Journal of Science and Medicine in Sport xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Original research

Performance pathways in elite middle- and long-distance track and field athletes: The influence of a successful youth

Paolo Riccardo Brustio [a,b,g], Mattia Stival [c], Marco Cardinale [d,e], Anna Mulasso [b,f], Alberto Rainoldi [b,f], Gennaro Boccia [a,b,*]

[a] Department of Clinical and Biological Sciences, University of Turin, Italy
[b] Neuromuscular Function Research Group, School of Exercise & Sport Sciences, University of Turin, Italy
[c] Department of Economics, Ca' Foscari University of Venice, Italy
[d] Aspetar Orthopaedic Hospital, Department of Research and Scientific Support, Qatar
[e] University College London, Institute of Sport Exercise and Health, UK
[f] Northumbria University, UK
[g] Department of Medical Sciences, University of Turin, Italy

ARTICLE INFO

Article history:
Received 8 January 2024
Received in revised form 19 March 2024
Accepted 15 May 2024
Available online xxxx

Keywords:
Athletics
Youth-to-senior transition rate
Talent development
Athlete development

ABSTRACT

Objectives: There is limited information on the performance progression of athletics endurance athletes from junior-to-senior status and the determinants of success in adulthood. This study aimed to quantify the youth-to-senior transition rate, the likelihood of success and the relationship between youth and senior performance amongst world-class athletes competing in middle- and long-distance disciplines.
Design: Retrospective design examining public data between 2000 and 2019.
Methods: The performances of 4678 international athletes (45.3 % female) were analysed. World's all-time top 50 athletes were identified for U18 and Senior categories (age ≥ 20 years). Youth-to-senior transition rate and transition probabilities were calculated. Correlations between best U18 and Senior performances were determined to assess the stability of the performance.
Results: The youth-to-senior transition rate for top U18 athletes was low for males and females (~19 % and 21 %). Nevertheless, the probability of transition to a top senior was ~7 times higher for top U18 athletes than for non-top U18 athletes. The correlations between youth and senior best performances were low-to-high.
Conclusions: Few top U18 athletes maintained top world ranking status during their senior careers. Still, they are more likely to become top senior athletes than those who did not perform at the top level in U18. The association between youth and senior performance is stronger when comparing the same discipline or when athletes competed over longer distances in their senior compared to U18 career. Being a successful youth athlete may represent a small advantage for future success, however, it does not guarantee advancement to the senior top level.

Practical implications

- The present findings, in relation to middle- and long-distance athletics, argue against talent identification/selection strategies based solely on youth performance. Whilst excellence in youth disciplines may be indicative of potential, it is not a definitive guarantee of future success in senior competition.
- The variability in performance development during late adolescence and early adulthood calls for caution in talent selection: coaches, sporting institutions and governing bodies should consider additional factors beyond youth performance to identify and develop the most promising athletes.
- Our analyses suggest the need for a more comprehensive and articulated approach to talent identification and development strategies, emphasising the importance of a long-term vision.

1. Introduction

The performance progressions from youth to adult age, usually studied in sports where performance is measured in centimetres, grams, or seconds (CGS, e.g., Track & Field and Swimming), provide realistic long-term performance goals for athletes, policymakers, sporting organisations, and coaches. The road towards senior success is influenced by different intrinsic and extrinsic factors that inevitably impact talent identification and development.[1–4] Track & Field is no exception, with many (inter-) national

* Corresponding author.
E-mail address: gennaro.boccia@unito.it (G. Boccia).
Social media: @PRBrustio (P.R. Brustio) @Marco_Cardinale (M. Cardinale) @gennaro_boccia (G. Boccia).

https://doi.org/10.1016/j.jsams.2024.05.007

Please cite this article as: P.R. Brustio, M. Stival, M. Cardinale, et al., Performance pathways in elite middle- and long-distance track and field athletes: The influence of a successful youth, Journal of Science and Medicine in Sport, https://doi.org/10.1016/j.jsams.2024.05.007

studies evidencing that performance progression from youth to adult age could be an appropriate approach to understand better the real potential of individual athletes.[5–8] For example, observational studies showed that successful U18 athletes that did not reach the top level during their senior career had career-best performances at earlier ages and presented a plateau in performance at about 20 years of age.[5,9–11] On the contrary, successful senior athletes showed a more consistent and durable improvement in performances from young ages up to 26–27 years of age.

The youth-to-senior transition rate has been used in some studies to define the percentage of elite youth athletes who became elite senior athletes.[5,8,10,11] With this approach, successful youth-to-senior transition rates have been reported analysing world performances in various events. In the studies of Boccia et al.,[5,10,11] the youth-to-senior transition rate (i.e., from U18 to Senior carrier) amongst elite world-class athletes was, on average, ~12 % for male and ~20 % for female athletes competing in sprint, jump and throw events. These findings highlighted that at least two-thirds of elite senior athletes were sub-elite athletes during youth competitions. On the other hand, the studies highlighted that the youth-to-senior transition is a demanding and challenging phase towards the elite level.[12] The studies also implicated that talent identification and selection at young ages can be biased and do not guarantee the ability to identify future senior performers in athletics. Nevertheless, a recent study on swimmers[13] underlined that performance corridors for youth (i.e., minimal and maximal performance benchmarks) may help to predict success chances at peak performance age. These corridors can enhance the talent identification process and permit coaches or/and federations to effectively identify and nurture potential talent and guide youth swimmers along their talent pathway.

