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

Purpose

This study aimed to describe the career performance progression of elite early- and later-success international swimmers competing in sprint events (i.e., 50m and 100m).

Methods

The career performance trajectories of 6,003 swimmers (50.9% females; 58,760 unique records) competing in the four swimming strokes were evaluated. Early- and later-success swimmers were identified. We identified the top 50 all-time swimmers competing in junior career who did not reach the top 50 rankings in the senior career and vice versa, and successful swimmers both in junior and senior career.

Results

Early-success swimmers mainly achieved their peak performance before the age of 20 yrs and ~5-6 yrs before successful senior swimmers or ~3-4 yrs before successful swimmers both in junior and senior careers. The annual performance improvements of later-success swimmers were higher (about 1-2%) until the age of 20-24 yrs while early-success swimmers showed a performance stagnation at about 16-18 yrs in females and 19-20 yrs in males.

Conclusions

Early-success swimmers who achieved peak performance at a young age were unable to maintain the same level of competitiveness in adulthood since they experienced a plateau in performance from the age of 20 yrs. The procedure of considering early performances solely for talent identification (and not the current rate of progression) might represent a limited approach for selecting future elite swimmers. Our results indicate that performance progression in the transition towards adult career 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 precending 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 generally low, and the ability to predict adult performance was reasonably robust only at age of 16.[4] These data were also confirmed at the international level.[11] Most studies have focused on few athletes participating in the Olympic Games. Therefore, there is not much clarity on the career progression details of elite performers. and the analysis of athletes who achieve success during their youth but not during adulthood and vice versa may be informative to provide benchmarking data of typical developments. Further, it may help identify gender differences and/or event-specific patterns. Nowadays, it is relatively well known that early success is not a pre-requisite for achieving success during adulthood in a few sports.[11-14] In fact, it has been reported that the early-success track and field athletes who were able to sustain the same level during adulthood reach their peak performance earlier than the rest,[13] and experience a plateau in performance around 19-20 years of age.[12,14] The average rate of performance improvement from junior to senior was lower in this group than athletes that reached their success only at the adult level.[11] Consequently, the junior-to-senior transition rate, usually identified as the chance for an early-success athlete to become an elite senior athlete, has been low in different CGS sports. We recently reported that the overall probability of becoming a senior elite swimmer competing in sprint events (i.e., 50 and 100m events in all swimming strokes) was ~21% in males and ~25% in females, confirming the low rate of the transition to elite junior-to-senior career.[11]

Nevertheless, while different studies provide retrospective information about sprinter swimmers' career pathways[6,9] achieving success during their senior career at the international level, little is known about the rate of progression and how those differ between gender and events using a prospective and retrospective longitudinal approach. A prospective and retrospective longitudinal approach that tracks the performances across the whole swimmers' career allows would allow to investigate better the career characteristics of early- and late-successful swimmers.[11-15] The prospective analysis of competition data helps identify elite young swimmers and allows tracking their performance across competitions. In contrast, a retrospective approach would enable the identification of elite senior athletes and trace back their career up to the beginning of their international competitions. The combination of the two analytical perspectives has already been implemented in other sports.[13] Considering the limited information on career progressions and the differences in elite vs. non-elite performers, we analysed the career performances of a large sample of international swimmers competing in the four swimming strokes of long course sprint events (i.e., 50m and 100m). The present study aimed to describe the career progression in terms of age of performance, peak performance, and annual performance improvement (i.e., annual percentage performance change) in elite international swimmers reaching success early or late. Considering previous studies conducted on track and field athletes,[12-14] we expected a different pattern in career progression between early- and later-successful swimmers.

Materials and Methods

This study further analyzed the data collected for one previously published.[11] The source of data collection was the public database Swimrankings (https://www.swimrankings.net/) supplied by the European Swimming Federation (LEN- Ligue Européenne de Natation). This database provides the official annual ranking of European swimmers considering junior (athletes aged up to 17 or 18, in females and males respectively) and senior categories (athletes aged upper 17 or 18 according to gender) and the career performance times of each swimmer.

In the initial step, the names of swimmers competing in long course sprint events (i.e., 50m – 100m) of freestyle, backstroke, breaststroke, and butterfly ranked in the top 50 official lists in junior or senior categories between the competition's years 2004-2019 were downloaded. Data were screened for removing duplicate participants' names (i.e., swimmers in the Top 50 in one more year). In the second step, seasonal best performance times were retrospectively extracted from these swimmers. To create each swimmer's career path, the seasonal best performance times were collected from the age of 10 until career termination or on December 31, 2019, if the individual was still competing.

Swimmers who registered their best personal performance in the last 3 yrs of the calendar age (i.e., from 2017 to 2019) were excluded to avoid including swimmers who have not fully expressed their potential due to their young age.[11] Moreover, a swimmer was only included in the final database if he/she registered at least five seasonal best performance times during his/her career, not necessarily consecutive. The specific information about the sample selection is reported in Supplementary File 1. Since the data were available on publicly available resources, no informed consent was obtained. The local ethics committee approved the study at the University of Torino.

