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Research article

Start Fast, Swim Faster, Turn Fastest: Section Analyses and Normative Data for Individual Medley

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Abstract

The aims of the study were to provide benchmarks and normative data for 100 m, 200 m, and 400 m short-course individual medley (IM) races, investigate differences between the various swimming strokes and turns involved in IM, and quantify the effect and contribution of various race sections on swimming performance. All IM races (n = 320) at the 2019 European Short-Course Swimming Championships were video monitored and digitized with interrater reliability described by a mean intra-class correlation coefficient of 0.968. Normative data were provided for the eight finalists of each event (FINA points = 886 ± 37) and the eight slowest swimmers from each event (FINA points = 688 ± 53). Contribution and effects of race sections on swimming performance were investigated using stepwise regression analysis based on all races of each event. Regression analysis explained 97-100% of total variance in race time and revealed turn time ($\beta \geq 0.53$) as distinguishing factor in short-course IM races in addition to swim velocity ($\beta \geq -0.28$). Start time only affected 100 m ($\beta \geq 0.14$) and 200 m ($\beta \geq 0.04$) events. Fastest turn times were found for the butterfly/backstroke turn. Breaststroke showed slowest swim velocities and no difference between fastest and slowest 100 m IM swimmers. Therefore, breaststroke may provide largest potential for future development in IM race times. Correlation analyses revealed that distance per stroke ($r \geq -0.39$, $P < 0.05$) rather than stroke rate ($r \leq -0.18$, $P > 0.05$) is a performance indicator and may be used by coaches and performance analysts to evaluate stroke mechanics in male IM swimmers despite its more complex assessment. Performance analysts, coaches, and swimmers may use the present normative data to establish minimal and maximal requirements for European Championship participation and to create specific drills in practice.

Key words: Acyclic phases, reference values, elite athlete, race analysis, swimming.

Introduction

In competitive sports, athletes strive towards the best performance possible. To set goals, establish guidelines for long-term athlete development, and create specific drills in practice, benchmarks and normative data are therefore derived from world-class athletes and finalists at important international competitions (Marinho et al., 2020; Morais et al., 2019). This approach is particularly feasible in swim sports, as competitions provide highly standardized conditions. Based on the official rulebook of the world governing swimming federation FINA (Fédération Internationale de Natation), water temperature is regulated to no less than 25°C with an in-pool current < 1.25 m/min (FINA, 2021). The tolerance for pool length is + 0.01 m and wave-breaking lane ropes are obligatory (FINA, 2021) to reduce performance interference by other competitors (Menting et al., 2019). Therefore, benchmarks established by video-based motion analysis from real race scenarios are comparable between various swim events, competitions, and venues.

However, continuously improving world best times require regular updates of benchmarks and normative data (Marino, 1984; USA Swimming, 2021). Although, race times can be corrected for the current world record (Post et al., 2020), key performance indicators and section times probably do not develop equally with race times. As such, the recent development in swimming with emphasis on on-land strength and power training regimes (Crowley et al., 2017; Crowley et al., 2018) increased interest in and importance of the acyclic phases, i.e. start and turn performances (Marinho et al., 2020; Morais et al., 2019; Nicol et al., 2021; Veiga and Roig, 2016).

In particular, short-course races held during winter season in 25 m pools, involve a greater number of turns for a given event compared to long-course races (50 m pool length). Therefore, contribution of the turn section was larger compare to the free-swimming section as shown by a recent time trial (Olstad et al., 2020). Additionally, the repeated push-off from the pool-wall increases velocity (3.0 ± 0.1 m/s) beyond free-swimming speed (1.4 ± 0.1 m/s) after each turn (Olstad et al., 2020). Therefore, short-course races are on average 4.3 ± 3.2% faster compared to the same event held in a long-course pool (Wolfrum et al., 2014). While time trials provide a unique opportunity to apply sophisticated methods and study on-block/wall kinetics and underwater kinematics (Nicol et al., 2021; Olstad et al., 2020), experienced swimmers usually perform best in real races competing head-to-head against others (Mujika et al., 2019). Therefore, section analysis and benchmarks derived from such time trials require verification from real race scenarios. Additionally, the findings from swimmers with a mean performance level < 700 FINA points (Olstad et al., 2020) need to be confirmed in swimmers at a high international level, i.e. European Championship finalists (Marinho et al., 2020; Morais et al., 2019).

Despite the importance of benchmarks from high-level swimmers, short-course races are an understudied research area, as pointed out by a recent review (Gonjo and

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Olstad, 2020a). Research is particularly limited for Individual Medley (IM) events (Gonjo and Olstad, 2020a), during which swimmers transition between all four swimming strokes, i.e. Butterfly (BU), Backstroke (BA), Breaststroke (BR), and Freestyle (FR) and apply three different turn techniques (FINA, 2021). With the large variety of technical requirements of this unique event, the aims of the present study were to (I) provide benchmarks and normative data for fastest and slowest European Championship participants in 100 m, 200 m, and 400 m short-course IM races, (II) investigate differences between the various swimming strokes and turns involved in IM, and (III) to quantify the effect and contribution of various race sections on swimming performance.

Methods

Subjects

In total, 320 IM races of all male (FINA points = 806 ± 75) and female (FINA points = 772 ± 75) competitors at the 2019 European Short-Course Swimming Championships in Glasgow, Scotland were analyzed. Benchmarks and normative values were derived from the eight finalists (FINA points = 886 ± 37) and eight slowest swimmers (FINA points = 688 ± 53) of each event. All competitors of each event were used to quantify the effect and contribution of various race sections on swimming performance. All swimmers that participate at events hosted by the European Swimming Association LEN (Ligue Européenne de Natation) agree to be video monitored for television broadcasting and race analysis of the participating nations. The study was pre-approved by the leading institution's internal review board (registration number: 098-LSP-191119) and was in accordance to the latest version of the code of conduct of the World Medical Association for studies involving human subjects (Helsinki Declaration).

Data collection

All IM races were video monitored with a twelve camera system (Spiideo, Malmö, Sweden). Ten cameras filmed one of the ten lanes following the individual swimmer (V59 PTZ, Axis Communications AB, Lund, Sweden). Two additional cameras positioned at a 90° angle to the swimming lanes at the 5 m and 20 m mark, monitored the start and turn sections across all lanes. Video footages were collected with a 50 Hz sampling rate. Race times were provided by the championship's official timekeeper (Microplus Informatica, Marene CN, Italy).

Data analyses

Video footages were manually digitized using the Kinovea software (Kinovea 0.9.1; Joan Charmant & Contrib.,kinovea.org). Video footages were synchronized to the starting signal (electric gun and light flash). Section times were established by top of the head passing the 5 m, 10 m, 15 m, and 20 m markings of the lane ropes. According to official swimming rules, first hand contact with the pool wall determined end of the lap for BU, BR, and IM turns, i.e. BU to BA, BA to BR, and BR to FR (FINA, 2021). Foot contact with the pool wall determined end of the lap for BA and FR turns (200 m and 400 m events only) (FINA, 2021). After turns, swimmers are allowed to extend the underwater phase up to the 15 m mark (FINA, 2021). However, as excess breath holding may interfere with the subsequent free-swimming section, previous studies showed underwater distances below the permitted limit of 15 m. As such, male and female swimmers resurfaced no later than 11.0 ± 1.3 m and 10.6 ± 2.1 m, respectively, in 100 m and 200 m races (Morais et al., 2019; Veiga and Roig, 2016). Therefore, to isolate turn and free-swimming section and to make data comparable to recent studies (Gonjo and Olstad, 2020a; Nicol et al., 2021; Olstad et al., 2020), total turn time was determined from 5 m before wall contact (5 m in) until 10 m after wall contact (10 m out), with corresponding 5 m out split time. Swim velocities were measured between 15 m to 20 m of the first and between 10 m and 20 m of all following laps to isolate free-swimming (1.4 ± 0.1 m/s) from the faster start (4.7 ± 0.3 m/s) and turn (3.0 ± 0.1 m/s) velocities (Olstad et al., 2020). Stroke rate (SR) was determined by the time needed for one complete arm stroke. Initial water contact at entry of the same hand marked beginning and end of the arm stroke. Distance per stroke (DPS) was derived from SR and swim velocity of that particular race section. Time events digitized in the analyzing software were imported to Microsoft Excel 2016 (Microsoft Corporation, Redmond, WA, USA) to calculate start, turn, and swim parameters.

