the number of years with results available for the individual. Due to low numbers of results from female athletes, only the men's data were analyzed. The following events were included in the analysis: 100 m, 200 m, 400 m, 800 m, 5000 m, 10000 m, long jump and high jump. The throwing events were not included, as the weights of the throwing implements (javelins, hammers, discusses, and shots) change step-wise with age, thereby altering performance decline trajectories. In contrast to our previous study using data from the same Swedish database where we applied second-order polynomials without further constraints (13), here we combined pure quadratic functions (i.e. functions with only a quadratic and without a linear term, but including a constant term) with an aggregated analysis. This allowed us to analyze differences in performance and decline rates for each number of data-points per individual.

Statistical analysis

[1] http://www.friidrott.info/veteran/index.php

The median performance of each event at age 35 was calculated to normalize the data and to allow for an aggregated analysis of all events. Outliers in the data were removed by thresholding ($P < 20\%$, $P > 200\%$) and by using Grubbs's test for outliers (17). For each event, a quadratic model for the evolution of performance over time was assumed,

$$P_n(a) = P_{n,35} - \alpha_n (a-35)^2,$$

where $P_n(a)$ is the performance in percent at age $a \geq 35$, $P_{n,35}$ is the estimated starting performance at age 35, and α_n is the decline factor in percent per year squared. In all parameters, n signifies the number of data-points per subject with $n = 1, 2, \ldots, 10$. An individual analysis was performed for each event and in addition, a combined analysis was conducted with the data of all events pooled. All computations and statistical analyses were performed using MATLAB R2019b (The MathWorks, Natick, MA, USA). To determine significance, an Analysis of Covariance (ANCOVA / ANOCOVA) using MATLAB's "aoctool" was performed. Subsequent comparison of the n groups was conducted using MATLAB's "multcompare" functionality. Significance was assumed at $p < 0.05$ and marked in blue with diamond-shaped markers; high significance was assumed at $p < 0.001$ and marked in red and with circular markers.

RESULTS

A total of 33,254 out of 33,570 results of 14,118 male athletes with an average age of 51.15 years (standard deviation 11.08 years) were analyzed after the removal of outliers. **Table 1** shows the size of the data set for each discipline and number of results. The lowest number of data was available in long jump and 400 m sprint and the highest in the 5000 m and 10000 m runs. Details on the distribution of consecutive datapoints per subject and the age range of results are given in **eFigures 1 and 2** in the supplement. There were 9 athletes who had results over a period of 40 or more years and one athlete had even data spanning more than 50 years (**eFigure 3**).

Separate analyses of events

Figure 1 shows the average estimated performance at age 35 years for $n = 1$ and for each number of results onwards ($n \geq 2\ldots10$), and the estimated performance decline rates in percent per year squared for $n = 1$ and each number of results onwards in the data set. The estimated performance at age 35 in athletes with $n = 1$ was lower compared to athletes who have competed for several years, and in most disciplines increased with the number of results. In the sprints, jumps and 10000 m runs, one result in the data set was associated with higher performance decline rates than several results. In 800 m running, significant differences to $n = 1$ could only be found from $n = 8$ onwards. The 5000 m was an exception where no significant differences in decline rates were found between one-off and repeated competitors.

Pooled analysis of all events

We pooled the data of all events for a separate analysis. Results are shown in **Figure 2**. The performance at age 35 (**Figure 2A**) was lower in those athletes only competing in one year compared to those competing more years and the performance increased further with higher numbers of years competing, not reaching a plateau. The performance decline rate in (percent per year)^2 (**Figure 2B**) was highest in the analysis of athletes with $n = 1$ compared to those with more results (all $p < 0.001$). **Figure 3** shows all individual performances (**Figure 3A**) and the regression lines for $n = 1$ to 10 (**Figure 3B**). The regression line for $n = 1$ shows a much lower performance compared to $n \geq 2$ to 10 for any age.

Decline trajectories of younger compared to older master athletes

The comparison of younger (< 55 years) and older (≥ 55 years) athletes showed that although the starting performances were significantly lower in the older athletes, the rates of performance decline were significantly diminished (**Figure 4 and eFigure 4**).

DISCUSSION

The present study analyzed 33,254 results of 14,118 male athletes from the database of 'Swedish Veteran Athletics'. The main observations were that 1) the estimated age-related rate of performance decline was smaller and 2) the average performance at any age better when derived from athletes with results in 2 or more years than that derived from athletes competing only once.

Comparison of cross-sectional and longitudinal decline rates

The pooled ANOVA/ANCOVA analysis revealed that the rate of performance decline becomes smaller with increasing numbers of results for an athlete. In addition, compared to the LN data, the CS exhibit a lower starting performance. LN data are preferable to CS data as they reflect physiologic performance declines in healthy and active individuals better than the data of individuals with fewer results, thereby attenuating the inter-individual variation. Our study and previous studies (4,14,15) indicate that CS data may underestimate the benefits of an active lifestyle to attenuate the age-related decline in performance. Perhaps most striking is that our model indicated that the performance at age 95 is about 2.5x as high in repeat performers than in one-off performers.

