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(Article begins on next page)

1 **Corrective procedures remove relative age effect from world-class junior sprinters**

3 **Abstract**

4 This retrospective study aimed to investigate whether corrective adjustment procedures can
5 remove the relative age effect (RAE) from track and field world-class junior sprinters. A total
6 of 2918 male and 3029 female athletes competing in sprint races (100m, 200m, and 400m) and
7 ranked in the first 100 positions of the World Athletics lists between 2000 and 2018 were
8 considered. Longitudinal quadratic trendline equations across ages 16–25 yrs were calculated
9 considering athletes' exact age and respective performance for each discipline and gender.
10 Corrective adjustment calculations from estimated longitudinal quadratic equations were
11 applied at 16yrs. Considering the uncorrected and corrected performance, Chi-square and Odds
12 Ratio were calculated to investigate RAE in top-level athletes (i.e., first top50 and top100
13 ranked of the whole sample). When analyzing the uncorrected performance moderate to large
14 RAE was observed in Top50 and Top100 (Crammer's V effect size ranged=0.21-0.38). When
15 re-examining the data using the corrective adjustment calculations, the RAE disappeared in all
16 sprint and both genders. Corrective adjustment procedures can remove RAE in world-class
17 sprinters at the beginning of their career. Applying simple equations based on exact age might
18 improve the accuracy of performance evaluation and talent identification in international track
19 and field sprint competitions.

20
21 **Keywords** RAE; athlete development; re-balancing RAE; track and field; youth competition;
22 talent identification.

23 **Introduction**

24 Sports federations usually group young athletes according to their chronological age with the
25 purpose to arrange sports events. This is meant to reduce developmental differences and provide
26 equal opportunities and experiences during competitions (Cobley, Baker, Wattie, & McKenna,
27 2009; Romann & Cobley, 2015; Wattie, Cobley, & Baker, 2008). Nevertheless, this choice,
28 which is based on annual or biannual age-grouping cohorts, potentially leads to a chronological
29 age difference of up to 12 or 24 months among athletes in the same age-group. This potentially
30 increases the differences in terms of biological age across young athletes (Romann & Cobley,
31 2015), accentuating physical, cognitive and psychological differences (Cobley et al., 2009;
32 Musch & Grondin, 2001).

33 One of the most common problems within youth sports is the phenomenon of the relative
34 age effect (RAE). The RAE reflects an asymmetry in birth distribution due to an over- and
35 under-representation of athletes born close (relative older) and far away (relative younger) to
36 the date of selection. In other words, the RAE reflects the possible advantages/disadvantages in
37 early sport success and the process of talent identification (Cobley et al., 2018; Till & Baker,
38 2020; Wattie, Schorer, & Baker, 2015). The RAE has been observed in several youth sports
39 and is particularly pronounced in sports requiring high physical demands (Cobley et al., 2019),
40 including track and field disciplines (Brustio et al., 2019; Kearney, Hayes, & Nevill, 2018;
41 Romann & Cobley, 2015) and swimming (Abbott et al., 2020; Cobley et al., 2018; Cobley et
42 al., 2019; Costa, Marques, Louro, Ferreira, & Marinho, 2013). Of note, the RAE in females is
43 lower and occurs earlier if compared to males (Smith, Weir, Till, Romann, & Cobley, 2018).
44 According to the *maturation-selection hypothesis* (Cobley et al., 2009), relatively older athletes
45 may have sporting performance advantages due to the favorable anthropometric (e.g., body
46 weight) and physical characteristics (e.g., muscular strength and power, endurance and speed)
47 in comparison with relatively younger peers (Abbott et al., 2020). This advantage may offer a

48 higher likelihood of being selected in the first stage of within a sport (Brustio et al., 2019;
49 Brustio et al., 2018; Lupo et al., 2019). On the other hand, from a long-term point of view, this
50 advantage may be transient (Cobley et al., 2018) or partially disappear during adulthood
51 (Brustio et al., 2019; Lupo et al., 2019) underlining how the relative younger athletes might
52 have the greatest potentiality for later success (McCarthy, Collins, & Court, 2016; Till et al.,
53 2016).

54 To solve the problem of the RAE, many different solutions have been proposed and
55 studied. These structural solutions, adopting different methodological approaches, highlighted
56 that the disadvantage in terms of biological age can be partially resolved focusing on
57 organizational (e.g., rotating cut-off dates or classifying athletes by maturation status) or
58 practical strategies (e.g., shirt numbering based on month age or correction factor to
59 performance results) (Cobley et al., 2018; Cobley et al., 2019; Mann & van Ginneken, 2017;
60 Romann & Cobley, 2015).