To investigate interrater reliability of the video analysis process, 5% of the races (n = 16) were analyzed in duplicate by a second expert swimming race analyst. Start performance showed an intra-class correlation coefficient (ICC) with 95% confidence interval of 0.969 (0.911-0.989), 0.999 (0.996-1.00), and 0.999 (0.998-1.00) for 5 m, 10 m, 15 m split times, respectively. Turn performance showed an ICC of 0.852 (0.577-0.948), 0.974 (0.925-0.991), 0.993 (0.979-0.997), and 0.918 (0.766-0.971) for 5 m in, 5 m out, 10 m out, and total turn time. Swim velocity, SR, and DPS showed an ICC of 0.991 (0.975-0.997), 0.994 (0.982-0.998), and 0.988 (0.966-0.996).

Statistical Analyses

Start and race times were compared between finalists and the eight slowest swimmers from the same event using an unpaired t-test. Turn and swim parameters were compared using three separate 2-way analysis of variance (ANOVA): group (fastest swimmers – slowest swimmers) x swimming stroke (BU - BA - BR - FR) or type of turn (BU/BA turn - BA/BR turn - BR/FR turn) or race section (start - turn - swim) and partial eta-square effect size ($_p\eta^2$) was calculated. To account for the large number of dependent variables, False Discovery Rate correction was applied to the main effects and alpa-levels adjusted based on the number of rejected null hypotheses according to Benjamini and Hochberg (1995). To control the family-wise error rate, a Bonferroni correction was applied to the post-hoc pairwise comparisons. For the second heat of the males' 400 m event, the light flash from the start signal was not visible in the video footages. Therefore, these ten races were excluded from a total of 320 races from the mechanistic analysis. Before the statistical analysis, outliers were removed from the raw data if values were larger than three times the standard deviation apart from the group mean (Field, 2013). Missing values were replaced with the mean of that particular heat (Field, 2013). From a total of 30,798 data points, 72 outliers (0.23%) were excluded and 16 missing values (0.05%) replaced with the nearby mean.

To quantify the effect of various race sections on swimming performance, a stepwise regression analysis was performed with race time as the dependent variable and start time, turn time, swim velocity, SR, and DPS as predictors. Based on standard procedure for analysis of large sample sizes, normality was confirmed with standardized residuals showing a straight diagonal line across the theoretical quantiles in the Q-Q plot (Field, 2013). Pearson's product-moment correlation coefficient was used to relate start, turn, swim, and stroke parameters to race time with coefficients < 0.1, 0.1-0.3, 0.3-0.5, 0.5-0.7, 0.7-0.9, and > 0.9 classified as trivial, small, medium, large, very large, and excellent, respectively (Hopkins, 2002). Data are presented as mean ± standard deviation with an alpha-level < 0.05 indicating statistical significance. Analyses were performed with JASP statistical software package version 0.14 (JASP-Team, University of Amsterdam, Amsterdam, The Netherlands).

Results

Benchmarks and normative data derived from fastest and slowest swimmers of each event are presented for start (Table 1), turn (Table 2a, 2b), and swim performance (Table 3a, 3b) across the 100 m, 200 m, and 400 m IM races for both sexes and all swimming strokes (BU - BA - BR - FR) involved in IM. The 15 m start time was faster for male finalists for 100 m and 200 m but not 400 m races. Female finalists showed faster start times across all race distances.

Comparing turn times between fastest and slowest swimmers, analysis of variance revealed a significant main effect for group for all events. Post-hoc test revealed that female finalists showed faster turn times than the slowest swimmers across all types of turns and all race distances. Male finalists were also faster in all turns, except for the BU to BA turn in 400 m IM. Comparing the three IM turns, the BU/BA turn revealed faster turn times compared to BA/BR and BR/FR turns. Male finalists showed faster swim velocities compared to the slowest swimmers except for BR during the 100 m race as well as BU and BA during the 400 m race. Female finalists were faster than slowest swimmers, with exception of BU and BR during the 100 m race. Comparing swimming strokes, BU and FR showed fastest swim velocities followed by BA. BR showed slowest swim velocities. SR and DPS did not differ between finalists and the slowest male and female swimmers. Comparing swimming strokes, BU showed the highest SR with no difference between BA, BR, and FR. DPS was not different between swimming strokes of female finalists. Slowest female 100 m IM swimmers showed lower DPS for BU and BR compared to BA and FR.

Finalists showed significantly faster swim times over all race distances. However, percent contribution to race time of the start, turn, and swim section was not different between the fastest and slowest swimmers. For both the fastest and slowest swimmers, percent contribution was highest (significant main effect for race section, $P < 0.001$) for turn (45.1-55.0%) followed by lower contribution for swim (42.5-44.1%) and start sections (2.5-11.2%). Additionally, turn section contribution increased from 100 m to 400 m IM races (from 45.1 to 54.4%) while start section contribution decreased (from 10.8 to 2.6%; Table 4).

Stepwise regression analysis explained 97 to 100% of the dependent variable. Turn time had the largest effect on race time, followed by swim velocity over all race distances for male and female swimmers. Start time affected 100 m and 200 m events only. Stroke parameters, i.e. SR and DPS, had no effect on the regression model (Table 5). Correlation analysis revealed very large correlations ($r > 0.70$) between start performance and 100 m and 200 m race times in both sexes. In 400 m IM, start performance correlated with race time in females only. Turn time and swim velocity showed very large correlations ($r > 0.70$) with race times of all distances and both sexes. While SR showed no significant correlations, DPS revealed medium correlations with race time in male swimmers (Figure 1).