In wealthy countries, the normal level of daily physical activity in the population was higher in the past compared to the present-day population. A sedentary lifestyle, prevalent in the modern society, is associated with the occurrence of the metabolic syndrome, including adiposity and diseases such as diabetes, dyslipidemia and hypertension (18). Here we show that an active and healthy lifestyle seems to be associated with a slower performance decline rate and perhaps provides an indirect indication of the trajectory of optimal ageing (19).

The slower decline seen in longitudinal than cross-sectional data may to some extent be attributable to better experience and techniques, such as pacing, of athletes that repeatedly compete compared to one-off competitors. Indeed, it has been shown that pacing plays an important role in running events (20), where pacing can be adjusted based on the understanding of the lactate threshold, sprint ability and tactical decisions during the race, such as whom to follow and when to let go of a competitor (21). Such pacing perfection comes with experience in competitive running, and may thus explain the slower age-related decline in performance in longitudinal than cross-sectional data.

It should be noted that the rate of performance decline is not constant across life (1,2,13) and that the data set presented here is a *time-unstructured* data set, which means data collection dates vary among subjects (22). For this reason, a model was computed to assume decline rates for separate groups, based on the time-unstructured individual data, and all further analyses were conducted based on the model. As a next step, the same type of analysis could be conducted for other master sports.

Our results indicated that in the sprint disciplines, jumps and 10000 m runs, one result in the data set was associated with higher performance decline rates than several results. This is particularly nicely illustrated by the better relative performance at any age in the person for whom we had data over a period of 50 years. In 5000 m, however, no differences could be found between result numbers. It is indeed possible that long before their one-off 5000 m competition these athletes participated in other running events outside track and field competitions, and hence in reality had competed more than one time. This of course could apply to any event, but more likely so to the common recreational 5000 m than the less common other track and field events, and obscure the difference between longitudinal and cross-sectional data in this event.

The performance decline rates are similar in the jumps, sprint, and 10000 m running events, despite the fact that physiological requirements of these disciplines vary substantially. In this context it is interesting that the age-related rate of decline in maximal oxygen uptake in endurance athletes (23) and power in power athletes (24) are similar, and that these relative rates in decline in VO_2max and power are similar to those seen in non-athletes (23,24). There thus appears to be an inherent ageing process that affects all physiological systems similarly that may well explain the similar rates of age-related decline in athletic events with different physiological demands.

In recent years, many national track and field organizations have started to publish their annual rankings online, such as the Canadian (4) and Swedish (13) one. It therefore seems likely that much larger LN data sets will be available in a few years to further evaluate longitudinally any potential differences in the rate of decline in performance between disciplines.

Master sports performance decline rates

Stones & Kozma (15) were the first to compare annual percent performance decline rates of master athletes from CS and LN results. In their relatively small data set including a LN five-year period of Canadian master track and field rankings, the LN decline was approximately half as steep as the CS decline. Our findings cannot confirm the extent of this difference, but do agree that CS data are associated with a faster rate of performance decline than LN data. A study published by Young & Starkes (14) analyzed the running performance of 15 master runners over a 20-year period and reported the LN performance decline to be more linear compared to the curvilinear decline of CS data. This result is in line with our findings. Sousa et al. (25) published results of two master triathlon athletes spanning 20 and 29 (35-55 and 40-69) years of age and showed that performance decline rates varied among the three disciplines swimming, cycling, and running with running being the discipline with the greatest performance-decline rate.

The present study is the first to report that both starting performance and the decline rate were significantly lower in athletes 55 years and older, compared to the younger master athletes. This finding is surprising, as the opposite was previously reported in studies where the decline rate increased with age (1,2,4). A possible explanation for this phenomenon is that at young age performance is relatively stable and there is not much of a decline even in non-athletes, whereas in older age the exercise may somewhat attenuate the age-related rate of decline, and has a larger relative benefit in old than young age. Nevertheless, this suggestion needs to be treated with caution.

Limitations of the computational model

A straight-forward way of processing longitudinal data is to fit separate models to each subject's individual decline trajectory and then to analyze their distribution. In this work, however, only one quadratic model with two parameters (starting performance $P_{n,35}$ and decline factor α_n) was fitted to the data of all subjects that had the respective number of datapoints ($n = 1$, $n \geq 2$, etc.). This allowed a robust, combined analysis for many individuals and events rather than a per-subject approach. To illustrate this, consider a subject with two datapoints where the performance of the second measurement is higher than the first. A model fitted to this subject alone shows a negative decline, i.e., a performance increase. While this describes the data of that subject correctly, we argue that this is not a meaningful reflection about long-term age-related performance decline in a population, but rather is an outlier. While our model is robust to this type of artifacts, it has the unintuitive property of reporting starting performances ($P_{n,35}$) different from 100%, as it optimally describes the whole range of the data simultaneously rather than only the data at age 35, which was the point of normalization for the different events. Additionally, in particular subject data with a larger *n* may contain useful information that is currently not exploited by the approach and should be studied in detail in future work.

