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Original research

Normative data and percentile curves for long-term athlete development in swimming

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ABSTRACT

Objectives: To provide normative data and establish percentile curves for long-course (50 m pool length) swimming events and to compare progression of race times longitudinally for the various swimming strokes and race distances.
Design: Descriptive approach with longitudinal tracking of performance data.
Methods: A total of 2,884,783 race results were collected from which 169,194 annual best times from early junior to elite age were extracted. To account for drop-outs during adolescence, only swimmers still competing at age of peak performance (21–26 years) were included and analyzed retrospectively. Percentiles were established with z-scores around the median and the Lambda-Mu-Sigma (LMS) method applied to account for potential skewness. A two-way analysis of variance (ANOVA) with repeated measure and between-subject factor was applied to compare race times across the various events and age groups.
Results: Percentile curves were established based on longitudinal tracking of race times specific to sex, swimming stroke, and race distance. Comparing performance progression, race times of freestyle sprint events showed an early plateau with no further significant improvement ($p > 0.05$) after late junior age (15–17 years). However, the longer the race distance, the later the race times plateaued ($p < 0.05$). Female swimmers generally showed an earlier performance plateau than males. Backstroke and freestyle showed an earlier performance plateau compared to the other swimming strokes ($p < 0.05$).
Conclusions: Performance progression varied between sex, swimming strokes, and race distances. Percentile curves based on longitudinal tracking may allow an objective assessment of swimming performance, help discover individual potentials, and facilitate realistic goal setting for talent development.
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Practical implications

- To obtain normative values with a predictive character, percentiles should be accounted for drop-out and be established retrospectively based on longitudinal tracking.
- For talent selection and development, coaches and federation officials should use percentiles to evaluate performance progression rather than current competition performance.
- With the large range of performance levels covered, percentiles help to establish development guidelines and set realistic goals for a wide range of swimmers from regional to international level.
- While junior swimmers' race times naturally show annual improvements due to biological maturation, changes in percentile ranking from one season to another provide an objective assessment of performance progression and determines over- and underperformers.
- Percentiles provide a relative assessment of race times to compare swimming performance between various swimming strokes and race distances and assess strengths, weaknesses, and future potential.

1. Introduction

Elite sports continuously strive towards the best performance possible. Young swimmers dream of the Olympic games and are inspired by gold medalists and former champions. For development programs, these young swimmers are typically selected based on their age-related competition performance rather than progression of predictors related to anthropometrics, kinematic variables, and movement efficiency.[1] As such, some top-elite swimmers outperform their elite, sub-elite and competitive peers from 12 years of age onwards.[2] However, the development process of top-elite swimmers shows large variations between individuals. Male swimmers usually do not reach

Abbreviations: BU, butterfly; BA, backstroke; BR, breaststroke; FR, freestyle; IM, individual medley.

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top-elite level before the age of 17 years, and often closer to the age of 21 years.[2] This discrepancy is even larger in female swimmers reaching top-elite level aged 14 to 24 years.[2] As such, junior level swimming success does not predict success at senior age.[3]

Therefore, performance progression and potential for elite age success rather than the current competition performance during adolescence should be considered for talent selection and identification.[4–6] Percentile curves are a practical method to provide normative values for swimmers[7] and assess non-linear performance progression across various age groups.[8] While mean values ± standard deviation (SD) of race times provide an insight into a specific age and performance group of swimmers,[9] percentiles cover performance progression the entire range of performance levels from regional to world-class swimmers. Therefore, expected annual performance improvements[9,10] can be adjusted to provide realistic goals and expectations for lower and higher ranked swimmers of a particular age-group. Annually improving race times, due to biological maturation during adolescence,[5,9–11] provide a challenge for the identification of over- and underperformers. Comparing development of the percentile ranking from one year to another provides an objective assessment to identify performance progressions above or below average. Additionally, mean values ± SD of race times are specific to the swimming event and age-group. Therefore, the z-score around the median, i.e. percentiles,[12] provide a relative performance assessment.[12] Race times can be objectively compared between different events, i.e. various swimming strokes and race distance, to identify individual strengths and weaknesses and predict future potential.

