

AperTO - Archivio Istituzionale Open Access dell'Università di Torino

World-Class Sprinters' Careers: Early Success Does Not Guarantee Success at Adult Age

This is the author's manuscript

Original Citation:

Availability:

This version is available <http://hdl.handle.net/2318/1768479> since 2023-02-25T10:15:26Z

Published version:

DOI:10.1123/ijsp.2020-0090

Terms of use:

Open Access

Anyone can freely access the full text of works made available as "Open Access". Works made available under a Creative Commons license can be used according to the terms and conditions of said license. Use of all other works requires consent of the right holder (author or publisher) if not exempted from copyright protection by the applicable law.

(Article begins on next page)

Sprinting to success at early age does not guarantee success ad adult age

Authors: Gennaro Boccia¹, Marco Cardinale^{2,3,4}, Paolo Riccardo Brustio¹

¹ NeuroMuscularFunction Research Group, School of Exercise & Sport Sciences, Department of Medical Sciences, University of Turin, Turin, Italy.

² Research and Scientific Support Department, Aspetar Orthopaedic and Sports Medicine Hospital, Doha, Qatar

³ Faculty of Sport, Health and Wellbeing, Plymouth MARJON University, Derriford Rd, Plymouth PL6 8BH, UK

⁴ Department of Computer Science and Institute of Sport Exercise and Health, University College London, London,UK

Abstract

Purpose. This study aimed to quantify how many of the top 50 Under-18 (U18) sprinters in the world managed to become top 50 ranked as adult competitors. We also described the career trajectory of athletes ranked in the top 50 during either U18 or senior category.

Methods. The performance progression of 4924 male and female athletes competing in sprint races and ranked in the IAAF lists (now World Athletics) in any of the seasons between the 2000 and 2018 were included in the study. Then, the athletes ranked in the top 50 positions of all-time lists during U18, senior or both categories were analysed.

Results. Only 17% of the male and 21% of the female top 50 ranked U18 managed to become top 50 ranked senior athletes. The top 50 ranked senior athletes consistently produced yearly larger improvements during late adolescence and early adulthood compared to those who ranked in the top 50 at U18. Furthermore, top 50 ranked senior athletes reached their peak performance later compared to the top 50 ranked only in U18.

Conclusions. This study confirms that early success in track and field is not a good predictor of success at senior level in sprinting events. The yearly performance improvements and its tracking provide the most suitable approach to identify athletes more likely to succeed as elite performers in adulthood. We hope that the results of this study can provide useful comparative data and reference criteria for talent identification and development programs.

Keywords:

Performance progression, career trajectories, talent identification, youth training, track and field.

Introduction

There is debate over whether junior success is prerequisite for success as a senior athlete. The path that leads a young athlete to become an adult champion is not linear and is characterized by a conspicuous amount of uncertainty.^{1,2} Previous studies attempting to describe the extent of the transition from successful junior to successful senior performer showed inconsistent results, probably because the conclusions largely depends on how the data are analyzed.³ In fact, there are two main approaches to analyze the athletes' performance progression: a prospective or a retrospective viewpoint.^{3,4}

Prospective approaches are based on the possibility to track the career of young athletes participating, for example, at World Junior Championships up to the end of their career.⁵ These studies allow quantifying the successful transition rate (or conversion rate) which represents the chance for an elite junior athlete to become an elite senior athlete. Previous studies found a transition rate of 21% for track and field medalist in World junior championships⁴ and of 17% for participants at swimming junior World Championship.⁶ However, there are some limitations with such prospective approach, since it is mostly focused on a small selected group of athletes, (e.g. only those participating at one specific World Junior Championship). Furthermore, the possibility to participate at a World Junior Championship is based not only on the performance level, but sometimes (e.g. in the case of swimming) on selection policies of the national federations, on the athletes' fitness in the months before the competitions, and may be strongly influenced by injuries occurring just before or at the championship. For all these reasons, reconstructing careers and success rate as seniors from analysis of individual championships is based on datasets that can be considered somewhat incomplete.

