

AperTO - Archivio Istituzionale Open Access dell'Università di Torino

## Elite Junior Throwers Unlikely to Remain at the Top Level in the Senior Category

### **This is the author's manuscript**

*Original Citation:*

*Availability:*

This version is available <http://hdl.handle.net/2318/1845008> since 2023-02-28T12:53:24Z

*Published version:*

DOI:10.1123/IJSPP.2020-0699

*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)



**Elite junior throwers unlikely remain at the top level in the senior category**

Journal:	<i>International Journal of Sports Physiology and Performance</i>
Manuscript ID	IJSPP.2020-0699.R1
Manuscript Type:	Original Investigation
Date Submitted by the Author:	n/a
Complete List of Authors:	Boccia, Gennaro; University of Turin, department of medical sciences Cardinale, Marco; Aspire Academy, Sports Science; University College London, Department of Computer Science. Brustio, Paolo; University of Turin, NeuroMuscular Function Research Group, School of Exercise & Sport Sciences , Department of Medical Sciences
Keywords:	Career trajectories, talent identification, youth training, track and field, relative age effect, development programs

SCHOLARONE™  
Manuscripts

**Title: Elite junior throwers unlikely remain at the top level in the senior category**

Submission type: Original investigation.

Authors: Gennaro Boccia<sup>1</sup>, Marco Cardinale<sup>2,3,4</sup>, Paolo Riccardo Brustio<sup>1</sup>

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

<sup>2</sup> Research and Scientific Support Department, Aspetar Orthopaedic and Sports Medicine Hospital, Doha, Qatar

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

<sup>4</sup> Department of Computer Science and Institute of Sport Exercise and Health, University College London, London, UK

Corresponding author:

Gennaro Boccia

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

Phone: +39 0117764708

Email: gennaro.boccia@unito.it

Preferred running head: Careers of World-class throwers

Abstract word count: 248

Text-only word count: 3335

Number of figures and tables: 3

Supplementary file: 1

## 1 **Abstract**

2

3 Purpose. This study investigated 1) the transition rate of elite world-class throwers, 2) the  
4 age of peak performance in either elite junior and/or elite senior athletes, and 3) if relative age effect  
5 influences the chance of being considered elite in junior and/or senior category.

6 Methods. The career performance trajectories of 5108 throwers (49.9% females) were  
7 extracted from the World Athletics database. We identified throwers who had reached the elite level  
8 (operationally defined as the World all-time top 50 ranked for each age category) in either junior  
9 and/or senior category and we calculated the junior-to-senior transition rate. The age of peak  
10 performance and the relative age effect (RAE) were also investigated.

11 Results. **The transition rate at 16 and 18 yrs of age was 6% and 12% in males, and 16% and**  
12 **24% in females, respectively.** Furthermore, elite senior throwers reached their personal best later in  
13 life than elite junior throwers. The athletes of both genders considered elite in the junior category  
14 showed a large RAE. Interestingly, male athletes that reached the elite level in senior category also  
15 showed appreciable RAE.

16 Conclusions. Only a few of the athletes that reach the top 50 in the World **at 16 or 18 yrs of**  
17 **age** manage to become elite senior athletes, underlining that success at the beginning of an athletic  
18 career does not predict success in senior career. Moreover, data suggest that being relatively older  
19 may confer a benefit across the whole career of male throwers.

20

21

### 22 **Keywords:**

23 Career trajectories, talent identification, youth training, track and field, relative age effect,  
24 development programs

## 25 **Introduction**

26           Within sports measured in centimetres, grams, or seconds, the selection of talented athletes  
27 is often based on objective and measurable traits, such as the actual performances. Performance  
28 outcomes in such sports are pretty clear and simple and success comes from throwing farther,  
29 running faster and lifting more. However, while identifying successful athletes on the field of play  
30 is easier, less clarity exists on identifying talented youngsters capable of developing into successful  
31 senior athletes. In fact, individual career performances present an amount of uncertainty because  
32 they are characterised by non-linear improvements in performance with highly variable oscillations  
33 across the years.<sup>1</sup> Previous work has already highlighted that in some sporting disciplines early age  
34 performances show low stability over the time<sup>2,3</sup> and do not constitute a prerequisite for senior  
35 success.<sup>4-7</sup> The transition rate, usually identified as the chance for an elite youth athlete to become  
36 an elite senior athlete has been reported to vary in difference disciplines.

37           Overall, the various studies investigating the transition rate at national and international  
38 level in track and field has determined that the chances for elite junior athletes to become an elite  
39 athlete in adulthood are low. For example, more than 50% of New Zealand and Australian elite  
40 youth athletes were not present and did not represent their countries at the senior level.<sup>8</sup> In the UK,  
41 only ~ 20% of male and 25% of female athletes were top 20 ranked both in youth (Under 15, U15)  
42 and senior (U20) competitions.<sup>5</sup> A similar pattern was observed in the Italian national rankings  
43 where only ~ 24% and 38% of male and female athletes respectively were considered top-level  
44 athletes both during their youth (age range: 14-17 years) and senior career.<sup>3,6</sup> At the international  
45 level, in a prospective cohort, Hollings et al.<sup>9</sup> found that only the 21% of medallist and 13% of the  
46 finalist athletes in the World Junior Championships (WJC) had reached success later at senior level  
47 and more than half (54%) did not compete at all as an elite senior athlete. In middle-distance events,  
48 only 31% of the junior finalists in the WJC had been ranked among the top 10 later at senior level.<sup>10</sup>  
49 We recently reported robust estimates of transition rate in World-class sprinters **and jumpers**.<sup>7,11</sup>  
50 After analysing the World Athletics and WJC lists over a large multigenerational sample, we found  
51 that only 20% of the sprinters and jumpers top 50 ranked at 17 years of age managed to become a  
52 top 50 ranked athlete in the senior category.