Most Track & Field research focussed on studying career paths and youth-to-senior transition rates in sprint, jump and throw events rather than middle- and long-distance ones. Research in the elite middle- and long-distance runners (i.e., athletes competing in Olympic and World Athletics Championships) showed that, on average, men reached peak performance before (~25 years of age) women (~27 years of age),[14] despite having a similar peak performance window (~5 years). As per other Track & Field disciplines, individual performance progression might be a better predictor of athlete's success at later stages of their careers.[15] For example, the top 10 world-ranked athletes improved more than the top 11–100 athletes, both for middle (i.e. 1.0 %) and long distances (i.e. 1.7 %), and had larger improvements for women than for men (i.e. 0.4 and 1.2 % for middle and long distances respectively).[16] Nevertheless, even if reaching high level performances in late teens may be important to succeed at the senior level,[16,17] this is not the only condition to reach success on the world stage. In fact, youth-to-senior transitions in terms of performances remain challenging as identified by a low rate of confirmation of success at junior level in adulthood. For example, only ~6 % of finalists in youth championships later won medals at senior championships, and 42.7 % stopped producing high-level performances as indicated by their presence in World rankings.[18] However, when analysing the transition rate data, it should be noted that it is possible for an athlete's ranking to drop whilst their performance is increasing (if the other athletes are increasing their performance at a faster rate). Currently, there is a paucity of data and comprehensive analysis of performance progression and transition rates in endurance events in Track & Field. In particular, for the endurance disciplines between 800 and 10,000 m. Considering the lack of analyses and limited reports, focussing on male and female runners competing in the middle- (i.e., 800 and 1500 m) and long-distance events (3000 m, 5000 m and 10,000 m), we aimed to quantify 1) the youth-to-senior top-level transition rate, 2) the likelihood of transitioning to senior top-level for top-level and non-top-level youth athletes, and 3) the relationship between youth and senior performances.

2. Methods

Selected events included the 800 m, 1500 m, and 3000 m for the young category and 800 m, 1500 m, 5000 m and 10,000 m for the senior category. These disciplines were chosen because they are the official competitions for U18 and senior categories for World Athletics. Data on male and female athletes included in the Top 100 World Athletics rank from 2000 to 2019 or competing in the World U18 or U20 Championships from 1985 to 2000 were considered. The seasonal best performances encompassing the entire career progression of each athlete were considered for the analysis. All performances considered were achieved in official competitions provided by World Athletics. To avoid bias in youth-to-senior transition rates, young athletes who registered their best personal performance in the last three years of the calendar age and did not reach the senior level again were excluded.[6] The study was conducted according to the Ethics Committee of the University of Torino (protocol number: 0635113).

2.1. Statistical analysis

Due to athletes in the dataset competing in different decades, all performances were adjusted for year- and event-specific world records. Specifically, let $p\_\{a,e,y\}$ be the seasonal best performance of athlete a, in event e, and year y; let also $r\_\{e,y\}$ be the record of event e during year y. We obtained an adjusted seasonal best performance by considering the following scaling transformation $\hat{pstar}\_\{a,e,y\} = p\_\{a,e,y\}/r\_\{e,y\}$. To investigate the youth-to-senior transition rate for top-level athletes, we calculated how many top U18 athletes (i.e., all-time top 50 ranked athletes at 17 years or18 years) of the 800 m, 1500 m, and 3000 m events were top senior athletes in the 800 m, 1500 m, 5000 m and 10,000 m. We arbitrarily selected the threshold of the top 50 athletes according to our previous studies.[5,8,10,11] Due to the small number of athletes able to be ranked in the top 50 in two or more events at the same time, we have not taken this possibility into account when calculating the transition rates between youth and adult rankings.

In order to understand the mechanisms that lead to excellence in the senior career, we decided to investigate the probabilistic mechanisms that explain the observed variability in the senior class. Therefore, we classified the athletes into the following non-exclusive categories to describe athletes belonging to the youth category:

C_{U-NT} = Not Top 50 as U18

C_{U-800} = Top 50 in 800 m as U18

C_{U-1500} = Top 50 in 1500 m as U18

C_{U-3000} = Top 50 in 3000 m as U18

and this classification describe belonging in senior categories:

C_{S-NT} = Not Top 50 as Senior

C_{S-800} = Top 50 in 800 m as Senior

C_{S-1500} = Top 50 in 1500 m as Senior

C_{S-5000} = Top 50 in 5000 m as Senior

$C_{S-10000}$ = Top 50 in 10,000 m as Senior

Due to the low number of athletes able to compete as top performers in more than one race, the classes derived as a combination of single races were not considered.

