Don't Throw the Baby Out With the Bathwater: Talent in Swimming Sprinting Events Might Be Hidden at Early Age

(Article begins on next page)

12 May 2024

Don't throw the baby out with the bathwater: talent in swimming sprinting events might be hidden at early age

SCHOLARONE™
Manuscripts

Abstract

1   **Purpose**

2   This study aimed to describe the career performance progression of elite early- and later-success

3   international swimmers competing in sprint events (i.e., 50m and 100m).

4   **Methods**

5   The career performance trajectories of 6,003 swimmers (50.9% females; 58,760 unique records)

6   competing in the four swimming strokes were evaluated. Early- and later-success swimmers were

7   identified. We identified the top 50 all-time swimmers competing in junior career who did not reach

8   the top 50 rankings in the senior career and vice versa, and successful swimmers both in junior and

9   senior career.

10   **Results**

11   Early-success swimmers mainly achieved their peak performance before the age of 20 yrs and ~5-6

12   yrs before successful senior swimmers or ~3-4 yrs before successful swimmers both in junior and

13   senior careers. The annual performance improvements of later-success swimmers were higher (about

14   1-2%) until the age of 20-24 yrs while early-success swimmers showed a performance stagnation at

15   about 16-18 yrs in females and 19-20 yrs in males.

16   **Conclusions**

17   Early-success swimmers who achieved peak performance at a young age were unable to maintain the

18   same level of competitiveness in adulthood since they experienced a plateau in performance from the

19   age of 20 yrs. The procedure of considering early performances solely for talent identification (and

20   not the current rate of progression) might represent a limited approach for selecting future elite

21   swimmers. Our results indicate that performance progression in the transition towards adult career

22   might be a strong indicator of performance potential.

Keywords: Talent identification; talent development; rate of performance improvement; career trajectories**.**

Introduction

Within sports where performance is measured in centimetres, grams, or seconds (CGS), information related to the performance progression are of interest to policy-makers, sporting organizations, and coaches alike for talent selection and development purposes. In this regard, the longitudinal analysis of performances throughout an athlete's career from junior to senior may provide helpful information to define realistic goals and identify adequate performance expectations[1-3] In swimming, different studies conducted on national and international level provided benchmarks for career trajectories.[1,2,4-10] Examining the career progression between the 1980s and 2000s of elite international swimmers (i.e., top best swimmers in history or the top world-ranked performers), some authors found that the top swimmers reached their personal best performance between 18-23 yrs of age.[8,9] Also, Allen et al.[1] reported that males reached their peak performance later than females (~ 24 Vs. 22 yrs).

Additional information on career progression, analyzing the rate of performance development of successful swimmers, was also provided by previous studies in limited cohorts. Retrospectively evaluating the career progression (i.e., from junior to senior career) of the top-elite international swimmers of 100 m freestyle, Post et al.[7] found that these athletes followed a unique pathway in comparison with elite and sub-elite counterparts (i.e., better seasonal performances from 12 yrs onwards). Similarly, the top 150 ranked swimmers in the freestyle events improved their performances by 3 – 4% over the five seasons preceding the Olympic Games.[2] Finalist and semi-finalist Olympic swimmers improved their performance of ~ 9% over the 8 years preceding the peak performance.[1] Similar data were prospectively confirmed by studying the career patterns of sub-elite swimmers competing in school swimming championships that showed performance improvements between age 12 yrs and peak age from ~22 to 26% in males and from ~8 to 10% in females.[5,6] A comprehensive study on Portuguese male swimmers reported that the relationship between performances at age 12 and 18 yrs was

48 generally low, and the ability to predict adult performance was reasonably robust only at age of

49 16.[4] These data were also confirmed at the international level.[11] Most studies have focused on

50 few athletes participating in the Olympic Games. Therefore, there is not much clarity on the

51 career progression details of elite performers. and the analysis of athletes who achieve success

52 during their youth but not during adulthood and vice versa may be informative to provide

53 benchmarking data of typical developments. Further, it may help identify gender differences

54 and/or event-specific patterns. Nowadays, it is relatively well known that early success is not a

55 pre-requisite for achieving success during adulthood in a few sports.[11-14] In fact, it has been

56 reported that the early-success track and field athletes who were able to sustain the same level

57 during adulthood reach their peak performance earlier than the rest,[13] and experience a plateau

58 in performance around 19-20 years of age.[12,14] The average rate of performance improvement

59 from junior to senior was lower in this group than athletes that reached their success only at the

60 adult level.[11] Consequently, the junior-to-senior transition rate, usually identified as the chance

61 for an early-success athlete to become an elite senior athlete, has been low in different CGS

62 sports. We recently reported that the overall probability of becoming a senior elite swimmer

63 competing in sprint events (i.e., 50 and 100m events in all swimming strokes) was ~21% in

64 males and ~25% in females, confirming the low rate of the transition to elite junior-to-senior

65 career.[11]

66   Nevertheless, while different studies provide retrospective information about sprinter

67 swimmers' career pathways[6,9] achieving success during their senior career at the international

68 level, little is known about the rate of progression and how those differ between gender and

69 events using a prospective and retrospective longitudinal approach. A prospective and

70 retrospective longitudinal approach that tracks the performances across the whole swimmers'

71 career allows would allow to investigate better the career characteristics of early- and late-

72 successful swimmers.[11-15] The prospective analysis of competition data helps identify elite

73   young swimmers and allows tracking their performance across competitions. In contrast, a

74   retrospective approach would enable the identification of elite senior athletes and trace back

75   their career up to the beginning of their international competitions. The combination of the two

76   analytical perspectives has already been implemented in other sports.[13] Considering the limited

77   information on career progressions and the differences in elite vs. non-elite performers, we

78   analysed the career performances of a large sample of international swimmers competing in the

79   four swimming strokes of long course sprint events (i.e., 50m and 100m). The present study

80   aimed to describe the career progression in terms of age of performance, peak performance, and

81   annual performance improvement (i.e., annual percentage performance change) in elite

82   international swimmers reaching success early or late. Considering previous studies conducted

83   on track and field athletes,[12-14] we expected a different pattern in career progression between

84   early- and later-successful swimmers.

Materials and Methods

86   This study further analyzed the data collected for one previously published.[11] The source

87   of data collection was the public database Swimrankings (https://www.swimrankings.net/)

88   supplied by the European Swimming Federation (LEN- Ligue Européenne de Natation). This

89   database provides the official annual ranking of European swimmers considering junior

90   (athletes aged up to 17 or 18, in females and males respectively) and senior categories (athletes

91   aged upper 17 or 18 according to gender) and the career performance times of each swimmer.

92   In the initial step, the names of swimmers competing in long course sprint events (i.e.,

93   50m – 100m) of freestyle, backstroke, breaststroke, and butterfly ranked in the top 50 official

94   lists in junior or senior categories between the competition's years 2004-2019 were downloaded.

95   Data were screened for removing duplicate participants' names (i.e., swimmers in the Top 50

96   in one more year). In the second step, seasonal best performance times were retrospectively

97   extracted from these swimmers. To create each swimmer's career path, the seasonal best

98　performance times were collected from the age of 10 until career termination or on December

99　31, 2019, if the individual was still competing.

100　　　　Swimmers who registered their best personal performance in the last 3 yrs of the

101　calendar age (i.e., from 2017 to 2019) were excluded to avoid including swimmers who have

102　not fully expressed their potential due to their young age.[11] Moreover, a swimmer was only

103　included in the final database if he/she registered at least five seasonal best performance times

104　during his/her career, not necessarily consecutive. The specific information about the sample

105　selection is reported in Supplementary File 1. Since the data were available on publicly

106　available resources, no informed consent was obtained. The local ethics committee approved

107　the study at the University of Torino.

108　**Statistical analysis**

109　　　　Separate analyses were performed for each event and gender. The seasonal best

110　performance times were recorded across an extensive range of years. Thus, the dataset

111　contained swimmer generations competing with different FINA rules (e.g., full-body

112　polyurethane swimsuits). Therefore, we normalized all seasonal best performance times

113　considering the best time in the relative year using the following formula:[7,11,14,16]

114　　$\text{Normalized Seasonal Best Performance Times} = \left(\dfrac{\text{seasonal best performance times}}{\text{best times in the relative year}}\right) \times 100$

115　　　　A Normalized Seasonal Best Performance Times value of 100 corresponds to the best

116　performance of that relative year. Subsequently, swimmers were ranked according to their

117　Normalized Seasonal Best Performance Times in an all-time ranking according to their age

118　(i.e., junior, and senior category). According to the FINA World Junior Swimming

119　Championships rules, the junior category included female swimmers between ages 14 and 17

120　and male swimmers between ages 15 and 18. Consequently, the senior category included female

121　swimmers over age 17 and male swimmers over 18.

