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Original research

Elite national athletes reach their peak performance later than non-elite in sprints and throwing events

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ABSTRACT

Objectives: The aim of this study was to describe and analyse the performance career trajectories for Italian athletes that participated in sprint, hurdles, discus throw, and shot-put athletics events.
Design: Retrospective study, data collected between 1994 and 2014.
Methods: A total of 5929 athletes (female: n = 2977, 50.2%) were included in the study. The age of entering competition and personal best performance was identified in the official competition records. Personal best performances were ranked in percentiles and top-level athletes were considered those in the highest 4% of the performance distribution.
Results: Overall, when controlling for the age of entering competition, top-level athletes reached their personal best later (i.e., around 23–25 years old) for all events compared to the rest of the athletes. Moreover, regression analysis showed that entering competitions later was linked to better performances during adulthood. Also, only 17%–26% [90% CI] of the top-level adult athletes were considered as such when they were 14–17 years old.
Conclusions: Together, these findings suggest that early sport success is not a strong predictor of top-level performance at senior level. Entering sport-specific competitions later and lengthening the sports career at beyond 23–25 years of age may be important factors to reach top-level performance in sprint and throwing events.

1. Introduction

Recently, in many countries there has been an increased focus on talent identification and development programmes[1] with the main aim to identify talented athletes and develop them to compete at senior level.[2] In sports where performance is determined in centimeters, grams, or seconds (CGS) there is a tendency to define talent based on competitive results at a young age. A comprehensive definition of "sports talent" is lacking, however, it is accepted that a talented sports-person is an individual whose athletic performances are superior to his peer/age group and is capable of reaching or has achieved performances at top level in his/her event/discipline.[3] With this approach, coaching communities have tended to identify talent at a young age based on performance of physical traits mostly based on Eastern European models. Few authors have argued the need to consider late developers[4] because of the risks of selecting and nurturing early maturers at early stages of athletics careers, neglecting children with the real potential to excel at later stages in life.[2] Furthermore, few studies have suggested to include psychological and learning aspects.[5] In CGS sports, talent identification and confirmation are usually based on assessing specific physical traits and/or results in competitions/qualifications in major international events. In athletics, it is relatively simple to track progress in competitions as nowadays most of the official competitions are recorded with international judging standards and results are kept in publicly available databases of national and/or international federations (e.g.: https://www.iaaf.org/home).

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Athletic abilities are determined to a certain extent by genetic factors,[6–8] they are affected by growth and maturation[9,10] and can be improved in the lifespan with training. Recent attempts of database analysis have presented normative development data of performances in track and field athletes suggesting typical development pathways in various age groups.[12–14] However, some authors highlighted that sports performance progression is rarely linear and does not guarantee that someone performing well in development stages as a young athlete will perform well as an adult.[15,16] Within track and field athletics, this hypothesis could explain why, as indicated by Piacentini et al.,[17] success at World Junior Championships is not a good predictor of success in adult competitions in throwing events. Furthermore, recent literature supports the notion that early stage success is not a prerequisite for later success. For example, Shibli and Barrett (2011)[30] reported that only 12% of top 20 Under 15 athletes in the United Kingdom retained their ranking when competing as Under 20. More supportive evidence came from recent study[18] reporting similar findings in sprinting, throwing, jumping and middle-distance events within the United Kingdom. Outside the United Kingdom, we recently reported that only 12–25% of Italian long and high jumpers were considered top-level when they were younger than 18 years old (yo).[12] However, this study was restricted to jumping events, therefore, more data about sprint, hurdles and throwing events are needed.