53           Throwing events are peculiar if compared to other track and field events. The scaling of  
54 implements' weight during the youth career, especially for males, and the consequent modification  
55 in throwing technique may make the career progression even more unpredictable and performance  
56 less stable.<sup>4,12</sup> Additionally, since the **duration** of top senior throwers' career is longer than in other  
57 events, it is more challenging for a junior thrower to progress into a successful senior compared to  
58 other athletics events.<sup>13</sup> In throwing events, the anthropometric characteristics combined with

59 strength and power are crucial for performance, making earlier maturing athletes more capable of  
60 winning junior category competitions.<sup>14,15</sup> Also, relatively older young athletes, i.e. those born at the  
61 beginning of the calendar year, may also have more opportunities to be considered elite in the junior  
62 category.<sup>16</sup> This may be particularly valid in track and field competitions where age limits in  
63 competitions determine a field of play of biannual age-grouping cohorts. With such wide age-  
64 grouping, a **difference between** athletes born close and far to the date of selection may increase the  
65 possibility to observe an asymmetry in birthdate distribution of successful athletes that is known as  
66 the relative age effect (RAE). Nevertheless, even if the RAE reflects the possible  
67 advantages/disadvantages in early sport success, it does not seem to translate into senior excellence.  
68 In sprinters, middle-distance runners, and jumping athletes, the RAE disappeared with the transition  
69 to the senior category.<sup>15</sup> Instead, previous work analysing performance and RAE in throwing events  
70 has indicated its influence also in the senior category both in female and male athletes.<sup>17</sup> However,  
71 the study mentioned above used a cross-sectional approach, and a causal mechanism cannot be  
72 drawn for career progression. A longitudinal approach should be more appropriate to analyse career  
73 progression and provide evidence if RAE in throwing events is linked with early youth success and  
74 is a prerequisite for success at the senior level.

75 The literature shows conflicting findings regarding the transition rate in throwing events.  
76 Sholz et al.<sup>13</sup> reported that almost all WJC finalists in the 90s were also successful in the major  
77 international events for senior-level athletes after they transitioned. **One could argue that the lack of**  
78 **systematic antidoping campaigns possibly influenced such a high transition rate.** More recently,  
79 only eight throwing finalists **from** five editions of WJC (in the last 20 years) achieved the same  
80 level of success in the Olympics and/or in World Championships.<sup>12</sup> Additionally, 46% of the  
81 finalists did not compete at a high-level anymore, and javelin and hammer events appeared to have  
82 the highest drop-out.<sup>12</sup> However, because these data were focused on the few athletes that  
83 participated in the WJC it is not possible to accurately explain and analyse the evolution of  
84 performances from junior to senior in throwing events. Unfortunately, the studies that tracked a  
85 larger sample of athletes were performed only on national level athletes (from Italy and the UK).  
86 Research on the performance databases of these two countries reported a successful transition rate  
87 to senior success of about 20% and 30% for male and female athletes respectively.<sup>6,5</sup>

88 Tracking the career of a large sample of multigenerational World-class athletes,<sup>17</sup> not only  
89 those participating in the WJC, would provide a more robust and comprehensive analysis of  
90 performance evolution and could improve the estimation of the actual transition rate.<sup>11</sup> Additionally,  
91 using this approach, it is possible to study the athletes' career both prospectively and  
92 retrospectively. The prospective approach would facilitate the identification of the elite young

93 athletes and the tracking of their performance across competitions. The retrospective approach  
94 would enable to identify elite senior athletes and trace back their career up to the beginning of their  
95 international competitions. We believe that the combination of the two different perspectives would  
96 be useful to understand the importance of early age success on senior performance.

97 Tracking the whole career of elite athletes will also help to elucidate if junior performance  
98 might have an impact on when athletes reach their peak performance compared to the typical age  
99 reported in the literature.<sup>17,18</sup> Indeed the data available in the literature do not distinguish between  
100 early-success and late-success athletes, providing only the average age of peak performance of top  
101 level competitors.<sup>17,18</sup> Nevertheless, it is reasonable to hypothesize that early-success athletes would  
102 reach their peak performance earlier than late-success athletes. Being aware of this would allow  
103 coaches to have a more realistic prediction of the future development of their athletes.

104 Therefore, the aim of this study was to expand previous knowledge on throwers' career  
105 investigating 1) the transition rate, 2) the age of peak performance in those athletes who had  
106 reached an elite level in either junior and/or senior category and 3) if relative age effect influenced  
107 the chance of being considered elite in junior and/or senior category.