Strength and weaknesses

The present analysis is based on data from the Swedish Master Athletics database and therefore delivers results that are at least true for a northern European population. It might well be that average performances and decline rates differ among nations and continents, caused by differences in typical body characteristics and lifestyle. Another shortcoming is that only the results of men were analyzed due to a very low number of results from women in the data set. This strategy was unfortunately necessary for statistical reasons, and we hope to be able to collect enough data for a similar analysis in women in the future. Women participate in competitive sports only half as often as men (26) and their participation in competitive athletics only started as a mass-phenomenon in the second half of the 20th century (27). Finally, another shortcoming is that only up to ≥ 10 results were analyzed due to the rarity of athletes with more than 10 results. Analyses of larger numbers may be possible in the future with the ever-expanding data sets. The main strengths of the study are that these research questions are addressed for the first time in a large data set, where previous studies always had much smaller data sets that did not allow for such analyses as presented here.

Conclusions

The present study used a large data set and a big data statistical approach. We showed that a significantly smaller performance decline rate and a higher performance were observed when analyzing longitudinal compared to cross-sectional data. The rates of decline in the longitudinal data set may be closest to the best achievable trajectory of healthy ageing.

FUNDING

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CONFLICT OF INTEREST

None declared.

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TABLES

Table 1: Numbers of results in the data set for each discipline and number of results (≥ n)

	100 m	200 m	400 m	800 m	5000 m	10000 m	Long Jump	High Jump	Sum
$n = 1$	767	654	659	918	1777	1738	604	551	7668
$n \geq 2$	2345	2179	2223	3083	5723	5636	1951	2446	25586
$n \geq 3$	1903	1781	1793	2449	4519	4396	1603	2086	20530
$n \geq 4$	1573	1448	1433	2011	3544	3319	1327	1777	16432
$n \geq 5$	1301	1196	1129	1635	2756	2547	1103	1581	13248
$n \geq 6$	1041	996	909	1325	2211	1987	913	1346	10728
$n \geq 7$	885	858	735	1085	1779	1543	745	1124	8754
$n \geq 8$	738	690	616	896	1443	1200	619	977	7179
$n \geq 9$	650	562	512	696	1155	1008	547	833	5963
$n \geq 10$	551	463	395	498	876	693	421	743	4640

FIGURE LEGENDS

Figure 1: Comparison of the estimated performance at age 35 years $P_{n,35}$ and the estimated performance decline α_n for $n = 1$ and $n \geq 2$ to ≥ 10 in eight events. Blue markers indicate a significant ($p < 0.05$) difference comparing $n \geq 2$, $n \geq 3$, etc. to $n = 1$ (marked in black). Red markers indicate a high significance level ($p < 0.001$).

Figure 2: Aggregated analysis over all events for the estimated performance at age 35 years $P_{n,35}$ and decline α_n for $n = 1$ to ≥ 10. Blue numbers indicate a significant ($p < 0.05$, *) difference, and to which $\geq n$ and $n = 1$ (marked in black). Red markers and numbers indicate a high level of significance ($p < 0.001$, **).

Figure 3: Plot of all results in all events pooled and regression lines for $n = 1$ to ≥ 10 with differences between groups indicated by their delta for the ages 35 and 95.

Figure 4: Comparison of the younger (< 55 years) and older ($\geq$ 55 years) athletes for $n = 1$ and $n = 10$ only. The steeper decline rate in the younger athletes is evident for both n.