61 The solution of individual's performance correction is a recent and promising method
62 adopted in sports where performance is determined in centimeters, grams, or seconds (Cobley,
63 Abbott, Moulds, Hogan, & Romann, 2020). Previous studies showed that using performance
64 correction may reduce the disadvantages of relatively younger sprinters and swimmers (Abbott
65 et al., 2020; Cobley et al., 2019; Romann, Rossler, Javet, & Faude, 2018). In the context of
66 national Swiss 60m sprinter event, Roman et al. (2015) identified a performance difference
67 about 10% to 5% in annual age-grouping cohorts aged 8-15 yrs and an over-representation of
68 athletes born close to the date of selection for the top tiers. Applying performance correction,
69 based on the expected performance differences from being one day to one year older in each
70 annual age group, the authors found that the RAE became completely absent in top 10% athletes
71 and was removed or at least reduced in top 50% and top 25% athletes. Similar results were
72 obtained in Australian male 100 m Freestyle (Cobley et al., 2019) and female 100 and 200 m

73 breaststroke swimmers (Abbott et al., 2020) where generally a moderate to large RAE was
74 observed in top 25%, and top 10% swimmers. Nevertheless, after a performance correction by
75 using quadratic trendline equations based on longitudinal data, distribution ratios between the
76 relatively older and younger quartiles disappeared in most of the considered age-groups.

77 The above-mentioned findings clearly emphasize the utility of corrective adjustments
78 for obtaining a symmetry quartile distribution and an accurate performance evaluation,
79 especially in top-level young athletes. Consequently, this would help to understand the real
80 value of young athletes better (Abbott et al., 2020; Cobley et al., 2019). Nevertheless, no study
81 investigated this approach at the international level where the RAE is markedly present (Brustio
82 et al., 2019). Thus, to fill this gap we aimed to examine whether corrective adjustment
83 procedures may remove or at least reduce RAE in world-class athletes track and field sprinters
84 in the early steps of their international career (i.e., at 16 yrs old).

85 **Material and Methods**

86 This study was a further analysis of the data collected for a previously published
87 (blinded for review). Here we maintained the same database but rethinking the analysis with
88 different research questions. Male and female world-class sprinters competing in 100m, 200m,
89 and 400m disciplines ranked in the top 100 official lists of the World Athletics (from 2000 to
90 2018) and/or who participated in the World U18 and U20 Championships (from 1998 to 2015)
91 were considered for the study. For each sprinter listed in the database, the annual best
92 performance, the date of annual best performance and the birthdate were downloaded and
93 included in an anonymous dataset. Athletes were included in the databases (i.e., primary
94 dataset) only if they presented a minimum of three personal annual best performances, also non-
95 consecutively. Due to the longitudinal nature of the database, all the included performances
96 were recorded during international events from 1988 to 2018. All the data were available in the
97 public database of World Athletics (<https://www.worldathletics.org/>) and thus no informed

98 consent was obtained. This study was approved by the local ethics committee of the blind for
99 review and conducted according to the declaration of Helsinki.

100 **Statistical Analysis**

101 To calculate performance correction based on longitudinal data, a subset of data was
102 initially extracted from the primary dataset. Specifically, athletes were included in this
103 secondary database only if they presented a minimum of 5 personal annual best performances,
104 also non-consecutively per year ranging from 16 to 24 years. These boundaries were chosen to
105 establish accurate estimates of performance changes up to the expected personal best
106 performance (Boccia, Cardinale, & Brustio, 2020b). Upper extreme outliers (Z-score
107 values > 2) of performance times, i.e., those with poorest performances, were identified and
108 removed. The exact age (based on the year and day of athletes' birthdate) at which athletes
109 achieved the performances in the database, was calculated. Subsequently, considering
110 performance time as a dependent variable, separate mixed models for each discipline and
111 gender were used to calculate the best fit model trendline equations (i.e., linear vs quadratic
112 trendline). The exact age of the best performance was considered in the model as a fixed factor
113 while subjects as a random factor. The model fit was assessed with the *likelihood ratio test*.