## 108 **Methods**

109 This prospective/retrospective study is focused on throw events (i.e., Shot Put, Hammer Throw,  
110 Discus Throw and Javelin Throw) considering both male and female athletes. To investigate the  
111 career progression, athletes' names participating in the WJC U18  
112 (<https://www.iaaf.org/competitions/iaaf-world-u18-championships>) and U20 Championship  
113 (<https://www.iaaf.org/competitions/iaaf-world-u20-championships>) from the seasons 1998 to 2015  
114 were collected. Differently, for the retrospective analysis, the names of the 100 top athletes in each  
115 season from 2000 to 2019 were extracted from the databases provided by the World Athletics  
116 (<https://www.worldathletics.org/home>). After merging the two databases and removing all duplicate  
117 names, the seasonal best performances (SBPs) for each athlete obtained in outdoor competitions  
118 were downloaded and included in the dataset for analysis. For each athlete, the SBPs were  
119 downloaded from the first to last appearance in the World Athletics database, or on December 31,  
120 2019, if the athlete was still competing. According to the World Athletics rules, only results with  
121 regular wind were considered. Athletes, who were found to have used banned substances and  
122 disqualified for doping offences, were excluded from the analysis.

123 All the data were collected from the publicly available resources of World Athletics  
124 Federation, and therefore no informed consent was obtained. The local ethics committee of the  
125 University of Torino approved the study.

126

## 127 **Procedure**

128           Given that the database contained a multigenerational sample of throwers (i.e., from 2000 to  
129 2019), all the SBPs were normalised according to the World Record of the corresponding discipline  
130 and gender presented in the specific years. **To calculate the transition rates**, athletes were firstly  
131 ranked according to their normalised **SBP** in an all-time ranking according to their age, i.e. 16, 17,  
132 18, 19, 20, and >20 yrs. According to previous studies<sup>7,19</sup> we arbitrarily defined the elite throwers as  
133 the top 50 in the all-time ranking. We also tried to change this threshold and to calculate the  
134 transition rate for the top 10 and top 25 athletes. Since the overall results of those calculations were  
135 similar (within a range of  $\pm 6\%$ ), for conciseness, we kept the threshold of top 50 for the analysis  
136 reported in this study. In this way, the present study is also representative of a larger sample of  
137 World-Class athletes. For the analysis, the all-time top 50 ranked throwers at each age group were  
138 identified. Using a prospective and retrospective approach, the proportion of athletes that were top  
139 50 ranked across different ages were calculated. Prospectively, we calculated how many top 50  
140 ranked throwers at 16 yrs old remained in the top 50 ranked in the following stage of their career  
141 (e.g., at 17, 18, 19, 20, and Senior). Retrospectively we calculated how many top 50 ranked Senior  
142 throwers were already top 50 ranked at younger ages (e.g., at 20, 19, 18, 17, 16 yrs).

143           **To answer the second experimental question**, the age of peak performance was calculated on  
144 the **SBP trends of each athlete**. Then the following three subgroups were identified considering the  
145 overall ranking:

- 146           1. *Only Junior*: athletes top 50 ranked in U18 (i.e. aged 16 or 17 yrs) but not in Senior  
147           category
- 148           2. *Only Senior*: athletes top 50 ranked in Senior but not in U18 category
- 149           3. *Junior and Senior*: Athletes top 50 ranked both in U18 and Senior category

150           **Finally, to answer the third experimental question**, for each athlete, the date of birth was  
151 recorded. All the above analyses were performed for each discipline and gender. An athlete was  
152 included in the analysis only if his/her SBPs were presented for a minimum of three years, also non-  
153 consecutively as previously suggested.<sup>6,11</sup>

154

## 155 **Statistical analysis**

156           The transition rates were calculated prospectively (from 16 yrs and from 18 yrs to senior  
157 category) and retrospectively (from senior to 16 yrs) using binomial proportion confidence interval  
158 (90% CI).

159           To compare the age of peak performance among *Only Junior* and *Junior & Senior* and *Only*  
160 *Senior* subgroups and disciplines two-way ANOVAs for unequal sample size were carried out.



161 Separate analyses were performed for gender. Tukey's honestly significant difference procedure  
162 was used to identify specific subgroup differences.

163 Finally, athletes in the subgroups were classified according to their month birthdate in 4  
164 different quartiles. Specifically, athletes born from January to March, from April to June, from July  
165 and September, and from October and December were classified in the 1<sup>st</sup> (Q1), 2<sup>nd</sup> (Q2), 3<sup>rd</sup> (Q3),  
166 and 4<sup>th</sup> (Q4) quartile respectively. Chi-Square was used to verify the difference between observed  
167 and expected subgroups' quartile distributions. The magnitudes of the differences were calculated as  
168 Crammer's V effect size. Threshold values for effect size statistics were:  $\leq 0.17$ , small;  $> 0.18$ ,  
169 moderate  $V \geq 0.29$  large.<sup>20</sup> Comparison between the first and last quartile (Q1 Vs Q4) and **between**  
170 **the first and last semesters (Q1,2 Vs Q3,4)** was calculated using Odds ratios (ORs) and 95%  
171 confidence intervals (95% CIs). A uniform distribution (i.e., 25% for each quartile) was used as  
172 reference.<sup>15,21</sup> For the RAE analysis, the different disciplines were merged to increase the sample  
173 size.

174 All data were analysed using custom-written software in MATLAB R2020a (Mathworks,  
175 Natick, Massachusetts). The graphs were prepared with GraphPad Prism 8 (San Diego: CA, USA).  
176 The level of significance was set at  $p \leq 0.05$ .

177

## 178 Results

179 A total of 60 athletes (37.5% female) was excluded from the analysis because of  
180 disqualification for doping offences. A total of 5108 career profiles was evaluated. Specifically,  
181 1344 athletes were shot putters (female:  $n=643$ , 47.8%), 1284 discus throwers (female:  $n=636$ ,  
182 49.5%), 1158 hammer throwers (female:  $n=616$ , 53.2%), and 1322 javelin throwers (female:  $n=604$ ,  
183 45.7%).