Previous research has found differences between elite and non-elite athletes in terms of performance development and training regimes. For example, few studies found that on CGS sports elite athletes specialized later than near-elite athletes.[4,19] However, as these studies examined athletes of specific nationalities, their findings may not be applicable to other contexts. While performance databases cannot be used to understand training regimens, they can provide important information to study athletes' career development.[12,18] For example, the age of entering sport-specific competitions and its possible effect on the performance in the adulthood can be extrapolated from performance databases. This would be useful information for track and field coaches and sports administrators. Such data could in fact provide better information on youth competitions, typical development pathways to refer to as well as more evidence to support progressive specialisation programmes. Furthermore, while it is established that the mean age to reach peak performance is typically 25–27 years in World-class athletes,[14] more data are needed to understand how their pathway to excellence looks like and gain a better understanding of the differences in development between elite and non-elite athletes. Overall, these data could provide coaching communities with realistic progression patterns and better inform talent development and retention pathways.

Therefore, to address the aforementioned gap, we aimed to answer the following three experimental questions considering speed, hurdles, discus throw and shot-put events. We aimed to determine (1) possible differences in the age of reaching peak performance between top-level athletes compared to athletes performing at a lower level; (2) if early appearance on national ranking affected their developed; (3) the distribution of appearance in the top ranking of senior elite athletes when they were younger than 18 years of age.

2. Methods

All data were collected from the database of FIDAL (Italian Track and Field Federation) and included the following groups events: 100 m sprint, 100/110 m hurdles, discus throw, and shot put. The technical rules of these disciplines are reported in the following link https://www.iaaf.org/about-iaaf/documents/rules-regulations. Adolescent athletes competed in age categories grouped every two years: 12–13 years; 14–15 years; 16–17 years; 18–19 years. Following FIDAL rules, the adolescent competition formats are scaled-down in relation to the age categories. Indeed, the younger categories competed with shorter distance (in run events), with shorter distance and lower hurdles height (in hurdles events), or lighter weight equipment (in throwing events) with respect to adult category. Therefore, it is impossible to calculate the rate of performance improvement.

The athletes ranked in the top 200 official lists in each season were included in the analysis. Competitive seasons from 1994 to 2014 were analysed. Data about rankings were collected (1) from 12 to 35 yo, (2) or until career termination, (3) or until the 31/12/2014 if the athletes were not retirement. Only results obtained with legal wind speed ($\leq$2 m/s) were included according to IAAF rules. The naturalized Italian athletes were excluded from the analysis as many appeared on the rankings only at later stages and/or sporadically. This study was approved by the local ethics committee of the University of Verona and involved access to publicly available databases. Therefore, no informed consent was sought.

Longitudinal data of each athletes were extrapolated from custom-written software in MATLAB R2015a (Mathworks, Natick, Massachusetts). Separate analyses were performed considering discipline and gender. Records were included in the analysis only if the correspondent athlete was present in the ranking list at least for three years, also non-consecutively. Considering each discipline separately, athletes were ranked on the basis of the percentile of their personal best performance thus generating an "all-time" ranking. Then, athletes were sub-grouped in 25 groups (i.e. 4 percentiles for each sub-group) according with their personal best percentiles. Thus, the worst performers were those with a percentile $\leq$ 4, whereas the best performers (top-level) were those with a percentile $\geq$ 97. In order to analyze the athletes' rank when they were younger than 18 yo, the above-mentioned calculations were also performed for each year of ages lower than 18.

Using the age at which each athlete entered official competitions as a covariate, an ANCOVA with rank as between factor (from 1st to 25th sub-group of performance) was conducted to test the significant differences on age of best performance in the different disciplines (i.e., sprint, hurdles, discus throw, and shot put). A multiple regression was run to predict rank (from 1st to 25th sub-group of performance) from initial ages. Finally, the percentages of top-level adult athletes that were considered top-level (i.e., percentiles of performance $\geq$ 97) when they were younger than 18 yo were computed. All the above analyses were performed separately for male and female athletes. The Statistical Package for Social Sciences (SPSS 24.0 for Windows) was used for all statistical analyses. Alpha was set at $P \leq 0.05$.

3. Results

After error and duplication removals a total of 5929 (male: n = 2949, 49.8%; female: n = 2977, 50.2%) athletes were included in the study. Specifically, 2037 athletes (male: n = 1012, 49.7%; female: n = 1025, 50.3%) were sprinters, 1453 were discus throwers (male: n = 778, 53.5%; female: n = 675, 46.5%), 873 were hurdlers (male: n = 384, 44%; female: n = 486, 56%), 1563 were shot putters (male: n = 775, 49.6%; female: n = 788, 50.4%).