Retrospective analysis on individual careers allows to track back the performances of senior elite athletes (e.g. the World champions), providing useful information about the performance progression of those who succeed at senior level.^{7,8} They can illustrate the developmental experiences of those who achieve elite performances as senior athletes.⁹ They may also present anecdotal experience of successful case studies.¹⁰ However, findings from this kind of studies may not be useful to explain and describe the differences between individuals attaining success at senior level from the individuals unable to progress. The developmental stages addressed by a small group of elite champions may not be considered as a rigid benchmark, in particular since a certain amount of variability for the path to success is indisputable.^{1,2} Taken together, these arguments suggest that the adoption of both retrospective and prospective approaches are necessary to thoroughly characterize the developmental phases of those who achieve and do not achieve senior elite performances.^{3,4,11}

70 In track and field, few studies tracked the career trajectories of large samples of athletes,
71 including both junior and senior elite performers¹²⁻¹⁴ but these research efforts were confined to
72 national level athletes and thus the conclusions might not apply to world-class performers. In
73 particular, despite its popularity, sprinting events seem to be the least analysed. Sprinting races are
74 cornerstone events of the Olympic Games and World championships and attract considerable
75 attention. Because of this, the training and development of elite sprinters are gaining consideration
76 in the literature.¹⁵ Since an overall view of career trajectories of best performers are lacking, it is
77 still difficult to understand what determines the transition of a talented junior athlete to a World-
78 class adult performer. Despite this gap in the literature, some studies focused on the second part of
79 the athletes' career providing plausible arguments on the importance of performance progression
80 during the transition from elite junior to senior phase.^{16,17} For example, the improvement in
81 performance from 18 years of age to the peak performance was about 8% for world-class sprinters
82 and only 1.4% for national-level athletes (Norwegian athletes).¹⁷ Furthermore, Haugen et al.⁸
83 provided an in-depth analysis of performance progressions in the five years before the peak
84 performance of world-class athletes and revealed that the annual improvements in world-class
85 sprinters (range 0.1-0.2%) was greater in the top 10 athletes than the ones observed in athletes
86 ranked from 11 to 100 . Despite this, the authors did not include the analysis of the junior to senior
87 transition phases. In general, we can state that a more comprehensive understanding of the
88 relationship between young and senior performances of world-class track and field athletes is
89 lacking. To fill this gap, we tracked the career performances of a large sample of world-class
90 sprinters and we investigated the transition rate of elite U18 sprinters to elite senior level. Since the
91 definition of elite performers remains elusive, we operationally defined being "elite" as those
92 athletes in the top 50 ranking in their category. Thus, the first experimental question was to quantify
93 how many top 50 ranked U18 managed to become top 50 ranked as seniors. Secondly, we aimed to
94 describe the performance progression of athletes classified in the top 50 ranking in U18 and senior
95 categories.

96

97 **Methods**

98 The sample of this study involved the sprinters competing in 100m, 200m, and 400m races.
99 The names of males and females' athletes ranked in the top 100 official lists of the International
100 Association of Athletics Federations (IAAF – now called World Athletics;
101 <https://www.iaaf.org/home>) in each season from 2000 to 2018 and the athletes who participated in
102 the IAAF World U18 Championships (from 1998 to 2014; [https://www.iaaf.org/competitions/iaaf-](https://www.iaaf.org/competitions/iaaf-world-u18-championships)
103 [world-u18-championships](https://www.iaaf.org/competitions/iaaf-world-u18-championships)) and IAAF World U20 Championship (from 1999 to 2015;

104 <https://www.iaaf.org/competitions/iaaf-world-u20-championships>) were collected from the publicly
105 available results database. The dataset of names coming from these lists were merged and, after
106 duplication removal, the IAAF database was used to download the career performance progression
107 of each athlete included in the dataset. Athletes disqualified for doping offences were excluded
108 from the analysis. IAAF database provides athletes' career progression, which consists in the best
109 results for each competitive year from the beginning to the end of the athletes' career or until
110 December 31, 2018 if he/she was still in activity. According to IAAF rules, only results with regular
111 wind readings were considered.

112

113 **Statistical analysis**

114 Data were separately analyzed for gender and discipline. Records were included only if the
115 individuals were present in the dataset for a minimum of three years, also non-consecutively.
116 Longitudinal data of each athlete were extrapolated by custom-written software in MATLAB
117 R2018b (Mathworks, Natick, Massachusetts).