184

<Figure 1 about here>

185

186 Figure 1 summarises the overall prevalence of transition rate considering the prospective  
187 analysis (Figure 1a) and the retrospective analysis (Figure 1b). However, the junior-to-senior  
188 transition rate increased with increasing the reference age. Indeed, at 16 yrs of age, the transition  
189 rate was 6% for males and 16% for females while at 18 yrs of age it was larger, being 12% for  
190 males and 24% for females.

191

192 The junior-to-senior transition rates slightly varied across disciplines. In males, the javelin  
193 throw showed the largest transition rate at all ages, while in females the various disciplines showed  
194 a different behaviour. In particular, the transition rates from 16 yrs to senior category were 0%, 8%,  
2% and 11.8 % in male and 14%, 14%, 26% and 8% in female for shot put, discus throw, hammer

195 throw and javelin throw respectively. The transition rates from 18 yrs to senior category were 4%,  
196 10%, 2% and 31 % in male and 28%, 24%, 22% and 20% in female for shot put, discus throw,  
197 hammer throw and javelin throw respectively.

198 The data about the age of peak performance are presented in Table 1. In both genders and all  
199 disciplines, *Only senior* and *Junior & Senior* reached their peak performance later compared to  
200 *Only Junior* subgroup. When merging all disciplines, *Junior & Senior* reached the peak  
201 performance 1.5 and 2.0 yrs before *Only Senior* subgroup in males and females, respectively.  
202 Moreover, male Javelin throwers reached their peak performance earlier than Hammer and Discus  
203 throwers.

204 < Table 1 about here>

205 <Figure 2 about here>

206

207 The prevalence of athletes in the different quartile (i.e., RAE analysis) is presented in Figure  
208 2. The detailed results of RAE are reported in the supplementary file 1. In both genders, *Only*  
209 *Junior* showed a substantial over-representation of athletes born in the Q1 [ $\chi^2=50.50$ ,  $p<0.001$ ,  
210 Cramer's  $V=0.30$  for male and  $\chi^2=33.20$ ,  $p<0.001$ , Cramer's  $V=0.26$  for female]. The probabilities  
211 of finding an athlete born in the Q1 was 3.3 [95%CI (2.0,5.4)] and 3.1 [95%CI (1.8, 5.3)] times  
212 higher than in Q4. Although the  $\chi^2$  test showed an asymmetry in the birth distribution in the *Junior*  
213 *& Senior subgroup* in both genders, no difference in Q1 vs Q4 was observed. On the contrary, while  
214 in male *Only Senior* subgroup an asymmetry in birth distribution and in quartile comparison was  
215 observed, the female throwers showed a more symmetric distribution.

216

## 217 Discussion

218 This study examined the career progression of 5108 world-class multigenerational throwers.  
219 We aimed at describing the junior-to-senior transition rate as well as the presence of RAE in elite  
220 athletes. i.e. those athletes who were top 50 ranked in junior and/or senior category. The main  
221 finding of this study was that the junior-to-senior transition rate at 16 and 18 yrs of age was 6% and  
222 12% in males, and 16% and 24% in females, respectively. The early-success athletes reached their  
223 peak performance earlier than late-success counterparts. Finally, a substantial over-representation of  
224 athletes born close to the beginning of the calendar year was evident particularly in the top 50  
225 ranked U18 athletes.

226 The prospective analysis of the data evidenced a low transition rate from junior to senior  
227 stage. Only a few (6–16%) of the throwers considered elite (top 50 ranked) at 16 yrs of age  
228 managed to maintain the same level of performance later in adulthood (Figure 1a). The transition

229 rates calculated at 18 yrs of age was larger than those calculated at 16 yrs, but it was still low (12%  
230 and 24% for males and females, respectively). Therefore, predicting future success based on the  
231 performances obtained at 18 yrs of age is still inaccurate. These findings are similar to what we  
232 previously found on World-class sprinters<sup>19</sup> and jumpers.<sup>7</sup> However, we found a lower transition  
233 rate when compared with national level athletes,<sup>5,6</sup> indicating that the higher the level of  
234 competitiveness the lower the transition rate to senior success. In this regard, the earlier study of  
235 Sholz et al.<sup>13</sup> suggested that the participation in the WJC and the consequent acquired international  
236 experience during the early stage of career could be beneficial for the success at the major senior  
237 competitions later on in life. Here we do not necessarily deny that claim, but we provide evidence  
238 that the success at junior level is not an absolute prerequisite for future success. In general, the  
239 transition rate was lower in male athletes than their female counterparts. It is possible to speculate  
240 that the early maturation of young females<sup>22</sup> make them more physically similar to senior athletes,  
241 and this might increase the transition rate. However, in both genders, most of the elite junior  
242 athletes did not maintain the same level of competitiveness later in their career. Different factors  
243 such as early maturation<sup>22</sup> and specialization<sup>23</sup> or injuries,<sup>24</sup> may explain this high attrition rate as  
244 previously suggested. Moreover, both psychological and social factors may influence success at the  
245 senior level. Indeed, psychological factors (e.g., determination, confidence, motivation, clearly  
246 defined and realistic goals)<sup>25,26</sup> and a larger support network, as dedication and support of parents  
247 and peers, knowledge and guidance of coaches, are essential in long-term the athlete's success.<sup>27,28</sup>