Statistical analysis

Separate analyses were performed for each event and gender. The seasonal best performance times were recorded across an extensive range of years. Thus, the dataset contained swimmer generations competing with different FINA rules (e.g., full-body polyurethane swimsuits). Therefore, we normalized all seasonal best performance times considering the best time in the relative year using the following formula:[7,11,14,16]

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

A Normalized Seasonal Best Performance Times value of 100 corresponds to the best performance of that relative year. Subsequently, swimmers were ranked according to their Normalized Seasonal Best Performance Times in an all-time ranking according to their age (i.e., junior, and senior category). According to the FINA World Junior Swimming Championships rules, the junior category included female swimmers between ages 14 and 17 and male swimmers between ages 15 and 18. Consequently, the senior category included female swimmers over age 17 and male swimmers over 18.

In the first data analysis step, individual trends were generated from all swimmers by fitting a quadratic curve.[12,14,17] Successively, the following parameters were calculated:

a) age of peak performance;
b) peak performance;
c) rate of performance improvement from the last years of junior career 17 (or 18 if male) to the senior peak performance;
d) annual best performances from 14 (or 15 if male) to 30 yrs of age;
e) annual performance improvement (percentage) from 14 (or 145 if male) to 30 yrs of age.

Early- and later-success swimmers were identified using an all-time ranking in the second data analysis step. To identify elite early- and later-success swimmers, we considered the first 50 swimmers (now called Top 50 – unique individuals) that ranked elite status during junior and/or senior categories. The junior-to-senior transition rate remained similar using the same approach but selected swimmers from the top 100 to the top 10 ranked athletes. The proportion did not change,[11] so for conciseness, we decided to discuss and present only the results of the Top 50. Subsequently, three subgroups (separately for male and female athletes) of swimmers were defined:

(1) *Only Junior:* swimmers that reached the top 50 rankings during their junior career (from 14 and 17 yrs or 15 to 18 yrs in females and males, respectively) but that did not reach the top 50 rankings in the senior career;

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

(3) *Only Senior*: swimmers that reached the top 50 rankings during their senior category (over 17 yrs or 18 yrs in females and males, respectively) but did not reach the top 50 rankings in the junior career.

Based on this selection criteria, all swimmers that did not reach the annual top 50 rankings during junior and/or the top 50 rankings during senior careers were excluded from further analysis.

A series of one-way analyses of variance (ANOVA) was carried out to compare the career features among the three subgroups (i.e., age of peak performance, the peak performance, and the rate of performance improvement). Welch's F test was applied when homogeneity of variances was violated (i.e., Levene's Test of Homogeneity of Variance, i.e., $P< 0.05$). When the main effect in group comparison was relevant, post-hoc pairwise comparisons were performed.

Separately for gender and events, linear mixed models were used to investigate the difference in performance progression between *Only Junior, Junior and Senior*, and *Only Senior* subgroups. Specifically, the annual best performances and the annual performance improvement from the age of 14 (or age of 15 if male) to age of 30 yrs were separately included in the model as dependent variables, while swimmer subgroups and age were considered fixed effects. Subjects were included as a random effect. Interaction between swimmer subgroups and age (subgroup × age) was considered for the analysis. All career progression data were analyzed through custom-written software in MATLAB (version R2021b; Mathworks, Natick, Massachusetts, USA). Linear mixed model analyses were carried out using the statistical package R (version 4.0.3; R Core Team, Foundation for Statistical Computing, Vienna, Austria). The graphs were prepared with GraphPad Prism (version 8; San Diego, USA). The level of significance was set at $P \leq 0.05$.

Results

The initial dataset included a total of 6,003 swimmers with a total of 58,760 unique records with an average of 9.9 ± 3.2 and 9.7 ± 3.2 observations per male and female swimmer, respectively. Specifically, 2,126 athletes were freestyle swimmers (50m: n=1,012, 32.0%

females; 100m: n=1,114, 33.2% females), 1,270 were backstroke, (50m: n=630, 48.6% females; 100m: n=640, 46.4% females), 1,301 were breaststroke swimmers (50m: n=646, 48.5% females; 100m: n=655, 46.0% females), and 1,306 were butterfly swimmers (50m: n=662, 45.8% females; 100m: n=644, 47.5% females). From this dataset, swimmers in the O*nly Junior, Junior and Senior,* and *Only Senior sub-category* were identified. The specific information about the total sample size of swimmers included in the first screening and selected swimmer in each subgroup are reported in Supplementary File 2.

< Table 1 about here>

Table 1 shows the mean and 95% CI of the peak performance, the peak age performance, and the rate of performance improvement for *Only Junior, Junior and Senior,* and *Only Senior* subgroups. The ANOVA outcomes are reported in Supplementary File 3. Significant differences were observed among the subgroups. In all swimming events, the age of personal peak performance was lower for *Only Junior* (average age of 19.7 and 18.1 yrs in males and females, respectively) than for *Junior and Senior* (average age of 23.4 and 22.6 yrs in males and females, respectively) and *Only Senior* subgroup (average age of 25.0 and 24.5 yrs in males and females, respectively) subgroup. *Junior and Senior* and *Only Senior* subgroups recorded the best peak performance compared to that of the *Only Junior* subgroup, while in general, the *Junior and Senior* and *Only Senior* subgroups showed similar peak performances in all disciplines. Finally, the *Only Senior* subgroup showed a larger rate of performance improvement (average of -7.5 and -6.2% in males and females respectively) compared with that of the *Only Junior* (average of -1.2 and -0.3% in males and females respectively) and *Junior and Senior* subgroups (age of -4.3 and -3.3% in males and females respectively). Further details about post-hoc comparisons are provided in Table 1.