Table 1 reports the performance thresholds to be considered a top-level athlete in Italian competitions. Table 1 also reports the descriptive statistics of the age of entering competitions and the age of reaching personal best performance. Nevertheless, the performance thresholds demarcate the best 20–40 athletes of each discipline that can be considered top-level in the national context.

Fig. 1 shows when athletes achieved their personal best performance for each discipline for males (Fig. 1a) and females (Fig. 1b), respectively.

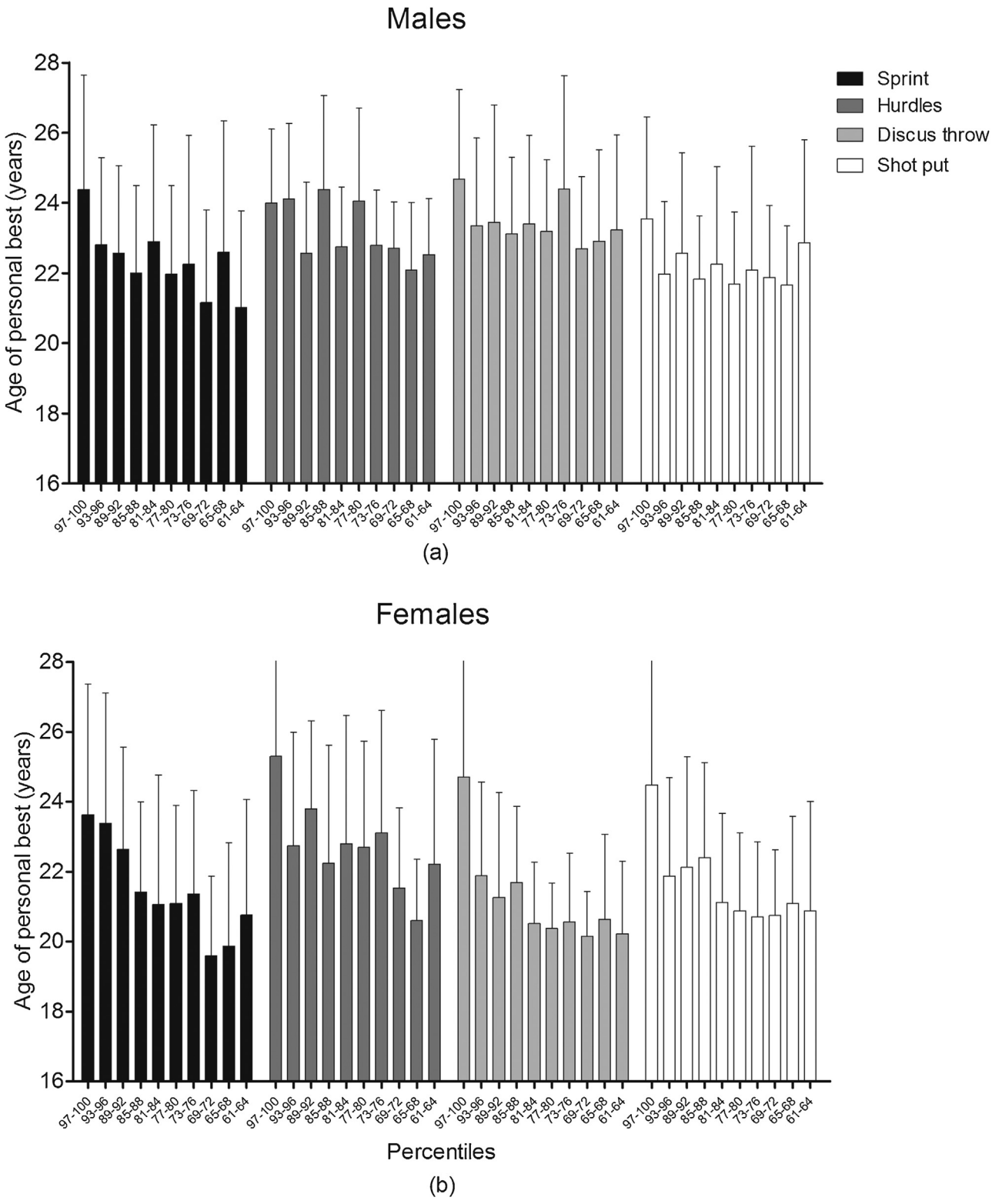

Fig. 1. Age of personal best performance for males and females.
Age of personal best performance (mean ± SD) for male (a) and female (b) athletes. The sample was sub-grouped on based on the percentiles of the personal best performance (reported in the x axis). The sample consisted of Italian athletes that took part in official athletics competition in sprint (100 m), hurdles (110 m hurdles), discus throw, and shot-put events from the 1994 to 2014. Overall, top-level (percentile ≥ 97) reached their personal best performance later than the rest of the sample in all disciplines (see Section 3 for statistics).

Overall, the age of achieving personal best performance of top-level athletes was higher compared to the rest of the sample (Fig. 1). When analyzing male athletes, the one-way ANCOVA yielded significant main effects of rank in sprint ($F_{24,986} = 8.553$, $P < 0.001$, partial $\eta^2 = 0.172$), hurdles ($F_{24,358} = 2.306$, $P = 0.001$, partial $\eta^2 = 0.134$), discus ($F_{24,752} = 3.891$, $P < 0.001$, partial $\eta^2 = 0.110$) and shot-put disciplines ($F_{24,749} = 3.324$, $P < 0.001$, partial $\eta^2 = 0.096$). Considering female athletes, the one-way ANCOVA yielded significant main

Table 1
Descriptive statistics of top-level athletes.

Gender	Sprint					Hurdles					Discus throw					Shot put				