248 Interesting findings also arise by analysing the retrospective approach. This analysis  
249 provides quantitative information on how the top 50 senior athletes were ranked during their junior  
250 careers. Less than 10% of elite senior male athletes were top 50 ranked in U18, and less than 20%  
251 in U20 category (Figure 1b). This means that most elite senior men outperformed their early-  
252 success counterparts later than 19 yrs of age. The trend in women was similar, but it was less  
253 pronounced. In fact, 34% of the top 50 senior women were already top 50 ranked at 19 yrs of age.  
254 This means that while few successful throwers were at the top level since the beginning of their  
255 career, most of them gained the elite status later. Throwing requires high muscle strength, power  
256 and coordination.<sup>4</sup> The present findings suggest that many years of training and experience are  
257 necessary to master such qualities in the international arena.<sup>4,29</sup> The retrospective analysis also  
258 shows that 38% of elite senior throwers of both genders were considered elite at 20 yrs of age. At  
259 20 yrs, i.e. at the beginning of the senior career, the physical maturation is complete<sup>22</sup> and the  
260 athletes use the Senior implements. Together these factors make the prediction of future success  
261 much easier at 20 yrs than before. Nevertheless, more than 50% of elite senior throwers gain the  
262 elite status only later than this age.

263 In all disciplines the *Only Junior* subgroup reached their best performance before the age of  
264 22, while the *Junior & Senior* and *Only Senior* subgroups reached their best performance from 2 to  
265 6 yrs later (Table 1). The age of peak performance for *Only senior* subgroup was similar to those  
266 reported in previous studies.<sup>17,18</sup> However, the most interesting result was that the elite senior  
267 athletes that were considered elite already in the junior category (*Junior and Senior*) reached their  
268 peak performance earlier than the rest of the elite senior athletes (*Only Senior*). This finding  
269 provides useful information to construct a more realistic expectation for the future development of  
270 elite junior athletes. Indeed, this finding suggests that if athletes are already at the top level at 16-17  
271 yrs of age, they may reach the peak performance earlier - and therefore have less margin of  
272 development - compared to their peers .

273 In men, we observed a marked difference between disciplines. Indeed, the Javelin throw  
274 showed the larger transition rate (31% at 18 yrs) and the lower age of peak performance (27 yrs).  
275 Both these findings could be related to the lighter implement and therefore the less strength/power  
276 needed to throw as well as less technical adjustments needed. In fact, the javelin throwers do not  
277 have to deal with the change of implement from U20 to Senior category, as opposed to what occurs  
278 in the shot put and discus throw. In women, the transition rate and the age of peak performance are  
279 more homogeneous across disciplines. This is possibly due to the lack of change in implements'  
280 weight from U18 to U20 category.

281 The *Only Junior* subgroup presented a large RAE. In this subgroup, athletes born in the first  
282 three months of the year were three times more numerous than the athletes born in the last three  
283 months (see Figure 2). This means that being relatively older (within one constituent year) at the  
284 beginning of the career may confer a large benefit on throwing performance. **This is in line with**  
285 **previous studies reporting a** large presence of RAE in disciplines, such as throwing, with a great  
286 emphasis on speed and strength/power.<sup>15,29,30</sup> The prevalence of RAE is consistent also in *Junior &*  
287 *Senior* where asymmetry in birth distribution was observed in favour of relatively older athletes. A  
288 different trend in birth distribution was observed in *Only Senior* subgroup between males and  
289 females. While the RAE **disappeared** in women, a **significant** small effect of RAE was still observed  
290 in men. **In fact, the men born in the first quartile had twice the chance of being top 50 ranked in**  
291 **senior category compared to those born in the last quartile. These results confirm a previous cross-**  
292 **sectional study in World-class track and field athletes<sup>15</sup> and suggest that male throwers born earlier**  
293 **in the year could more easily reach the top ranking in the late stages of their career (Figure 2, *Only***  
294 ***Senior*). Similarly to other competitive sport contexts,<sup>16</sup> it seems that the RAE produced a selection**  
295 **bias in the early stage of the career that still affected the later phases. Due to the longitudinal**  
296 **analysis of this study, the present finding is of particular importance because it shows how RAE**

297 differently affected the various phases of throwers' career. We expand the understanding of the  
298 RAE in track and field since previous studies on this topic analysed the phenomenon using cross-  
299 sectional designs<sup>15,30,31</sup> or on small sample sizes of WJC athletes.<sup>29,32</sup>

300 Some limitations should be pointed out. Firstly, we tracked the performance trends  
301 analysing the World Athletics database and thus focusing only on international level performers. It  
302 is possible that some throwers started their career before appearing in this database, possibly  
303 competing in lower-level national competitions. Secondly, according to World Athletics (former  
304 IAAF) rules for U18 and U20 competitions we considered December 31<sup>st</sup> as the cut-off date for  
305 calculating the RAE. However, in some countries (e.g., UK), the cut-off date is different. Therefore,  
306 the RAE findings need to be applied only in this particular context.

307

### 308 **Practical applications**

309 In talent identification and developmental perspective, coaches and practitioners should  
310 focus on throwers' long-term potential rather than on short-term. In fact, our study indicates that  
311 focusing on early exceptional achievement does not guarantee later success. Since most early  
312 successful throwers were born in the first part of the calendar year, corrective procedures for bias in  
313 the birthdate distribution are warranted in youth category<sup>33</sup>. Furthermore, the assessment of  
314 maturation status<sup>34</sup> should be considered when analysing youth and junior performers in order to  
315 place performance results into context and avoid early de-selection of late maturers.