122   In the first data analysis step, individual trends were generated from all swimmers by

123   fitting a quadratic curve.[12,14,17] Successively, the following parameters were calculated:

124   a) age of peak performance;

125   b) peak performance;

126   c) rate of performance improvement from the last years of junior career 17 (or 18 if

127   male) to the senior peak performance;

128   d) annual best performances from 14 (or 15 if male) to 30 yrs of age;

129   e) annual performance improvement (percentage) from 14 (or 145 if male) to 30 yrs of

130   age.

131   Early- and later-success swimmers were identified using an all-time ranking in the

132   second data analysis step. To identify elite early- and later-success swimmers, we considered

133   the first 50 swimmers (now called Top 50 – unique individuals) that ranked elite status during

134   junior and/or senior categories. The junior-to-senior transition rate remained similar using the

135   same approach but selected swimmers from the top 100 to the top 10 ranked athletes. The

136   proportion did not change,[11] so for conciseness, we decided to discuss and present only the

137   results of the Top 50. Subsequently, three subgroups (separately for male and female athletes)

138   of swimmers were defined:

139   (1) *Only Junior:* swimmers that reached the top 50 rankings during their junior career

140   (from 14 and 17 yrs or 15 to 18 yrs in females and males, respectively) but that did

141   not reach the top 50 rankings in the senior career;

142   (2) *Junior and Senior*: swimmers that reached the top 50 rankings during both junior

143   and senior careers;

144   (3) *Only Senior*: swimmers that reached the top 50 rankings during their senior category

145   (over 17 yrs or 18 yrs in females and males, respectively) but did not reach the top

146   50 rankings in the junior career.

147   Based on this selection criteria, all swimmers that did not reach the annual top 50 rankings

148   during junior and/or the top 50 rankings during senior careers were excluded from further

149   analysis.

150   A series of one-way analyses of variance (ANOVA) was carried out to compare the

151   career features among the three subgroups (i.e., age of peak performance, the peak performance,

152   and the rate of performance improvement). Welch's F test was applied when homogeneity of

153   variances was violated (i.e., Levene's Test of Homogeneity of Variance, i.e., P< 0.05). When

154   the main effect in group comparison was relevant, post-hoc pairwise comparisons were

155   performed.

156   Separately for gender and events, linear mixed models were used to investigate the

157   difference in performance progression between *Only Junior, Junior and Senior*, and *Only*

158   *Senior* subgroups. Specifically, the annual best performances and the annual performance

159   improvement from the age of 14 (or age of 15 if male) to age of 30 yrs were separately included

160   in the model as dependent variables, while swimmer subgroups and age were considered fixed

161   effects. Subjects were included as a random effect. Interaction between swimmer subgroups

162   and age (subgroup × age) was considered for the analysis. All career progression data were

163   analyzed through custom-written software in MATLAB (version R2021b; Mathworks, Natick,

164   Massachusetts, USA). Linear mixed model analyses were carried out using the statistical

165   package R (version 4.0.3; R Core Team, Foundation for Statistical Computing, Vienna,

166   Austria). The graphs were prepared with GraphPad Prism (version 8; San Diego, USA). The

167   level of significance was set at P ≤0.05.

168   **Results**

169   The initial dataset included a total of 6,003 swimmers with a total of 58,760 unique

170   records with an average of 9.9 ± 3.2 and 9.7 ± 3.2 observations per male and female swimmer,

171   respectively. Specifically, 2,126 athletes were freestyle swimmers (50m: n=1,012, 32.0%

172 females; 100m: n=1,114, 33.2% females), 1,270 were backstroke, (50m: n=630, 48.6%

173 females; 100m: n=640, 46.4% females), 1,301 were breaststroke swimmers (50m: n=646,

174 48.5% females; 100m: n=655, 46.0% females), and 1,306 were butterfly swimmers (50m:

175 n=662, 45.8% females; 100m: n=644, 47.5% females). From this dataset, swimmers in the O*nly*

176 *Junior, Junior and Senior,* and *Only Senior sub-category* were identified. The specific

177 information about the total sample size of swimmers included in the first screening and selected

178 swimmer in each subgroup are reported in Supplementary File 2.

179   < Table 1 about here>

180   Table 1 shows the mean and 95% CI of the peak performance, the peak age performance,

181 and the rate of performance improvement for *Only Junior, Junior and Senior,* and *Only Senior*

182 subgroups. The ANOVA outcomes are reported in Supplementary File 3. Significant

183 differences were observed among the subgroups. In all swimming events, the age of personal

184 peak performance was lower for *Only Junior* (average age of 19.7 and 18.1 yrs in males and

185 females, respectively) than for *Junior and Senior* (average age of 23.4 and 22.6 yrs in males

186 and females, respectively) and *Only Senior* subgroup (average age of 25.0 and 24.5 yrs in males

187 and females, respectively) subgroup. *Junior and Senior* and *Only Senior* subgroups recorded

188 the best peak performance compared to that of the *Only Junior* subgroup, while in general, the

189 *Junior and Senior* and *Only Senior* subgroups showed similar peak performances in all

190 disciplines. Finally, the *Only Senior* subgroup showed a larger rate of performance

191 improvement (average of -7.5 and -6.2% in males and females respectively) compared with that

192 of the *Only Junior* (average of -1.2 and -0.3% in males and females respectively) and *Junior*

193 *and Senior* subgroups (age of -4.3 and -3.3% in males and females respectively). Further details

194 about post-hoc comparisons are provided in Table 1.

195   Figure 1 shows a representative example (i.e., 100m freestyle) for the performance

196 progression (Figure 1 a-b) and the annual performance improvement (Figure 1 c-d) throughout

197 the career of male and female swimmers. The details for all events and gender are reported in

198 Supplementary Files 4 and 5. The results of the linear mixed models are reported in

199 Supplementary File 3. Significant subgroup × age interactions were observed in annual

200 performance progression for all events and in both genders (see Supplementary File 3).

201 Differently for the annual performance improvement, significant subgroup × age interactions

202 were observed in all events and both genders, excluding 50m Freestyle and Backstroke in males

203 and 50m and 100m breaststroke in females (see Supplementary File 3).

204 <Figure 1 about here>

Discussion

206 The present study aimed to provide a robust understanding of the career pathway

207 differences between early- and later-success international swimmers competing in the four

208 swimming strokes of long course sprint events (i.e., 50m and 100m). For this purpose, we

209 evaluated the performance pathway of ~ 6,000 international swimmers. By tracking the career

210 of a large sample of swimmers, it was possible to differentiate the career trajectories of

211 successful senior swimmers from early successful swimmers (i.e., swimmers who did not

212 achieve success in the second part of their career). The main findings of the present study were:

213 1) the top senior swimmers reached their peak performance later than their early-success

214 counterparts, 2) top senior swimmers (considering both *Junior and Senior* and *Senior*

215 subgroups) showed a more sustained improvement in performance at the senior age, while

216 early-success swimmers experience stagnation in their performances. On the other hand, data

217 suggested that 3) performance progression is not unique among successful swimmers (i.e.,

218 *Junior and Senior* and *Senior* subgroups) and that there are different pathways to reach an elite

219 level performance.

220 As a preliminary note, the four disciplines shared the same patterns for the age of peak

221 performance and the rate of performance improvements. Indeed, the confidence intervals of

222   those estimates are largely crossing each other (see Table 1). This means that despite the

223   obvious technical differences between strokes, the swimmers' career trajectories mostly depend

224   on disciplines. Similarly, no clear differences can be found between the 50 and 100m distance.

225   For this reason, the following discussion will apply without major differences to all strokes and

226   distances.

227   The *Only Junior* subgroup achieved the best performance, on average, before the age of

228   20 and ~3-4 yrs before the *Junior and Senior* or 5-6 yrs before the *Only Senior* counterparts

229   (see Table 1). In the *Junior and Senior* and *Only Senior* subgroups, the peak performance

230   occurred quite a few years after reaching biological maturity. This data was in accordance with

231   previous studies on swimming[1,8,10] and track and field athletes.[12,14] On the other hand, the age

232   ranges (i.e., from about 18 to 21 yrs) at which the *Only Junior* subgroup reached the best

233   performance are similar to the results reported by Dormehel et al.[5,6] that modeled progression

234   performance of female and male swimmers through adolescence. Moreover, as recently

235   demonstrated in track and field disciplines,[12,13] the elite senior swimmers considered elite

236   during their junior career (i.e., *Junior and Senior* subgroup) reached their peak performance

237   earlier than the rest of the elite senior athletes (*Only Senior*). Although there were differences

238   in age of peak performance for both male and female subgroups, female swimmers meanly

239   reached the peak performance one year before than their male counterparts.[3,5,6,10] Indeed, the

240   females' earlier growth and maturation might explain this difference.[18] . Also, young female

241   swimmers of international caliber already compete with older counterparts from the age of 15

242   yrs.[6]

243   As expected, the *Only Junior* subgroup showed a lower peak performance than the *Only*

244   *Senior* and *Junior and Senior* subgroup (see post hoc comparison in Table 1). *Junior and Senior*