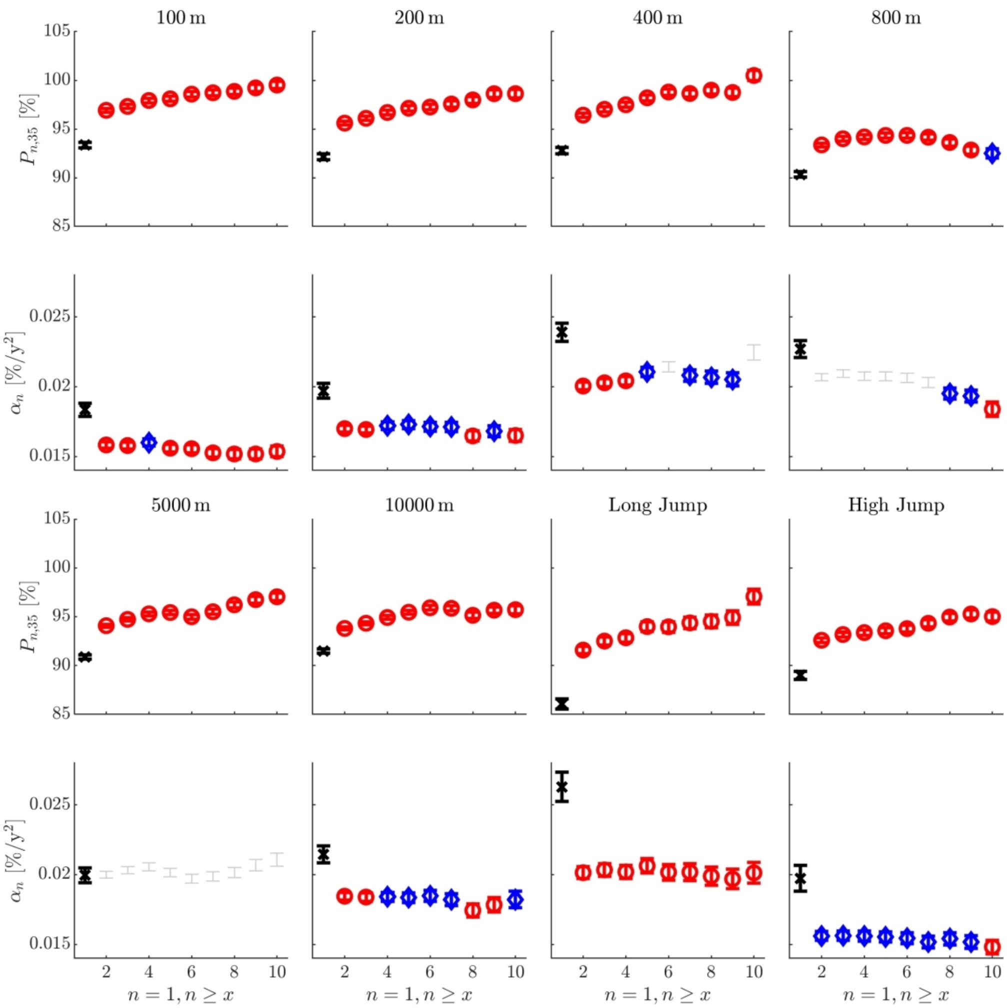

Figure 1: Comparison of the estimated performance at age 35 years Pn,35 and the estimated performance decline αn for n = 1 and n ≥ 2 to ≥ 10 in eight events. Blue markers indicate a significant ($p < 0.05$) difference comparing n ≥ 2, n ≥ 3, etc. to n = 1 (marked in black). Red markers indicate a high significance level ($p < 0.001$).

832x828mm (72 x 72 DPI)

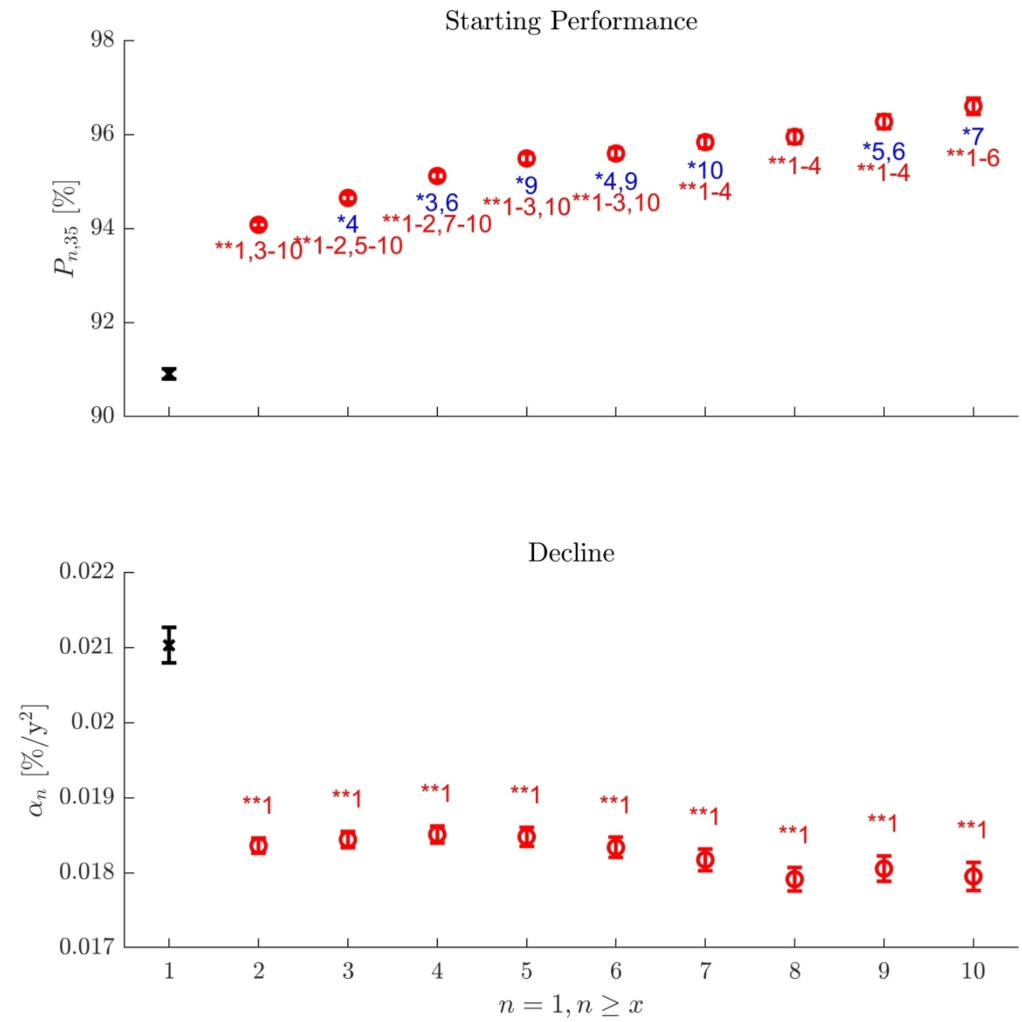

Figure 2: Aggregated analysis over all events for the estimated performance at age 35 years Pn,35 and decline αn for n = 1 to ≥ 10. Blue numbers indicate a significant ($p < 0.05$, *) difference, and to which ≥ n and n = 1 (marked in black). Red markers and numbers indicate a high level of significance ($p < 0.001$, **).