Youth to senior transition rates were then computed according to the following conditional (transition) probabilities considering events separately:

$$p(u \to s) = \Pr(\text{Athlete} \in C_{S-s} \| \text{Athlete} \in C_{U-u}) = \frac{N_{C_s,C_u}}{N_{C_u}}$$

for any $u \in \{U-NT, U-800, U-1500, U-3000\}$ and $s \in \{S-NT, S-800, S-1500, S-5000, S-10000\}$ and where N_{C_u} and N_{C_u,C_s} denote the number of athletes belonging to each class

C_u or to both C_u and C_s, respectively. Here, u represents the starting class, s the arrival class.

This transition probability from the starting class u to the arrival class s quantifies the youth-to-senior rate of athletes that were ranked a top 50 athletes in one youth category (or at least one), and were also top 50 performers in one (or at least one) of the senior races considered. The transition rates were calculated using a binomial proportion confidence interval [90 % CI].[19]

To shed light on probabilistic mechanisms that lead to the observed variability in Senior classes and understand if U18 top50 athletes in different races were advantaged in transitioning to top 50 Senior classes, we computed the following odds ratios (ORs)

$$OR(p(u \to s), p(C_{U-NT} \to s)) = \frac{\frac{p(u \to s)}{1 - p(u \to s)}}{\frac{p(C_{U-NT} \to s)}{1 - p(C_{U-NT} \to s)}},$$

that allows to quantify the increase (or decrease) of the odds in the probability of transiting from starting class $u \in \{U-NT, U-800, U-1500, U-3000\}$ to arrival class $s \in \{S-NT, S-800, S-1500, S-5000, S-10000\}$ concerning the reference transition probability from class $U-NT$ to class $s \in \{S-NT, S-800, S-1500, S-5000, S-10000\}$. A value of the OR > 1 indicates an advantage (higher chance) for class u of transiting to class s with respect to non-top athletes. On the contrary, the OR < 1 indicates a disadvantage. Confidence interval for youth-to-senior transition rate and the OR [90 % CI] were computed using non-parametric bootstrap.[19]

Finally, considering the whole sample, Pearson's product–moment correlation coefficients (r) between best U18 and senior performances were determined to assess the relationship of the best performance recorded during youth and senior careers. Effect size magnitudes were determined by r and interpreted as follows: <0.1 trivial, $0.1 \geq r < 0.3$ small, $0.3 \geq r < 0.5$ medium, $0.5 \geq r < 0.7$ large, $0.7 \geq r < 0.9$ very large, $0.7 \geq r < 0.9$ very large, and $r = 1$ perfect effect size.[20]

The significance level was set at $p < 0.05$. All data were analysed with custom-written software in R-Studio. The Sankey diagrams to represent transition rates were prepared by an online tool (https://sankeymatic.com/build/).

3. Results

The following number of athletes across both junior and senior categories was identified based on their seasonal performances in the events of interest: 2810 athletes competing in 800 m (47.3 % females), 3524 in 1500 m (47.2 % females), 2710 in 3000 m (46.7 % females), 2751 in 5000 m (45.1 % females) and 1961 in 10,000 m (45.1 % females).

3.1. Transition rate from youth to senior top-level

Table 1 shows the youth-to-senior transition rate of male and female athletes. Overall, the top 50 athletes from a U18 race that confirmed themselves at the top-level in Senior categories were 18.9 % [90 % CI: 12.4, 25.9] for males and 21.3 % [90 % CI: 14.1, 28.7] for females. Nevertheless, transition rates varied slightly across distances. Briefly, the transition rates for 800 m and 1500 m (i.e. the two disciplines that remain