Previous studies established normative values based on swimmers of a particular nation[9,10] and swimming stroke.[2,9,10] Therefore, a database is required that includes data from multiple swimming nations that represent the international performance level. As early junior success does not predict success at elite age,[6] transfer-rates of junior elite swimmers to senior elite swimmers are low, with only one third of pre-junior national squat swimmers being reselected at senior elite level.[3] To provide normative values with a predictive character, percentiles should be established based on longitudinal tracking[5,11] and account for drop-outs at early stages of the talent pathway.[3,6] Thus, only race times of swimmers who were still actively competing at age of peak performance (21–26 years)[13] should be retrospectively analyzed.

In regard to race distance, annual percentage improvements were lower the longer the race distance,[9,10] as swimmers may need more time to develop the aerobic capacity for these long-distance events.[16] Additionally, performance progression may alter between swimming strokes due to different technical demands and movement economy.[14] As such, swimmers may reach their top level earlier in backstroke (BA) and freestyle (FR), as these swimming strokes are commonly introduced earlier in learn-to-swim programs compared to the other swimming strokes.[15] However, differences in performance progression between the various swimming strokes are yet to be determined, in particular between butterfly (BU), breaststroke (BR), and individual medley (IM).

The aim of the study was (1) to provide normative data based on longitudinal tracking for swimming long-course (50 m pool length) events and to establish percentile curves for the four swimming strokes (BU, BA, BR, FR), as well as individual medley (IM) across up to six distances (50 m, 100 m, 200 m, 400 m, 800 m, and 1500 m) for both male and female swimmers and (2) to compare performance progression of race times between the various swimming strokes and race distances. The hypothesis was that performance progression is different between swimming strokes and race distances with earlier plateau in BA and FR as well as short-distance events.

2. Methods

In total, 2,884,783 long-course (50 m pool length) race results of male and female swimmers were collected from the publicly accessible, official database (Swimrankings.net, Splash Software Ltd., Spiegel bei Bern, Switzerland) of the European Swimming Association LEN (Ligue Européenne de Natation), with permission for scientific analyses and anonymous publication of the findings. The study was pre-approved by the leading institutions internal review board (Reg.-Nr.: 124_LSP_234-3.2.127) and is in line with the code of conduct of the World Medical Association for research involving human participants (Helsinki Declaration).

In the initial step, race times of all swimmers were extracted from the 2018 database to account for all performance levels from international to regional competitions. In the second step, a longitudinal analysis was performed to account for drop-out at an early stage of the talent pathway. Therefore, all cross-sectional data were excluded and only swimmers still actively competing at the age of peak performance (21–26 years)[13] further analyzed. From these swimmers, 169,194 annual best times were retrospectively extracted. One annual best time for age of peak performance (between 21 and 26 years of age) and one for each year from 20 to 10 years of age. A minimum of two annual best times per swimmer for the particular swimming event were required to be included in the data analysis in order to investigate trends over the years but include the maximal number of swimmers in the percentile curves. Specifically, 12,128 (43.3%), 12,878 (45.9%), and 3031 (10.8%) swimmers showed 2–5, 6–9, and > 10 annual best times, respectively, in a particular swimming event. Details are provided in the supplementary material (Table A1). Percentile curves were established separately for both sexes across all events, i.e. BU (50 m, 100 m, 200 m), BA (50 m, 100 m, 200 m), BR (50 m, 100 m, 200 m), FR (50 m, 100 m, 200 m, 400 m, 800 m, 1500 m), and IM (200 m, 400 m). Race results that were slower than three times the standard deviation of each particular age were excluded as outliers.[17]

Talent development programs are typically characterized by Learn-to-swim programs from the age of 6–10 years, followed by regional and national leagues with regular competition participation for talented junior swimmers.[15] Race distances typically increase the older the swimmers.[18] Therefore, percentiles for 50 m, 100 m, 200 m/400 m, and 800 m/1500 m events were displayed from the age of 10, 11, 12, and 13 years, respectively. However, there was a low number of 1500 m FR races ($n = 8$) in the female 13 year age group, which affected 85th to 99th percentile. As such, the 85th to 99th percentiles were interpolated for the 13 year age group of female 1500 m FR swimmers based on the mean improvement of 5.59 ± 8.63 s per year across the other age groups.

