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

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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.

For Peer Review

23 Introduction

24 Within sports where performance is measured in centimetres, grams, or seconds (CGS),
25 information related to the performance progression are of interest to policy-makers, sporting
26 organizations, and coaches alike for talent selection and development purposes. In this regard,
27 the longitudinal analysis of performances throughout an athlete's career from junior to senior
28 may provide helpful information to define realistic goals and identify adequate performance
29 expectations¹⁻³ In swimming, different studies conducted on national and international level
30 provided benchmarks for career trajectories.^{1,2,4-10} Examining the career progression between
31 the 1980s and 2000s of elite international swimmers (i.e., top best swimmers in history or the
32 top world-ranked performers), some authors found that the top swimmers reached their personal
33 best performance between 18-23 yrs of age.^{8,9} Also, Allen et al.¹ reported that males reached
34 their peak performance later than females (~ 24 Vs. 22 yrs).

35 Additional information on career progression, analyzing the rate of performance
36 development of successful swimmers, was also provided by previous studies in limited cohorts.
37 Retrospectively evaluating the career progression (i.e., from junior to senior career) of the top-
38 elite international swimmers of 100 m freestyle, Post et al.⁷ found that these athletes followed
39 a unique pathway in comparison with elite and sub-elite counterparts (i.e., better seasonal
40 performances from 12 yrs onwards). **Similarly, the top 150 ranked swimmers in the freestyle**
41 **events improved their performances by 3 – 4% over the five seasons preceding the Olympic**
42 **Games.² Finalist and semi-finalist Olympic swimmers improved their performance of ~ 9%**
43 **over the 8 years preceding the peak performance.¹** Similar data were prospectively confirmed
44 by studying the career patterns of sub-elite swimmers competing in school swimming
45 championships that showed performance improvements between age 12 yrs and peak age from
46 ~22 to 26% in males and from ~8 to 10% in females.^{5,6} A comprehensive study on Portuguese
47 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.

85 **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}

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

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 \times 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 $P \leq 0.05$.

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 *Only*
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 \times 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 \times 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>

205 **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 \sim 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 *Only*
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 factors³⁰ 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.

324 **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.**

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341 **Conflict of Interest Statement**

342 The authors declare no conflict of interest.

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344

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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.

For Peer Review

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.

Male								
	50m Freestyle	100m Freestyle	50m Backstroke	100m Backstroke	50m Breaststroke	100m Breaststroke	50m Butterfly	100m Butterfly
Age of Peak Performance (years)								
<i>Only Junior</i>	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)
<i>Junior and Senior</i>	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)
<i>Only Senior</i>	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)								
<i>Only Junior</i>	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)
<i>Junior and Senior</i>	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)
<i>Only Senior</i>	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 (%)								
<i>Only Junior</i>	-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)
<i>Junior and Senior</i>	-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)
<i>Only Senior</i>	-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)								
<i>Only Junior</i>	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)
<i>Junior and Senior</i>	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)
<i>Only Senior</i>	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)								
<i>Only Junior</i>	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)
<i>Junior and Senior</i>	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)
<i>Only Senior</i>	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 (%)								
<i>Only Junior</i>	-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)
<i>Junior and Senior</i>	-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)
<i>Only Senior</i>	-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*.