118 As previously suggested,⁸ individual trends were generated by fitting a quadratic curve
119 separately to each athlete's performance and age. From the quadratic curve, the following outcome
120 variables characterizing the career of athletes were calculated: 1) age of first appearance in the
121 IAAF database; 2) age of last appearance in the IAAF database; 3) personal peak performance; 4)
122 age of peak performance; 5) improvement from the age of 17 to peak performance; performance at
123 6) 16 years of age; 7) 17 years of age; (8) 18 years of age; (9) 19 years of age; 10) 20 years of age;
124 annual performance improvement (%) between 11) 16-17 years; 12) 17-18 years; 13) 18-19 years;
125 14) 19-20 years.

126 To answer the first experimental question, we created two all-time rankings, respectively for
127 the performances in U18 (16 and 17 years of age) and senior categories (≥ 18 years of age).
128 Subsequently, we quantified how many top 50 ranked U18 managed later to become top 50 ranked
129 as seniors. We also quantified how many top 50 ranked as seniors were top 50 ranked as U18. To
130 do this, athletes were categorized in four subgroups: (1) *only U18*, i.e. those who were top 50
131 ranked in U18 but not in senior category; (2) *U18 and senior* i.e. those who were top 50 ranked both
132 in U18 and senior categories (3) *only senior* i.e. those who were top 50 ranked in senior but not in
133 U18 category; (4) *others*, i.e. those who never appeared in the top 50 ranked. The frequency of
134 athlete in each category was calculated. We selected the threshold of the top 50 athletes because this
135 is approximately the common sample size for participants in Olympic Games in sprinting events.
136 However, we also tried to assess the threshold to the top 100 athletes in a preliminary analysis.

137 Since the overall finding of the study did not differ, for conciseness here we reported and discussed
138 the results for the threshold posed at the top 50 only.

139 To answer to the second experimental question and to compare the four subgroups of
140 performers, a series of one-way analyses of variance (ANOVA) was carried out for each outcome
141 variables. When the homogeneity of variances was violated, as assessed by Levene's Test of
142 Homogeneity of Variance (all P values < .05), the Welch's *F* test was used. When necessary,
143 Bonferroni and Games-Howell post hoc analysis was used to identify differences between
144 subgroup.

145 The relationships between the personal peak performance and age of first appearance in the
146 IAAF database, performance at 17 years of age (i.e. the last year of U18) and age of peak
147 performance were analysed using Pearson's correlation. A series of multiple regressions was run to
148 predict the personal peak performance in each sprint event (i.e., dependent factor) from age of first
149 appearance in the IAAF database and performance at 17 years of age (i.e., independent factors).

150

151 **Results**

152 A total of 58 men and 60 women were removed from the database because they were
153 disqualified for doping. After error and duplication removals, a total of 4924 (females: $n = 2865$,
154 58.2%) sprinters were included in the study. The sample size of each subgroup is reported in Table
155 1. On average, only 17% (90%CI from 12 to 23) of the male athletes and 21% (90% CI from 16 to
156 28) of the female athletes were in the top 50 rankings both in U18 and in the senior category (*U18*
157 *and senior* subgroup).

158 Descriptive statistics of the performances of subgroups: *only U18*, *U18 and senior*, *only*
159 *senior* are reported in Figure 1. Table 2 reports the descriptive statistics and post hoc comparisons
160 of age of first and last appearance in the IAAF database personal best performance, age of peak
161 performance. The one-way ANOVA outcomes are reported in Supplementary Table 1. In general,
162 the *only U18* subgroup reached their personal peak performance, made their first and last
163 appearance in the IAAF database earlier than the *U18 and senior* and *only senior* subgroups (Table
164 2). The *only senior* subgroup made their first appearance in the IAAF database later than *U18 and*
165 *senior* subgroup and reached the personal peak performance later than the *U18 and senior*
166 subgroups (Table 2).

167 Figure 2 shows the relative annual change of the subgroups of performers over the course of
168 their career. The detailed descriptive statistics of performances and relative annual changes from 16
169 to 20 years of age are reported in Supplementary material 2. The *only senior* subgroup consistently
170 showed greater annual improvement prior to age of peak performance from 16 to 19 years of age

171 compared to the *only U18* subgroup. Furthermore, the *only U18* athletes did not show any
172 significant improvement in performance from 19/20 years of age onwards, while the *only senior*
173 group improved their performances up to 26/27 years of age (Figure 2 and Supplementary Table 2).