Elite sports strives towards the best performance possible, with athletes aiming to win medals at international championships. Therefore, long-term athlete development was analyzed based on the 90th to 99th percentile and compared between the pooled age groups of early junior (10–14 years), late junior (15–17 years), transition (18–20 years), and elite age (21–26 years). Performance progression may be different between swimming strokes and race distances,[9,10] and swimmers specialize in a particular swimming stroke rather than race distance.[19] As the 200 m distance is the only common race distance across all swimming strokes in the Olympic events, performance progression between the swimming strokes were compared across their 200 m events, as such unbiased from interference of race distance. As only FR provides the complete range of race distances from 50 m to 1500 m, differences in performance progression between race distances were analyzed based on FR.

3. Statistical analysis

Data are presented as mean ± SD. Percentiles across age groups were compared using a two-way analysis of variance (ANOVA) with repeated measure and between-subject factor: age groups (early junior – late junior – transition – elite age) x swimming stroke (BU–BA–BR–FR–IM) or race distance (50 m–100 m–200 m–400 m–800 m–1500 m). An alpha-level of 0.05 indicated statistical significance. Partial eta[2] (${}_p\eta^2$) of 0.01, 0.06, and 0.14 indicated a small, medium, and large effect, respectively. Residuals were normally distributed in the Q-Q plot displaying a diagonal straight line of predicted values across standardized residuals.[17] If variances were unequal between within-subject factors based on Mauchly's test of sphericity, the Greenhouse-Geisser correction was applied to the main effects based on $\varepsilon < 0.75$.[17] Tukey's *post-hoc* test was used with homogenous variances based on Levene's test. If violated, *post-hoc* comparisons were corrected according to Bonferroni.[17] All calculations were performed with race times expressed in seconds [s]. For better practicability of the percentiles, race times were displayed as [mm:ss.00] in tables and diagrams. Percentile data were prepared in Microsoft Excel 2016 (Microsoft Corporation, Redmond, WA) for the subsequent statistical analyses in JASP statistical software package version 0.14 (JASP-Team, University of Amsterdam, Amsterdam, The Netherlands).

Percentiles were determined by the z-scores around the median using RStudio (version 1.1.456, RStudio Team, Boston, United States) to compare performance data between the various events. To account for potential deviation from Gaussian distribution, the Lambda-Mu-Sigma (LMS) method was applied.[12,20] With its three-factors, the LMS method is an extension of the square (root) power transformation using lambda (L), the median (M), and corresponding coefficient of variation (S).[12,20] Accounting for right- and left-sided skewness in particular, is important, as it represents the dominant contributor to non-normality.[21] With the LMS method the percentiles are smoothed as a whole and the curves are matched to each other.[12] The LMS method is often used to establishing percentile curves of performance data with a non-linear increase across different age groups during adolescence.[8,12,20,21] Cubic spline interpolation was applied in the diagrams.[12] This interpolation procedure creates multiple cubic polynomials that add interpolated data points to the gaps between existing points so the percentile curve transverses smoothly between the age groups.[12]

4. Results

Percentile curves were established based on retrospective longitudinal tracking for race times specific to sex (male – female), swimming stroke (BU–BA–BR–FR–IM), race distance (50 m–100 m–200 m–400 m–800 m–1500 m), and age group (early junior – late junior – transition – elite). Percentile curves during talent development of male and female 50 m FR swimmers are shown in Fig. 1.