	N	Top	Performance threshold (s)	Enter	Best	N	Top	Performance threshold (s)	Enter	Best	N	Top	Performance threshold (m)	Enter	Best	N	Top	Performance threshold (m)	Enter	Best
Males	1012	40	10.45	16.8 ± 2.4	23.4 ± 3.3	384	15	14.00	15.3 ± 1.5	24.0 ± 2.1	778	31	51.26	15.6 ± 2.3	24.7 ± 2.5	775	31	15.79	15.4 ± 2.3	23.5 ± 2.9
Females	1025	41	11.83	14.8 ± 1.6	23.6 ± 3.7	486	20	13.83	14.5 ± 0.9	25.3 ± 3.6	675	27	46.35	15.4 ± 2.2	24.7 ± 4.0	788	32	13.24	15.2 ± 1.8	24.5 ± 3.7

Notes: The number of tracked athletes are reported for each discipline and gender (N). The number of identified top-level athletes (Top, those with peak performance higher or equal to the 97th percentile) and the performance thresholds (that is the performance associated to the 97th percentile) are also reported. For top-level athletes the descriptive statistics of the age of entering competition (Enter) and the age of reaching of best performance (Best) are also reported.

Table 2
Percentages of top-level adult athletes that were considered top-level when they were younger than 18 yo.

Disciplines		Age (years)			
		14	15	16	17
Sprint	Males	0	10	7	22
	Females	14	21	29	34
Hurdles	Males	0	0	26	40
	Females	15	30	40	35
Discus throw	Males	2	23	23	38
	Females	14	20	35	50
Shot put	Males	2	12	12	33
	Females	7	23	38	43
90% confidence intervals (for age)		2–11	11–23	18–34	31–42
90% confidence intervals (overall)		17–26			

Notes: For each age from 14 to 17, each cell represents the percentage of the top-level adult athletes who were top-level performer when they were younger than 18 yo.

effects of rank in sprint athletes ($F_{24,999}$ = 13.019, P < 0.001, partial η^2 = 0.238), hurdles ($F_{24,463}$ = 7.598, P < 0.001, partial η^2 = 0.283), discus ($F_{24,679}$ = 6.007, P < 0.001, partial η^2 = 0.182) and shot-put disciplines ($F_{24,762}$ = 7.549, P < 0.001, partial η^2 = 0.192).