Figure 1 shows a representative example (i.e., 100m freestyle) for the performance progression (Figure 1 a-b) and the annual performance improvement (Figure 1 c-d) throughout the career of male and female swimmers. The details for all events and gender are reported in Supplementary Files 4 and 5. The results of the linear mixed models are reported in Supplementary File 3. Significant subgroup × age interactions were observed in annual performance progression for all events and in both genders (see Supplementary File 3). Differently for the annual performance improvement, significant subgroup × age interactions were observed in all events and both genders, excluding 50m Freestyle and Backstroke in males and 50m and 100m breaststroke in females (see Supplementary File 3).

<Figure 1 about here>

Discussion

The present study aimed to provide a robust understanding of the career pathway differences between early- and later-success international swimmers competing in the four swimming strokes of long course sprint events (i.e., 50m and 100m). For this purpose, we evaluated the performance pathway of ~ 6,000 international swimmers. By tracking the career of a large sample of swimmers, it was possible to differentiate the career trajectories of successful senior swimmers from early successful swimmers (i.e., swimmers who did not achieve success in the second part of their career). The main findings of the present study were: 1) the top senior swimmers reached their peak performance later than their early-success counterparts, 2) top senior swimmers (considering both *Junior and Senior* and *Senior* subgroups) showed a more sustained improvement in performance at the senior age, while early-success swimmers experience stagnation in their performances. On the other hand, data suggested that 3) performance progression is not unique among successful swimmers (i.e., *Junior and Senior* and *Senior* subgroups) and that there are different pathways to reach an elite level performance.

As a preliminary note, the four disciplines shared the same patterns for the age of peak performance and the rate of performance improvements. Indeed, the confidence intervals of those estimates are largely crossing each other (see Table 1). This means that despite the obvious technical differences between strokes, the swimmers' career trajectories mostly depend on disciplines. Similarly, no clear differences can be found between the 50 and 100m distance. For this reason, the following discussion will apply without major differences to all strokes and distances.

The *Only Junior* subgroup achieved the best performance, on average, before the age of 20 and ~3-4 yrs before the *Junior and Senior* or 5-6 yrs before the *Only Senior* counterparts (see Table 1). In the *Junior and Senior* and *Only Senior* subgroups, the peak performance occurred quite a few years after reaching biological maturity. This data was in accordance with previous studies on swimming[1,8,10] and track and field athletes.[12,14] On the other hand, the age ranges (i.e., from about 18 to 21 yrs) at which the *Only Junior* subgroup reached the best performance are similar to the results reported by Dormehel et al.[5,6] that modeled progression performance of female and male swimmers through adolescence. Moreover, as recently demonstrated in track and field disciplines,[12,13] the elite senior swimmers considered elite during their junior career (i.e., *Junior and Senior* subgroup) reached their peak performance earlier than the rest of the elite senior athletes (*Only Senior*). Although there were differences in age of peak performance for both male and female subgroups, female swimmers meanly reached the peak performance one year before than their male counterparts.[3,5,6,10] Indeed, the females' earlier growth and maturation might explain this difference.[18] . Also, young female swimmers of international caliber already compete with older counterparts from the age of 15 yrs.[6]

As expected, the *Only Junior* subgroup showed a lower peak performance than the *Only Senior* and *Junior and Senior* subgroup (see post hoc comparison in Table 1). *Junior and Senior* and *Only Senior* subgroups showed similar peak performances in all disciplines with no significant difference. Based on these results, it is possible to suggest that for some athletes competing at a higher level, both in junior and senior competitions, there could be a little career advance if they are capable of continuing the progression. These data partially agree with the notion that competing in the Junior World Championship may also translate into later success at the senior level.[19,20] However, considering the large cohort of athletes identified in the O*nly Junior* subgroup, it is likely that this group of athletes might have been mostly constituted by early matures and/or individuals who were unable to progress for various reasons. The annual best performance progression (see, for example, Figure 1 a-b) and the annual performance improvement (see, for example, Figure 1 c-d) clearly distinguish the career pathway of successful and unsuccessful swimmers. The annual best performance progression showed a similar trajectory between *Only Junior* and *Junior and Senior* subgroups in the early part of their career and is largely comparable up to age around 18-19 yrs. Nevertheless, starting from the age of around 18-20 yrs, the career pathways of these two subgroups started to differentiate significantly. While the *Junior and Senior* subgroup showed a higher trend in the annual performance improvement, the *Only Junior* subgroup seemed just to reach the performance plateau. The *Only Senior* subgroup showed a different tendency in the annual best performance progression. While worse performances were observed during the entire junior career in comparison with the *Only Junior* and the *Junior and Senior* subgroup, starting from age around 19-20 yrs, the *Junior and Senior* subgroup showed the best career pathway in comparison with the *Only Junior* subgroup, reaching the same performance level of the *Junior and Senior* subgroup from age around 20-21 yrs. The data about the rate of performance improvement from the last years of junior career to the senior peak performance confirmed these observations. In general, the *Only Senior* subgroup obtained about 6-8% performance improvements. The annual performance improvements of *Junior and Senior* and *Only Senior* subgroups were higher until the age of 20-24 yrs, with annual improvements of 1-2% until their peak performance. The Only Junior showed a performance stagnation at about 16-18 yrs in females and 19-20 yrs in males. These data suggest that the swimmers that reach senior success exhibit a continued progression during their career. Therefore, considering talent selection and development strategies, our results may indicate that performance progression in the transition towards adult career might be a strong indicator of performance potential in sprinting events. Together, these results continue supporting the idea of the low prediction abilities performances in the early part of the youth career to identify successful swimmers in adulthood.[4,11]