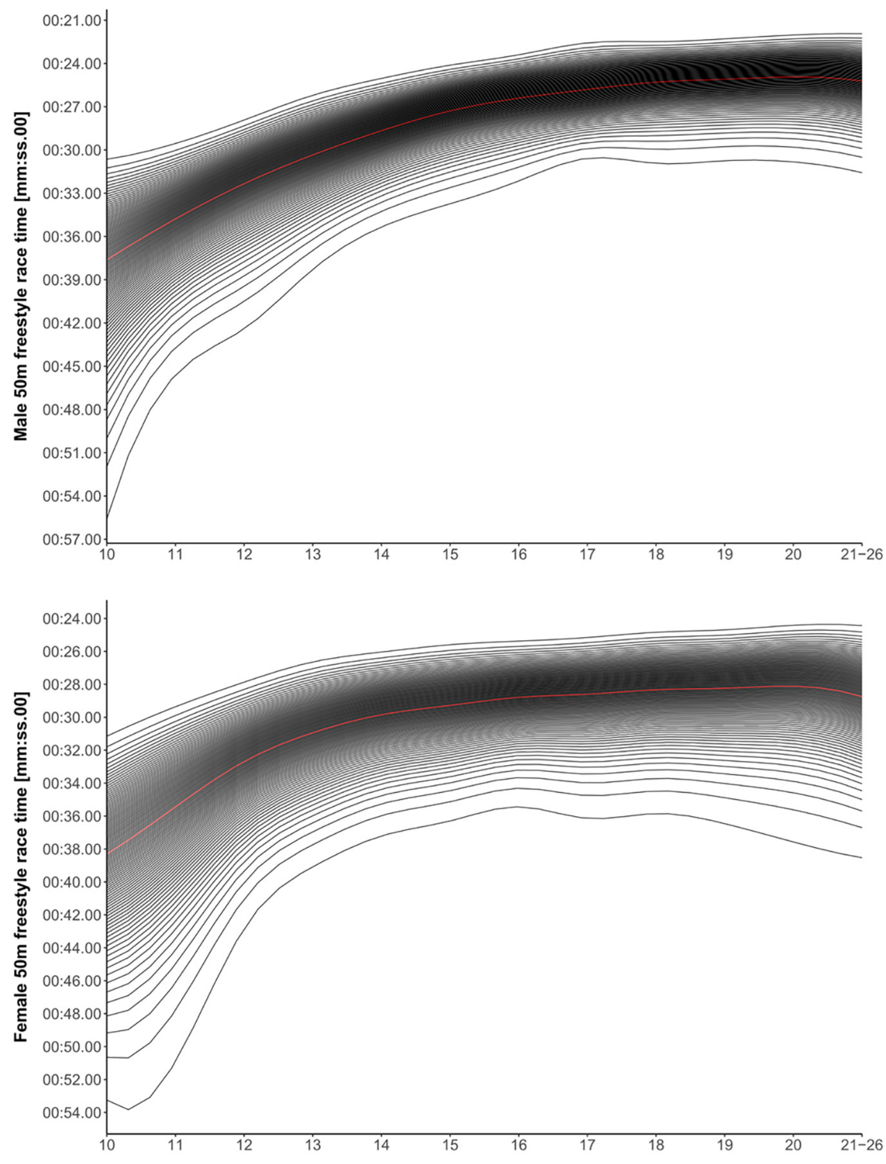

Fig. 1. Percentile curves for 50 m freestyle race times during talent development of male and female swimmers from the age of 10 years to age of peak performance (21–26 years). Diagrams for all swimming strokes and race distances for both sexes are implemented in the percentile calculator and can be retrieved from the supplementary material.

Table 1
Race times [s] across the 99th to 90th percentiles during long-term athlete development of male swimmers. Performance progression between swimming strokes were compared with a two-way analysis of variance (ANOVA) with repeated measure and between-subject factor and corresponding partial eta-square ($_p\eta^2$) effect size across 200 m races. Performance progression between race distances were compared using the freestyle events.