174 The results of the correlations analysis are reported in Table 3. Briefly, small to moderate
175 correlations were identified between the performance at 17 years of age and the personal peak
176 performance depending on gender and discipline. Women tend to show larger correlations (r values
177 from 0.49 to 0.55) than men (r values from 0.16 to 0.40). The age of first appearance in the IAAF
178 database showed large correlation with the age of personal peak performance (all r values greater
179 than 0.51). Furthermore, the personal peak performance showed moderate to large correlation with
180 the age of personal peak performance (all r values from -0.44 to -0.60).

181 Table 4 presents the summary of the multiple regression analyses to predict the personal
182 peak performance using as independent variables the age of first appearance in the IAAF database
183 and performance at 17 years of age. In all disciplines and gender, the age of first appearance in the
184 IAAF database had trivial negative effect on the personal peak performances in senior category, i.e.
185 later age of first appearance in the IAAF database were trivially but significantly related to an
186 improvement of peak performance. The performance at 17 years of age positively, despite weakly,
187 influenced the personal peak performance: on average the variance explained by the models were
188 29% in females and lower than 15% in males (Table 4).

189

190 **Discussion**

191 We tracked the career performance trajectories of a large set of world-class sprinters from
192 the first to the last appearance in the IAAF database. We compared key features of career
193 progressions between the top 50 ranked U18 and senior sprinters. This gave us the possibility to
194 present the details of a realistic successful transition rate with an unprecedented robustness. Around
195 20% of the top 50 ranked U18 managed later to become top 50 ranked as seniors. Those who were
196 among the top 50 senior athletes first appeared in the IAAF database, reached their personal peak
197 performance, and last appeared in IAAF database later than those who were top 50 ranked only in
198 U18. The top 50 senior athletes also showed a greater annual change of improvement from 16 to 19
199 years of age compared to those who were among the top 50 only when competing in the U18
200 category.

201 Being an elite young athlete does not guarantee a transition to an elite adult athlete. Indeed,
202 when removing from the analysis athletes disqualified for doping, only 17% of male and 21% of
203 female top 50 ranked athletes successfully transitioned to be among the top 50 as senior athletes.
204 Consequently, an attrition rate of 79-83% highlights that it is quite rare for an elite young sprinter to

205 become an elite adult sprinter. This is in line with previous evidence presented on track and field
206 athletes.⁴ The reasons for such a high attrition rate are manifold and are likely include early
207 maturation,¹⁸ early specialization,^{19,20} relative age effect,^{3,21,22} injuries,^{16,23} drop-out,²⁴ and dual
208 career barriers.^{16,25} Even more importantly, most elite senior athletes were not considered as such
209 when they were young. Indeed 79-83% of top 50 senior athletes were not present in the top 50
210 ranking when they were U18. Consequently, being an elite young sprinter is not a prerequisite to
211 become an elite senior athlete. This confirms previous observations in national level populations¹²⁻
212 ¹⁴. Taken together, these findings constitute a solid base to affirm that success in young categories is
213 not strongly related to success in the adulthood.

214 Assuming success at adult level solely based on performance at U18 level can be
215 misleading. Indeed, the correlation between the personal peak performance and the performance at
216 17 years of age in this cohort of world-class athletes is small in men and moderate in women (Table
217 3). Even when including the age of first appearance in the IAAF database in the regression model,
218 the performance at 17 years of age may explain only up to about 26% of the variance in personal
219 peak performance in males, and up to about 31% in females (Table 4). This finding confirms that
220 performances during adolescence do constitute a predictor of success in the adulthood. A certain
221 association between the performance at young ages and the personal best performance is expected
222 and somewhat obvious,^{7,13,26} but care should be applied when using U18 performances to predict
223 adult success.