245   and *Only Senior* subgroups showed similar peak performances in all disciplines with no

246   significant difference. Based on these results, it is possible to suggest that for some athletes

247   competing at a higher level, both in junior and senior competitions, there could be a little career

248   advance if they are capable of continuing the progression. These data partially agree with the

249   notion that competing in the Junior World Championship may also translate into later success

250   at the senior level.[19,20] However, considering the large cohort of athletes identified in the O*nly*

251   *Junior* subgroup, it is likely that this group of athletes might have been mostly constituted by

252   early matures and/or individuals who were unable to progress for various reasons. The annual

253   best performance progression (see, for example, Figure 1 a-b) and the annual performance

254   improvement (see, for example, Figure 1 c-d) clearly distinguish the career pathway of

255   successful and unsuccessful swimmers. The annual best performance progression showed a

256   similar trajectory between *Only Junior* and *Junior and Senior* subgroups in the early part of

257   their career and is largely comparable up to age around 18-19 yrs. Nevertheless, starting from

258   the age of around 18-20 yrs, the career pathways of these two subgroups started to differentiate

259   significantly. While the *Junior and Senior* subgroup showed a higher trend in the annual

260   performance improvement, the *Only Junior* subgroup seemed just to reach the performance

261   plateau. The *Only Senior* subgroup showed a different tendency in the annual best performance

262   progression. While worse performances were observed during the entire junior career in

263   comparison with the *Only Junior* and the *Junior and Senior* subgroup, starting from age around

264   19-20 yrs, the *Junior and Senior* subgroup showed the best career pathway in comparison with

265   the *Only Junior* subgroup, reaching the same performance level of the *Junior and Senior*

266   subgroup from age around 20-21 yrs. The data about the rate of performance improvement from

267   the last years of junior career to the senior peak performance confirmed these observations. In

268   general, the *Only Senior* subgroup obtained about 6-8% performance improvements. The

269   annual performance improvements of *Junior and Senior* and *Only Senior* subgroups were

270   higher until the age of 20-24 yrs, with annual improvements of 1-2% until their peak

271   performance. The Only Junior showed a performance stagnation at about 16-18 yrs in females

272   and 19-20 yrs in males. These data suggest that the swimmers that reach senior success exhibit

273   a continued progression during their career. Therefore, considering talent selection and

274   development strategies, our results may indicate that performance progression in the transition

275   towards adult career might be a strong indicator of performance potential in sprinting events.

276   Together, these results continue supporting the idea of the low prediction abilities performances

277   in the early part of the youth career to identify successful swimmers in adulthood.[4,11]

278   There are different pathways to reaching an elite-level performance. In the present

279   study, we identified two main possible patterns. The first one, obtained by the *Junior and Senior*

280   subgroup, consisted of reaching top-level in the early ages and then maintaining it in adulthood

281   (albeit less frequent). The second one, obtained by the *Only Senior* subgroup, was more frequent

282   and consisted of larger performance improvements until later in life despite limited success at

283   earlier ages. In fact, the prevalence of *Only Senior* was generally higher than *Junior and Senior*

284   subgroup (see supplementary File 1). This study also shows that the consistent performance

285   improvement in the years before peak performance is a fundamental factor that distinguishes

286   athletes that reach the top-level compared to those who do not. For this reason, it may be

287   possible to speculate that greater time is required to develop and maintain an efficient aquatic

288   motion necessary for success.[3] At the same time, it is possible to speculate that earlier

289   maturation and the consequence of early strength gains could be responsible for the early

290   success in sprint events. Previous work has already indicated that maturity status is a substantial

291   predictor of swim performance, and early maturing swimmers reach more early success than

292   their late-mature counterparts.[21] Moreover, another possible explanation may be related to the

293   early training specialization. It is possible to suppose that an early emphasis on training volumes

294   and intensities partially contribute to the early peaking phenomenon observed in the *Only*

295   *Junior* subgroup. Consequently, early-success swimmers may benefit from an early

296   specialization in the short-term but not in the long-term.[22,23] Previous work has suggested that

297   successful swimmers who experienced more multiport practices in their adolescent years

298   without excessive specialization may better develop senior success.[22,23] Again, different aspects

299   such as injuries,[24] relative age effects,[25-28] dual-career barriers,[29] and social and personal

300   factors[30] may explain why swimmers in the *Only Junior* subgroup reached the short-term but

301   not the long-term success. Together, these possible explanations are only speculations that

302   should be investigated more in-depth in future studies. At the current stage and with our data,

303   it is impossible to identify what exactly causes this phenomenon, and more studies are

304   definitively needed.

305   The study has some limitations that should be underlined. Our analysis was solely based

306   on rankings and did not include information about success at the major international level

307   competitions. Moreover, our results are based only on swimming performance progression; no

308   information was available on the individuals' maturity status and training load characteristics

309   in the database. Finally, the results of this study are based on European rankings and not on

310   Worldwide rankings.

311   **Practical implication**

312   Practically, these results provide useful information to construct a more realistic

313   expectation based on the annual performance progression for the future development of elite

314   junior swimmers and may help coaches and talent development programs with realistic

315   benchmarks to assess athletes' progression. The results of this study suggest that performance

316   progression in the transition towards adult career might be a strong indicator of performance

317   potential. Also, data suggested that it is hardly justifiable to select swimmers from talent

318   development programs (and de-select others) only based on pre-adolescence performances. In

319   simple terms, young swimmers in sprinting events might still develop after adolescence and

320   reach an international level of performance if the pre-requisites are there. Increasing awareness

321   of these findings among athletes, parents, and coaching communities might help develop better

322 approaches to retain and develop athletes that may be discouraged by selection policies favoring

323 early maturity.

Conclusion

325 In conclusion, our results showed differences in career pathways between early- and

326 later-successful swimmers or swimmers who managed success during their youth and

327 adulthood. Most of the early-successful swimmers did not maintain the same level of

328 competitiveness during adulthood and showed a different age of peak performance and career

329 pathway. The research results indicated that early-success swimmers achieved earlier their peak

330 performance than their peers and, therefore, with less development margin.[13] On average, this

331 group experienced a plateau in performance around the age of 20 yrs, while the two other groups

332 continued to produce consistent performance improvements up to around 25 yrs. The policy

333 makers of talent developmental programs should notice that only swimmers that over the last

334 year of junior career still improve their performance by 1-2% have real chances to achieve

335 success at the senior level on sprinting events.

Acknowledgments

Conflict of Interest Statement

342 The authors declare no conflict of interest.

References

1. Allen SV, Vandenbogaerde TJ, Hopkins WG. Career performance trajectories of Olympic swimmers: benchmarks for talent development. *Eur J Sport Sci.* 2014; 14(7):643-651.

2. Costa MJ, Marinho DA, Reis VM, et al. Tracking the performance of world-ranked swimmers. *J Sports Sci Med.* 2010; 9(3):411-417.

3. Allen SV, Hopkins WG. Age of Peak Competitive Performance of Elite Athletes: A Systematic Review. *Sports Med.* 2015; 45(10):1431-1441.

4. Costa MJ, Marinho DA, Bragada JA, Silva AJ, Barbosa TM. Stability of elite freestyle performance from childhood to adulthood. *Journal of Sports Sciences.* 2011; 29(11):1183-1189.

5. Dormehl SJ, Robertson SJ, Williams CA. Modelling the progression of male swimmers' performances through adolescence. *Sports.* 2016; 4(1):2.

6. Dormehl SJ, Robertson SJ, Williams CA. How confident can we be in modelling female swimming performance in adolescence? *Sports.* 2016; 4(1):16.

7. Post AK, Koning RH, Visscher C, Elferink-Gemser MT. Multigenerational performance development of male and female top-elite swimmers–A global study of the 100 m freestyle event. *Scand J Med Sci Sports.* 2020; 30(3):564-571.

8. Berthelot G, Len S, Hellard P, et al. Exponential growth combined with exponential decline explains lifetime performance evolution in individual and human species. *Age (Dordr).* 2012; 34(4):1001-1009.

9. Sokolovas G. When will you peak? . *Swimming World Magazine.* 2006; 47:37–38.

10. Wolfrum M, Knechtle B, Rust CA, Rosemann T, Lepers R. Sex-related differences and age of peak performance in breaststroke versus freestyle swimming. *BMC Sports Sci Med Rehabil.* 2013; 5(1):29.

11. Brustio PR, Cardinale M, Lupo C, Varalda M, De Pasquale P, Boccia G. Being a top swimmer during the early career is not a prerequisite for success: a study on sprinter strokes. *J Sports Sci Med.* 2021.

12. Boccia G, Cardinale M, Brustio PR. World-Class Sprinters' Careers: Early Success Does Not Guarantee Success at Adult Age. *Int J Sports Physiol Perform.* 2021.