	Age group					ANOVA		
	Early junior *10–14 years*	Late junior *15–17 years*	Transition *18–20 years*	Elite *21–26 years*		*F*-value	*P*	$_p\eta^2$
Swimming stroke								
Butterfly	141.6 ± 3.1 $^{BR\ FR\ IM}$	122.8 ± 1.8 $^{*\ BR\ FR\ IM}$	117.4 ± 1.6 $^{*\ BR\ FR}$	116.5 ± 1.8 $^{*\ BR\ FR}$				
Backstroke	142.2 ± 2.6 $^{BR\ FR}$	124.9 ± 1.9 $^{*\ BR\ FR}$	118.8 ± 1.7 $^{*\ BR\ FR}$	118.3 ± 2.1 $^{BR\ FR}$	(a)	$F_{(1 \mid 47)} = 27,344$	< 0.001	0.998
Breaststroke	160.7 ± 3.4 $^{BU\ BA\ FR\ IM}$	139.8 ± 2.2 $^{*\ BU\ BA\ FR\ IM}$	131.9 ± 2.0 $^{*\ BU\ BA\ FR\ IM}$	130.7 ± 2.4 $^{*\ BU\ BA\ FR\ IM}$	(b)	$F_{(4 \mid 45)} = 192$	< 0.001	0.945
Freestyle	128.5 ± 2.3 $^{BU\ BA\ BR\ IM}$	113.2 ± 1.7 $^{*\ BU\ BA\ BR\ IM}$	108.4 ± 1.4 $^{*\ BU\ BA\ BR\ IM}$	107.7 ± 1.8 $^{BU\ BA\ BR\ IM}$	(c)	$F_{(4 \mid 47)} = 96$	< 0.001	0.895
Individual medley	145.4 ± 2.7 $^{BU\ BR\ FR}$	126.6 ± 2.1 $^{*\ BU\ BR\ FR}$	120.8 ± 1.8 $^{*\ BR\ FR}$	119.9 ± 2.3 $^{*\ BR\ FR}$				
Race distance								
50 m	29.0 ± 0.6	24.1 ± 0.4 *	22.9 ± 0.4	22.7 ± 0.4				
100 m	61.5 ± 1.3 ^{50}	52.5 ± 0.8 $^{*\ 50}$	49.9 ± 0.7 $^{*\ 50}$	49.4 ± 0.9 ^{50}	(a)	$F_{(1 \mid 54)} = 17,776$	< 0.001	0.997
200 m	128.5 ± 2.3 ^{100}	113.2 ± 1.7 $^{*\ 100}$	108.4 ± 1.4 $^{*\ 100}$	107.7 ± 1.8 ^{100}	(b)	$F_{(5 \mid 54)} = 36,945$	< 0.001	1.000
400 m	270.2 ± 4.8 ^{200}	239.0 ± 3.5 $^{*\ 200}$	229.1 ± 3.0 $^{*\ 200}$	228.2 ± 3.8 ^{200}	(c)	$F_{(5 \mid 54)} = 3000$	< 0.001	0.996
800 m	546.3 ± 7.3 ^{400}	498.6 ± 5.3 $^{*\ 400}$	477.0 ± 4.6 $^{*\ 400}$	473.4 ± 5.6 $^{*\ 400}$				
1500 m	1030.2 ± 16.4 ^{800}	941.0 ± 11.1 $^{*\ 800}$	903.8 ± 10.0 $^{*\ 800}$	896.6 ± 11.9 $^{*\ 800}$				

Main effects:
(a) time: early junior – late junior – transition – elite age.
(b) group: swimming stroke | race distance.
(c) interaction: time × group.
Post-hoc comparison:
* significant difference ($p < 0.05$) compared to previous age group.
$^{BU,\ BA,\ BR,\ FR,\ IM}$ significant difference ($p < 0.05$) compared to butterfly, backstroke, breaststroke, freestyle, or individual medley, respectively, within particular age group.
$^{50,\ 100,\ 200,\ 400,\ 800}$ significant difference ($p < 0.05$) compared to the 50 m, 100 m, 200 m, 400 m, or 800 m event, respectively, within particular age group.