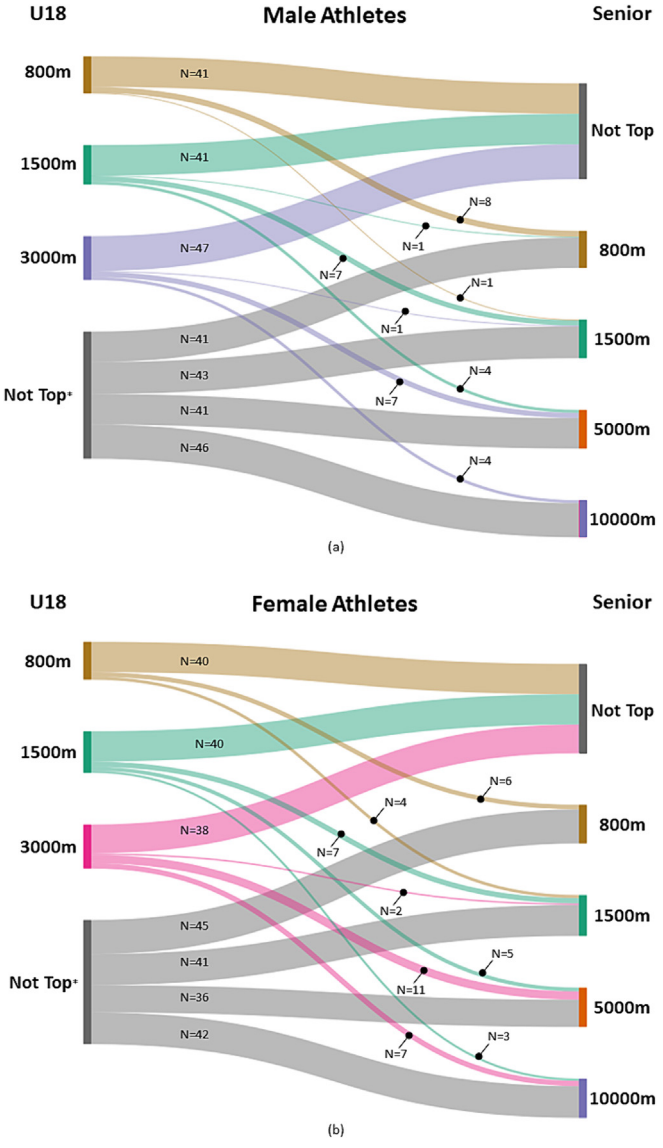

Fig. 1. Overall visual inspection of the youth-to-senior transition rate from young events (i.e., 800 m, 1500 m, and 3000 m) to senior events (i.e., 800 m, 1500 m, 5000 m and 10,000 m). The Sankey diagram provides the number of top U18 male (a) and female (b) athletes who maintain top status at the senior level. The figure also provides the number of athletes who drop to the top-level status and those who reach the top status only in senior competitions. N.B. For some senior events, the sum of top 50 athletes is higher than 50 because it is possible that some top U18 athletes could reach top-level status in more than one senior event.

Table 1
Percentage of youth-to-senior transition rate [90 % CI] for male and female athletes.

Under 18	Senior male athletes					Senior female athletes				
	Not Top % [90 % CI]	800 m % [90 % CI]	1500 m % [90 % CI]	5000 m % [90 % CI]	10,000 m % [90 % CI]	Not top % [90 % CI]	800 m % [90 % CI]	1500 m % [90 % CI]	5000 m % [90 % CI]	10,000 m % [90 % CI]
Not Top	94.3 [93.3, 95.2]	1.7 [1.2, 2.2]	1.8 [1.3, 2.3]	1.7 [1.2, 2.2]	1.9 [1.4, 2.5]	93.4 [92.3, 94.5]	2.3 [1.6, 2.9]	2.1 [1.5, 2.7]	1.8 [1.3, 2.4]	2.1 [1.5, 2.8]
800 m	82.0 [70.5, 92.1]	16.0 [6.5, 26.9]	2.0 [0.0, 6.7]	0.0 [0.0, 0.0]	0.0 [0.0, 0.0]	80.0 [68.0, 90.7]	12.0 [3.8, 21.8]	8.0 [1.8, 16.3]	0.0 [0.0, 0.0]	0.0 [0.0, 0.0]
1500 m	80.4 [68.6, 90.7]	2.0 [0, 6.5]	13.7 [5.0, 24.0]	7.8 [1.8, 15.9]	0.0 [0.0, 0.0]	80.0 [68.1, 90.5]	0.0 [0.0, 0.0]	14.0 [5.0, 24.1]	10.0 [2.2, 18.9]	6.0 [0.0, 13.6]
3000 m	82.0 [70.5, 91.9]	0.0 [0.0, 0.0]	2.0 [0.0, 6.8]	14.0 [5.0, 24.4]	8.0 [1.8, 16.7]	76.0 [63.6, 87.3]	0.0 [0.0, 0.0]	4.0 [0.0, 10]	22.0 [10.8, 34.2]	14.0 [5.0, 24.4]

Note: All the data refer to the all-time top 50 ranked athletes.

constant at U18 and senior level) were 16.0 % and 13.7 % for males and 12 % and 14 % for females, respectively. The transition rate from U18 3000 m to 5000 m was 14.0 %, to 10,000 m was 8.0 % for men and 22.0 % to 5000 m and 14.0 % to 10,000 m for women. The transition rate was higher when comparing the same discipline in youth and senior career or when athletes competed over longer distances in their senior compared to U18 career, e.g. considering the transition from 1500 m to 5000 m or from 3000 m to 5000 m and 10,000 m (See Table 1 for details).

Fig. 1 offers an overall visual inspection of raw data about the overall youth-to-senior transition rate (i.e., from U18 to senior) for athletes competing in 800 m, 1500 m and 3000 m during youth career for male (Fig. 1-a) and female athletes (Fig. 1-b).