224 Entering competitions early does not constitute an advantage for reaching elite performance
225 in sprinting events. The age of first appearance in IAAF database (which can be associated to the
226 age of entering competition) was around 17-18 years for the *only senior* subgroup, while less than
227 16 years for the *only U18* subgroup. Furthermore, age of first appearance in the IAAF database was
228 positively correlated to the performances at 17 years of age, but negatively correlated to the
229 personal peak performance (see Table 3). This means that early competition may increase the
230 chance of being considered elite at 17 years but may blunt the chance to become an elite adult
231 athlete. Taken together, these findings suggest that entering competition too early does not represent
232 an advantage, and may, at some extent, be considered as a detrimental factor for future
233 performance.

234 The annual rate of improvement was one of the most evident characteristics distinguishing
235 the career trajectory of successful compared to non-successful athletes. Those who were among the
236 top 50 athletes only in U18 plateaued at an earlier age compared to the other athlete subgroups
237 (Figure 2, supplementary Table 3). The improvement of performance of *only senior* subgroup

238 across the 16-20 years of age was larger than all other subgroups, suggesting that continue
239 progression,⁸ instead of early success, may characterize those who reach the elite level in the world.

240 The age of peak performance has been widely investigated in track and field studies.^{3,8,27}
241 Here we expand previous findings showing that the age of peak performance is positively correlated
242 to the age of first appearance in the IAAF database (see Table 3). This means that those who started
243 the competitions later reached the peak performance later compared to those who started the
244 competitions at an early age. Furthermore, the *only senior* subgroup reached their personal best
245 approximately 1-3 years later than the *U18 and senior* subgroup. Taken together, these findings
246 reinforce the opinion that more time to reach the peak performance should be given to those who
247 started the competition at a later age.¹²

248 The top 50 U18 athletes that did not become top 50 senior athletes showed a peculiar pattern
249 of performance trajectory. Indeed, they appeared in the IAAF database, reached their peak
250 performance,³ and last appeared in database (retired from competitions) earlier than those who
251 managed to become top 50 ranked in the senior category (Table 2). They also showed blunted
252 annual rate of improvement across the young ages compared to top 50 ranked in the senior
253 category. All these features may be explained in the following way: a young athlete that starts its
254 sport specific activity early, may have more chance to be an elite U18 athlete but also has less room
255 for improvement and consequently may reach the personal peak performance early probably due to
256 intense specialized training. The successive levelling of performance may increase the chance of
257 drop out and thus may induce to conclude the career early.²⁴ However, since details of reasons to
258 stop careers are lacking, this can only be considered speculation.

259 On average, the relationship between U18 performance and adult performance was stronger
260 in women than in men, in all disciplines. Indeed, women showed larger correlations between
261 performances at 17 years of age and in the senior category (Table 3 and Table 4). This is in line
262 with previous observations on national athletes¹²⁻¹⁴ and may be explained by the fact that young
263 females are more biologically mature at 17 years compared to their male counterparts.^{18,28} This
264 makes young female athletes closer (from a biological standpoint) to the adult women athletes,
265 hence decreasing the gap between young and adult performances.

266 Some limitations should be highlighted when interpreting the current data. We describe the
267 career trajectory using the IAAF database. However, it is possible that many athletes started their
268 career before being appearing in the IAAF database possibly competing in lower-level national
269 competitions. Despite this, it is reasonable to assume that the abovementioned issues/problems are
270 similar across all the athlete subgroups. From the data available, it is impossible to know if these

271 U18 athletes were already specialized in sprinting and/or if they were involved in other
272 competitive/sporting activities or performing and training for different events.

273

274 **Practical applications**

275 This study provides a robust estimation of transition rate (or conversion rate) for world-class
276 sprinters: from our analysis, 17% of male and 21% of female top 50 U18 sprinters managed to
277 become top 50 adult athletes, thus informing the coaches and governing bodies about the realistic
278 possibility to infer future success from young performances. This poses important concerns about
279 the recent emphasis posed on world level competitions like youth Olympics which may push
280 athletes to early specialization pathways. Therefore, a more cautious approach to athletic
281 development is required as suggested by a recent IOC consensus statement.²⁶ The present study also
282 suggests that beyond the absolute performance in U18 category, the age of entering competition and
283 the annual change of performance represent the best approach for talent identification and
284 development tracking in sprint disciplines.