764x771mm (72 x 72 DPI)

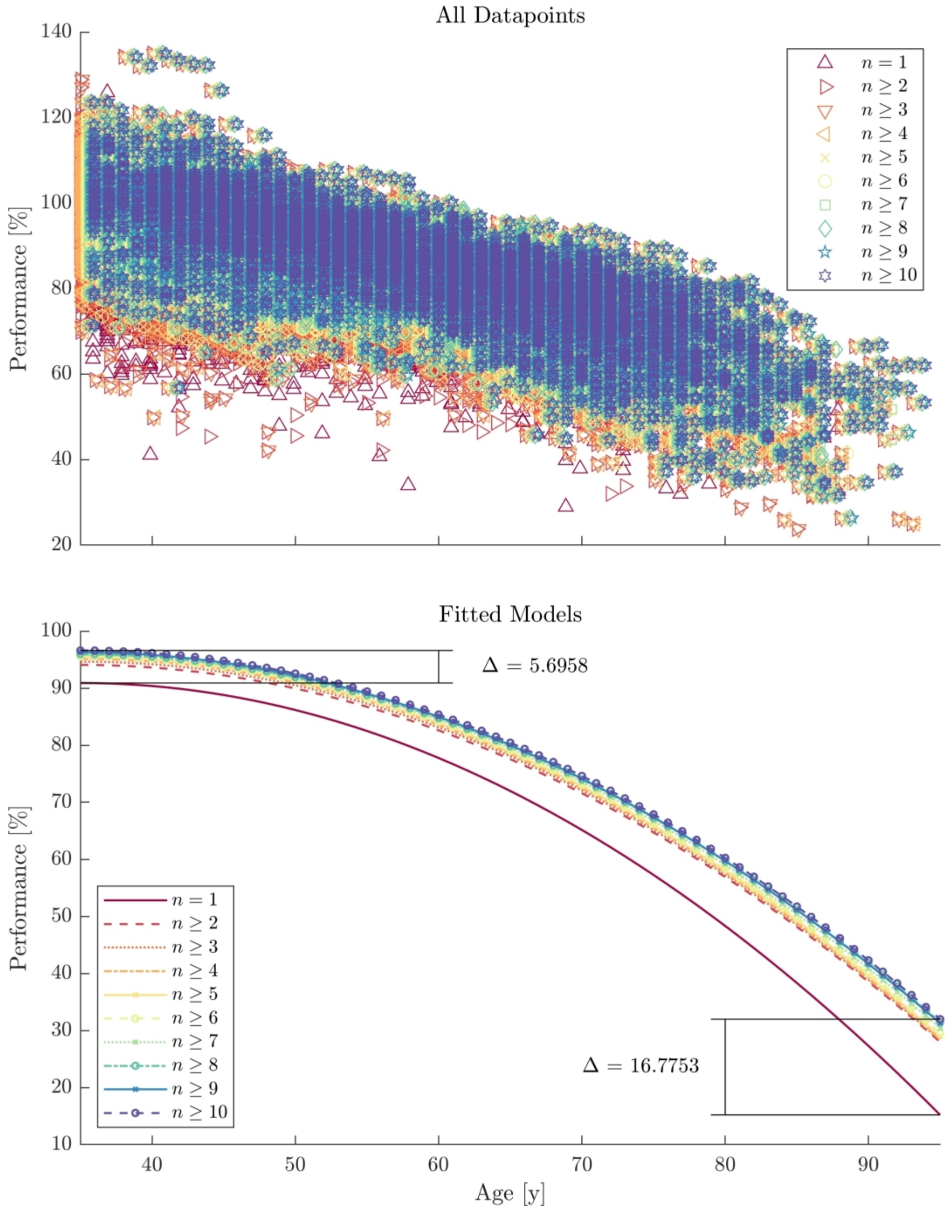

Figure 3: Plot of all results in all events pooled and regression lines for n = 1 to ≥ 10 with differences between groups indicated by their delta for the ages 35 and 95.

835x1068mm (72 x 72 DPI)