Table 1. **The 15 m start performances [s] with corresponding 5 m and 10 m split times of the eight finalists (fastest) compared to the eight slowest swimmers from the heats by an unpaired *t*-test.**

			Fastest swimmers (n = 8)	**Slowest swimmers** (n = 8)	***P*-value**
Males	**100 m IM**	5 m	1.40 ± 0.05	1.53 ± 0.06	< 0.001
		10 m	3.16 ± 0.12	3.73 ± 0.09	< 0.001
		15 m	5.60 ± 0.14	6.49 ± 0.16	< 0.001
	200 m IM	5 m	1.42 ± 0.05	1.52 ± 0.07	< 0.01
		10 m	3.27 ± 0.11	3.71 ± 0.15	< 0.001
		15 m	5.83 ± 0.15	6.48 ± 0.21	< 0.001
	400 m IM	5 m	1.53 ± 0.04	1.56 ± 0.05	n.s.
		10 m	3.59 ± 0.17	3.64 ± 0.11	n.s.
		15 m	6.41 ± 0.23	6.45 ± 0.19	n.s.
Females	**100 m IM**	5 m	1.56 ± 0.03	1.66 ± 0.08	< 0.01
		10 m	3.71 ± 0.11	4.26 ± 0.31	< 0.001
		15 m	6.49 ± 0.18	7.33 ± 0.52	< 0.001
	200 m IM	5 m	1.60 ± 0.03	1.75 ± 0.10	< 0.01
		10 m	3.88 ± 0.13	4.31 ± 0.26	< 0.01
		15 m	6.77 ± 0.19	7.39 ± 0.35	< 0.001
	400 m IM	5 m	1.66 ± 0.03	1.75 ± 0.11	n.s.
		10 m	4.03 ± 0.15	4.34 ± 0.23	< 0.01
		15 m	7.07 ± 0.15	7.54 ± 0.21	< 0.001

Table 2a. **Turn performances [s] from 5 m before to 5 m and 10 m after wall contact of the eight *male* finalists (fastest) compared to the eight slowest *male* swimmers from the heats by a 2-way analysis of variance (ANOVA).**

			Type of turn				ANOVA		
			BU to BA turn	**BA to BR turn**	**BR to FR turn**		***F*-value**	***P*-value**	$_p\eta^2$
100 m IM	5 m in	fastest	2.38 ± 0.08	3.24 ± 0.17 $^{\text{BU/BA}}$	3.08 ± 0.11 $^{\text{BU/BA}}$	(a)	$F_{(1 \mid 42)} = 4$	0.04	0.10
		slowest	2.64 ± 0.14	3.04 ± 0.26 $^{\text{BU/BA, BR/FR}}$	3.33 ± 0.23 $^{\text{BU/BA}}$	(b)	$F_{(2 \mid 42)} = 75$	< 0.001	0.78
						(c)	$F_{(2 \mid 42)} = 9$	< 0.001	0.29
	5 m out	fastest	2.48 ± 0.11	1.70 ± 0.10 * $^{\text{BU/BA, BR/FR}}$	2.51 ± 0.09	(a)	$F_{(1 \mid 42)} = 77$	< 0.001	0.65
		slowest	2.75 ± 0.16	2.63 ± 0.39	2.79 ± 0.14	(b)	$F_{(2 \mid 42)} = 30$	< 0.001	0.59
						(c)	$F_{(2 \mid 42)} = 15$	< 0.001	0.41
	10 m out	fastest	4.97 ± 0.12 *	4.70 ± 0.33 *	5.09 ± 0.12 *	(a)	$F_{(1 \mid 42)} = 167$	< 0.001	0.80
		slowest	5.64 ± 0.25	6.25 ± 0.35	5.63 ± 0.21	(b)	$F_{(2 \mid 42)} = 2$	n.s.	
						(c)	$F_{(2 \mid 42)} = 20$	< 0.001	0.49
	Total turn time	fastest	7.34 ± 0.14 *	7.94 ± 0.42 * $^{\text{BU/BA}}$	8.17 ± 0.15 * $^{\text{BU/BA}}$	(a)	$F_{(1 \mid 42)} = 160$	< 0.001	0.79
		slowest	8.28 ± 0.25	9.29 ± 0.27 $^{\text{BU/BA}}$	8.96 ± 0.35 $^{\text{BU/BA}}$	(b)	$F_{(2 \mid 42)} = 41$	< 0.001	0.66
						(c)	$F_{(2 \mid 42)} = 4$	0.02	0.17
200 m IM	5 m in	fastest	2.62 ± 0.14	2.93 ± 0.06 * $^{\text{BU/BA, BR/FR}}$	3.29 ± 0.05 * $^{\text{BU/BA}}$	(a)	$F_{(1 \mid 42)} = 78$	< 0.001	0.65
		slowest	2.79 ± 0.12	3.23 ± 0.14 $^{\text{BU/BA, BR/FR}}$	3.72 ± 0.15 $^{\text{BU/BA}}$	(b)	$F_{(2 \mid 42)} = 186$	< 0.001	0.90
						(c)	$F_{(2 \mid 42)} = 5$	0.02	0.18
	5 m out	fastest	2.61 ± 0.11 *	2.55 ± 0.14 *	2.71 ± 0.12	(a)	$F_{(1 \mid 42)} = 55$	< 0.001	0.57
		slowest	2.87 ± 0.15	2.98 ± 0.18	2.92 ± 0.10	(b)	$F_{(2 \mid 42)} = 1$	n.s.	
						(c)	$F_{(2 \mid 42)} = 3$	n.s.	
	10 m out	fastest	5.22 ± 0.16 *	5.77 ± 0.40 * $^{\text{BU/BA}}$	5.52 ± 0.15 *	(a)	$F_{(1 \mid 42)} = 112$	< 0.001	0.73
		slowest	5.96 ± 0.22	6.76 ± 0.20 $^{\text{BU/BA, BR/FR}}$	5.93 ± 0.16	(b)	$F_{(2 \mid 42)} = 38$	< 0.001	0.64
						(c)	$F_{(2 \mid 42)} = 6$	< 0.01	0.23
	Total turn time	fastest	7.84 ± 0.24 *	8.70 ± 0.41 * $^{\text{BU/BA}}$	8.81 ± 0.17 * $^{\text{BU/BA}}$	(a)	$F_{(1 \mid 42)} = 175$	< 0.001	0.81
		slowest	8.75 ± 0.30	9.99 ± 0.21 $^{\text{BU/BA}}$	9.65 ± 0.19 $^{\text{BU/BA}}$	(b)	$F_{(2 \mid 42)} = 75$	< 0.001	0.78
						(c)	$F_{(2 \mid 42)} = 3$	n.s.	
400 m IM	5 m in	fastest	2.94 ± 0.08	3.24 ± 0.23 $^{\text{BU/BA}}$	3.44 ± 0.12 * $^{\text{BU/BA}}$	(a)	$F_{(1 \mid 42)} = 32$	< 0.001	0.43
		slowest	3.03 ± 0.1	3.39 ± 0.09 $^{\text{BU/BA, BR/FR}}$	3.90 ± 0.16 $^{\text{BU/BA}}$	(b)	$F_{(2 \mid 42)} = 94$	< 0.001	0.82
						(c)	$F_{(2 \mid 42)} = 8$	< 0.01	0.27
	5 m out	fastest	2.89 ± 0.15	2.76 ± 0.31	2.87 ± 0.13	(a)	$F_{(1 \mid 42)} = 9$	< 0.01	0.18
		slowest	3.01 ± 0.18	3.01 ± 0.26	3.03 ± 0.12	(b)	$F_{(2 \mid 42)} = 1$	n.s.	
						(c)	$F_{(2 \mid 42)} = 0$	n.s.	
	10 m out	fastest	6.00 ± 0.23	6.32 ± 0.39 $^{\text{BR/FR}}$	5.80 ± 0.22	(a)	$F_{(1 \mid 42)} = 17$	< 0.001	0.29
		slowest	6.25 ± 0.30	6.72 ± 0.16 $^{\text{BU/BA, BR/FR}}$	6.07 ± 0.21	(b)	$F_{(2 \mid 42)} = 21$	< 0.001	0.50
						(c)	$F_{(2 \mid 42)} = 0$	n.s.	
	Total turn time	fastest	8.95 ± 0.22	9.56 ± 0.45 * $^{\text{BU/BA}}$	9.24 ± 0.21 *	(a)	$F_{(1 \mid 42)} = 40$	< 0.001	0.49
		slowest	9.29 ± 0.32	10.11 ± 0.17 $^{\text{BU/BA}}$	9.97 ± 0.31 $^{\text{BU/BA}}$	(b)	$F_{(2 \mid 42)} = 25$	< 0.001	0.54
						(c)	$F_{(2 \mid 42)} = 2$	n.s.	