285

286 **Conclusions**

287 According to our analysis of the performance trajectories of the best sprinters in the world,
288 being an elite young athlete is not a prerequisite to become an elite adult sprinter. Indeed, most elite
289 adult sprinters were not considered as such when they were young, but they showed a more rapid
290 and durable improvement of performances during the young ages, compared to their early success
291 counterparts. For this reason, performance progression rather than only performance *per-se* should
292 be considered when determining chances of success at a later stage in the athletic career.

293

294 **Acknowledgements**

295 The authors acknowledge the contribution of Stefano Ferrero and Alberto Visconti for
296 entering data in the electronic sheets of the database.

297
298
299
300
301
302
303
304
305
306
307
308
309
310
311
312
313
314
315
316
317
318
319
320
321
322
323
324
325
326
327
328
329
330

References

1. Gulbin J, Weissensteiner J, Oldenzel K, Gagne F. Patterns of performance development in elite athletes. *European journal of sport science*. 2013;13(6):605-614.
2. Barreiros A, Cote J, Fonseca AM. From early to adult sport success: analysing athletes' progression in national squads. *European journal of sport science*. 2014;14 Suppl 1:S178-182.
3. Foss J, Sinex J, Chapman R. Career Performance Progressions of Junior and Senior Elite Track and Field Athletes. *Journal of Science in Sport and Exercise*. 2019.
4. Hollings SC, Hume PA. Is success at the World Junior Athletics Championships a prerequisite for success at World Senior Championships or Olympic Games? Prospective and retrospective analyses. *New Stud Athl*. 2010;25(2):65–77.
5. Pizzuto F, Bonato M, Vernillo G, La Torre A, Piacentini MF. 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.
6. Yustres I, Santos Del Cerro J, Martin R, Gonzalez-Mohino F, Logan O, Gonzalez-Rave JM. Influence of early specialization in world-ranked swimmers and general patterns to success. *PloS one*. 2019;14(6):e0218601.
7. Allen SV, Vandenberg TJ, Hopkins WG. Career performance trajectories of Olympic swimmers: benchmarks for talent development. *European journal of sport science*. 2014;14(7):643-651.
8. Haugen TA, Solberg PA, Foster C, Moran-Navarro R, Breitschadel F, Hopkins WG. Peak Age and Performance Progression in World-Class Track-and-Field Athletes. *Int J Sports Physiol Perform*. 2018;13(9):1122-1129.
9. Huxley DJ, O'Connor D, Larkin P. The pathway to the top: Key factors and influences in the development of Australian Olympic and World Championship Track and Field athletes. *Int J Sports Sci Coa*. 2017;12(2):264-275.
10. Svendsen IS, Tonnesen E, Tjelta LI, Orn S. Training, Performance, and Physiological Predictors of a Successful Elite Senior Career in Junior Competitive Road Cyclists. *Intj Sport Physiol*. 2018;13(10):1287-1292.
11. Schumacher YO, Mroz R, Mueller P, Schmid A, Ruecker G. Success in elite cycling: A prospective and retrospective analysis of race results. *J Sports Sci*. 2006;24(11):1149-1156.
12. Boccia G, Brustio PR, Moisé P, et al. Elite national athletes reach their peak performance later than non-elite in sprints and throwing events. *J Sci Med Sport*. 2019;22(3):342-347.