316

### 317 **Conclusions**

318 In conclusion, the results of this study indicate that only a small percentage of elite junior  
319 throwers have maintained the same level of performance in adulthood. In other words, the present  
320 study suggests that being an elite young thrower is not a prerequisite of becoming an elite senior  
321 performer. Consequently, success in the junior category does not represent a springboard to success  
322 in adulthood and more attention should be placed on the development and encouragement of late  
323 maturers who may be capable of success at a later stage in life.

324

### 325 **Acknowledgements**

326 The authors acknowledge the contribution of Silvia Nicola and Luciano Passoni for entering  
327 data in the electronic sheets of the database. The authors also acknowledge Paolo Moisè, who  
328 originally inspired us to investigate the athletes' career both prospectively and retrospectively.

## 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. Costa MJ, Marinho DA, Bragada JA, Silva AJ, Barbosa TM. Stability of elite freestyle performance from childhood to adulthood. *J Sports Sci*. 2011;29(11):1183-1189.
3. Boccia G, Moise P, Franceschi A, et al. Career Performance Trajectories in Track and Field Jumping Events from Youth to Senior Success: The Importance of Learning and Development. *PloS one*. 2017;12(1):e0170744.
4. Allen SV, Hopkins WG. Age of Peak Competitive Performance of Elite Athletes: A Systematic Review. *Sports Med*. 2015;45(10):1431-1441.
5. Kearney PE, Hayes PR. Excelling at youth level in competitive track and field athletics is not a prerequisite for later success. *J Sports Sci*. 2018:1-8.
6. 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.
7. Boccia G, Cardinale M, Brustio PR. Performance progression of elite jumpers: early performances do not predict later success. *Scand J Med Sci Sports*. in press.
8. Zelichenok V. The long-term competition activity of the world's top athletes. *New Stud Athl*. 2005;20(2):19-24.
9. 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.
10. 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.
11. Boccia G, Cardinale M, Brustio PR. Sprinting to success at early age does not guarantee success at adult age. *Int J Sports Physiol Perform*. in press.
12. Piacentini MF, Comotto S, Guerriero A, Bonato M, Vernillo G, La Torre A. Does the junior IAAF athletic world championship represent a springboard for the success in the throwing events? A retrospective study. *J Sports Med Phys Fitness*. 2014;54(4):410-416.
13. Scholz W. The throwing events at the IAAF World Junior Championships: A whistle stop on the journey to elite athletics. *New Stud Athl*. 2006;21(2):7.

14. Malina RM, Rogol AD, Cumming SP, Coelho e Silva MJ, Figueiredo AJ. Biological maturation of youth athletes: assessment and implications. *Br J Sports Med*. 2015;49(13):852-859.
15. Brustio PR, Kearney PE, Lupo C, et al. Relative Age Influences Performance of World-Class Track and Field Athletes Even in the Adulthood. *Front Psychol*. 2019;10:1395.
16. Cogley S, Baker J, Wattie N, McKenna J. Annual age-grouping and athlete development: a meta-analytical review of relative age effects in sport. *Sports Med*. 2009;39(3):235-256.
17. 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.
18. Hollings SC, Hopkins WG, Hume PA. Age at Peak Performance of Successful Track & Field Athletes. *International Journal of Sports Science & Coaching*. 2014;9(4):651-661.
19. Boccia G, Cardinale M, Brustio PR. World-class sprinters' career: early success does not guarantee success at adult age. *Int J Sports Physiol Perform*. 2020.
20. Cohen J. *Statistical power analysis for the behavioral sciences*. Academic press; 2013.
21. Brustio PR, Lupo C, Ungureanu AN, Frati R, Rainoldi A, Boccia G. The relative age effect is larger in Italian soccer top-level youth categories and smaller in Serie A. *PloS one*. 2018;13(4):e0196253.
22. Malina RM. Physical growth and biological maturation of young athletes. *Exerc Sport Sci Rev*. 1994;22:389-433.
23. Moesch K, Elbe AM, Hauge ML, Wikman JM. Late specialization: the key to success in centimeters, grams, or seconds (cgs) sports. *Scand J Med Sci Sports*. 2011;21(6):e282-290.
24. Zaremski JL, Zeppieri G, Jr., Tripp BL. Sport Specialization and Overuse Injuries in Adolescent Throwing Athletes: A Narrative Review. *J Athl Train*. 2019;54(10):1030-1039.
25. 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 Coa*. 2014;9(3):457-471.
26. Drew K. *Investigating the Junior-to-Senior Transition in Sport: Interventions to Support the Transitional Process*, Liverpool John Moores University; 2020.
27. Bennie A, O'Connor D. Athletic transition: A qualitative investigation of elite, track and field participation in the years following high school. *Change: Transformations in education*. 2006;9(1):59-68.
28. Huxley DJ, O'Connor D, Bennie A. Olympic and World Championship track and field athletes' experiences during the specialising and investment stages of development: a