There are different pathways to reaching an elite-level performance. In the present study, we identified two main possible patterns. The first one, obtained by the *Junior and Senior* subgroup, consisted of reaching top-level in the early ages and then maintaining it in adulthood (albeit less frequent). The second one, obtained by the *Only Senior* subgroup, was more frequent and consisted of larger performance improvements until later in life despite limited success at earlier ages. In fact, the prevalence of *Only Senior* was generally higher than *Junior and Senior* subgroup (see supplementary File 1). This study also shows that the consistent performance improvement in the years before peak performance is a fundamental factor that distinguishes athletes that reach the top-level compared to those who do not. For this reason, it may be possible to speculate that greater time is required to develop and maintain an efficient aquatic motion necessary for success.[3] At the same time, it is possible to speculate that earlier maturation and the consequence of early strength gains could be responsible for the early success in sprint events. Previous work has already indicated that maturity status is a substantial predictor of swim performance, and early maturing swimmers reach more early success than their late-mature counterparts.[21] Moreover, another possible explanation may be related to the early training specialization. It is possible to suppose that an early emphasis on training volumes and intensities partially contribute to the early peaking phenomenon observed in the *Only Junior* subgroup. Consequently, early-success swimmers may benefit from an early specialization in the short-term but not in the long-term.[22,23] Previous work has suggested that successful swimmers who experienced more multiport practices in their adolescent years without excessive specialization may better develop senior success.[22,23] Again, different aspects such as injuries,[24] relative age effects,[25-28] dual-career barriers,[29] and social and personal factors[30] may explain why swimmers in the *Only Junior* subgroup reached the short-term but not the long-term success. Together, these possible explanations are only speculations that should be investigated more in-depth in future studies. At the current stage and with our data, it is impossible to identify what exactly causes this phenomenon, and more studies are definitively needed.

The study has some limitations that should be underlined. Our analysis was solely based on rankings and did not include information about success at the major international level competitions. Moreover, our results are based only on swimming performance progression; no information was available on the individuals' maturity status and training load characteristics in the database. Finally, the results of this study are based on European rankings and not on Worldwide rankings.

Practical implication

Practically, these results provide useful information to construct a more realistic expectation based on the annual performance progression for the future development of elite junior swimmers and may help coaches and talent development programs with realistic benchmarks to assess athletes' progression. The results of this study suggest that performance progression in the transition towards adult career might be a strong indicator of performance potential. Also, data suggested that it is hardly justifiable to select swimmers from talent development programs (and de-select others) only based on pre-adolescence performances. In simple terms, young swimmers in sprinting events might still develop after adolescence and reach an international level of performance if the pre-requisites are there. Increasing awareness of these findings among athletes, parents, and coaching communities might help develop better approaches to retain and develop athletes that may be discouraged by selection policies favoring early maturity.

Conclusion

In conclusion, our results showed differences in career pathways between early- and later-successful swimmers or swimmers who managed success during their youth and adulthood. Most of the early-successful swimmers did not maintain the same level of competitiveness during adulthood and showed a different age of peak performance and career pathway. The research results indicated that early-success swimmers achieved earlier their peak performance than their peers and, therefore, with less development margin.[13] On average, this group experienced a plateau in performance around the age of 20 yrs, while the two other groups continued to produce consistent performance improvements up to around 25 yrs. The policy makers of talent developmental programs should notice that only swimmers that over the last year of junior career still improve their performance by 1-2% have real chances to achieve success at the senior level on sprinting events.

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Conflict of Interest Statement

The authors declare no conflict of interest.

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Figure legends

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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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 J*unior & Senior* and *Only Senior.*