114 Using 16 yrs as reference age, the mean expected performance differences per decimal
115 age were calculated considering the whole sample (i.e., primary dataset). Thus, all
116 performances (from this moment called *uncorrected performances*) were adjusted (thus
117 generating the *corrected performance*) using the mean expected performance differences per
118 day. Using 16 yrs as reference age, it is possible that athletes performed his/her annual best
119 performance when he/she was from ~15.01 (e.g., athletes born on 31st December 2000
120 performing the annual best performance on the 1st January 2016) to ~16.99 yrs old (e.g., athletes
121 born on 1st January 2000 and performing the annual best performance on the 31st December
122 2016). Thus, for an athlete that was 16.0 yrs old when recorded his/her performance the

123 corrected performance corresponds to the uncorrected performance while for an athlete that was
124 15.01 or 16.99 yrs when recorded his/her performance the corrected performance corresponds
125 to the uncorrected performance less/plus the expected performance differences per year. Then,
126 considering the uncorrected and corrected performances, an all-time athletes' ranking of 16 yrs
127 old sprinters was created and two subgroups of athletes were defined: the first 100 (Top100)
128 and 50 (Top50) athletes' subgroups.

129 For each sprinter, the quartile of the birthdate was calculated. The following criteria
130 were used: sprinters born between January and March in the 1st quartile (Q1), between April
131 and June in the 2nd quartile (Q2), between July and September in the 3rd quartile (Q3) and
132 between October and December in the 4th quartile (Q4) (Brustio et al., 2019). The differences
133 between observed and expected quartile distributions in the Top100 and Top50 sprinters, both
134 using the uncorrected and corrected performances, were investigated by the means of Chi-
135 square (χ^2). The magnitudes of the differences were calculated as Crammer's V effect size.
136 Threshold values for effect size statistics were: ≤ 0.17 , small; > 0.18 , moderate $V \geq 0.29$ large
137 (Cohen, 2013). For the first and the last quartile (i.e., Q1-Q4) and the first and the second
138 semester of the year (i.e., Q12-Q34), odds ratios (ORs) and 95% confidence intervals [95% CIs]
139 were calculated. A uniform distribution (i.e., 25% for each quartile) was adopted as expected
140 distribution (Brustio et al., 2019; Brustio et al., 2018). All the above analysis was performed
141 separately for each discipline and gender and by custom-written software in MATLAB R2020b
142 (Mathworks, Natick, MA, USA).

143 **Results**

144 A total of 1462 (female: 51.3%; total performances n=9506), 1299 (female: 56.1%; total
145 performances n=8227) and 1316 (female: 46.8%; total performances n=8287) sprinters of
146 100m, 200m and 400m was analyzed to create longitudinal trendline equation. For all
147 disciplines and gender longitudinal quadratic trendline equations (i.e., $y=ax^2+bx+c$) provided

148 evidence of a significant improvement of model fit if compared to linear model ($\chi^2 < 0.05$) and
149 therefore considered for the corrective adjustment calculations. The variance explained
150 (adjusted R^2) by the fitted models ranged between 0.572 and 0.614. From longitudinal quadratic
151 trendline equations, the expected performances were estimated to reduce in 16yrs sprinters aged
152 **from 15.01 to 16.99 of** approximately: 10.89 to 10.77s (male sprinters) and 12.06 to 11.95s
153 (female sprinters) for the 100m discipline; 21.97 to 21.72s (male sprinters) and 24.69 to 24.45s
154 (female sprinters) for the 200m discipline; 48.87 to 48.28s (male sprinters) and 55.71 to 55.22s
155 (female sprinters) for the 400m discipline. Fig. 1 shows a representative example of the
156 quadratic trendline equation between exact age (i.e., year and day) and uncorrected
157 performances in 100 m male sprinters.

158 <Insert Fig.1 about here>

159 The chi-square statistics, effect size estimation, ORs, and 95% CIs in the Top100 and
160 Top50 sprinters considering the uncorrected and corrected performances for each discipline are
161 presented in Table 1.

162 <Insert Table 1 about here>

163 When analyzing the uncorrected performances, moderate to large effect sizes in male
164 sprinters were observed in Top100 (Crammer's V effect size ranged = 0.22–0.32). Differently,
165 in Top50 only a large effect was observed in 400 m sprinters (Crammer's V effect size = 0.38).
166 In general, female sprinters showed lower trends. Predominantly, moderate effect sizes were
167 identified in Top100 in 100m (Crammer's V effect size = 0.21) and 400 m sprinters (Crammer's
168 V effect size = 0.22) while in the Top50 moderate to large effect size was observed in all
169 disciplines (Crammer's V effect size ranged = 0.28–0.32).