3.2. Odds ratio between transition probabilities to success between top and non-top young performers

For male and female athletes, Fig. 2 shows the probability of success or failure to reach the top-level status during their senior career (i.e., OR and 90 % confidence intervals) for U18 Top and Not top athletes in the different events.

In males, the odds of being a top senior athlete in the 800 m and 1500 m were 10.9 and 8.6 times higher for athletes that were top in U18 category in the same event, respectively. The odds of being a top senior athlete in 5000 m and 10,000 m were 9.4 and 4.3 times higher for athletes that were top in U18 category in 3000 m, respectively. Furthermore, the odds of being a top senior athlete in the 3000 m were 4.8 times higher for athletes that were top in U18 in 1500 m. Conversely, for top U18 800 m, 1500 m and 3000 m athletes, there were no discernible improvements in success likelihood when transitioning to 1500 m, 5000 m, and 10,000 m, 800 m and 10,000 m, and 800 m and 1500 m events, respectively.

In females, the odds of being a top senior athlete in the 800 m and 1500 m were 5.8 and 7.6 times higher for athletes that were top in U18 category in the same event, respectively. Furthermore, the odds of being a top senior athlete in 5000 m and 10,000 m were 15.3 and 4.3 times higher for athletes that were top in U18 category in 3000 m, respectively. The odds of being a top senior athlete in 5000 m and 10,000 m were 5.8 and 2.9 times higher for athletes that were top in U18 category in 3000 m, respectively. Conversely, no significant increase in success likelihood was observed for top U18 800 m athletes for transitioning to 5000 m, and 10,000 m, for top U18 1500 m athletes for transitioning to 800 m and for top U18 3000 m athletes for transitioning to 800 m and 1500 m.

3.3. Correlation of youth and senior best performances

As expected, there is a general improvement in relative performance related to the transition to the senior category. Male athletes exhibited correlations ranging from low to high, whilst female athletes showed trivial to large effect sizes (ranging from 0.17 to 0.64 for males and 0.05 to 0.55 for females). U18 800 m and 1500 m performances generally showed moderate effect size with the same events in senior careers. The statistical analysis revealed decreased correlation coefficients as the competition distances increased. Notably, U18 performances in the 3000 m event exhibited a moderate to larger effect size when compared to the 5000 m and 10,000 m events (ranging from 0.475 to 0.557) and a trivial to low effect with the 800 m and 1500 m events.

For a visual inspection of Pearson's product–moment correlation coefficients between best U18 and senior performances for males and females, considering the three youth events (i.e., 800 m, 1500 m and 3000 m) and all the middle- and long-distance events in the senior category (i.e., 800 m, 1500 m, 5000 m and 10,000 m) (please refer to the supplementary material).

4. Discussion

This study aimed to quantify the youth-to-senior transition rate, the likelihood of success for top and no-top U18 athletes, and the relationship between youth and senior performance amongst elite athletes competing in middle and long distances. For this purpose, we identified top-level athletes (operationally defined as the world's all-time top 50