13. Boccia G, Cardinale M, Brustio PR. Elite Junior Throwers Unlikely Remain at the Top Level in the Senior Category. *Int J Sports Physiol Perform.* 2021; 16(9):1281-1287.

14. Boccia G, Cardinale M, Brustio PR. Performance progression of elite jumpers: Early performances do not predict later success. *Scand J Med Sci Sports.* 2020; 31(1):132-139.

15. Boccia G, Brustio PR, Moisè 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.

16. Stoter IK, Koning RH, Visscher C, Elferink-Gemser MT. Creating performance benchmarks for the future elites in speed skating. *Journal of Sports Sciences.* 2019; 37(15):1770-1777.

380 17. Haugen TA, Solberg PA, Foster C, Moran-Navarro R, Breitschadel F, Hopkins WG. Peak Age and
381   Performance Progression in World-Class Track-and-Field Athletes. *Int J Sports Physiol Perform.*
382   2018; 13(9):1122-1129.

383 18. Malina RM, Rogol AD, Cumming SP, Coelho e Silva MJ, Figueiredo AJ. Biological maturation of
384   youth athletes: assessment and implications. *Br J Sports Med.* 2015; 49(13):852-859.

385 19. Yustres I, Santos Del Cerro J, Martin R, Gonzalez-Mohino F, Logan O, Gonzalez-Rave JM.
386   Influence of early specialization in world-ranked swimmers and general patterns to success. *PLoS*
387   *One.* 2019; 14(6):e0218601.

388 20. Yustres I, Santos del Cerro J, González-Mohíno F, Peyrebrune M, González-Ravé JM. Comparing
389   the Pathway to Success in European Countries Competing in the Swimming World Championships.
390   *Frontiers in Psychology.* 2019; 10.

391 21. Abbott S, Hogan C, Castiglioni MT, et al. Maturity-related developmental inequalities in age-group
392   swimming: The testing of 'Mat-CAPs' for their removal. *J Sci Med Sport.* 2021; 24(4):397-404.

393 22. Gullich A. Sport-specific and non-specific practice of strong and weak responders in junior and
394   senior elite athletics - A matched-pairs analysis. *Journal of Sports Sciences.* 2018; 36(19):2256-
395   2264.

396 23. Moesch K, Elbe AM, Hauge ML, Wikman JM. Late specialization: the key to success in
397   centimeters, grams, or seconds (cgs) sports. *Scand J Med Sci Sports.* 2011; 21(6):e282-290.

398 24. Zaremski JL, Zeppieri G, Jr., Tripp BL. Sport Specialization and Overuse Injuries in Adolescent
399   Throwing Athletes: A Narrative Review. *J Athl Train.* 2019; 54(10):1030-1039.

400 25. Brustio PR, Kearney PE, Lupo C, et al. Relative Age Influences Performance of World-Class Track
401   and Field Athletes Even in the Adulthood. *Front Psychol.* 2019; 10:1395.

402 26. Costa AM, Marques MC, Louro H, Ferreira SS, Marinho DA. The relative age effect among elite
403   youth competitive swimmers. *Eur J Sport Sci.* 2013; 13(5):437-444.

404 27. Brustio PR, Boccia G. Corrective procedures remove relative age effect from world-class junior
405   sprinters. *Journal of Sports Sciences.* 2021; 39(22):2603-2610.

406 28. Brustio PR, Cobley S, Abbott S, et al. Corrective Adjustment Procedures as a strategy to remove
407   Relative Age Effects: Validation across male and female age-group long jumping. *J Sports Sci Med.*
408   2022.

409 29. Brustio PR, Rainoldi A, Mosso CO, de Subijana CL, Lupo C. Italian student-athletes only need a
410   more effective daily schedule to support their dual career. *Sport Sciences for Health.* 2020;
411   16(1):177-182.

412 30. Hollings SC, Mallett CJ, Hume PA. The transition from elite junior track-and-field athlete to
413   successful senior athlete: Why some do, why others don't. *Int J Sports Sci Coa.* 2014; 9(3):457-471.

415   **Figure legends**

416

417   **Figure 1**

418   Average and 90% CI annual best performance progression (panel a-b) and the annual

419   performance improvement (panel c-d) are reported for 100m freestyle of the three subgroups of

420   swimmers.

Table 1: Age of Peak Performance, Peak Performance and Rate of Performance **Improvement** differences among Only Junior, Junior & Senior, and Only Senior group according to gender and sprint events and post-hoc analysis.

	50m Freestyle	100m Freestyle	50m Backstroke	100m Backstroke	50m Breaststroke	100m Breaststroke	50m Butterfly	100m Butterfly
Male								
Age of Peak Performance (years)								
Only Junior	20.23 (19.86, 20.61)	19.99 (19.60, 20.38)	20.12 (19.72, 20.51)	20.18 (19.71, 20.64)	20.38 (19.92, 20.84)	20.02 (19.60, 20.44)	20.17 (19.80, 20.55)	19.82 (19.50, 20.14)
Junior and Senior	24.73[a] (23.70, 25.76)	23.57[a] (22.98, 24.17)	23.97[a] (23.20, 24.74)	23.79[a] (23.06, 24.52)	23.87[a] (22.92, 24.83)	24.50[a] (23.76, 25.25)	23.43[a] (22.57, 24.29)	23.38[a] (22.71, 24.05)
Only Senior	26.19[a] (25.30, 27.08)	25.60[a] (25.04, 26.17)	24.87[a] (23.91, 25.83)	26.03[a] (24.85, 27.22)	25.45[a] (24.81, 26.09)	25.37[a] (24.57, 26.17)	26.37[a] (25.28, 27.45)	25.95[a] (24.90, 27.00)
Peak Performance (s)								
Only Junior	23.01 (22.93, 23.09)	50.19 (50.05, 50.33)	26.22 (26.13, 26.30)	55.88 (55.67, 56.1)	28.65 (28.56, 28.74)	62.69 (62.50, 62.88)	24.56 (24.47, 24.64)	54.09 (53.90, 54.27)
Junior and Senior	22.15[a] (22.02, 22.28)	48.39[a] (48.17, 48.62)	25.16[a] (25.01, 25.31)	54.29[a] (53.94, 54.63)	27.61[a] (27.47, 27.75)	60.79[a] (60.46, 61.12)	23.56[a] (23.46, 23.65)	51.76[a] (51.4, 52.12)
Only Senior	22.24[a] (22.11, 22.37)	48.66[a] (48.49, 48.83)	25.31[a] (25.15, 25.47)	54.14[a,b] (53.74, 54.55)	27.81[a] (27.71, 27.90)	60.70[a] (60.32, 61.08)	23.77[a] (23.63, 23.91)	52.30[a,b] (52.08, 52.52)
Rate of Performance Improvement (%)								
Only Junior	-1.20 (-1.49, -0.91)	-1.00 (-1.29, -0.71)	-1.35 (-1.70, -1.01)	-1.14 (-1.59, -0.69)	-1.27 (-1.60, -0.94)	-1.08 (-1.40, -0.76)	-1.29 (-1.64, -0.94)	-0.91 (-1.17, -0.65)
Junior and Senior	-4.56[a] (-5.12, -4.00)	-3.98[a] (-4.49, -3.48)	-4.73[a] (-5.54, -3.92)	-3.65[a] (-4.23, -3.07)	-4.10[a] (-4.90, -3.31)	-3.53[a] (-4.11, -2.95)	-4.50[a] (-5.15, -3.86)	-4.98[a] (-5.91, -4.05)
Only Senior	-7.32[a] (-9.99, -4.65)	-7.92[a,b] (-9.13, -6.71)	-7.77[a,b] (-8.94, -6.59)	-8.27[a,b] (-10.51, -6.04)	-7.07[a,b] (-7.74, -6.4)	-7.05[a,b] (-7.62, -6.47)	-8.36[a,b] (-9.45, -7.27)	-6.59 (-8.10, -5.08)
Female								
Age of Peak Performance (years)								
Only Junior	18.25 (17.80, 18.70)	18.04 (17.67, 18.42)	17.66[a] (17.26, 18.07)	17.80[a] (17.35, 18.26)	18.86 (18.29, 19.43)	18.43 (17.94, 18.92)	18.51 (18.09, 18.93)	18.91 (18.41, 19.41)
Junior and Senior	24.03[a] (22.36, 25.69)	25.20[a] (23.81, 26.6)	22.58[a] (21.53, 23.63)	22.95[a] (21.77, 24.12)	23.25[a] (21.84, 24.66)	22.77[a] (21.60, 23.95)	23.87[a] (22.68, 25.06)	23.35[a] (22.35, 24.36)
Only Senior	25.59[a] (24.31, 26.87)	25.24[a] (24.25, 26.22)	26.00[a] (24.99, 27.00)	24.90[a] (23.82, 25.99)	24.82[a,b] (23.76, 25.88)	24.17[a] (23.00, 25.33)	26.39[a] (24.91, 27.87)	25.23[a] (24.00, 26.46)
Peak Performance (s)								
Only Junior	26.01 (25.93, 26.10)	55.98 (55.78, 56.17)	29.52 (29.43, 29.61)	62.55 (62.33, 62.77)	32.42 (32.28, 32.56)	70.26 (69.99, 70.53)	27.47 (27.36, 27.59)	60.36 (60.13, 60.59)
Junior and Senior	25.19[a] (24.96, 25.42)	54.38[a] (54.04, 54.72)	28.47[a] (28.32, 28.63)	60.48[a] (60.17, 60.79)	31.36[a] (31.02, 31.69)	67.99[a] (67.38, 68.6)	26.36[a] (26.18, 26.55)	58.59[a] (58.20, 58.98)
Only Senior	25.25[a] (25.13, 25.37)	54.82[a] (54.62, 55.02)	28.56[a,b] (28.42, 28.71)	61.26[a] (60.87, 61.65)	31.96[a] (31.74, 32.19)	68.91[a] (68.46, 69.37)	26.78[a] (26.59, 26.97)	58.96[a] (58.73, 59.18)
Rate of Performance Improvement (%)								
Only Junior	-0.33 (-0.61, -0.06)	-0.12 (-0.40, 0.16)	0.05 (-0.34, 0.44)	-0.03 (-0.40, 0.34)	-0.73 (-1.14, -0.32)	-0.35 (-0.73, 0.03)	-0.75 (-1.06, -0.43)	-0.45 (-0.83, -0.07)
Junior and Senior	-3.19[a] (-4.07, -2.3)	-3.63[a] (-4.21, -3.05)	-2.91[a] (-3.52, -2.3)	-3.05[a] (-3.53, -2.56)	-2.98[a] (-3.71, -2.26)	-3.25[a] (-3.92, -2.57)	-3.98[a] (-4.68, -3.27)	-3.42[a] (-3.94, -2.89)
Only Senior	-4.80 (-6.27, -3.32)	-4.91 (-6.25, -3.57)	-6.56[a,b] (-7.26, -5.86)	-7.31[a,b] (-8.72, -5.89)	-7.79[a,b] (-10.30, -5.28)	-4.92 (-5.89, -3.95)	-7.63[a,b] (-11.68, -3.59)	-6.00[a,b] (-7.45, -4.55)