A percentile calculator, which can be retrieved from the supplementary material, includes all 34 percentile diagrams specific to sex, swimming stroke, and race distance for all age-groups from 10 years of age until age of peak performance. The software provides easy data access to retrieve the specific percentile for a given race time within a particular age-group.

The repeated measure ANOVA revealed a significant main effect of time across the age groups in both male and female swimmers ($p < 0.001$, Tables 1 and 2). For male swimmers, race times of the 99th to 90th percentile significantly improved across all age groups from early to late junior age, transition, and elite age for BU, BR, IM as well as 800 m and 1500 m FR races. A plateau after the transition age, defined as no further significant improvement of race times, was evident for BA as well as 100 m, 200 m, and 400 m FR races. The 50 m FR race times showed an even earlier plateau with no significant improvements after late junior age. Furthermore, female swimmers showed a later plateau in race times the longer the distance. The 100 m and 800 m race times by female swimmers plateaued at late junior and transition age, respectively, which was earlier than in male swimmers. Additionally, there was a main effect between swimming strokes ($p < 0.001$). Comparing swimming strokes, FR showed significantly faster race times than all other swimming strokes ($p < 0.05$) followed by BU, BA, and IM for both sexes while BR showed slowest race times ($p < 0.05$).

Table 2
Race times [s] across the 99th to 90th percentiles during long-term athlete development of female swimmers. Performance progression between swimming strokes were compared with a two-way analysis of variance (ANOVA) with repeated measure and between-subject factor and corresponding partial eta-square ($_p\eta^2$) effect size across 200 m races. Performance progression between race distances were compared using the freestyle events.

	Age group					ANOVA		
	Early junior *10–14 years*	Late junior *15–17 years*	Transition *18–20 years*	Elite *21–26 years*		*F*-value	*P*	$_p\eta^2$
Swimming stroke								
Butterfly	142.0 ± 3.0 $^{BR\ FR\ IM}$	132.2 ± 2.1 $^{*\ BR\ FR\ IM}$	129.7 ± 1.8 $^{*\ BR\ FR}$	129.1 ± 2.1 $^{BR\ FR}$				
Backstroke	144.4 ± 2.8 $^{BR\ FR}$	132.8 ± 2.2 $^{*\ BR\ FR}$	129.7 ± 2.2 $^{*\ BR\ FR}$	129.8 ± 2.6 $^{BR\ FR}$	(a)	$F_{(1 \mid 53)} = 14,692$	< 0.001	0.997
Breaststroke	160.5 ± 3.2 $^{BU\ BA\ FR\ IM}$	149.3 ± 2.5 $^{*\ BU\ BA\ FR\ IM}$	146.1 ± 2.3 $^{*\ BU\ BA\ FR\ IM}$	144.7 ± 3.0 $^{*\ BU\ BA\ FR\ IM}$	(b)	$F_{(4 \mid 45)} = 174$	< 0.001	0.939
Freestyle	130.9 ± 2.5 $^{BU\ BA\ BR\ IM}$	121.3 ± 1.9 $^{*\ BU\ BA\ BR\ IM}$	118.3 ± 1.8 $^{*\ BU\ BA\ BR\ IM}$	118.1 ± 2.2 $^{BU\ BA\ BR\ IM}$	(c)	$F_{(5 \mid 53)} = 25$	< 0.001	0.692
Individual medley	147.4 ± 2.8 $^{BU\ BR\ FR}$	136.5 ± 2.2 $^{*\ BU\ BR\ FR}$	133.5 ± 2.1 $^{*\ BR\ FR}$	133.0 ± 2.7 $^{BR\ FR}$				
Race distance								
50 m	29.4 ± 0.6	26.2 ± 0.4 *	25.5 ± 0.4	25.4 ± 0.5				
100 m	62.3 ± 1.2 ^{50}	56.5 ± 0.9 $^{*\ 50}$	54.9 ± 0.9 ^{50}	54.8 ± 1.1 ^{50}	(a)	$F_{(1 \mid 72)} = 4712$	< 0.001	0.989
200 m	130.9 ± 2.5 ^{100}	121.3 ± 1.9 $^{*\ 100}$	118.3 ± 1.8 $^{*\ 100}$	118.1 ± 2.2 ^{100}	(b)	$F_{(5 \mid 54)} = 32,471$	< 0.001	1.000
400 m	273.8 ± 5.0 ^{200}	254.1 ± 3.9 $^{*\ 200}$	248.8 ± 3.7 $^{*\ 200}$	247.7 ± 4.9 ^{200}	(c)	$F_{(7 \mid 72)} = 413$	< 0.001	0.975
800 m	545.1 ± 8.1 ^{400}	519.0 ± 7.1 $^{*\ 400}$	509.2 ± 6.7 $^{*\ 400}$	507.6 ± 8.1 ^{400}				
1500 m	1006.3 ± 13.6 ^{800}	981.5 ± 16.1 $^{*\ 800}$	977.5 ± 10.4 $^{*\ 800}$	965.1 ± 11.9 $^{*\ 800}$				