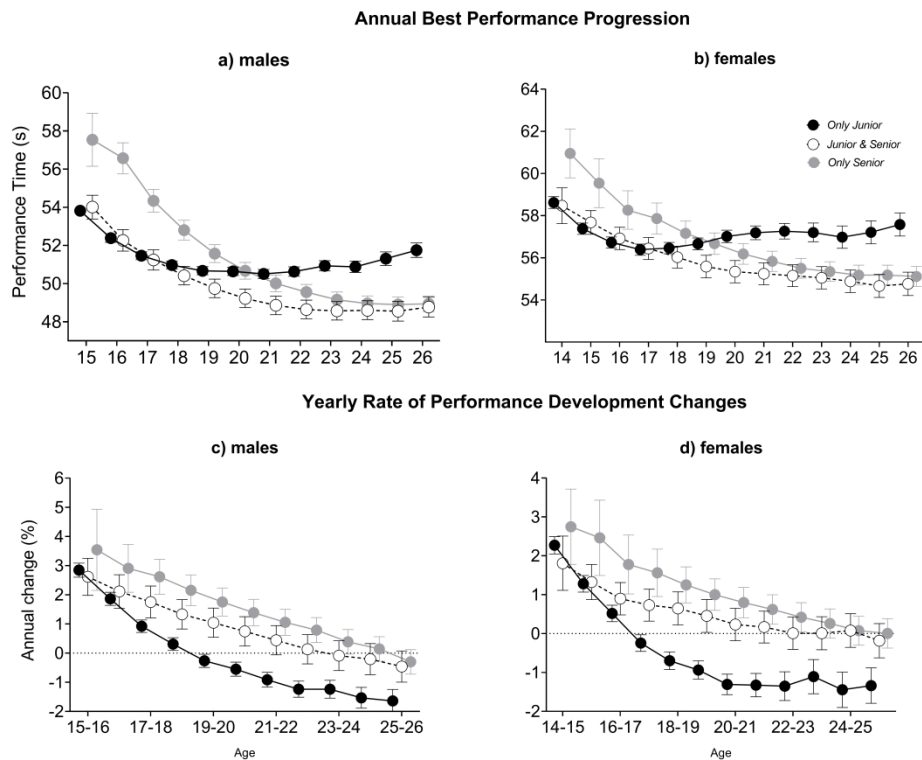
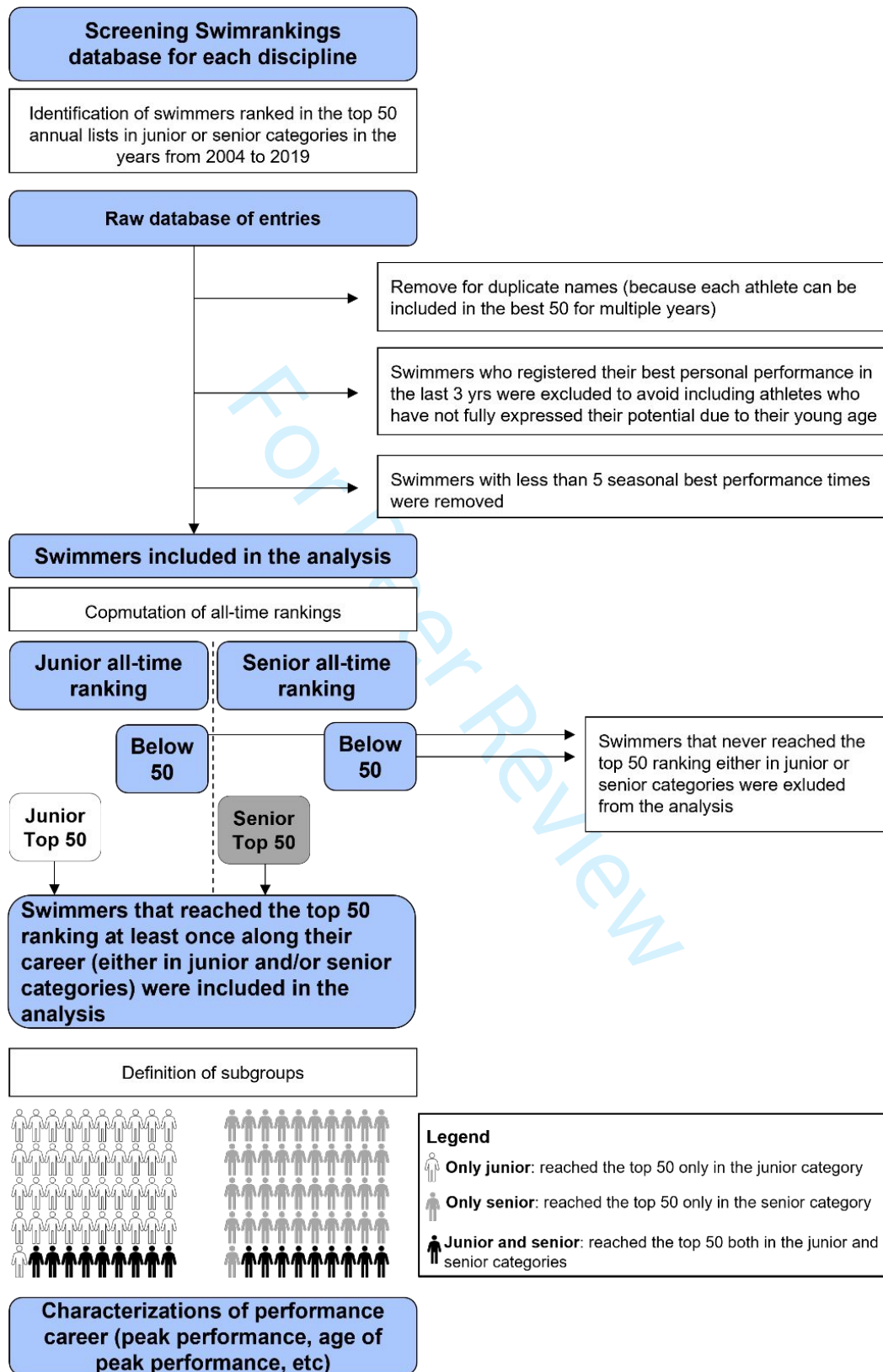