Notes: [a], post-hoc difference between *Only Junior and Junior & Senior;* [b], post-hoc difference between *Only Junior* and *Only Senior;* [c], post-hoc difference between *Junior & Senior* and *Only Senior.*
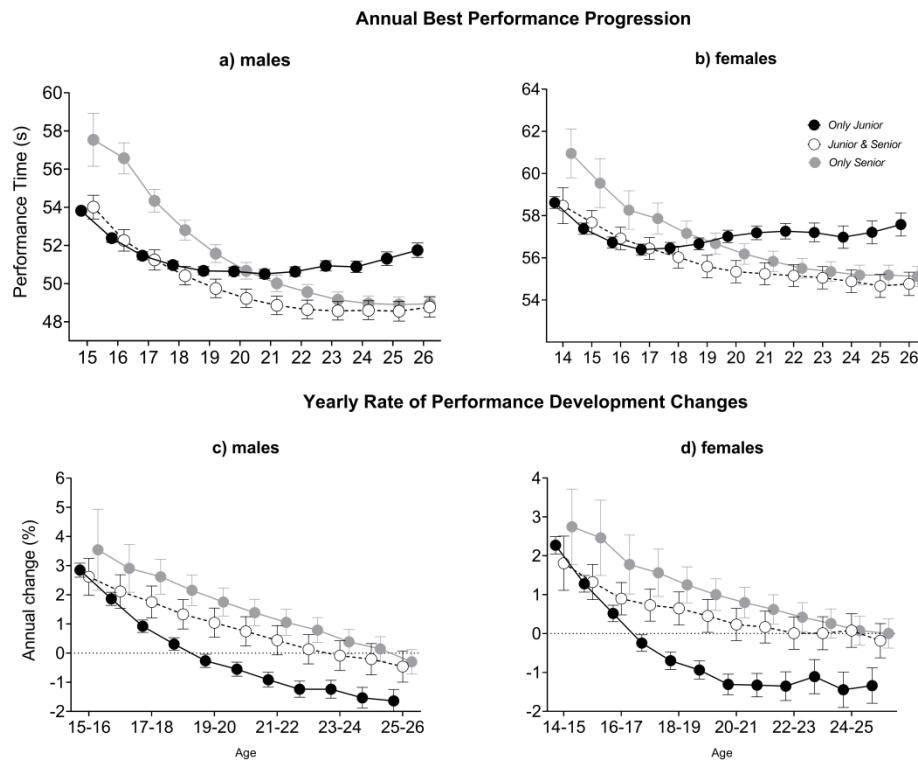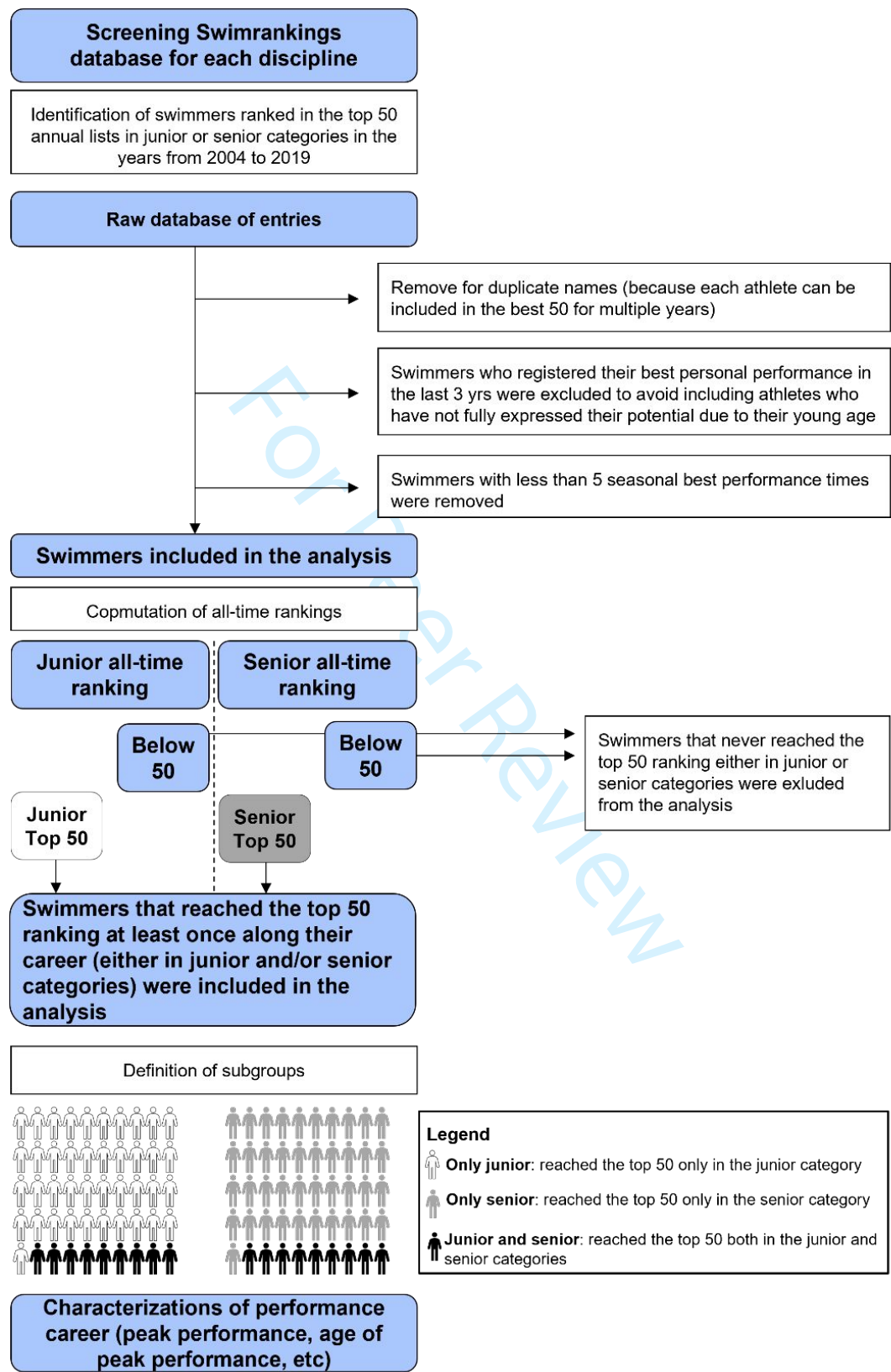
Annual Best Performance Progression

Figure 1 - Average and 90% CI annual best performance progression (panel a-b) and the annual performance improvement (panel c-d) are reported for 100m freestyle of the three subgroups of swimmers.