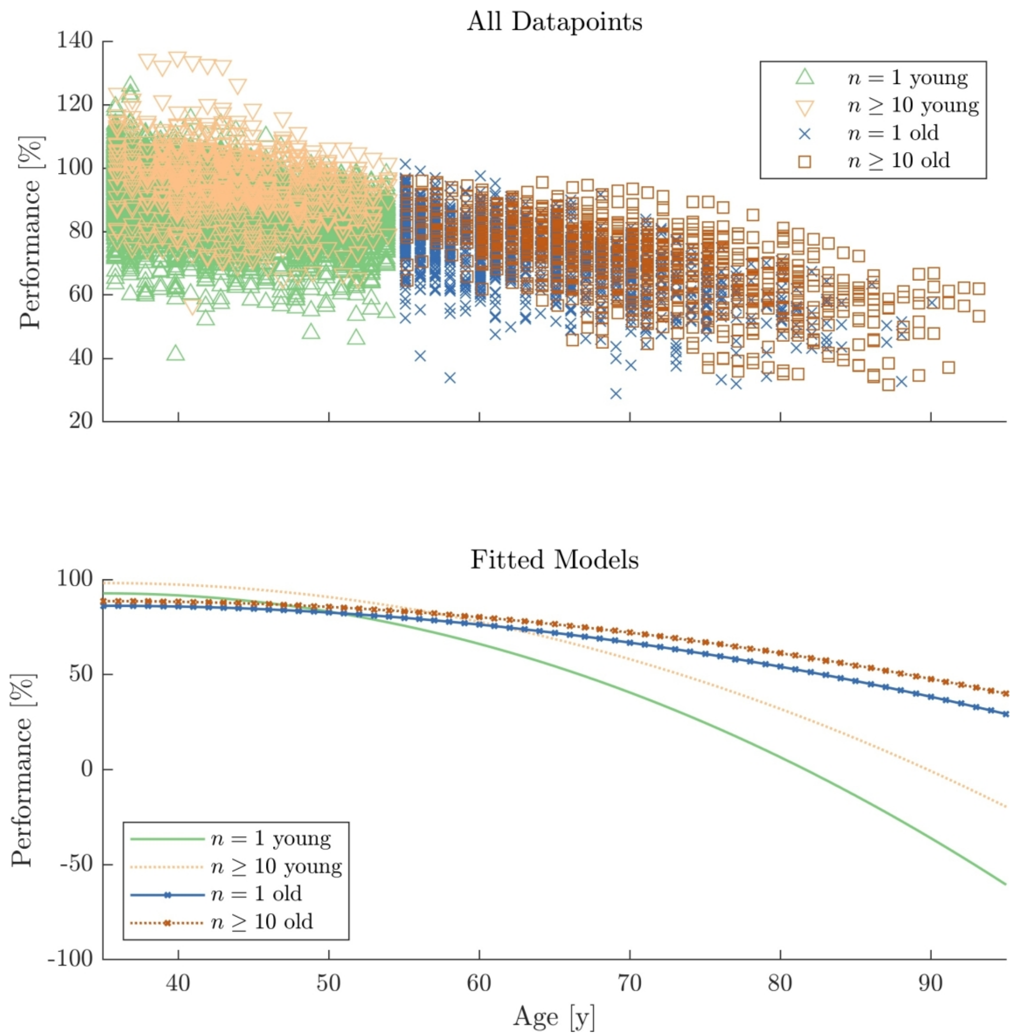

Figure 4: Comparison of the younger (< 55 years) and older (≥ 55 years) athletes for n = 1 and n = 10 only. The steeper decline rate in the younger athletes is evident for both n.

757x772mm (72 x 72 DPI)