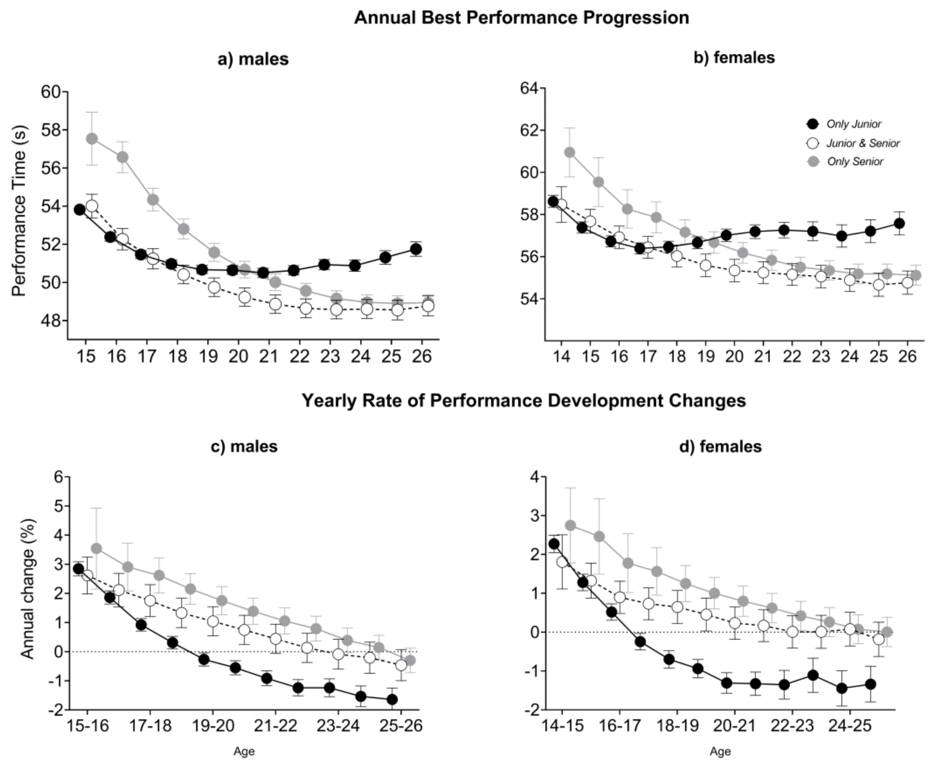
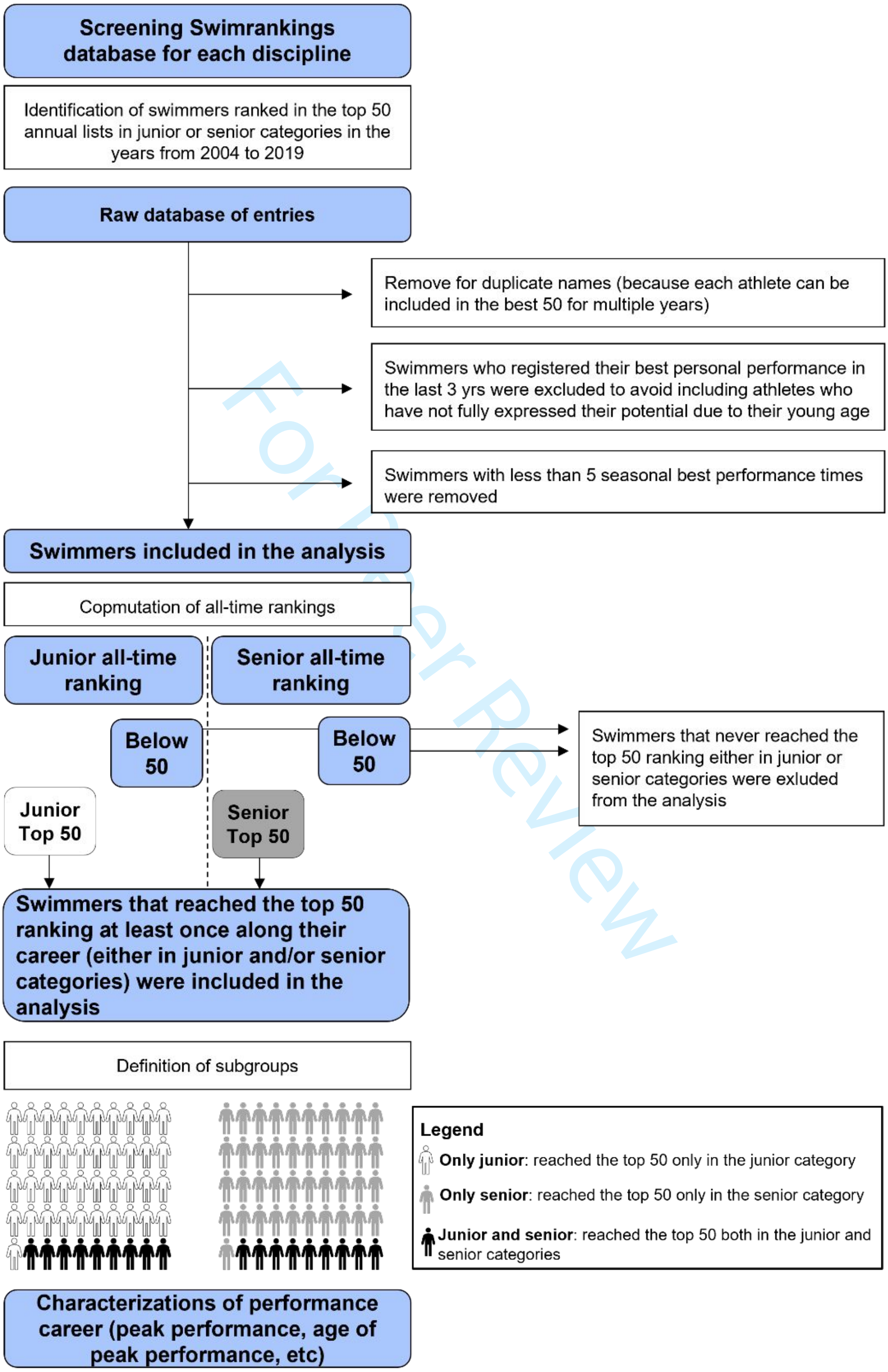


Figure 1 - Average and 90% CI annual best performance progression (panel a-b) and the annual performance improvement (panel c-d) are reported for 100m freestyle of the three subgroups of swimmers.

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.