Considering male athletes, the age of entering competition positively correlated with the rank in hurdles ($F_{1,382}$ = 7.767, R^2 = 0.017, β = 0.141, P = 0.006), discus ($F_{1,776}$ = 76.146, β = 0.088, P < 0.001), and shot put ($F_{1,774}$ = 91.015, R^2 = 0.104, β = 0.325, P < 0.001), disciplines. Considering female athletes, the age of entering competition positively correlated with the rank in sprint ($F_{1,1024}$ = 167.884, R^2 = 0.001, β = 0.375, P < 0.001), discus ($F_{1,674}$ = 25.908, R^2 = 0.036, β = 0.193, P < 0.001), and shot put ($F_{1,776}$ = 62.689, R^2 = 0.073, β = 0.272, P < 0.001) disciplines. This means that the higher the age of entering competition of a young athletes, the higher was the level of performance in the adulthood. Differently, no significance was observed in sprint discipline for male ($F_{1,1011}$ = 0.385, R^2 = 0.001, β = 0.020, P < 0.535) and hurdles discipline for female athletes ($F_{1,488}$ = 0.834, R^2 = 0.001, β = 0.041, P < 0.362).

The percentage of top-level adult athletes considered as top-level athletes too when they were younger than 18 yo is reported in Table 2. On the contrary, the followings are the amount of top-level adult athletes that started their competitions later than 18 yo, and thus do not appear in Table 2: 15 out of 40 male and 12 out of 41 female sprint top-level athletes; 4 out of 39 male and 3 out of 34 female discus-throw top-level athletes; 3 out of 15 male and 4 out 20 female hurdles top-level athletes; 4 out of 39 male and 4 out of 39 female shot-put top-level athletes.

4. Discussion

The present study tracked the career performance ranking of nearly 6000 Italian athletes that participated in official athletics competition of 100 m sprint, 100/110 m hurdles, discus throw, and shot-put events from the 1994 to 2014. We compared the career of those who performed at the highest national level with the rest of the sample, providing quantitative data about the age of career initiation, the youth performances, and the age of personal peak performances.

The present results showed that senior top-level athletes reached on average their personal best performance later than the others. Despite this trend was observable in male (Fig. 1a) and female athletes (Fig. 1b), the effect was more pronounced in females.[14] Since this statistical analysis was corrected for the age of entering competition, it is possible to state that the *duration* of someone's sporting career is a key factor for reaching high performance levels. Indeed, athletes involved in specialised training and competitions programmes at a young age, are more likely to reach

their best performance at a relatively younger age than their peers supporting the idea that delaying specialisation could be a much better approach to reach elite senior success.[19–21] Elite performance requires many hours of training and exposure to numerous competitions, thus it is obvious that the longer the career the greater the possibility to reach high performance level. An athlete's career can terminate because of many reasons: injuries, lack of motivation, and lack of performance improvements, can in fact reduce the chances of success.[22] Therefore, the lack of reaching high level performance may be both the cause and the effect of an early career termination.[23] Whatever the causes of early career termination, this study suggests that prolonging the athlete's career over 23–25 years of age seems to be essential in order to reach high levels of performance in the athletics events herein analysed. While we did not know the injury history of the athletes included in this analysis, it is possible to suggest that keeping them healthy until such age may increase the chances of them reaching their best performance.

The peak performance usually occurs quite a few years after biological maturity is reached.[20,21,24] In fact, previous studies on world-prominent athletes found that athletes reached their peak performance between 24 and 26 years of age for sprint and hurdles disciplines, and around 26-28 years for throwing disciplines.[20,21,24] In our study, the age of performance of the best national athletes was one to two years earlier than previously reported for top competitors on the World stage probably due to the difference in performance level.[14] In fact, only 1% of Italian athletes was present in the top 100 world-ranked in 2014 (https://www.iaaf.org/home).