- 331 13. Boccia G, Moise P, Franceschi A, et al. Career Performance Trajectories in Track and Field
332 Jumping Events from Youth to Senior Success: The Importance of Learning and
333 Development. *PloS one*. 2017;12(1):e0170744.
- 334 14. Kearney PE, Hayes PR. Excelling at youth level in competitive track and field athletics is
335 not a prerequisite for later success. *J Sports Sci*. 2018:1-8.
- 336 15. Haugen T, Seiler S, Sandbakk O, Tonnessen E. The Training and Development of Elite
337 Sprint Performance: an Integration of Scientific and Best Practice Literature. *Sports Med*
338 *Open*. 2019;5(1):44.
- 339 16. Hollings SC, Mallett CJ, Hume PA. The Transition from Elite Junior Track-and-Field
340 Athlete to Successful Senior Athlete: Why Some Do, Why others Don't. *Int J Sports Sci*
341 *Coa*. 2014;9(3):457-471.
- 342 17. Haugen T, Tonnessen E, Seiler S. 9.58 and 10.49: nearing the citius end for 100 m? *Int J*
343 *Sports Physiol Perform*. 2015;10(2):269-272.
- 344 18. Malina RM. Physical growth and biological maturation of young athletes. *Exerc Sport Sci*
345 *Rev*. 1994;22:389-433.
- 346 19. Moesch K, Elbe AM, Hauge ML, Wikman JM. Late specialization: the key to success in
347 centimeters, grams, or seconds (cgs) sports. *Scand J Med Sci Sports*. 2011;21(6):e282-290.
- 348 20. Malina RM. Early sport specialization: roots, effectiveness, risks. *Current sports medicine*
349 *reports*. 2010;9(6):364-371.
- 350 21. Kearney PE, Hayes PR, Nevill A. Faster, higher, stronger, older: Relative age effects are
351 most influential during the youngest age grade of track and field athletics in the United
352 Kingdom. *J Sports Sci*. 2018:1-7.
- 353 22. Brustio PR, Kearney PE, Lupo C, et al. Relative Age Influences Performance of World-
354 Class Track and Field Athletes Even in the Adulthood. *Front Psychol*. 2019;10:1395.
- 355 23. Zaremski JL, Zeppieri G, Jr., Tripp BL. Sport Specialization and Overuse Injuries in
356 Adolescent Throwing Athletes: A Narrative Review. *J Athl Train*. 2019;54(10):1030-1039.
- 357 24. Enoksen E. Drop-out rate and drop-out reasons among promising Norwegian track and field
358 athletes - A 25 year study. *Scandinavian Sport Studies Forum*. 2002(2):19-43.
- 359 25. Brustio PR, Rainoldi A, Mosso CO, López de Subijana C, Lupo C. Italian student-athletes
360 only need a more effective daily schedule to support their dual career. *Sport Sci Health*.
361 2020;16:177-182.
- 362 26. Bergeron MF, Mountjoy M, Armstrong N, et al. International Olympic Committee
363 consensus statement on youth athletic development. *Br J Sports Med*. 2015;49(13):843-851.

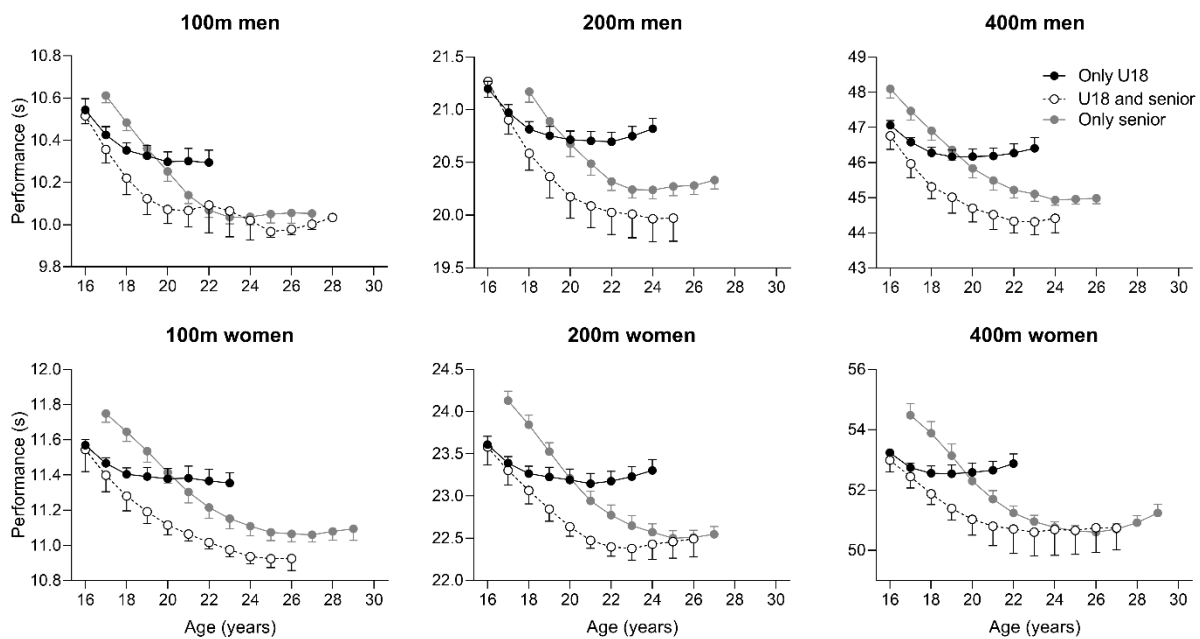
- 364 27. Allen SV, Hopkins WG. Age of Peak Competitive Performance of Elite Athletes: A
 365 Systematic Review. *Sports Med.* 2015;45(10):1431-1441.
 366 28. Malina RM, Slawinska T, Ignasiak Z, et al. Sex Differences in Growth and Performance of
 367 Track and Field Athletes 11-15 Years. *J Hum Kinet.* 2010;24:79-85.