IM: Individual Medley, BU: Butterfly, BA: Backstroke, BR: Breaststroke, FR Freestyle, n.s.: not significant. (a) Main effect group: fastest vs. slowest swimmers (b) Main effect type of turn: BU to BA turn vs. BA to BR turn vs. BR to FR turn (c) Interaction effect: group x type of turn *Post-hoc* comparisons: * significant difference to slowest swimmers $^{\text{BU/BA, BA/BR, BR/FR}}$ significant difference to particular type of turn.

Table 2b. Turn performances [s] from 5 m before to 5 m and 10 m after wall contact of the eight *female* finalists (fastest) compared to the eight slowest *female* swimmers from the heats by a 2-way analysis of variance (ANOVA).

			Type of turn				ANOVA		
			BU to BA turn	BA to BR turn	BR to FR turn		*F*-value	*P*-value	$_p\eta^2$
100 m IM	5 m in	fastest	2.69 ± 0.09	2.94 ± 0.07 * $^{\text{BR/FR}}$	3.50 ± 0.19 * $^{\text{BU/BA}}$	(a)	$F_{(1\,\mid\,42)} = 32$	< 0.001	0.43
		slowest	2.91 ± 0.25	3.25 ± 0.22 $^{\text{BU/BA, BR/FR}}$	3.88 ± 0.21 $^{\text{BU/BA}}$	(b)	$F_{(2\,\mid\,42)} = 96$	< 0.001	0.82
						(c)	$F_{(2\,\mid\,42)} = 1$	n.s.	
	5 m out	fastest	2.83 ± 0.14	2.74 ± 0.16 *	2.84 ± 0.07 *	(a)	$F_{(1\,\mid\,42)} = 62$	< 0.001	0.59
		slowest	2.97 ± 0.16	3.31 ± 0.26 $^{\text{BU/BA}}$	3.22 ± 0.11	(b)	$F_{(2\,\mid\,42)} = 3$	0.04	0.14
						(c)	$F_{(2\,\mid\,42)} = 7$	< 0.01	0.25
	10 m out	fastest	5.54 ± 0.08 *	6.38 ± 0.22 * $^{\text{BU/BA, BR/FR}}$	5.83 ± 0.18 *	(a)	$F_{(1\,\mid\,42)} = 146$	< 0.001	0.78
		slowest	6.26 ± 0.33	7.52 ± 0.31 $^{\text{BU/BA, BR/FR}}$	6.47 ± 0.22	(b)	$F_{(2\,\mid\,42)} = 84$	< 0.001	0.80
						(c)	$F_{(2\,\mid\,42)} = 5$	0.01	0.20
	Total turn time	fastest	8.24 ± 0.15 *	9.32 ± 0.22 * $^{\text{BU/BA}}$	9.33 ± 0.23 * $^{\text{BU/BA}}$	(a)	$F_{(1\,\mid\,42)} = 116$	< 0.001	0.73
		slowest	9.17 ± 0.55	10.77 ± 0.47 $^{\text{BU/BA}}$	10.36 ± 0.39 $^{\text{BU/BA}}$	(b)	$F_{(2\,\mid\,42)} = 62$	< 0.001	0.75
						(c)	$F_{(2\,\mid\,42)} = 2$	n.s.	
200 m IM	5 m in	fastest	2.96 ± 0.07 *	3.30 ± 0.12 * $^{\text{BU/BA, BR/FR}}$	3.76 ± 0.06 * $^{\text{BU/BA}}$	(a)	$F_{(1\,\mid\,42)} = 58$	< 0.001	0.58
		slowest	3.22 ± 0.08	3.63 ± 0.16 $^{\text{BU/BA, BR/FR}}$	4.05 ± 0.23 $^{\text{BU/BA}}$	(b)	$F_{(2\,\mid\,42)} = 152$	< 0.001	0.88
						(c)	$F_{(2\,\mid\,42)} = 0$	n.s.	
	5 m out	fastest	2.99 ± 0.08	2.75 ± 0.18 *	3.00 ± 0.13 *	(a)	$F_{(1\,\mid\,42)} = 44$	< 0.001	0.51
		slowest	3.13 ± 0.11	3.23 ± 0.21	3.24 ± 0.13	(b)	$F_{(2\,\mid\,42)} = 3$	n.s.	
						(c)	$F_{(2\,\mid\,42)} = 6$	< 0.01	0.21
	10 m out	fastest	6.20 ± 0.16 *	6.71 ± 0.31 * $^{\text{BU/BA, BR/FR}}$	6.12 ± 0.13 *	(a)	$F_{(1\,\mid\,42)} = 85$	< 0.001	0.67
		slowest	6.64 ± 0.26	7.54 ± 0.28 $^{\text{BU/BA, BR/FR}}$	6.67 ± 0.16	(b)	$F_{(2\,\mid\,42)} = 54$	< 0.001	0.72
						(c)	$F_{(2\,\mid\,42)} = 3$	n.s.	
	Total turn time	fastest	9.16 ± 0.16 *	10.02 ± 0.28 * $^{\text{BU/BA}}$	9.88 ± 0.14 * $^{\text{BU/BA}}$	(a)	$F_{(1\,\mid\,42)} = 143$	< 0.001	0.77
		slowest	9.86 ± 0.27	11.29 ± 0.42 $^{\text{BU/BA, BR/FR}}$	10.72 ± 0.26 $^{\text{BU/BA}}$	(b)	$F_{(2\,\mid\,42)} = 75$	< 0.001	0.78
						(c)	$F_{(2\,\mid\,42)} = 5$	0.01	0.19
400 m IM	5 m in	fastest	3.23 ± 0.15 *	3.63 ± 0.18 $^{\text{BU/BA, BR/FR}}$	4.00 ± 0.16 $^{\text{BU/BA}}$	(a)	$F_{(1\,\mid\,42)} = 32$	< 0.001	0.43
		slowest	3.58 ± 0.16	3.88 ± 0.18 $^{\text{BU/BA, BR/FR}}$	4.21 ± 0.17 $^{\text{BU/BA}}$	(b)	$F_{(2\,\mid\,42)} = 70$	< 0.001	0.77
						(c)	$F_{(2\,\mid\,42)} = 1$	n.s.	
	5 m out	fastest	3.18 ± 0.21	3.04 ± 0.31 *	3.21 ± 0.13	(a)	$F_{(1\,\mid\,42)} = 28$	< 0.001	0.40
		slowest	3.38 ± 0.12	3.46 ± 0.17	3.44 ± 0.07	(b)	$F_{(2\,\mid\,42)} = 1$	n.s.	
						(c)	$F_{(2\,\mid\,42)} = 2$	n.s.	
	10 m out	fastest	6.68 ± 0.31 *	7.11 ± 0.45 * $^{\text{BR/FR}}$	6.42 ± 0.19 *	(a)	$F_{(1\,\mid\,42)} = 40$	< 0.001	0.49
		slowest	7.13 ± 0.29	7.75 ± 0.22 $^{\text{BU/BA, BR/FR}}$	6.88 ± 0.16	(b)	$F_{(2\,\mid\,42)} = 31$	< 0.001	0.59
						(c)	$F_{(2\,\mid\,42)} = 1$	n.s.	
	Total turn time	fastest	9.92 ± 0.30 *	10.74 ± 0.55 * $^{\text{BU/BA}}$	10.42 ± 0.22	(a)	$F_{(1\,\mid\,42)} = 42$	< 0.001	0.50
		slowest	10.72 ± 0.35	11.97 ± 0.87 $^{\text{BU/BA, BR/FR}}$	11.09 ± 0.28	(b)	$F_{(2\,\mid\,42)} = 19$	< 0.001	0.47
						(c)	$F_{(2\,\mid\,42)} = 1$	n.s.	