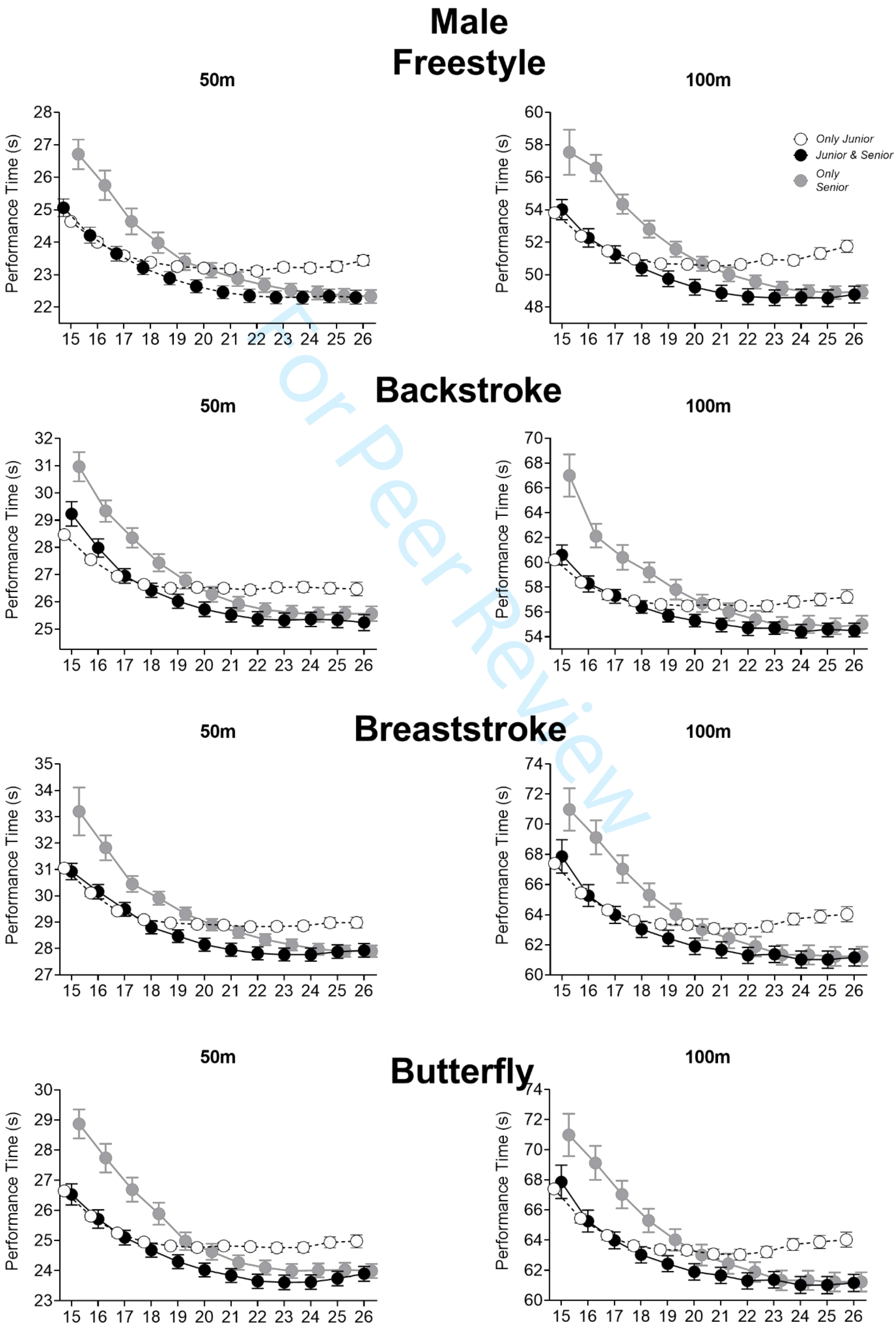
Supplementary File 3: One-way ANOVA and linear mixed model outcomes according to gender and sprint events