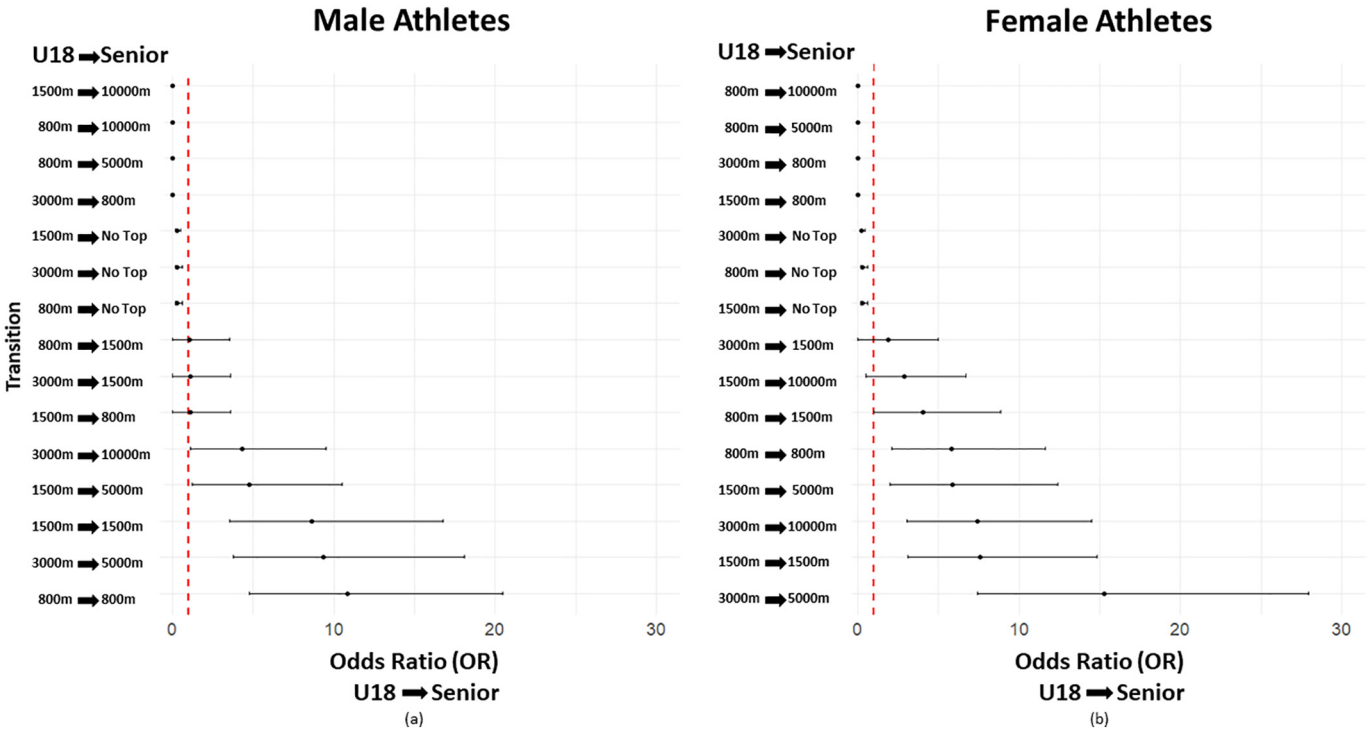

Fig. 2. Probability of success or unsuccess to reach the top-level status during senior career (i.e., OR and 95 % confidence intervals) for Top U18 athletes in the different events. Results are presented separately for male (a) and female (b) athletes.

athletes) in U18 and Senior categories (i.e., ≥20 years old) and investigated transition rate and odds of success from youth-to-senior top-level according to event and gender. The main findings of the study were that (a) the youth-to-senior transition rate was relatively low both for males and for females (i.e., ~19 % and 21 %) and modulated by the specific event; (b) the probability of being a top athlete at senior level was higher in top U18 compared no-top U18 counterparts; and (c) the correlations between youth and senior best performances were low-to-high depending on sex and considered distances.

Overall, the results of this study demonstrated that only ~19–21 % of the top 50 U18 athletes maintained the top-level during their senior career. Our results underlined a transition rate approximately three times greater than in the study of Pizzuto et al.,[18] who reported that only ~6 % of finalists in junior championships won later medals at senior championships. Nevertheless, it is necessary to consider that our transition rates are based on all-time top rankings and not only on the performance in the youth championships. Comparing our results to earlier studies on world-class sprinters, jumpers, and throwers, which indicated an average transition rate of approximately 12 % for males and 20 % for females,[5,10,11] our findings suggest the possibility of a higher transition rate favouring middle- and long-distance runners. Middle- and long-distance events exhibit distinctive metabolic pathway interactions than sprinters, jumpers, and throwers.[17,21] Unlike most other Track & Field events, the performance in middle- and long-distance races hinges on factors such as maximal oxygen consumption ($V\dot{O}_{2max}$), fractional $V\dot{O}_{2max}$ utilisation, and exercise efficiency/economy.[16] For this reason, it is feasible to speculate that, the lowest transition rate observed in sprinters/jumpers/throwers may be explained by the fact that neuromuscular power is more strongly affected by growth and maturation than endurance capacity.[22,23] Overall, the relatively low youth-to-senior transition rate (and the consequent high attrition rate) underlines how this phase is particularly critical and challenging for elite athletes.[12,24] Different factors can affect this delicate transition, such as early maturation[25] and specialisation,[26] relative age effect,[1] injuries,[27] school life transition (e.g., from high school to university),[24] and the management of the dual career (e.g., sports and school).[28] Again, psychological (i.e., determination, confidence, motivation) and social factors (i.e., supporting network) are all crucial for long-term athlete success.[29]

Despite the low transition rate of top U18 athletes, these athletes are more likely to transition successfully (on average 7.5 times more likely; see Fig. 2) than non-top U18 athletes. This trend is particularly evident when looking at events similar to those in which they excelled in their youth (e.g. from 800 m to 800 m or 1500 m to 1500 m). Furthermore, successful U18 athletes in the 3000 m event had a significantly higher chance of success (with odds ratios ranging from 4.3 to 9.4 for males and 7.4 to 15.3 for females) when transitioning to the 5000 m and 1000 m events. This finding confirms the speculation of Gozi et al.[30] that suggested middle-distance runners to have a greater propensity to convert to another athletic event, reporting that an increase of age of peak performance in parallel with an increase in competition distance. In contrast, the data suggest an exception in the transition from long to middle distance events (e.g., from 3000 m to 800 m) and from short to very long-distance events (e.g. from 800 m to 5000 m or from 800 m to 10,000 m). It can therefore be assumed that the changes in success transition from one event to another are easier when the transition is within the same or a longer distance. The loss of type II muscle fibres or the decrease in type II fibre contractile functions[31] might explain why it is challenging to move towards shorter disciplines, requiring higher muscle power, at increased age. Interestingly, when comparing the 800 m and 1500 m events, the odds ratio suggests that 1500 m athletes (both male and female) have a greater chance of maintaining elite status at a higher running distance, highlighting their versatility.[21] In contrast, the top U18 800 m runners seem to be specialists who only excel at the 800 m. In particular, it is also possible that the absence of these transitions is due to the choice of threshold for selecting top athletes (i.e., top 50). However, it should be noted that whilst these promising young athletes are more likely to transition, the percentage of individuals who maintain their strength into adulthood is only a small fraction of those who excel in the senior categories (see Fig. 1). These non-intuitive results may suggest that although youth excellence appears to be a factor in identifying top senior athletes, considering youth performance alone as a relevant predictor generally leads to extremely poor predictions. In fact, excelling in youth categories is not the only determinant of a successful career, as emphasised by numerous studies in different sports.[5,6,8,10,11] In addition, significantly more athletes are not classified as top U18 performers than those defined as top performers (i.e. only the top 50 in each youth event). This may have caused an artefact in the calculation of the odds ratio.