266x212mm (600 x 600 DPI)

Supplementary File 1

Fig. 1. The recruitment process for the definition of the *Only Junior*, *Junior and Senior*, and *Only Senior* subgroups.

Supplementary File 2: Sample Size of Each Subgroup according to gender and sprint events.

	50m Freestyle N %OR [90%CI]	100m Freestyle N %OR [90%CI]	50m Backstroke N %OR [90%CI]	100m Backstroke N %OR [90%CI]	50m Breaststroke N %OR [90%CI]	100m Breaststroke N %OR [90%CI]	50m Butterfly N %OR [90%CI]	100m Butterfly N %OR [90%CI]
Male								
Total Sample Size	688	744	324	343	333	354	359	338
Total Sample Sub-group	157 22.8 [20.2, 25.6]	161 21.6 [19.2, 24.3]	150 46.3 [41.6, 51]	129 37.6 [33.3, 42.1]	142 42.6 [38.1, 47.3]	148 41.8 [37.4, 46.3]	150 41.8 [37.4, 46.2]	147 43.5 [39, 48.1]
Only Junior	107 15.6 [13.3, 18.0]	111 14.9 [12.8, 17.2]	100 30.9 [26.6, 35.4]	79 23.0 [19.3, 27.1]	92 27.6 [23.6, 31.9]	98 27.7 [23.8, 31.9]	100 27.9 [24, 32]	97 28.7 [24.7, 33]
Junior and Senior	25 3.6 [2.5, 5.0]	20 2.7 [1.8, 3.9]	24 7.4 [5.2, 10.3]	31 9.0 [6.6, 12.0]	21 6.3 [4.3, 9.0]	29 8.2 [5.9, 11.0]	24 6.7 [4.7, 9.3]	18 5.3 [3.5, 7.8]
Only Senior	25 3.6 [2.5, 5.0]	30 4.0 [2.9, 5.4]	26 8.0 [5.7, 11]	19 5.5 [3.7, 8.0]	29 8.7 [6.3, 11.7]	21 5.9 [4.0, 8.4]	26 7.2 [5.1, 9.9]	32 9.5 [7.0, 12.5]
Female								
Total Sample Size	324	370	306	297	313	301	303	306
Total Sample Sub-group	146 45.1 [40.4, 49.8]	135 36.5 [32.3, 40.8]	137 44.8 [40, 49.6]	125 42.1 [37.3, 47]	144 46.0 [41.3, 50.8]	137 45.5 [40.7, 50.4]	148 48.8 [44.0, 53.7]	133 43.5 [38.7, 48.3]
Only Junior	96 29.6 [25.5, 34.1]	85 23.0 [19.4, 26.9]	87 28.4 [24.2, 33.0]	75 25.3 [21.1, 29.7]	94 30.0 [25.8, 34.6]	87 28.9 [24.6, 33.5]	98 32.3 [27.9, 37]	83 27.1 [23.0, 31.6]
Junior and Senior	19 5.9 [3.9, 8.5]	22 5.9 [4.1, 8.4]	32 10.5 [7.7, 13.8]	32 10.8 [7.9, 14.2]	20 6.4 [4.3, 9.1]	25 8.3 [5.8, 11.4]	27 8.9 [6.4, 12.1]	26 8.5 [6.0, 11.6]
Only Senior	31 9.6 [7.0, 12.7]	28 7.6 [5.4, 10.2]	18 5.9 [3.8, 8.6]	18 6.1 [4.0, 8.9]	30 9.6 [7.0, 12.8]	25 8.3 [5.8, 11.4]	23 7.6 [5.2, 10.6]	24 7.8 [5.5, 10.9]

Notes: Total Sample Size indicates all the swimmers analyzed; Total Sample Sub-group indicates subjects included in the Only Junior, Junior and Senior, and Only Senior.

Data are presented as frequency and percentage [90%CI]. The percentages are calculated according to the Total Sample Size.

Supplementary File 3: **One-way ANOVA and linear mixed model outcomes according to gender and sprint events**

	50m Freestyle	100m Freestyle	50m Backstroke	100m Backstroke	50m Breaststroke	100m Breaststroke	50m Butterfly	100m Butterfly
				Male				
Age of Peak Performance	$F=76.95^{***}$	$F=102.43^{***}$	$F=52.64^{***}$	$F=51.86^{***}$	$F=52.18^{***}$	$F=66.35^{***}$	$F=70.89^{***}$	$F=68.57^{***}$
Peak Performance	$F=53.55^{***}$	$F=100.76^{***}$	$F=70.01^{***}$	$F=33.05^{***}$	$F=82.16^{***}$	$F=51.94^{***}$	$F=98.08^{***}$	$F=79.60^{***}$
Rate of Performance Development	$F=46.18^{***}$	$F=73.96^{***}$	$F=69.92^{***}$	$F=28.29^{***}$	$F=76.77^{***}$	$F=69.41^{***}$	$F=60.31^{***}$	$F=45.01^{***}$
Annual performance progression (subgroup×age)	$F=23.14^{***}$	$F=23.29^{***}$	$F=19.79^{***}$	$F=15.18^{***}$	$F=16.86^{***}$	$F=14.37^{***}$	$F=16.86^{***}$	$F=23.71^{***}$
Yearly rate of performance development (subgroup×age)	$F=1.33$	$F=2.54^{***}$	$F=1.05$	$F=1.67^{*}$	$F=3.14^{***}$	$F=1.76^{**}$	$F=1.57^{*}$	$F=1.47^{***}$
				Female				
Age of Peak Performance	$F=53.27^{***}$	$F=92.78^{***}$	$F=102.68^{***}$	$F=68.02^{***}$	$F=41.63^{***}$	$F=46.13^{***}$	$F=57.92^{***}$	$F=54.20^{***}$
Peak Performance	$F=41.50^{***}$	$F=34.84^{***}$	$F=67.35^{***}$	$F=42.55^{***}$	$F=15.77^{***}$	$F=24.36^{***}$	$F=35.2^{***}$	$F=35.29^{***}$
Rate of Performance Development	$F=25.76^{***}$	$F=68.6^{***}$	$F=68.6^{***}$	$F=80.45^{***}$	$F=32.04^{***}$	$F=40.28^{***}$	$F=48.94^{***}$	$F=48.04^{***}$
Annual performance progression (subgroup×age)	$F=10.93^{***}$	$F=10.91^{***}$	$F=11.15^{***}$	$F=13.62^{***}$	$F=7.17^{***}$	$F=8.10^{***}$	$F=7.36^{***}$	$F=8.40^{***}$
Yearly rate of performance development (subgroup×age)	$F=1.88^{***}$	$F=3.65^{***}$	$F=1.50^{*}$	$F=2.30^{***}$	$F=0.81$	$F=0.74$	$F=3.23^{***}$	$F=3.86^{***}$

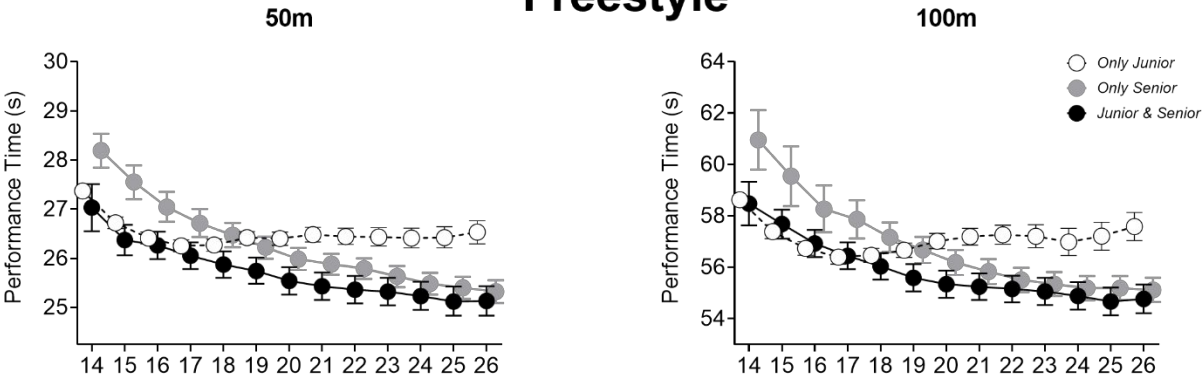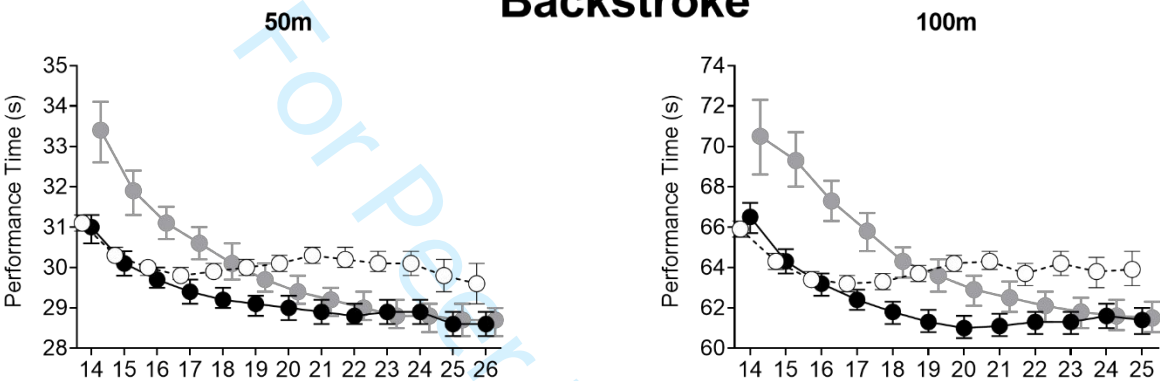Notes: *, $p<0.05$; **, $p<0.01$; ***, $p<0.001$.