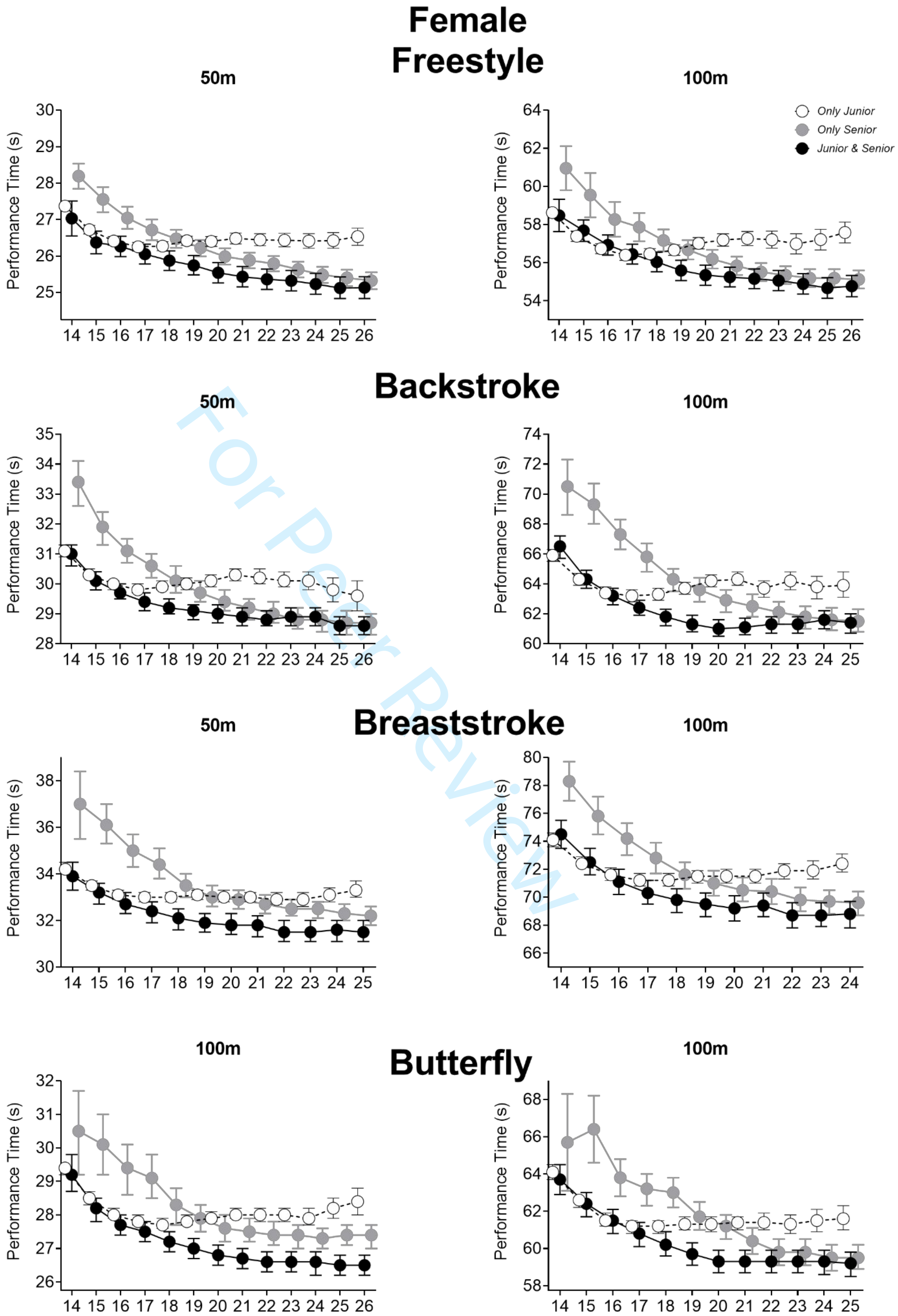
	Male							
	50m Freestyle	**100m Freestyle**	**50m Backstroke**	**100m Backstroke**	**50m Breaststroke**	**100m Breaststroke**	**50m Butterfly**	**100m Butterfly**
Age of Peak Performance	F=76.95***	F=102.43***	F=52.64***	F=51.86***	F=52.18***	F=66.35***	F=70.89***	F=68.57***
Peak Performance	F=53.55***	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

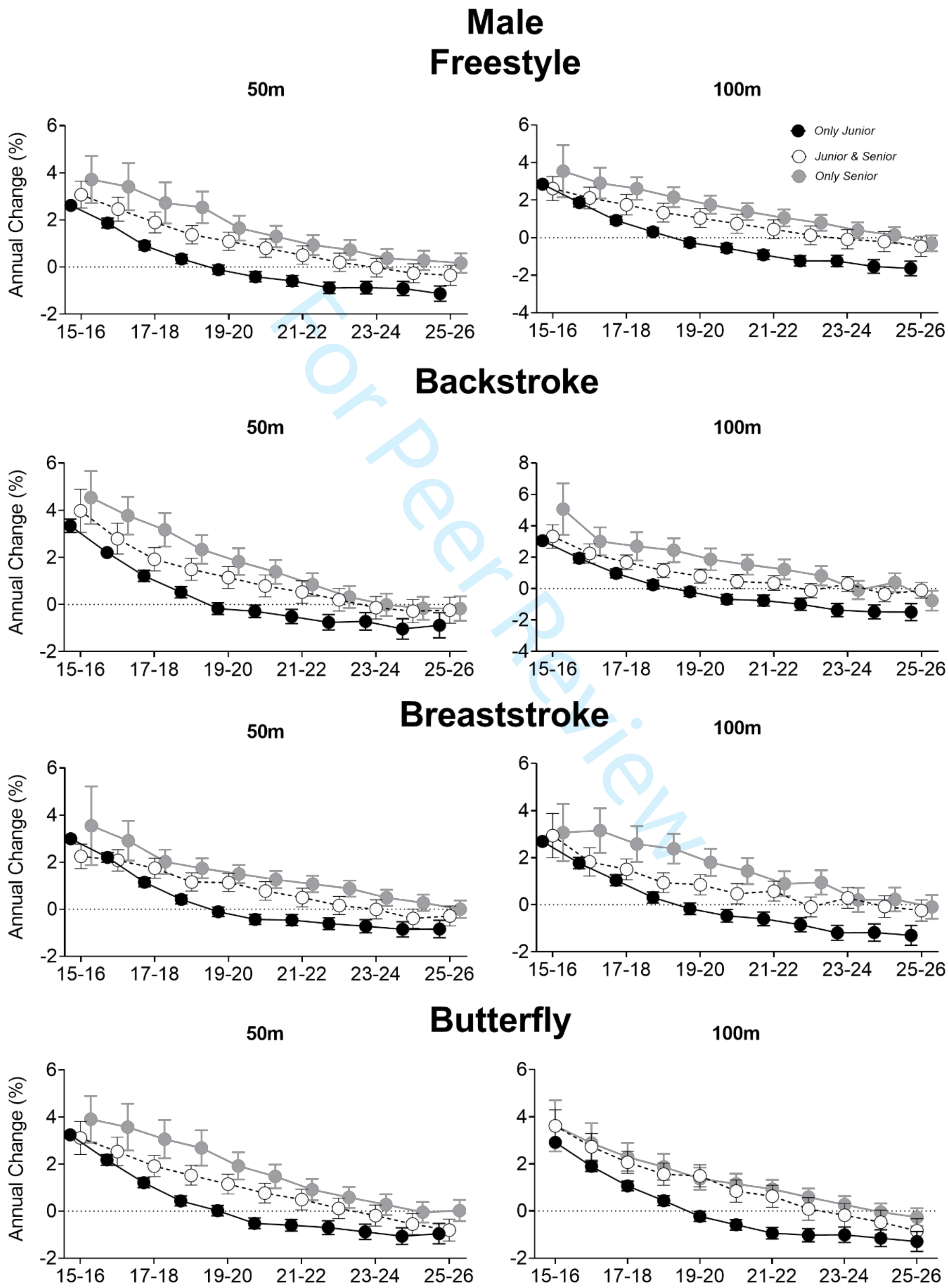
Annual best performance progression in the all considered events for *Only Junior, Junior and Senior,* and *Only Senior* subgroup. Data are presented separately for Male and Female Swimmers.