IM: Individual Medley, BU: Butterfly, BA: Backstroke, BR: Breaststroke, FR Freestyle, n.s.: not significant. (a) Main effect group: fastest vs. slowest swimmers (b) Main effect type of turn: BU to BA turn vs. BA to BR turn vs. BR to FR turn (c) Interaction effect: group x type of turn *Post-hoc* comparisons: * significant difference to slowest swimmers $^{\text{BU/BA, BA/BR, BR/FR}}$ significant difference to particular type of turn

Table 3a. Free-swimming parameters of the eight *male* finalists (fastest) compared to the eight slowest *male* swimmers from the heats by a 2-way analysis of variance (ANOVA).

			Swimming stroke					ANOVA		
			BU	**BA**	**BR**	**FR**		***F*-value**	***P*-value**	$_p\eta^2$
100 m IM	Swim velocity [m/s]	fastest	1.90 ± 0.07 * $^{BA, BR}$	2.08 ± 0.08 * $^{BR, FR}$	1.31 ± 0.04 ^{FR}	1.87 ± 0.08 *	(a)	$F_{(1\mid 56)} = 80$	< 0.001	0.59
		slowest	1.76 ± 0.09 $^{BA, BR}$	1.64 ± 0.09 ^{BR}	1.39 ± 0.06 ^{FR}	1.72 ± 0.05	(b)	$F_{(3\mid 56)} = 171$	< 0.001	0.90
							(c)	$F_{(3\mid 56)} = 35$	< 0.001	0.65
	Stroke rate [bpm]	fastest	59.6 ± 1.6 $^{BA, BR, FR}$	50.3 ± 2.4	49.7 ± 6.1	50.8 ± 2.7	(a)	$F_{(1\mid 56)} = 1$	n.s.	
		slowest	58.6 ± 2.6 $^{BA, BR, FR}$	46.3 ± 3.4	50.8 ± 7.5	50.3 ± 3.1	(b)	$F_{(3\mid 56)} = 22$	< 0.001	0.54
							(c)	$F_{(3\mid 56)} = 1$	n.s.	
	DPS [m/stroke]	fastest	2.02 ± 0.04	2.17 ± 0.16 ^{BR}	1.89 ± 0.22 ^{FR}	2.28 ± 0.09	(a)	$F_{(1\mid 56)} = 9$	< 0.01	0.14
		slowest	1.87 ± 0.07	2.12 ± 0.19 ^{BR}	1.75 ± 0.28 ^{FR}	2.13 ± 0.15	(b)	$F_{(3\mid 56)} = 18$	< 0.001	0.49
							(c)	$F_{(3\mid 56)} = 0$	n.s.	
200 m IM	Swim velocity [m/s]	fastest	1.81 ± 0.04 * $^{BA, BR, FR}$	1.63 ± 0.05 * $^{BR, FR}$	1.38 ± 0.02 * ^{FR}	1.73 ± 0.03 *	(a)	$F_{(1\mid 56)} = 95$	< 0.001	0.63
		slowest	1.70 ± 0.06 $^{BA, BR}$	1.48 ± 0.05 $^{BR, FR}$	1.30 ± 0.04 ^{FR}	1.62 ± 0.05	(b)	$F_{(3\mid 56)} = 249$	< 0.001	0.93
							(c)	$F_{(3\mid 56)} = 2$	n.s.	
	Stroke rate [bpm]	fastest	50.6 ± 5.2 $^{BA, BR, FR}$	43.2 ± 2.4	39.8 ± 2.6	44.8 ± 2.1	(a)	$F_{(1\mid 56)} = 0$	n.s.	
		slowest	53.1 ± 2.6 $^{BA, BR, FR}$	40.3 ± 2.2	41.4 ± 5.9	43.7 ± 2.8	(b)	$F_{(3\mid 56)} = 34$	< 0.001	0.64
							(c)	$F_{(3\mid 56)} = 2$	n.s.	
	DPS [m/stroke]	fastest	2.13 ± 0.05	2.23 ± 0.11	2.19 ± 0.13 *	2.28 ± 0.12	(a)	$F_{(1\mid 56)} = 18$	< 0.001	0.24
		slowest	2.00 ± 0.08	2.20 ± 0.11 ^{BR}	1.93 ± 0.23 ^{FR}	2.17 ± 0.09	(b)	$F_{(3\mid 56)} = 9$	< 0.001	0.32
							(c)	$F_{(3\mid 56)} = 2$	n.s.	
400 m IM	Swim velocity [m/s]	fastest	1.63 ± 0.02 $^{BA, BR}$	1.47 ± 0.06 $^{BR, FR}$	1.34 ± 0.03 * ^{FR}	1.66 ± 0.04 *	(a)	$F_{(1\mid 56)} = 50$	< 0.001	0.47
		slowest	1.61 ± 0.04 $^{BA, BR, FR}$	1.42 ± 0.04 $^{BR, FR}$	1.24 ± 0.04 ^{FR}	1.54 ± 0.04	(b)	$F_{(3\mid 56)} = 226$	< 0.001	0.92
							(c)	$F_{(3\mid 56)} = 5$	< 0.01	0.22
	Stroke rate [bpm]	fastest	48.6 ± 2.1 $^{BA, BR, FR}$	36.9 ± 3.8 ^{FR}	34.4 ± 2.2 ^{FR}	41.7 ± 2.6	(a)	$F_{(1\mid 56)} = 0$	n.s.	
		slowest	49.6 ± 2.5 $^{BA, BR, FR}$	37.3 ± 1.1	34.5 ± 2.7 ^{FR}	39.8 ± 2.4	(b)	$F_{(3\mid 56)} = 104$	< 0.001	0.85
							(c)	$F_{(3\mid 56)} = 1$	n.s.	
	DPS [m/stroke]	fastest	2.08 ± 0.08 $^{BA, BR, FR}$	2.36 ± 0.19	2.43 ± 0.15	2.35 ± 0.15	(a)	$F_{(1\mid 56)} = 17$	< 0.001	0.24
		slowest	2.02 ± 0.08 ^{FR}	2.23 ± 0.05	2.22 ± 0.13	2.23 ± 0.11	(b)	$F_{(3\mid 56)} = 17$	< 0.001	0.47
							(c)	$F_{(3\mid 56)} = 1$	n.s.	

IM: Individual Medley, BU: Butterfly, BA: Backstroke, BR: Breaststroke, FR: Freestyle, DPS: distance per stroke, n.s.: not significant. (a) Main effect group: fastest vs. slowest swimmers (b) Main effect swimming stroke: BU vs. BA vs. BR vs. FR (c) Interaction effect: group x swimming stroke *Post-hoc* comparisons: * significant difference to slowest swimmers $^{BU, BA, BR, FR}$ significant difference to particular swimming stroke

Table 3b. Free-swimming parameters of the eight *female* finalists (fastest) compared to the eight slowest *female* swimmers from the heats by a 2-way analysis of variance (ANOVA).