Main effects:
(a) time: early junior – late junior – transition – elite age.
(b) group: swimming stroke | race distance.
(c) interaction: time × group.
Post-hoc comparison:
* significant difference ($p < 0.05$) compared to previous age group.
$^{BU,\ BA,\ BR,\ FR,\ IM}$ significant difference ($p < 0.05$) compared to Butterfly, Backstroke, Breaststroke, Freestyle, or Individual medley, respectively, within particular age group.
$^{50,\ 100,\ 200,\ 400,\ 800}$ significant difference ($p < 0.05$) compared to the 50 m, 100 m, 200 m, 400 m, or 800 m event, respectively, within particular age group.

5. Discussion

The present study provides percentiles from 10 years of age up to age of peak performance for both sexes (males – females), all swimming stroke (BU–BA–BR–FR–IM), and all race distances (50 m–100 m–200 m–400 m–800 m–1500 m) of long-course pool events. Race times generally improved with increasing age. Regarding performance progression of different race distances, sprint events showed an early plateau with no further significant improvement in race times after late junior age (15–17 years). Race times plateaued later the longer the distance, but generally earlier for female swimmers than males. Comparing swimming strokes, race times significantly improved up to the elite age (>21 years) for BU, BR, and IM but plateaued at the transition age (18–21 years) for BA and FR.

While boys and girls typically showed similar swim velocities until the onset of puberty,[22] the present study showed a trend towards faster long-distance race times, i.e. 800 m and 1500 m FR, during early-junior age in girls. Due to earlier biological maturity, girls reach age of peak height velocity with 12.1 ± 1.4 years of age compared to 13.7 ± 1.4 years in boys,[23] thus providing girls with a temporary physical advantage. After that, male swimmers improve more rapidly until 17 years of age,[22] resulting in faster race times across all distances. Earlier biological maturation in girls may also explain earlier plateaus in race times and earlier age of peak performance in female (22.5 ± 2.4 years) compared to male swimmers (24.2 ± 2.1 years).[13] Additionally, the research by Senefeld and colleagues[22] indicated a lower performance depth in female compared to male swimmers. As such, less rivalry may contribute to the earlier plateaus in race times of female swimmers found in the present study.

The present study found differences in performance progression between swimming strokes, in particular in male swimmers. As such, FR and BA plateaued earlier (transition age) compared to the less economical swimming strokes, i.e. BU and BR,[14] which improved until elite age. The technical demands of BU and BR with the simultaneous arm and leg action and larger fluctuation in intra-cyclic swimming velocity[14] may require more training time and years of practice to reach the required level of swimming economy for peak performance. In contrast, the alternating arm movement of front crawl and backstroke are more economical[14] and are commonly introduced earlier in learn-to-swim programs than BU and BR.[15] As such, young swimmers have more time to develop the BA and FR technique, which in turn may contribute to their earlier performance plateau at transition age. This phenomenon may also be the reason IM race times improve until elite age. The technical complexity and variety of IM, for which swimmers must master all four swimming strokes, require more years of training until performance plateaus.