Figure 1 - Average and 90% CI annual best performance progression (panel a-b) and the annual performance improvement (panel c-d) are reported for 100m freestyle of the three subgroups of swimmers.

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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.

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

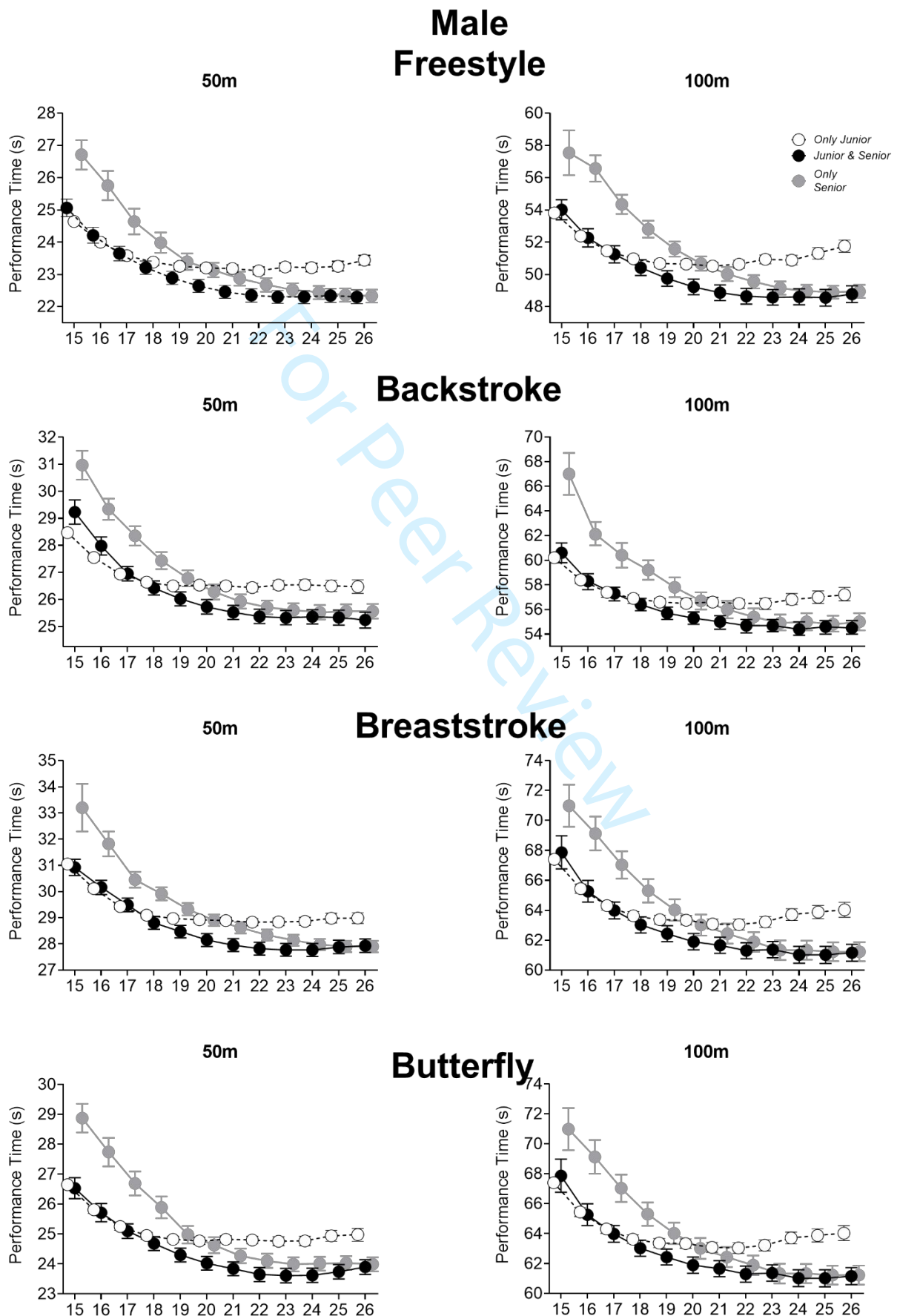
Supplementary File 3: One-way ANOVA and linear mixed model outcomes according to gender and sprint events