			Swimming stroke					ANOVA		
			BU	BA	BR	FR		*F*-value	*P*-value	$_p\eta^2$
100 m IM	Swim velocity [m/s]	fastest	1.67 ± 0.10 [BR]	1.64 ± 0.05 * [BR]	1.34 ± 0.05 [FR]	1.69 ± 0.10 *	(a)	$F_{(1 \mid 56)} = 46$	< 0.001	0.45
		slowest	1.61 ± 0.10 [BA, BR]	1.44 ± 0.09 [BR]	1.23 ± 0.05 [FR]	1.55 ± 0.06	(b)	$F_{(3 \mid 56)} = 69$	< 0.001	0.79
							(c)	$F_{(3 \mid 56)} = 2$	n.s.	
	Stroke rate [bpm]	fastest	61.8 ± 3.0 [BA, BR, FR]	49.6 ± 2.4	50.4 ± 3.8	52.1 ± 4.5	(a)	$F_{(1 \mid 56)} = 11$	< 0.01	0.17
		slowest	61.0 ± 2.9 [BA, BR, FR]	44.6 ± 5.7	46.3 ± 6.5	46.6 ± 5.8	(b)	$F_{(3 \mid 56)} = 34$	< 0.001	0.65
							(c)	$F_{(3 \mid 56)} = 1$	n.s.	
	DPS [m/stroke]	fastest	1.69 ± 0.08	1.97 ± 0.10	1.65 ± 0.10	1.97 ± 0.14	(a)	$F_{(1 \mid 56)} = 0$	n.s.	
		slowest	1.63 ± 0.13 [BA, FR]	1.99 ± 0.26 [BR]	1.65 ± 0.30 [FR]	2.06 ± 0.29	(b)	$F_{(3 \mid 56)} = 16$	< 0.001	0.46
							(c)	$F_{(3 \mid 56)} = 0$	n.s.	
200 m IM	Swim velocity [m/s]	fastest	1.62 ± 0.03 * [BA, BR]	1.45 ± 0.04 * [BR, FR]	1.25 ± 0.02 * [FR]	1.57 ± 0.03 *	(a)	$F_{(1 \mid 56)} = 118$	< 0.001	0.68
		slowest	1.53 ± 0.04 [BA, BR, FR]	1.31 ± 0.04 [BR, FR]	1.16 ± 0.06 [FR]	1.45 ± 0.05	(b)	$F_{(3 \mid 56)} = 273$	< 0.001	0.94
							(c)	$F_{(3 \mid 56)} = 1$	n.s.	
	Stroke rate [bpm]	fastest	54.7 ± 3.4 [BA, BR, FR]	40.7 ± 4.5	40.8 ± 3.1	44.4 ± 1.9	(a)	$F_{(1 \mid 56)} = 6$	0.02	0.10
		slowest	52.3 ± 3.7 [BA, BR, FR]	38.2 ± 2.6	37.6 ± 4.4	43.1 ± 5.9	(b)	$F_{(3 \mid 56)} = 47$	< 0.001	0.72
							(c)	$F_{(3 \mid 56)} = 0$	n.s.	
	DPS [m/stroke]	fastest	1.84 ± 0.11	2.13 ± 0.19	1.90 ± 0.17	2.09 ± 0.11	(a)	$F_{(1 \mid 56)} = 1$	n.s.	
		slowest	1.82 ± 0.13	2.04 ± 0.11	1.90 ± 0.24	2.03 ± 0.26	(b)	$F_{(3 \mid 56)} = 8$	< 0.001	0.29
							(c)	$F_{(3 \mid 56)} = 0$	n.s.	
400 m IM	Swim velocity [m/s]	fastest	1.51 ± 0.02 * [BA, BR]	1.35 ± 0.06 * [BR, FR]	1.19 ± 0.03 * [FR]	1.52 ± 0.04 *	(a)	$F_{(1 \mid 56)} = 74$	< 0.001	0.57
		slowest	1.42 ± 0.03 [BA, BR]	1.25 ± 0.05 [BR, FR]	1.12 ± 0.03 [FR]	1.43 ± 0.05	(b)	$F_{(3 \mid 56)} = 229$	< 0.001	0.92
							(c)	$F_{(3 \mid 56)} = 0$	n.s.	
	Stroke rate [bpm]	fastest	50.0 ± 4.3 [BA, BR, FR]	37.0 ± 4.1	36.5 ± 4.3	41.3 ± 3.2	(a)	$F_{(1 \mid 56)} = 1$	n.s.	
		slowest	49.5 ± 5.3 [BA, BR, FR]	35.2 ± 4.0	34.6 ± 4.0 [FR]	42.2 ± 5.8	(b)	$F_{(3 \mid 56)} = 35$	< 0.001	0.66
							(c)	$F_{(3 \mid 56)} = 0$	n.s.	
	DPS [m/stroke]	fastest	1.86 ± 0.16	2.13 ± 0.22	2.02 ± 0.25	2.13 ± 0.15	(a)	$F_{(1 \mid 56)} = 2$	n.s.	
		slowest	1.77 ± 0.15	2.09 ± 0.22	2.01 ± 0.21	1.98 ± 0.24	(b)	$F_{(3 \mid 56)} = 6$	< 0.001	0.26
							(c)	$F_{(3 \mid 56)} = 0$	n.s.	

IM: Individual Medley, BU: Butterfly, BA: Backstroke, BR: Breaststroke, FR: Freestyle, DPS: distance per stroke, n.s.: not significant. (a) Main effect group: fastest vs. slowest swimmers (b) Main effect swimming stroke: BU vs. BA vs. BR vs. FR (c) Interaction effect: group x swimming stroke *Post-hoc* comparisons: * significant difference to slowest swimmers [BU, BA, BR, FR] significant difference to particular swimming stroke

Table 4. The %-contribution of total race time of the start, turn, and free-swimming (swim) section of the eight finalists (fastest) compared to the eight slowest swimmers from the heats by a 2-way analysis of variance (ANOVA). Race times between fastest and slowest swimmers were compared with an unpaired *t*-test.