The SD between race times was largest at early junior age, probably due to different timing of growth spurts between individuals.[24] Thereafter, SD decreased and was lowest during transition age (18–20 years) at cessation of biological maturation.[24] However, SD increased again towards elite age. The percentiles charts revealed that highest ranked swimmers continued to improve their race times after 20 years of age, while race times of lower ranked swimmers declined. Due to missing success, these low ranked swimmers may develop other interests in their early twenties, i.e. other hobbies or focus on university studies. Resulting lower training effort, lack of motivation or accumulated injuries may explain the drop in performance before these swimmers eventually end their career.[25] This natural deselection of low ranked swimmers may explain the increased SD towards elite age.

While previous studies provided performance data for a selected population of swimmers, i.e. a particular nation[9,10] or swimming stroke,[2,9,10] the present study established normative data for all swimming strokes, race distances, and both sexes over long-course pool events. Additionally, the present percentiles represent the current performance level of international swimming by analyzing race times across 133 nations including USA, Australia, and Great Britain, the three most successful nations at the recent 2020 Tokyo Olympic Games. As performance progression, rather than the current competition performance, should determine talent selection,[4–6] coaches and federation official should use the present percentiles to compare percentile ranking between seasons. The seasonal increase and decrease in percentiles provide an objective assessment of performance progression, and thus determine over- and underperformers. Compared to mean ± SD as an insight into a selected population of swimmers,[9] percentiles provide a global approach and cover a larger range of swimming performances within a particular age-group from regional to international levels. With the use of percentiles, realistic goals can be set and expectations adjusted for lower and higher ranked swimmers. Finally, z-scores around the median, i.e. percentiles, provide a relative assessment[12] of swimming performance. Race times can be compared between various swimming strokes and race distances and help coaches and federation officials to discover a swimmer's strengths, weaknesses, and future potential.

Based on this large dataset of race times, a software-based percentile calculator was developed, to provide percentile diagrams and tables for all 34 swimming events. Using the calculator, the specific percentile for a particular race time within an age-group can be retrieved in addition to raw data of all 34 percentile curves. The percentile calculator provides a practical tool for poolside assessment of race times for coaches, performance analysts, and scientists. Implementing the dataset into a web application could further enhance its practical application by allowing data access from mobile devices, i.e. smart phones and tablet computers.

6. Conclusion

Long-term athlete development showed a non-linear progression in race times across the age groups and was specific to sex, swimming stroke, and race distance. The performance progression plateaued at an older age the longer the distance, i.e. at late junior age (15–17 years of age) for 50 m and at elite age for 1500 m FR (21–26 years of age). Earlier biological maturation may explain the earlier plateau in female swimmers. While race times plateaued at transition age for male BA and FR swimmers, development of technical skills rather than physiological aspects may explain performance progression up to elite age in BU, BR, and IM. As early junior success does not necessarily predict success at senior elite age, drop-outs were accounted for, and longitudinal tracking applied to the data analysis. The 34 percentile curves, to be found in the supplementary material, allow coaches and federation officials to compare their swimmers' race times and performance progression to a relevant population of international swimmers. The objective assessment of swimming performance across age-groups may improve talent selection and development, help discover individual potentials, and facilitate realistic goal setting and predictions for the talent pathway.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jsams.2021.10.002.

Data availability statement

Data and software-based percentile calculator can be retrieved from the supplementary material.

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Declaration of interest statement

The authors have no conflict of interest to report that may have affected data collection, analysis, or interpretation of the present study.

Confirmation of ethical compliance

The study was pre-approved by the internal review board of the Swiss Federal Institute of Sport Magglingen (Reg.-Nr.: 124_LSP_234–3.2.127) and is in line with the code of conduct of the World Medical Association for research involving human participants (Helsinki Declaration).

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