Our study also suggests that the peak ages for performance are different between athletics' events. For example, endurance events show that personal best performance in 800–1500 m distance runners peaks at about 26–28 yo, whereas longer distance runners peak at 30–35 years of age[25] suggesting that peak age tend to increase with increasing distance. While this is clear in endurance events, data of our study on events lasting less than 15 s and relying mainly on explosive contractions and anaerobic metabolic contribution suggest a different pattern and similarities between events.

Generally, the age of entering competition positively correlates with the peak performance in the regression analysis. This result indicates that the later the age of first competition, the higher the level of performance reached by an athlete in the specific sport event. This is in line with a previous study[26] showing that elite athletes began competition in their sport later than did near-elites. We did not check for competition entries in different disciplines in the same athletes, therefore, it was impossible to understand if those who started their competitive activity earlier, were competing in only one discipline. Hence, it was impossible to understand when athletes started to specialize, i.e. when started a year-round intense training activity focusing on a single main sport while excluding others.[27] However, while it is challenging to determine the optimal age of entering competition, our findings support the idea that early competition may not provide any advantage for later success. This is in agreement with previous literature suggesting that early sport specialization and competition do not facilitate the development of peak performance in adulthood.[19] Indeed, previous findings on CGS sports suggested that elite athletes specialized later than near-elite athletes.[4,19] This should be considered when developing competition and training strategies for youngsters, possibly favouring a more diverse experience in training and competition.

Most of the top-level adult athletes were not performing at the top level when they were between 14 and 17 years of age. Only 0–30% of them were at the top-level when they were 15, and this proportion grew up to 22–50% for the age of 17 (Table 2). The present findings are in line with previous studies on high jump and long jump[12] and, to some extent, on middle-distance running.[28] Thus, the career of most athletes at top-level markedly developed, when compared to their peers, after their 18th birthday. This agrees with the possibility that late maturers might be more likely to have a better career as adults in sprints and throwing events. The 100 m was the discipline in which this trend was more pronounced. On the contrary, the discus throw showed a slightly different trend. It is plausible that the anthropometric characteristics that are fundamental to compete at high level in throwing events, were already observable in young throwers in the cohort analysed.

When interpreting the current data, the following limitations should be considered. First of all, it should be recognized that the threshold used to define top-level athletes, as those who performed in the best 4% of the sample, may have affected the results. We arbitrarily choose this threshold because the performances identified by this threshold approximately correspond to the performances of the athletes ranked 4th/8th in the finals of track and field national championships in the last few years. However, we also tried to run the analysis by identifying top-level between 5% and 1% of the distribution and the significance of the study did not substantially change in any these cases. Moreover, no data of injury history or other reasons affecting competition stop were considered. Finally, as these data refer only to Italian athletes, and in the years of observation only a small percentage of them was considered '*elite*' in terms of World Ranking, caution should be applied when using our data as a reference. Future studies in individual countries should assess the typical development pathways of their athletes in key events. Furthermore, thanks to the access of international online databases, it should be possible in the near future to track the performance pathways of elite performers not only to have a better description of typical/a-typical developments but also to implement such approach for the fight against doping.[29]

5. Conclusions

The present study suggests that the duration of the competitive career in athletics was a key factor to determine the ability to reach elite national-level performances in athletes competing in sprint, hurdles, discus throw and shot-put events. Moreover, we found that only few top-level adult athletes were considered as such when they were younger than 18 yo. Taken together, these findings suggest that early sport success may not transfer to top-level performance at senior level and therefore caution needs to be applied when deciding upon athletes' progressions in funded/selection programmes.

Practical implication

- Being a top-level at a young age is not a prerequisite to become a top-level adult athlete in sprints and throwing events with the potential bias of early maturation.
- Focusing on results in early event-specific competitions should be considered with caution because it may blunt future performance in the adulthood.
- Coaches, clubs and governing bodies should aim to lengthen the athletes' sports career in athletics disciplines instead of focusing on early success.

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