368

369 Captions

370 Figure 1

371 Performance progressions (mean, 90%CI), from the first to the last appearance in IAAF database,
 372 are reported for each subgroup of athletes: 1) *only U18* (black circle), i.e. those who were among
 373 the top 50 ranked only at U18 but not in the adulthood; 2) *U18 and senior* (empty circle), i.e. those
 374 who were top 50 ranked both at U18 and in the adulthood; 3) *only senior* (gray circle), i.e. those
 375 who were top 50 ranked only in the adulthood.



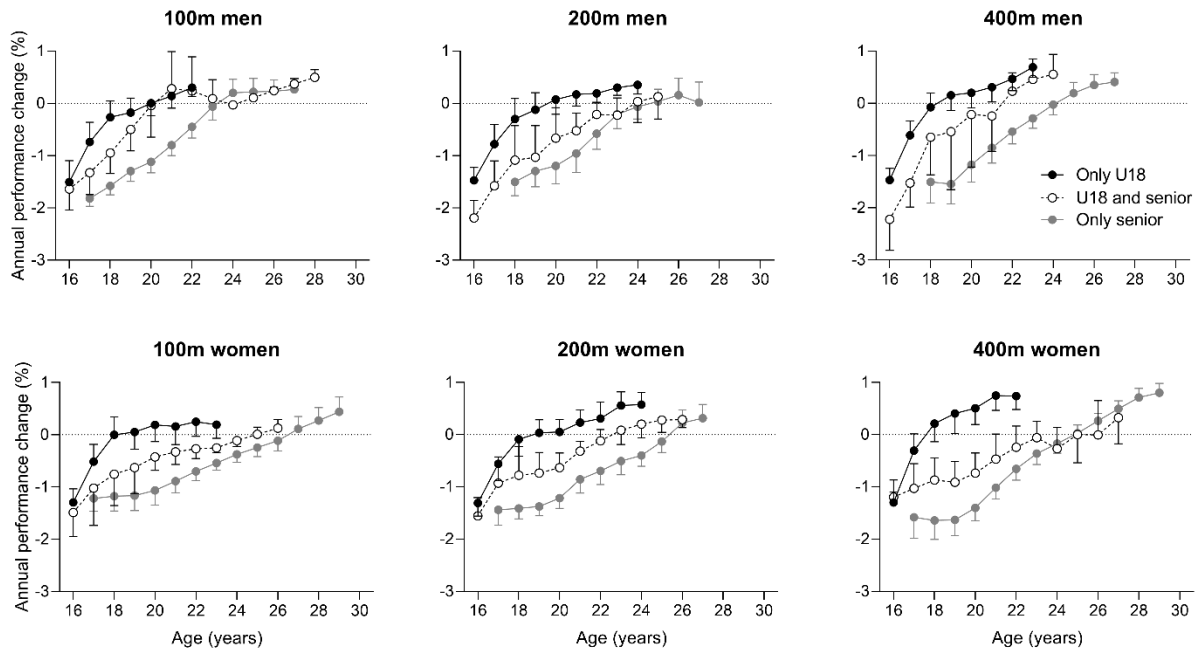
376

377

378 Figure 2

379 Percentage of yearly performance changes (mean, 90%CI), from the first to the last appearance in
 380 IAAF database, are reported for each subgroup of athletes: 1) *only U18* (black circle), i.e. those who
 381 were among the top 50 ranked only at U18 but not in the adulthood; 2) *U18 and senior* (empty

382 circle), i.e. those who were top 50 ranked both at U18 and in the adulthood; 3) *only senior* (grey
383 circle), i.e. those who were top 50 ranked only in the adulthood.



384