Supplementary File 4

Annual best performance progression in the all considered events for *Only Junior, Junior and Senior,* and *Only Senior* subgroup. Data are presented separately for Male and Female Swimmers.
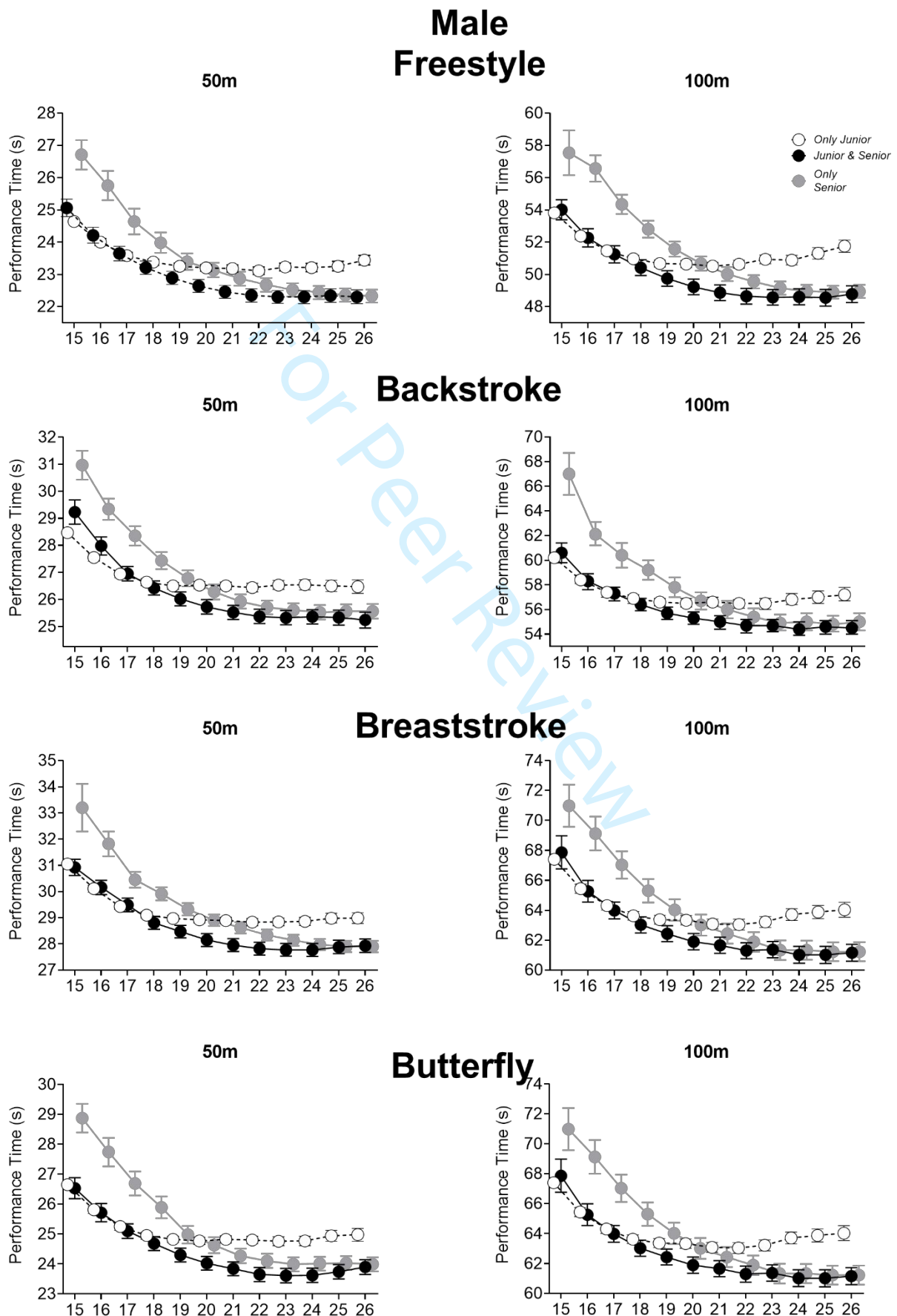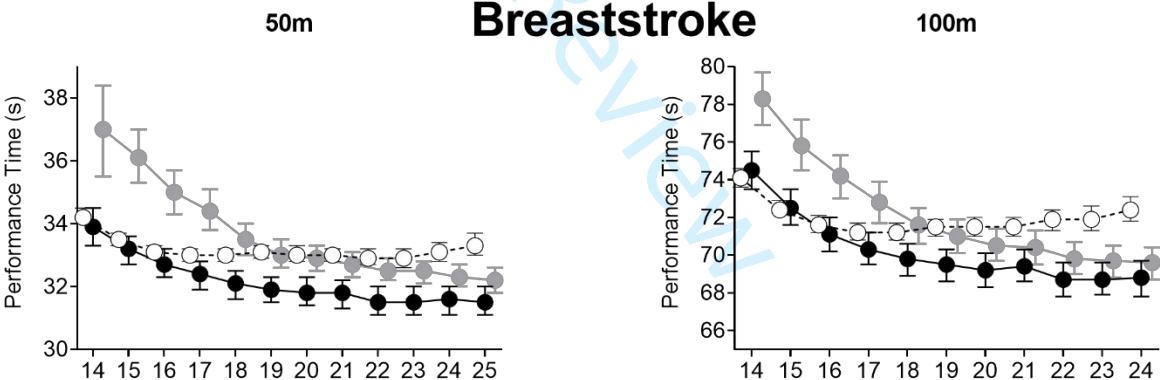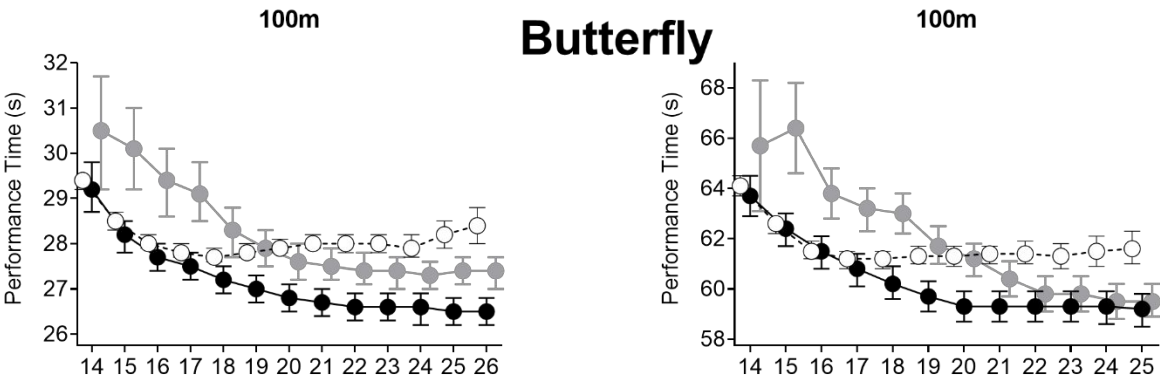
Male
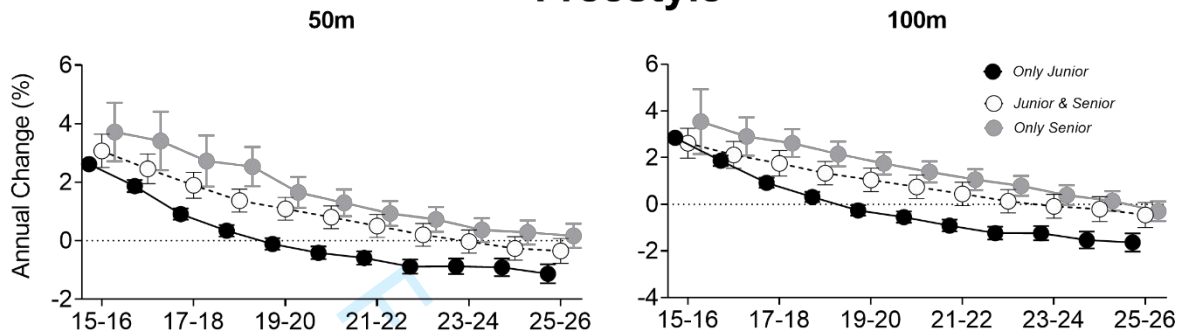# Freestyle