			Race time [mm:ss.00]	Contribution to total race time [%] Start	Turn	Swim		ANOVA *F*-value	*P*-value	$_p\eta^2$
Males	100 m IM	fastest	00:52.00 ± 00.50 *	10.8 ± 0.3 $^{Turn, Swim}$	45.1 ± 0.8 ^{Swim}	44.1 ± 1.0	(a)	$F_{(1 \mid 42)} = 0$	n.s.	
		slowest	00:57.75 ± 01.22	11.2 ± 0.2 $^{Turn, Swim}$	45.9 ± 0.5 ^{Swim}	42.8 ± 0.5	(b)	$F_{(2 \mid 42)} = 16299$	< 0.001	1.00
							(c)	$F_{(2 \mid 42)} = 14$	< 0.001	0.40
	200 m IM	fastest	01:53.05 ± 01.26 *	5.2 ± 0.1 $^{Turn, Swim}$	51.0 ± 0.5 ^{Swim}	43.8 ± 0.5	(a)	$F_{(1 \mid 42)} = 0$	n.s.	
		slowest	02:04.06 ± 01.48	5.2 ± 0.1 $^{Turn, Swim}$	51.8 ± 0.4 ^{Swim}	43.0 ± 0.4	(b)	$F_{(2 \mid 42)} = 67941$	< 0.001	1.00
							(c)	$F_{(2 \mid 42)} = 21$	< 0.001	0.49
	400 m IM	fastest	04:05.47 ± 02.18 *	2.6 ± 0.1 $^{Turn, Swim}$	54.4 ± 0.6 ^{Swim}	43.0 ± 0.7	(a)	$F_{(1 \mid 42)} = 0$	n.s.	
		slowest	04:19.50 ± 04.03	2.5 ± 0.1 $^{Turn, Swim}$	54.5 ± 0.3 ^{Swim}	43.1 ± 0.3	(b)	$F_{(2 \mid 42)} = 65334$	< 0.001	1.00
							(c)	$F_{(2 \mid 42)} = 0$	n.s.	
Females	100 m IM	fastest	00:58.74 ± 00.87 *	11.0 ± 0.2 $^{Turn, Swim}$	45.8 ± 0.4 ^{Swim}	43.2 ± 0.5	(a)	$F_{(1 \mid 42)} = 0$	n.s.	
		slowest	01:05.48 ± 03.07	11.2 ± 0.3 $^{Turn, Swim}$	46.3 ± 0.2 ^{Swim}	42.6 ± 0.3	(b)	$F_{(2 \mid 42)} = 47101$	< 0.001	1.00
							(c)	$F_{(2 \mid 42)} = 11$	< 0.001	0.33
	200 m IM	fastest	02:07.75 ± 01.71 *	5.3 ± 0.1 $^{Turn, Swim}$	51.7 ± 0.3 ^{Swim}	43.0 ± 0.4	(a)	$F_{(1 \mid 42)} = 0$	n.s.	
		slowest	02:18.66 ± 02.01	5.3 ± 0.2 $^{Turn, Swim}$	51.7 ± 0.6 ^{Swim}	42.9 ± 0.8	(b)	$F_{(2 \mid 42)} = 42914$	< 0.001	1.00
							(c)	$F_{(2 \mid 42)} = 0$	n.s.	
	400 m IM	fastest	04:32.41 ± 04.42 *	2.6 ± 0.0 $^{Turn, Swim}$	54.7 ± 0.5 ^{Swim}	42.7 ± 0.6	(a)	$F_{(1 \mid 42)} = 0$	n.s.	
		slowest	04:51.61 ± 05.02	2.6 ± 0.1 $^{Turn, Swim}$	55.0 ± 0.5 ^{Swim}	42.5 ± 0.5	(b)	$F_{(2 \mid 42)} = 66349$	< 0.001	1.00
							(c)	$F_{(2 \mid 42)} = 1$	n.s.	

IM: Individual Medley, n.s.: not significant. (a) Main effect group: fastest vs. slowest swimmers (b) Main effect race section: start vs. turn vs. swim (c) Interaction effect: group x race section *Post-hoc* comparisons: * significant difference to slowest swimmers $^{Start, Turn, Swim}$ significant difference to start, turn, or swim section.

Table 5. Mechanistic analysis of the effect of the 15 m start time, mean total turn time (5 m before to 10 m after wall contact), mean free-swimming velocity, mean stroke rate, and mean distance per stroke on Individual Medley (IM) race time as the dependent variable using stepwise regression analysis with all participants of each event.

			Regression model Entries	*R* square	*F*-value	*P*-value	Regression coefficients Beta	*T*-value	*P*-value
Males	100 m IM	Turn time [s]	70	0.98	$F_{(3 \mid 66)} = 1013$	$P < 0.001$	0.53	$T = 11$	$P < 0.001$
		Swim velocity [m/s]					-0.34	$T = -12$	$P < 0.001$
		Start time [s]					0.19	$T = 5$	$P < 0.001$
	200 m IM	Turn time [s]	59	0.99	$F_{(3 \mid 55)} = 3055$	$P < 0.001$	0.65	$T = 32$	$P < 0.001$
		Swim velocity [m/s]					-0.36	$T = -21$	$P < 0.001$
		Start time [s]					0.04	$T = 3$	$P = 0.009$
	400 m IM	Turn time [s]	26	0.97	$F_{(2 \mid 23)} = 313$	$P < 0.001$	0.78	$T = 16$	$P < 0.001$
		Swim velocity [m/s]					-0.29	$T = -6$	$P < 0.001$
Females	100 m IM	Turn time [s]	73	0.99	$F_{(3 \mid 69)} = 3181$	$P < 0.001$	0.63	$T = 26$	$P < 0.001$
		Swim velocity [m/s]					-0.28	$T = -15$	$P < 0.001$
		Start time [s]					0.14	$T = 7$	$P < 0.001$
	200 m IM	Turn time [s]	46	0.99	$F_{(3 \mid 42)} = 1858$	$P < 0.001$	0.57	$T = 19$	$P < 0.001$
		Swim velocity [m/s]					-0.42	$T = -18$	$P < 0.001$
		Start time [s]					0.06	$T = 3$	$P = 0.006$
	400 m IM	Turn time [s]	36	1.00	$F_{(2 \mid 33)} = 3791$	$P < 0.001$	0.58	$T = 27$	$P < 0.001$
		Swim velocity [m/s]					-0.46	$T = -21$	$P < 0.001$