Supplement

This file contains the supplementary figures to the paper

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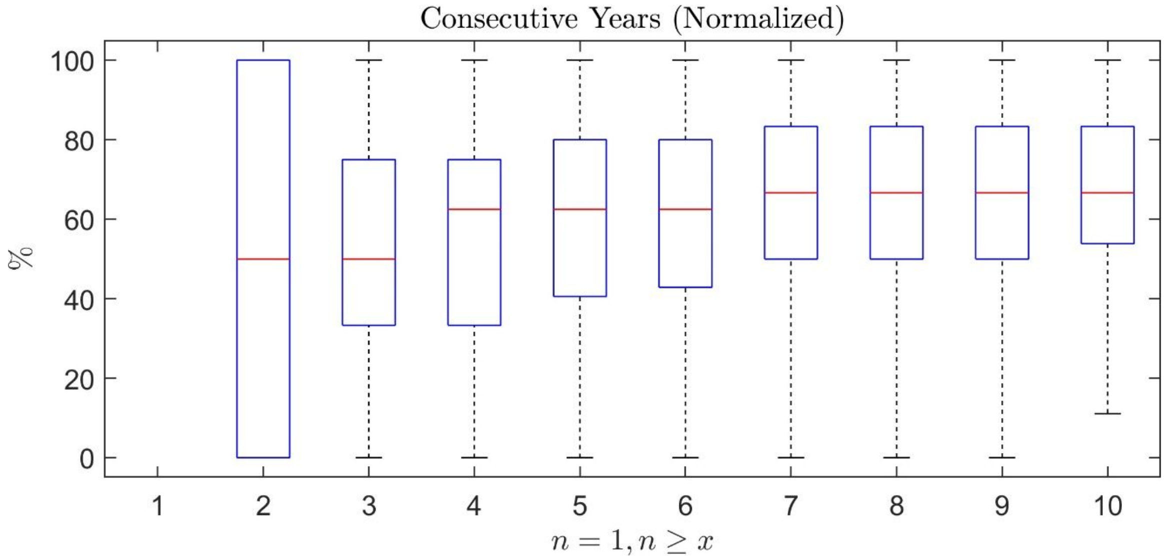
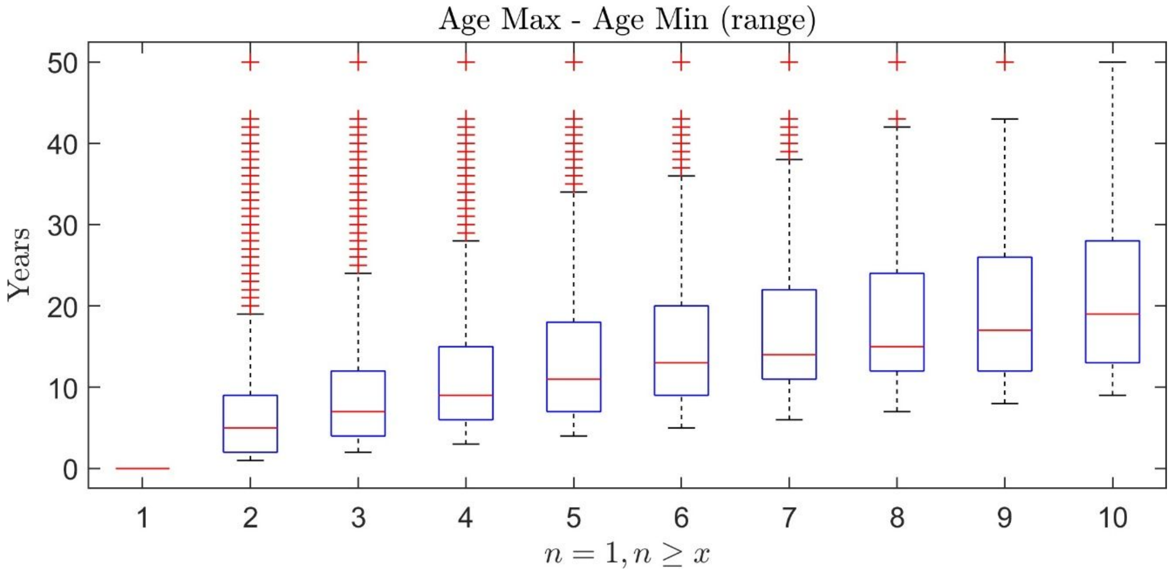
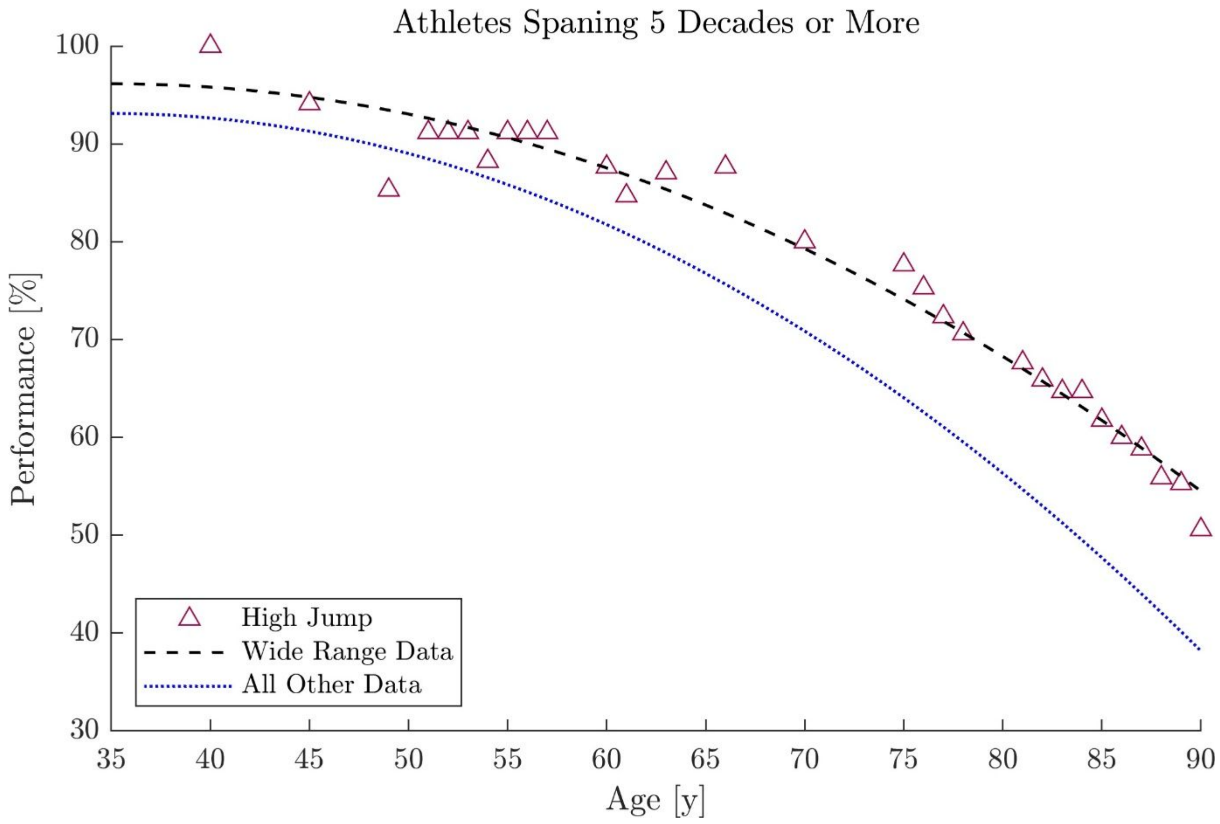