	Male							
	50m Freestyle	100m Freestyle	50m Backstroke	100m Backstroke	50m Breaststroke	100m Breaststroke	50m Butterfly	100m Butterfly
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***

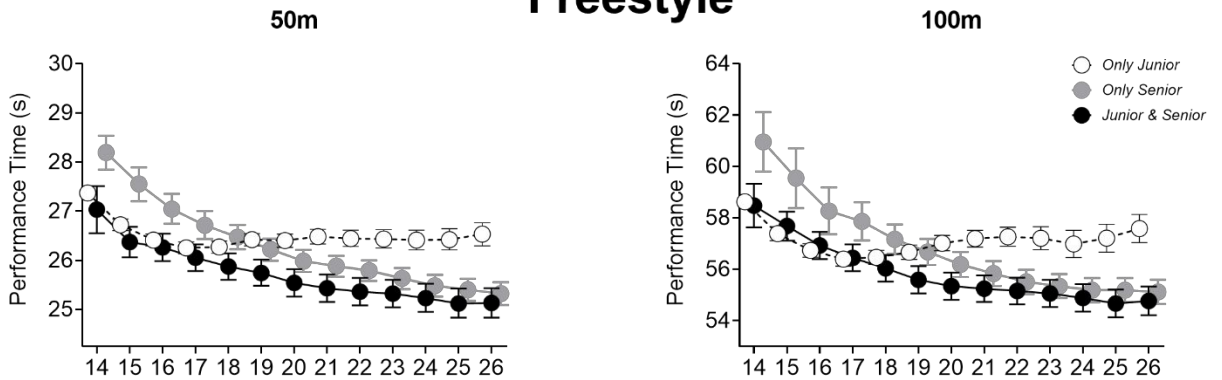
Notes: *, p<0.05; **, p<0.01; ***, p<0.001.

Supplementary File 4

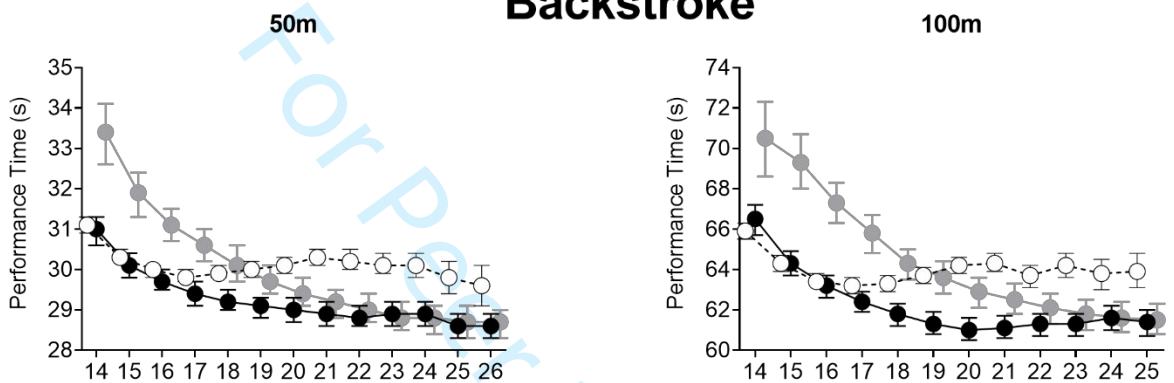
Annual best performance progression in the all considered events for *Only Junior, Junior and Senior, and Only Senior* subgroup. Data are presented separately for Male and Female Swimmers.