Backstroke
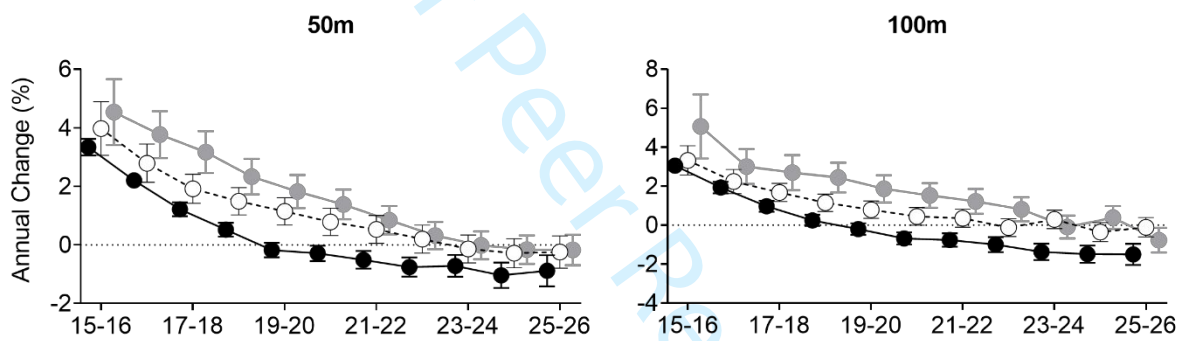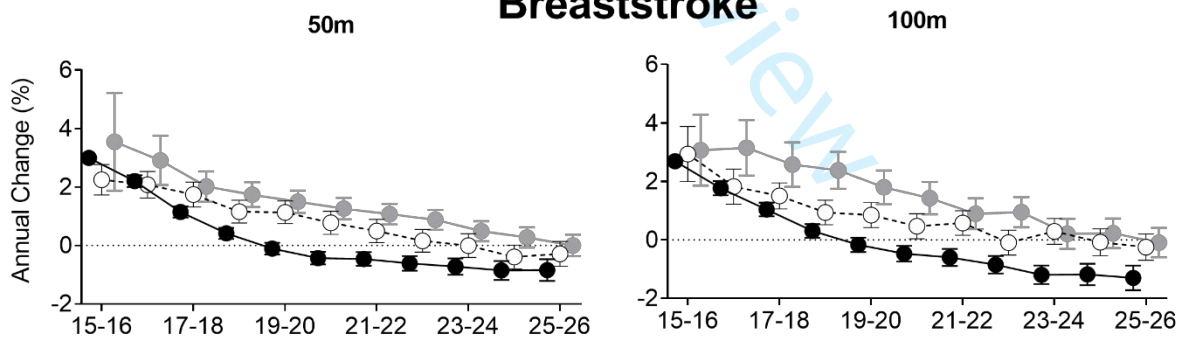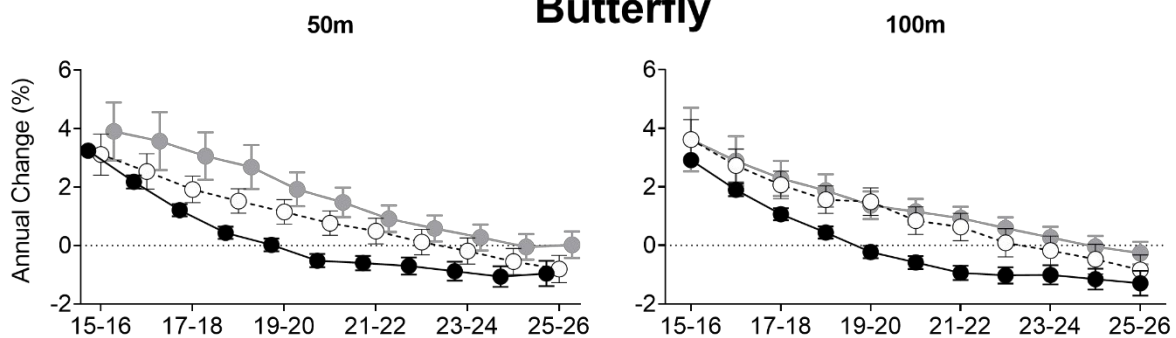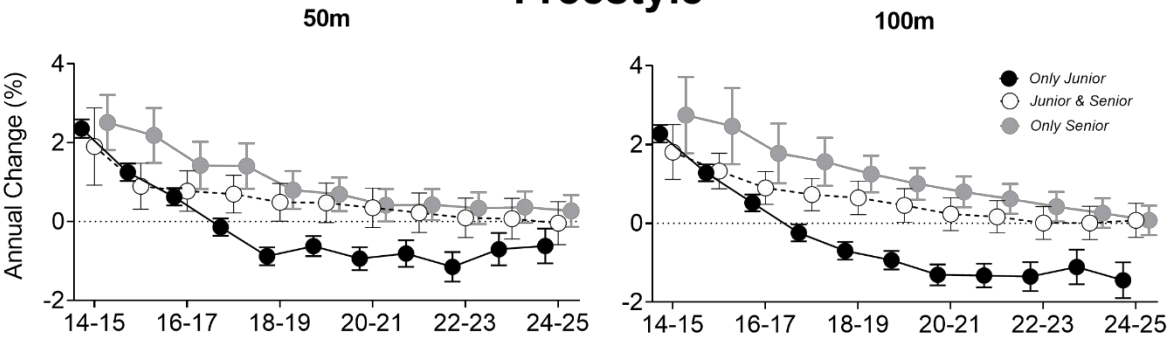
Breaststroke
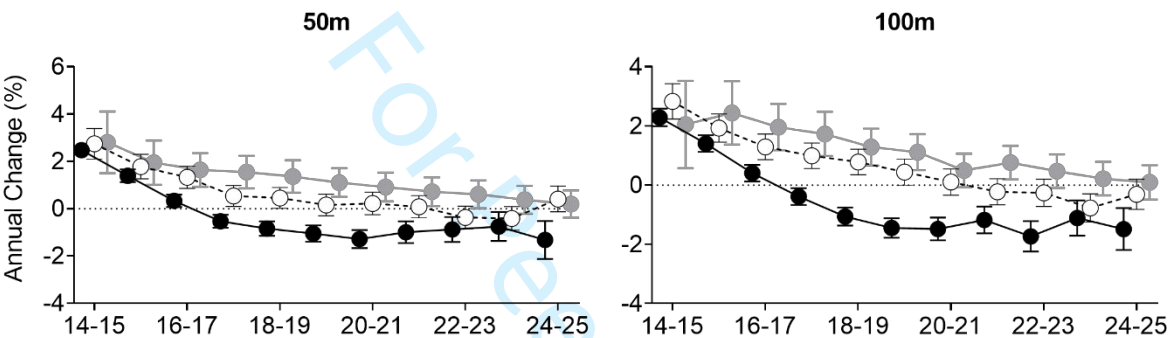
Butterfly

Supplementary File 5

Relative yearly rate of performance improvement in all considered events for Only Junior, Junior and Senior, and Only Senior subgroup. Data are presented separately for Male and Female Swimmers.
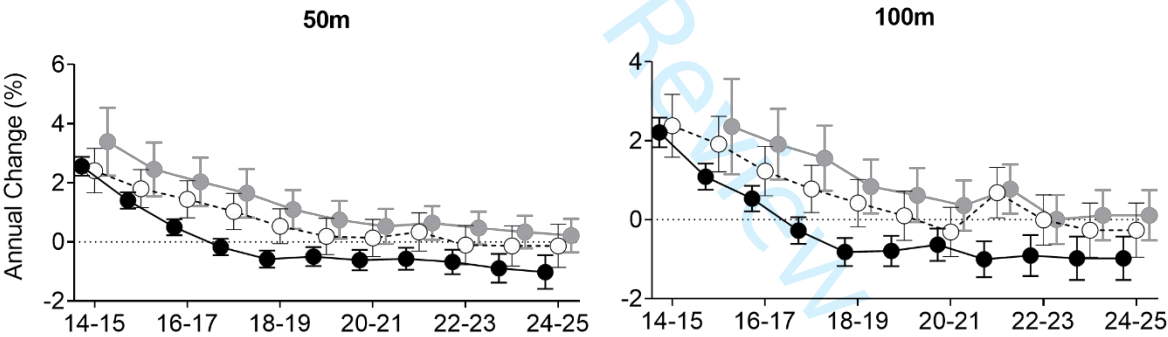
Male
Freestyle

Backstroke

Breaststroke

Butterfly

Female
Freestyle

Backstroke

Breaststroke

Butterfly