In line with the above findings, the correlation analysis revealed a high to low correlation between young and senior top performers, highlighting the limited stability of performance from youth to adulthood and the limitations of predicting senior top performers using only performance at youth level. Nevertheless, compared to other Track & Field disciplines,[10] data suggest a higher correlation between youth and adult performance in male and female athletes. Again, this effect size was modulated by sex (i.e., high-to-low for males and moderate-to-low effect size for females) and distance. Whilst the effect size of these associations was high to moderate between the same distances at 800 m and 1500 m or between 3000 m (youth) and 5000 m and 10,000 m (senior), the analysis revealed a reduced correlation coefficient when comparing the youth best performance with a senior best performance at a lower distance. Evidently, the results confirm the difficulty of moving from a higher to a lower distance. Furthermore, it is important to highlight that there was a significant proportion of athletes without recorded performances at U18 level, resulting in the inability to reach a high percentage of retrieved performance trajectories, suggesting that many top performers might enter the sport at later stages without the need for early specialisation.

The study has some limitations that should be underlined. We operationalised and studied the youth-to-senior transition rate using the U18 threshold as the cutoff age as well as focussed on Top 50 athletes. However, it can be suggested that the use of these thresholds may have influenced the study's results. Therefore, caution is needed when interpreting these findings. Future investigations should consider including this age group as well as different rank thresholds to further enrich our understanding of age transitions in middle- and long-distance Track & Field events. Additionally, the proposed approach identifies athletes who were able to “run faster”, i.e. improving their running times rather than the ranking position, an important aspect as this is the only true measure of performance improvement. Ranking times in fact depend also on performances of other athletes as well as race participations/points obtained and other variables. With this approach, we increase the external validity of the study, allowing us to make comparisons with the existing literature on the subject[5,6,10,11] and facilitating the identification of those athletes who have not yet reached their peak performance (and who are excluded from our sample). Middle- and long-distance running competitions are very tactical races, and the performance outcome depends on many aspects. Focussing on running times might be seen as a limitation of the study as some athletes are still able to achieve good placements producing running times below their personal bests and/or lack progression on running times. However, as performance in CGS sports is mostly assessed as a measurable improvement, we believe that this is the correct approach and comparisons with other studies should always be reported in terms of absolute performance progressions.

In summary, the data suggest that few successful youth athletes retain the ability to perform at the elite level during their senior careers. However, despite a relatively low transition rate, successful youth athletes are more likely to become top senior athletes than those who only succeed in their senior careers. This suggests that whilst being a successful youth athlete may be a prerequisite for future success, it

does not in itself guarantee progression to the top senior category. These findings highlight the complex dynamics of the youth–senior transition in athletics and the need for further research into the specific physiological and training aspects that influence the success trajectories of youth athletes as they progress to the senior level.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jsams.2024.05.007.

Funding information

No external financial supports the study.

Confirmation of ethical compliance

The study was conducted according to the declaration of Helsinki and was approved by the local ethics committee of the University of Torino. The authors also declare that the study was conducted following all ethical compliances.

CRediT authorship contribution statement

Paolo Riccardo Brustio: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing.

Mattia Stival: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing.

Marco Cardinale: Conceptualization, Supervision, Writing – review & editing.

Anna Mulasso: Data collection; Writing – review & editing.

Alberto Rainoldi: Supervision, Writing – review & editing.

Gennaro Boccia: Conceptualization, Methodology, Writing – review & editing.

Declaration of interest statement

The authors declare no conflict of interest.

Acknowledgements

The authors acknowledge the contribution of FIDAL for allowing the data and Aiello Francesco e Daniele Alberto for managing the dataset.