- qualitative study with Australian male and female representatives. *Qualitative Research in Sport, Exercise and Health*. 2018;10(2):256-272.
29. Hollings SC, Hume PA, Hopkins WG. Relative-age effect on competition outcomes at the World Youth and World Junior Athletics Championships. *European journal of sport science*. 2014;14(sup1):S456-S461.
30. 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*. 2018:1-7.
31. Brazo-Sayavera J, Martinez-Valencia MA, Muller L, Andronikos G, Martindale RJJ. Identifying talented track and field athletes: The impact of relative age effect on selection to the Spanish National Athletics Federation training camps. *J Sports Sci*. 2017;35(22):2172-2178.
32. 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.
33. Copley S, Abbott S, Eisenhuth J, Salter J, McGregor D, Romann M. Removing relative age effects from youth swimming: The development and testing of corrective adjustment procedures. *J Sci Med Sport*. 2019;22(6):735-740.
34. Martínez Silván D, Johnson A, Tramullas A. Skeletal maturity as injury risk factor in adolescent elite track and field athletes. *Orthopaedic journal of sports medicine*. 2018;6(6\_suppl3):2325967118S2325900038.



**Figure caption**

Figure 1. The transition rates (merged across disciplines) of the top 50 ranked throwers are reported for the prospective and retrospective approach. Panel a) shows how many **throwers** top-50 ranked at 16 yrs old managed to become top 50 ranked in the following stage of their career. Panel b) shows how many top 50 ranked Senior **throwers** were already top 50 ranked at younger ages.

Figure 2. Quartile birth date distribution of **throwers** in *Only Junior*, *Junior & Senior* and *Only Senior* subgroups. Data are merged between the different disciplines.

For Peer Review

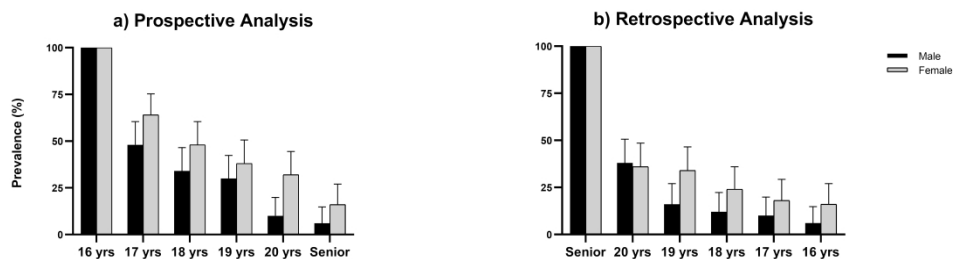


Figure 1. The transition rates (merged across disciplines) of the top 50 ranked throwers are reported for the prospective and retrospective approach. Panel a) shows how many jumpers top-50 ranked at 16 yrs old managed to become top 50 ranked in the following stage of their career. Panel b) shows how many top 50 ranked Senior jumpers were already top 50 ranked at younger ages.

257x79mm (600 x 600 DPI)

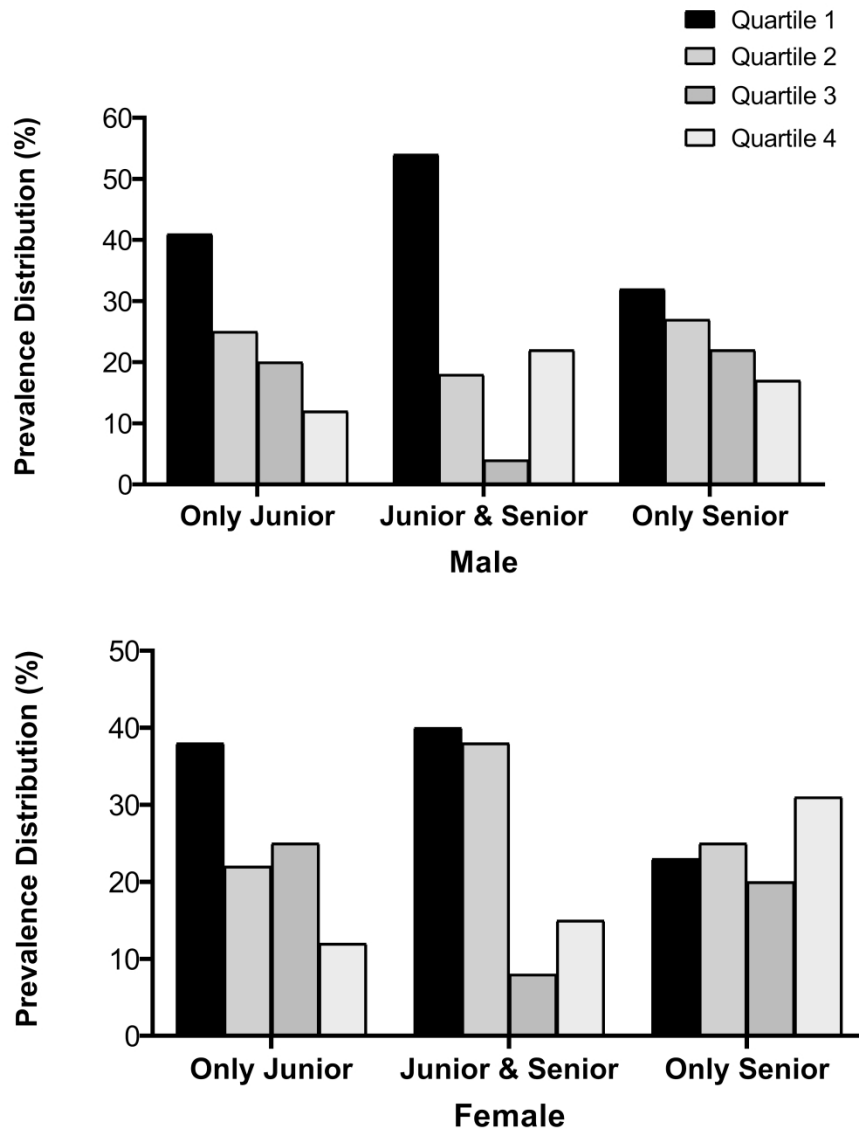


Figure 2. Quartile birth date distribution of swimmers in Only Junior, Junior & Senior and Only Senior subgroups. Data are merged between the different disciplines.