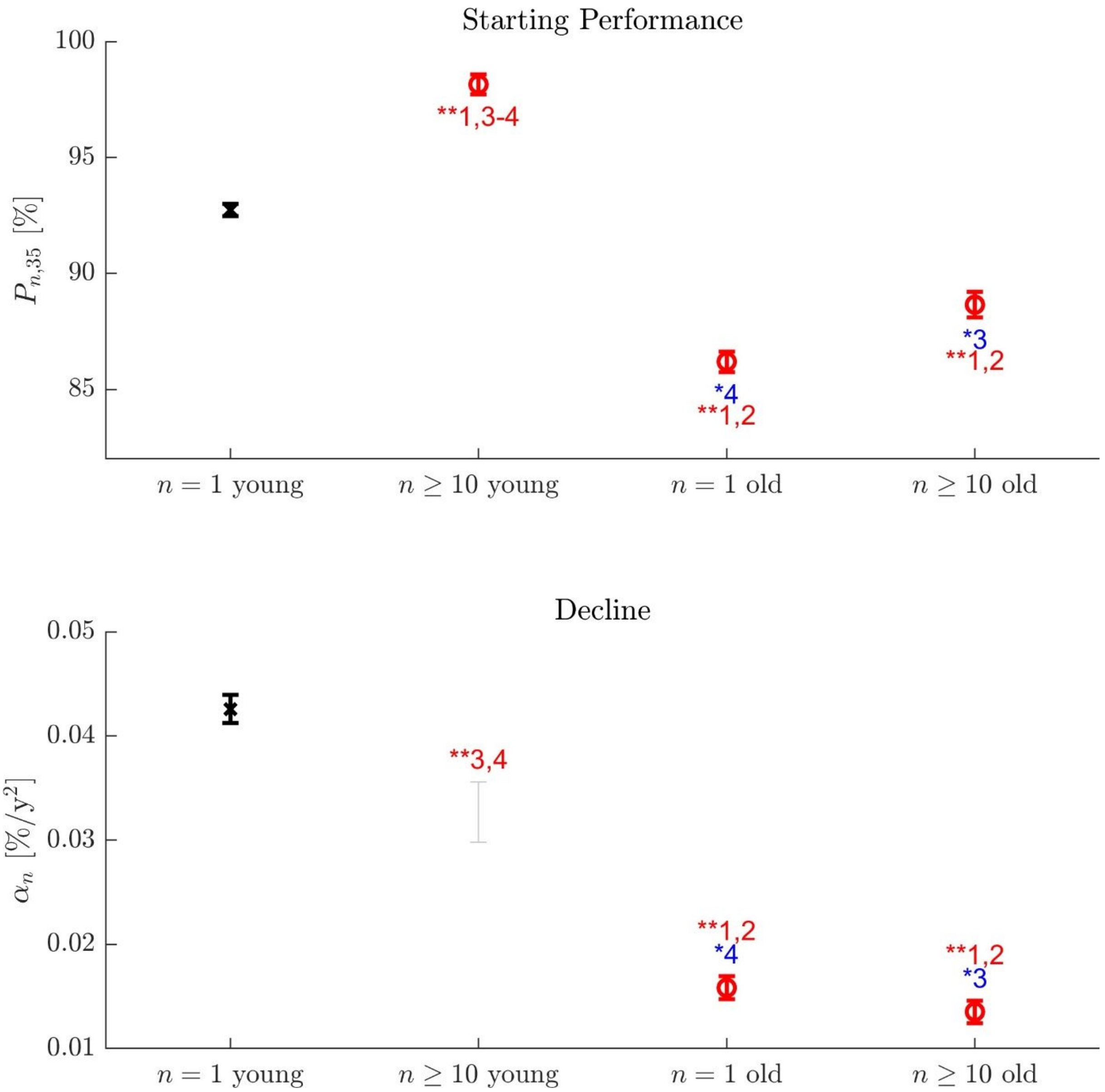
eFigure 1: Distribution of consecutive datapoints per subject. 100 % signifies that all data of a subject come from consecutive years, 0 % signifies that at least 2 years lie between each measurement. Cross-sectional data (*n* = 1) cannot contain consecutive datapoints.



eFigure 2: Number of results against the number of years (range) for all athletes in the data set. The outliers repeat, as each *n* includes the outliers of the previous *n*.



eFigure 3: Data points of the athlete spanning more than 50 years and corresponding quadratic regression line (Wide Range Data). The quadratic regression line for all data is shown dotted in blue colour.



eFigure 4: Average performance at age 35 and decline rate for the pooled older (55 years and older) vs. the younger (younger than 55 years) athletes. Blue: significant ($p < 0.05$, *) difference and to which $\geq n$ and $n = 1$ (marked in black). Red markers and numbers indicate a high level of significance ($p < 0.001$, **).