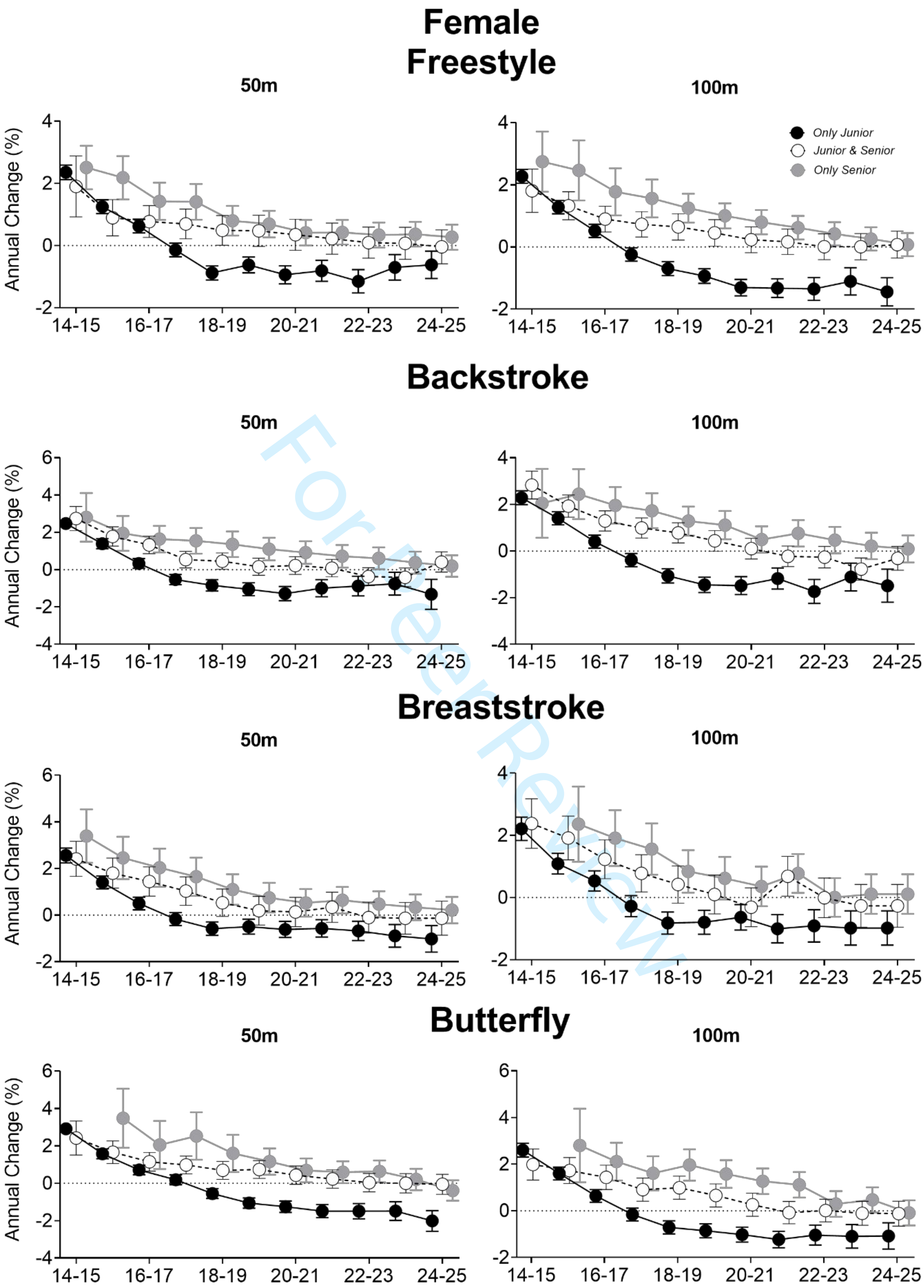



Female
Freestyle
Backstroke
Breaststroke
Butterfly
50m
100m
Performance Time (s)
Only Junior
Only Senior
Junior & Senior

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
50m
100m
Only Junior
Junior & Senior
Only Senior
Backstroke
50m
100m
Breaststroke
50m
100m
Butterfly
50m
100m
Annual Change (%)
14-15
16-17
18-19
20-21
22-23
24-25