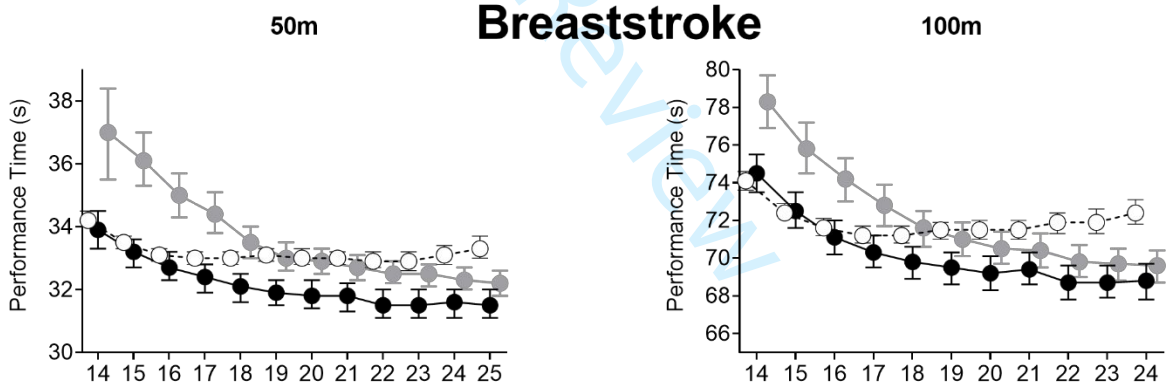
Female Freestyle



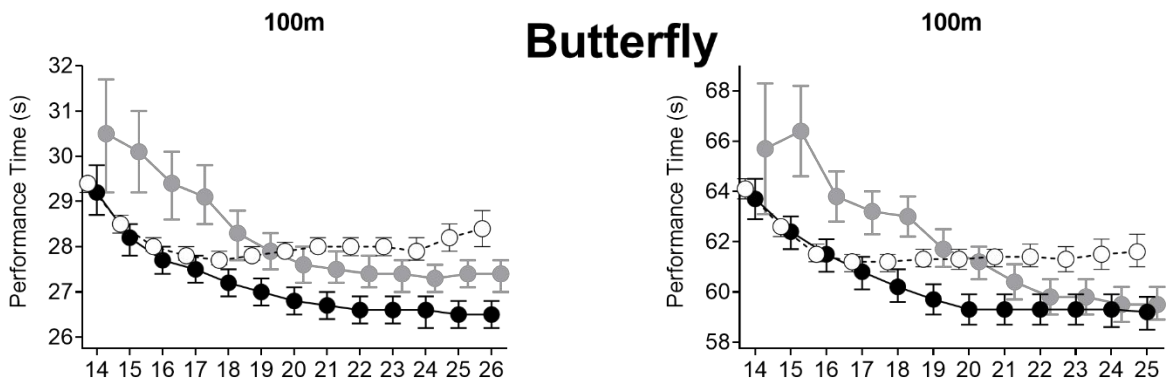
Backstroke



Breaststroke

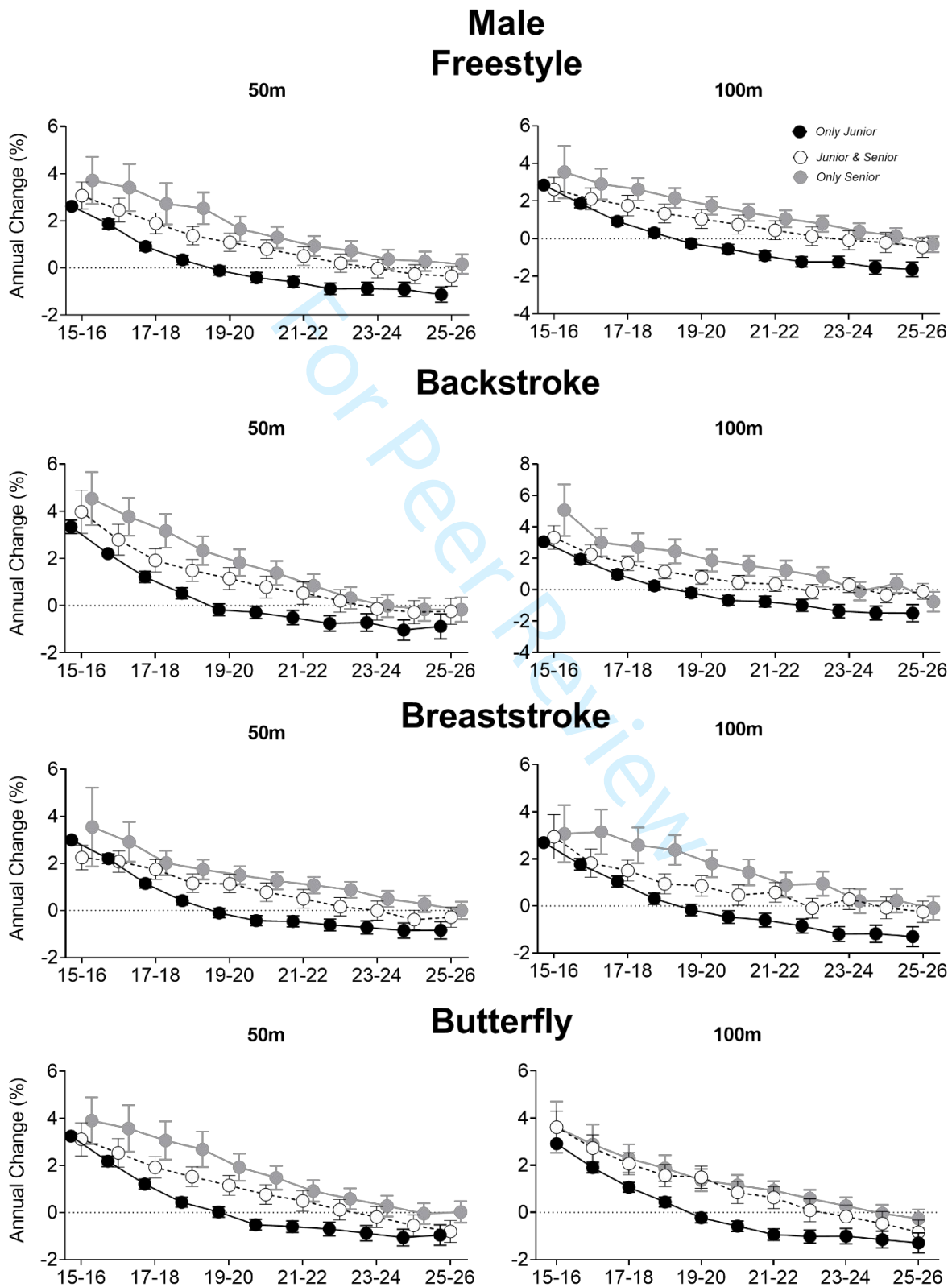


Butterfly