170 Except for 100m, the ORs and 95% CIs of Q1 versus Q4 (see Table 1 Q1-Q4) and
171 Q1+Q2 versus Q3+Q4 (see Table 1 Q12-Q34) showed that male sprinters born in the first
172 quartile (or in the first semester) of the year were, on the average, 3.34 (or 1.87) more likely to

173 be included in Top100 category, respectively. In Top50 category the same pattern was evident
174 only in 400m (OR for Q1-Q4 = 4.00; OR for Q12-Q34 = 2.33). Nevertheless, in 100 and 200m,
175 a trend suggested that the likelihood of being included in Top50 category is higher for an athlete
176 born in the first quartile or in the first semester rather than the counterpart. Differently, only the
177 400m female sprinters born in the first quartile of the year were 2.46 and 3.33 more likely to be
178 included in the Top100 and Top50 category, respectively. Nevertheless, in the other sprinter
179 disciplines, a trend suggested that the likelihood of being included in 16 yrs list was higher for
180 an athlete born in the first quartile or the first semester rather than the counterpart.

181 Performance adjustments were effective in removing (at least in part) the RAE (see right
182 part of the table 1, corrected performances). Indeed, a more even quartile distribution was
183 observed when re-examining the RAE using the corrected performances. Predominantly the
184 RAE disappears both in Top100 and Top50 category. This trend was evident in both genders.
185 The only exception was in 200 m male ($\chi^2=8.240$; moderate effect size) and female sprinters
186 ($\chi^2=8.480$; moderate effect size) for the Top100 category ($\chi^2=8.240$; moderate effect size).
187 Nevertheless, when examining the ORs and 95% CIs of Q1 versus Q4 (see table Q1-Q4) and
188 Q12 versus Q34 (see table Q12-Q34) there were no significant results (all $p > 0.05$) both for
189 male and female sprinters for any discipline and top-tiers.

190 **Discussions**

191 This study examined the presence of RAE in word-class sprinters in the early stages of
192 their career (i.e., 16 yrs old) and investigated whether corrective adjustment procedures may
193 remove or at least reduce the RAE. Since the RAE is known to be affected by the level of
194 competitiveness (Romann & Cobley, 2015), we examined the RAE and RAE correction
195 specifically on the top-tiers, i.e. the top 100 and top 50 athletes. The results showed an
196 asymmetry in birthdate distribution in top 100 and top 50 sprinter athletes at 16 years old and
197 that the RAE increases as competitiveness level increases. Nevertheless, using the corrective

198 adjustment procedures, the RAE was effectively removed, underlining the potential usefulness
199 of this method for improving the accuracy of performance evaluation and talent selection in a
200 youth context.

201 When examining the Top100 athletes of uncorrected performances, the RAE was
202 apparent in both genders. Male sprinters showing a general higher magnitude effect size.
203 However, when the selection criteria increased (i.e., from the Top100 to the Top50 category)
204 the RAE trends were less evident for male sprinters. According to the *Underdog Hypothesis*
205 (see Gibbs, Jarvis, & Dufur, 2012; Smith & Weir, 2020) these results may suggest the late birth
206 benefits to career benchmarks. On the other hand, it is possible that the relatively small sample
207 size in Top50 category may affect the results. Indeed, the trend in distribution was in favor of
208 the athletes born in the first part of the year. These are just speculations that remain to be
209 confirmed by future studies. The ORs were generally lower if compared to national sprinters,
210 confirming that the competitiveness level may affect the magnitude of the RAE (Kearney et al.,
211 2018; Romann et al., 2018). For example, in top 10% Swiss 60m sprinters (aged: 8-15 yrs old)
212 Roman et al. (2015) found large RAE (OR=3.34 [2.58–4.32]). Nevertheless, the considered
213 different age group and discipline make difficult the comparison. Of note, the data confirmed
214 that the RAE in females was generally lower than in male sprinters (Brustio et al., 2019) and
215 weaker in 100 and 200 m in comparison with 400m male sprinters (see Crammer's V effect size
216 and OR) confirming that the RAE is likely to be larger in events with a greater emphasis on
217 metabolic requirements (Hollings, Hume, & Hopkins, 2014; Kearney et al., 2018). Together,
218 the results suggested that according to the maturation-selection hypothesis (Cobley et al., 2009)
219 it is possible to suppose that relatively older athletes may have (Boccia, Cardinale, & Brustio,
220 2020a; Boccia, Cardinale, & Brustio, 2021) more favorable anthropometric and physical
221 characteristics to be considered top-level athletes in youth International athletic competitions.
222 On the other hand, relatively older athletes may have more chances to be included in youth

223 talented programs and decrease the constraints for the sports activity (Cobley et al., 2018; Till
224 & Baker, 2020; Wattie et al., 2015) even if, from a long-term point of view, excelling during
225 youth is not a strong predictor of success at senior level (Boccia et al., 2019; Boccia et al.,
226 2020b; Boccia et al., 2021; Boccia et al., 2017; Kearney & Hayes, 2018).