217x261mm (600 x 600 DPI)

Table 1. Descriptive data and ANOVA outcome of the Age of Peak Performance according to discipline and gender												
Age of Peak Performance	Male						Female					
	<i>Only Junior</i>	<i>Junior &amp; Senior</i>	<i>Only Senior</i>	ANOVA outcomes			<i>Only Junior</i>	<i>Junior &amp; Senior</i>	<i>Only Senior</i>	ANOVA outcomes		
	M (90% CI)	M (90% CI)	M (90% CI)	Subgroup	Discipline	Subgroup x Discipline	M (90% CI)	M (90% CI)	M (90% CI)	Subgroup	Discipline	Subgroup x Discipline
<b>Shot Put</b>	22.4 (22.0, 22.9)	25.5 (22.3, 28.7)	26.8 (26.0, 27.6) <sup>a</sup>	F=222.42 P< 0.001	F=6.05 P< 0.001	F=2.72 P=0.013	20.7 (20.1, 21.3)	26.3 (24.4, 28.2) <sup>a</sup>	26.3 (25.4, 27.3) <sup>a</sup>	F=191.43 p<0.001	F=0.04 P=0.993	F=1.42 P=0.206
<b>Discus Throw</b>	22.0 (21.5, 22.5)	26.1 (24.8, 27.5) <sup>a</sup>	28.1 (27.5, 29.2) <sup>a</sup>				20.8 (20.2, 21.4)	24.6 (22.4, 26.8) <sup>a</sup>	28.2 (27.0, 29.4) <sup>a</sup>			
<b>Hammer Throw</b>	21.5 (21.2, 21.7)	27.0 (24.0, 30.0) <sup>a</sup>	27.8 (26.9, 28.8) <sup>a</sup>				21.4 (20.7, 22.1)	24.7 (23.5, 25.9) <sup>a</sup>	27.4 (26.6, 28.2) <sup>a</sup>			
<b>Javelin Throw</b>	21.0 (20.5, 21.5)	22.25 (20.8, 23.7)	27.0 (26.0, 28.0) <sup>a,b</sup>				20.5 (19.9, 21.1)	26.0 (23.6, 28.4) <sup>a</sup>	27.4 (26.5, 28.4) <sup>a</sup>			
<b>All disciplines</b>	21.7 (21.5, 22.0)	24.9 (23.8, 26.0) <sup>a</sup>	27.5 (27.0, 27.9) <sup>a</sup>				20.8 (20.5, 21.1)	25.3 (24.5, 26.1) <sup>a</sup>	27.3 (26.8, 27.8) <sup>a</sup>			

Note: <sup>a</sup>, significant difference from Only Junior subgroup; <sup>b</sup>, significant difference from Junior & Senior subgroup.

Supplementary 1. Quartile birth date distribution of swimmers in *Only Junior*, *Junior & Senior* and *Only Senior* subgroups and  $\chi^2$  and OR analysis.

	Male							Female						
	Q1(%)	Q2(%)	Q3(%)	Q4(%)	Chi Square outcomes	OR Q1/Q4	OR (Q1+Q2)/(Q3+Q4)	Q1(%)	Q2(%)	Q3(%)	Q4(%)	Chi Square outcomes	OR Q1/Q4	OR (Q1+Q2)/(Q3+Q4)
<i>Only Junior</i>	41.6	25.3	20.3	12.8	$\chi^2 = 50.50$ P < 0.001 V = 0.30	3.3 (2.0, 5.4)	3.0 (2.1, 4.4)	38.8	22.8	25.7	12.7	$\chi^2 = 33.20$ P < 0.001 V = 0.26	3.1 (1.8, 5.3)	1.6 (1.1, 2.3)
<i>Junior &amp; Senior</i>	54.5	18.2	4.5	22.7	$\chi^2 = 11.00$ P = 0.01 V = 0.49	2.4 (0.5, 11.2)	2.7 (0.8, 8.36)	40	38	8	15	$\chi^2 = 12.60$ P = 0.007 V = 0.40	3.0 (0.7, 9.6)	3.4 (1.3, 8.8)
<i>Only Senior</i>	32.4	27.4	22.3	17.9	$\chi^2 = 8.42$ P = 0.038 V = 0.15	1.8 (1.0, 3.3)	1.5 (1.0, 2.2)	23.1	25	20	31.9	$\chi^2 = 4.85$ P = 0.183 V = 0.12	0.7 (0.4, 1.0)	0.9 (0.6, 1.4)

Notes: Q1-Q4%, quartile percentage;  $\chi^2$ , Chi-square value; P, p-value; V, Cramer's V; OR, odds ratio and 95% confidence intervals (95% CI); Q1/Q4, first vs. last quartile; (Q1+Q2)/(Q3+Q4), first and second Vs third and fourth quartile.