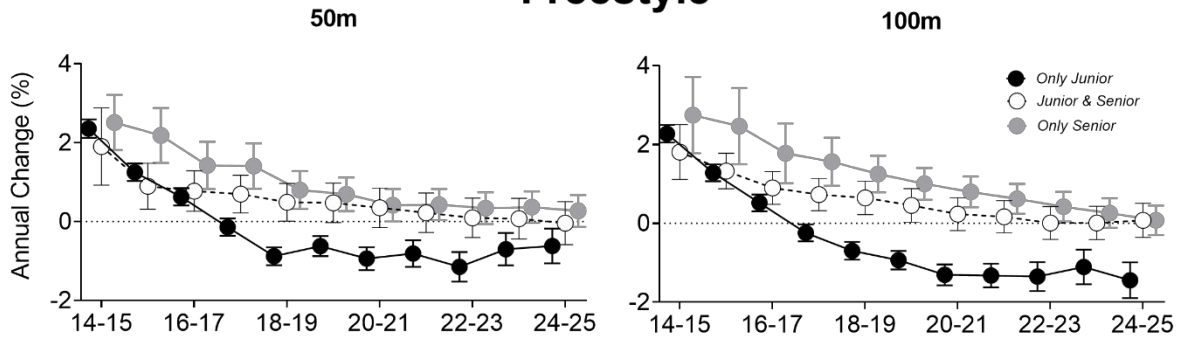


Supplementary File 5

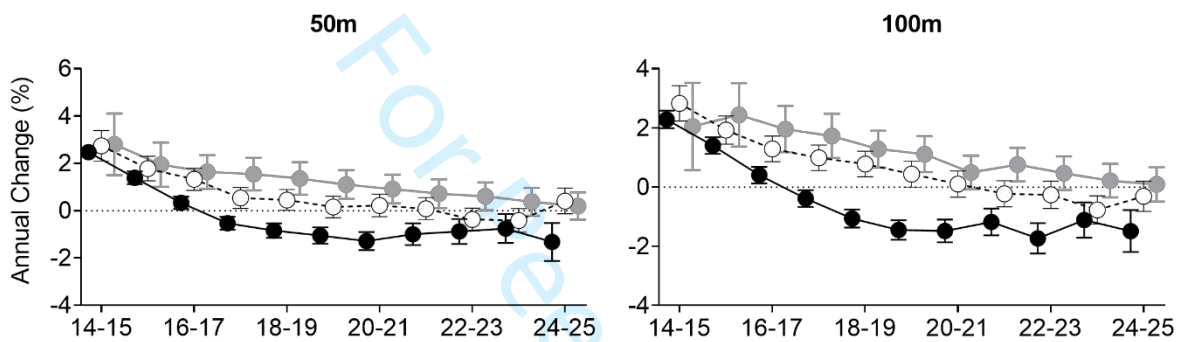
Relative yearly rate of performance improvement in all considered events for *Only Junior*, *Junior and