227 To provide RAE corrections we analyzed the performance progression of world-class
228 sprinters across ages 16–25 yrs and estimated the performance difference based on decimal yrs
229 using longitudinal quadratic trendline equations. To our knowledge, this study is the first that
230 provides information on corrective adjustment procedures in world-class junior sprinters. A
231 similar approach was only previously provided in national track and field youth sprinters
232 (ranged aged: 8-15 yrs) (Romann & Cobley, 2015) or swimmers (ranged aged: 10-18 yrs)
233 (Abbott et al., 2020; Cobley et al., 2019). With this approach, we were able to estimate
234 developmental performance changes (Abbott et al., 2020; Cobley et al., 2019; Cobley et al.,
235 2020). Results suggested that the percentage differences in performance at 16yrs old ranged
236 from 1.10% to 1.23% for male and from 0.88% to 0.95% for female sprinters. These differences
237 were lower if compared to Roman et al. (2015) (mean year difference about 7%), but in line
238 with annual percentual improvement observed in world-class sprinters (Boccia et al., 2020b).
239 Our higher competition level (i.e., world-class athletes) and age (i.e., 16 yrs), and the difference
240 distance investigated may explain the difference. Nevertheless, despite the small percentage
241 differences observed, different trends in quartile distribution were observed when considering
242 corrected performances. Using corrective adjustment procedures based on world-class sprinters
243 across ages 16–25 yrs, the asymmetry in quartile distribution disappeared (all p values < 0.05),
244 irrespective of gender and tiers considered. A more even birthdate distribution suggests the
245 removal of RAE in these groups of athletes. Correspondingly, the ORs analyses between the
246 first versus the last quartile and between the first and second semester suggested a more equal
247 birthdate distribution with respect to uncorrected performances. Only Top100 200m male and

248 female sprinters still presented a moderate RAE after performance adjustments. Nevertheless,
249 it necessary to note that after performance adjustments a more equal distribution was observed
250 if compared to the uncorrected performance time.

251 Some limitation should be pointed out. We calculated the RAE at 16yrs of age because
252 the World Athletics database is consistently updated from 16 yrs of age on. It is well known
253 that RAE is larger at lower ages, particularly before 16 yrs of age. Consequently, future studies
254 investigating younger ages might find an even larger effect of corrective procedures than we
255 did. The present analysis did not evaluate for other factors, such as training history, sport
256 specialization, and maturation, that may influence the athletes' performance evolution progress
257 (Cobley et al., 2020). Then it should be pointed out that the corrective adjustment procedure is
258 only one of the possible strategies to remove RAE (Cobley et al., 2020).

259 Together, these results provide further evidence for the usefulness of this method to
260 remove RAE-related inequalities in sports participation and performance. Given that RAE was
261 observed in 16 yrs top tiers when using unadjusted performances, results suggested a practical
262 strategy to solve the problem with RAE. The corrective adjustment procedures may
263 successfully re-balance age distribution also in world-class junior sprinters at international level
264 as previously observed in national sprinters (Romann & Cobley, 2015) and swimmers (Abbott
265 et al., 2020; Cobley et al., 2019). Practically, the application of this procedure may have
266 implications during athletes' developmental and talent identification process. The correction of
267 the performance according to birthdate may remove inequality in physical characteristics and
268 provide a more plausible understanding of the real athletes' potential, consequently improving
269 the evaluation procedures. Sports federations, coaches and practitioners should consider this
270 approach to correct performances and consequently increase the equality in the access to talent
271 identification and race participation.

272 To summarize, the present results underline the usefulness of corrective adjustment
273 procedures to remove RAE in top-level sprinters competing in international level competitions.
274 Corrective adjustment procedures may minimize the RAE and provide practical strategies to
275 solve the asymmetry in birthdate distribution in the centimeters, grams, or seconds sports
276 context and create solution to minimize disadvantages in terms of biological age in the early
277 steps of an international career. This data driven strategy may improve the accuracy of
278 performance evaluation and long-term talent identification.

279

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282

283 **Declaration of interest statement**

284 The authors report no conflict of interest.

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379

380 **Figure Legends**

381 **Figure 1** Representative example of quadratic equation model considering chronological age
382 and performance times in 100 m male sprinters.