References

1. Brustio PR, Stival M, Boccia G. Relative age effect reversal on the junior-to-senior transition in world-class athletics. *J Sports Sci* 2023:1-7.
2. Cobley S et al. Annual age-grouping and athlete development: a meta-analytical review of relative age effects in sport. *Sports Med* 2009;39(3):235-256.
3. Till K, Baker J. Challenges and [possible] solutions to optimizing talent identification and development in sport. *Front Psychol* 2020;11(664).
4. Smith KL et al. Relative age effects across and within female sport contexts: a systematic review and meta-analysis. *Sports Med* 2018:1-30.
5. Boccia G, Cardinale M, Brustio PR. Performance progression of elite jumpers: early performances do not predict later success. *Scand J Med Sci Sports* 2021;31(1):132-139.
6. Brustio PR et al. Don't throw the baby out with the bathwater: talent in swimming sprinting events might be hidden at early age. *Int J Sports Physiol Perform* 2022;17(11):1550-1557.
7. Kearney PE, Hayes PR, Nevill A. Faster, higher, stronger, older: relative age effects are most influential during the youngest age grade of track and field athletics in the United Kingdom. *J Sports Sci* 2018;36(20):2282-2288.
8. Brustio PR et al. Being a top swimmer during the early career is not a prerequisite for success: a study on sprinter strokes. *J Sci Med Sport* 2021;24(12):1272-1277.
9. Foss JL, Sinex JA, Chapman RF. Career performance progressions of junior and senior elite track and field athletes. *J Sci Sport Exerc* 2019;1(2):168-175.
10. Boccia G, Cardinale M, Brustio PR. World-class sprinters' careers: early success does not guarantee success at adult age. *Int J Sports Physiol Perform* 2020;16(3):367-374.
11. Boccia G, Cardinale M, Brustio PR. Elite junior throwers unlikely remain at the top level in the senior category. *Int J Sports Physiol Perform* 2021;16(9):1281-1287.
12. Stambulova NB et al. ISSP position stand: career development and transitions of athletes. *Int J Sport Exerc Psychol* 2009;7(4):395-412.
13. Born D-P et al. Predicting future stars: probability and performance corridors for elite swimmers. *J Sci Med Sport* 2024;27(2):113-118.
14. Hollings SC, Hopkins WG, Hume PA. Age at peak performance of successful track & field athletes. *Int J Sports Sci Coach* 2014;9(4):651-661.
15. Weippert M et al. Individual performance progression of German elite female and male middle-distance runners. *Eur J Sport Sci* 2021;21(3):293-299.
16. Haugen T et al. Peak age and performance progression in world-class track-and-field athletes. *Int J Sports Physiol Perform* 2018;13(9):1122-1129.
17. Haugen T et al. Crossing the golden training divide: the science and practice of training world-class 800- and 1500-m runners. *Sports Med* 2021;51(9):1835-1854.
18. Pizzuto F et al. Are the world junior championship finalists for middle- and long-distance events currently competing at international level? *Int J Sports Physiol Perform* 2017;12(3):316-321.
19. Efron B, Tibshirani RJ. *An Introduction to the Bootstrap,* CRC Press, 1994.
20. Hopkins WG. Linear models and effect magnitudes for research, clinical and practical applications. *Sportscience* 2010;14:49-59.
21. Haugen T et al. The training characteristics of world-class distance runners: an integration of scientific literature and results-proven practice. *Sports Med Open* 2022;8(1):46.
22. Meyers RW et al. New insights into the development of maximal sprint speed in male youth. *Strength Cond J* 2017;39(2):2-10.
23. Oliver JL, Lloyd RS, Rumpf MC. Developing speed throughout childhood and adolescence: the role of growth, maturation and training. *Strength Cond J* 2013;35(3):42-48.
24. Stambulova NB, Ryba TV, Henriksen K. Career development and transitions of athletes: the International Society of Sport Psychology Position Stand Revisited. *Int J Sport Exerc Psychol* 2021;19(4):524-550.
25. Malina RM et al. Biological maturation of youth athletes: assessment and implications. *Br J Sports Med* 2015;49(13):852-859.
26. Moesch K et al. Late specialization: the key to success in centimeters, grams, or seconds (cgs) sports. *Scand J Med Sci Sports* 2011;21(6):e282-e290.
27. Daniel M-S et al. Injury characteristics in male youth athletics: a five-season prospective study in a full-time sports academy. *BJSM* 2021;55(17):954.
28. Brustio PR et al. Italian student-athletes only need a more effective daily schedule to support their dual career. *Sport Sci Health* 2020;16(1):177-182.
29. Hollings SC, Mallett CJ, Hume PA. The transition from elite junior track-and-field athlete to successful senior athlete: why some do, why others don't. *Int J Sports Sci Coach* 2014;9(3):457-471.
30. Gorzi A et al. Prediction of elite athletes' performance by analysis of peak-performance age and age-related performance progression. *Eur J Sport Sci* 2022;22(2):146-159.
31. Grosicki GJ, Zepeda CS, Sundberg CW. Single muscle fibre contractile function with ageing. *J Physiol* 2022;600(23):5005-5026.