Senior*, and *Only Senior* subgroup. Data are presented separately for Male and Female Swimmers.



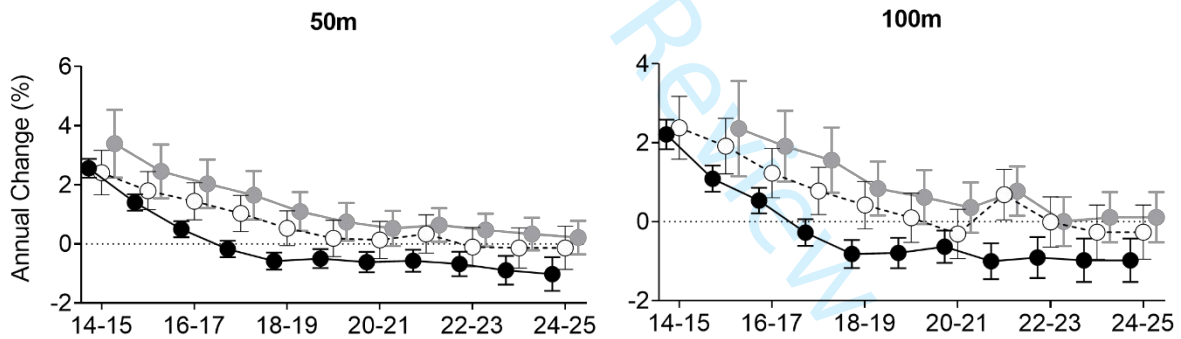
Female Freestyle



Backstroke



Breaststroke



Butterfly