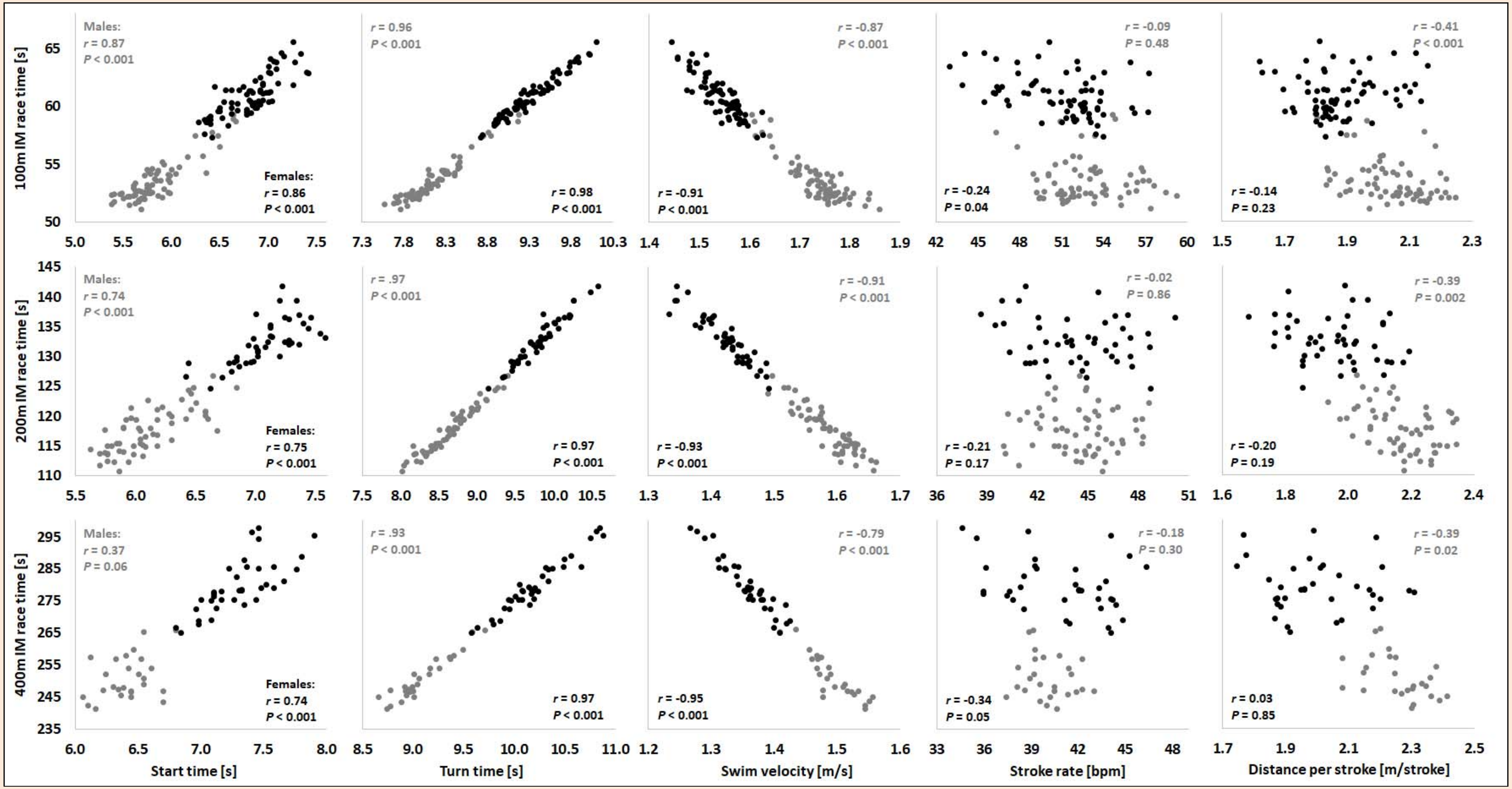

Figure 1. **Correlation analysis of 15 m start time, mean total turn time (from 5 m before to 10 m after wall contact), mean free-swimming velocity, mean stroke rate, and mean distance per stroke with Individual Medley (IM) race time for male (black markers) and female competitors (grey markers) of each event.**

Discussion

The present study provides benchmarks and normative data for fastest (finalists) and slowest European Championship participants regarding start time (5 m, 10 m, and 15 m split times), turn time (5 m in, 5 m out, and 10 m out split times as well as total turn time), swim velocity, SR, and DPS across all swimming strokes involved in IM (BU - BA - BR - FR), both sexes (males - females), and all short-course IM race distances (100 m - 200 m - 400 m). Finalists showed faster start times, turn times, and swim velocities than the slowest swimmers from the heats. However, the two groups did not differ regarding SR and DPS. Section analysis revealed fastest times for BU/BA turns. Fastest swim velocities were found for BU and FR followed by BA and BR. SR was highest for BU with no difference between BA, BR, and FR. While percent contribution was not different between fastest and slowest swimmers, ANOVA revealed largest percent contribution for turn (45.1 - 55.0%) followed by lower contribution for swim (42.5 - 44.1%) and start sections (2.5 - 11.2%). Using stepwise regression analysis, turn performance revealed the largest effect on race time followed by swim velocity. Start time affected 100 m and 200 m events only. While SR showed no significant correlations, DPS revealed medium correlations with race time in male swimmers.

Compared to long-course events (50 m pool length), in which turn performance contributed up to 20% of race time (Morais et al., 2019), the increased number of turns in the present short-course races increased percent contribution of turns up to 45%. Additionally, correlation analysis revealed excellent correlations ($r \geq 0.93$, $P < 0.001$) of turn performances with race times. In the regression model, beta coefficients showed a larger effect of turn performance on race time compared to swim performance ($\beta \geq 0.53$ and $\beta \geq -0.28$, respectively). While turn times were measured across 15 m (5 m before until 10 m after wall contact) and swim times across the remaining 10 m per lap, the faster turn velocities after push-off from the pool wall (2.96 ± 0.14 m/s) that were beyond free-swimming speed (1.41 ± 0.06 m/s) may have contributed to the large effect of turn times in the regression model (Olstad et al., 2020). Basically, the fluid characteristics of water that reduce movement efficiency far below that of on-land activities (Zamparo et al., 2020). In contrast, the pool wall provides a solid base for the swimmer's push-off during the turn and swimmers can utilized the explosive strength of their lower limbs (Nicol et al., 2021). Additionally, swimmers transfer propulsion gained from the wall push-off to full-stroke swimming by utilizing undulating kicking (Zamparo et al., 2012) and benefit from lower drag forces during prolonged underwater phases (Tor et al., 2015). The benefits associated with the greater number of turns in short-course races, result in $4.3 \pm 3.2\%$ faster race times compared to the same IM event held in a long-course pool (Wolfrum et al., 2014) and emphasizes the importance of the acyclic phases, i.e. turn performance, in IM swim races. If training regimes that prepare for short-course races and are mainly based on a high volume of low intensity swimming and conditioning of free-swimming skills (Nugent et al., 2017; Pollock et al., 2019), an addition of a substantial volume of race-pace specific turn drills should possibly be considered. Specific on-land strength and conditioning programs are discussed to build the necessary lower body power for the repeated wall push-offs involved in turns (Crowley et al., 2018).

Male finalists had significantly faster start times than the slowest swimmers for 100 m and 200 m but not 400 m IM. With the significant lower percent contribution of the start (< 3%) compared to the turn and swim sections (> 40%) in 400 m IM races, there was no effect of start performance in the regression model. A similar effect has previously been reported in males' 100 m, 200 m, and 400 m FR short-course races, where start time contribution decreased the longer the distance (Born et al., 2021). However, the start may affect the subsequent free-swimming section despite its low percent contribution. While the FR section would be expected to show the fastest swim velocities based on the better movement efficiency (Barbosa et al., 2006), the high velocity transferred from the start to the free-swimming section (Gonjo and Olstad, 2020b) may explain faster or equally fast swim velocities in the BU compared to the FR section of the present and previous IM swimmers (Saavedra et al., 2012).

While the effect of start performance decreased in the regression model the longer the race distance, turn performance revealed a high importance across all race distances and showed excellent correlations with race time. Comparing the various types of turns, fastest times were found for the BU/BA turns which may result from positive pacing strategies applied in IM races (Saavedra et al., 2012). The positive pacing strategy was in particular evident in the slowest 400 m IM swimmers showing turn times and swim velocities that were equally fast as the finalists' during the first half of the race but significantly slower during the second half of the race. Therefore, a more conservative pacing strategy and adequate energy distribution across the entire race may provide an important key indicator (Saavedra et al., 2012) in addition to maintenance of swim velocity and fatigue resistance (McGibbon et al., 2018).

BR showed slowest swim velocities. However, unlike the other swimming strokes, there was no difference between finalists and slowest 100 m IM swimmers regarding swim velocities. Generally, BR shows different characteristics to the other swimming strokes. As such, loss in velocity throughout the race is most pronounced in BR (McGibbon et al., 2018; Menting et al., 2019), possibly due to lower mechanical efficiency resulting in higher energy expenditure compared to the other swimming strokes (Barbosa et al., 2006; Zamparo et al., 2020) and important technical aspects such as intra-cyclic velocity fluctuation being related to the performance level (Takagi et al., 2004). As most IM swimmers are no BR specialists, during short-course races the expected loss in swim velocity may be compensated by the repeated push-off the pool wall with each turn. With the largest percent contribution to IM races (Saavedra et al., 2012), BR may therefore provide a potential for future performance improvements in IM races.

Compared to the other parameters, i.e. start, turn, and swim time, SR and DPS were of minor importance and showed no effect in the regression model. While SR revealed no significant correlations, DPS showed a medium effect on race times in male swimmers and may be of higher practical relevance when assessing stroke mechanics in training and competition despite its limited effect in the regression model. When comparing DPS with 200 m single stroke specialists as reported previously, 200 m IM swimmers from the present study showed very similar values for BU (1.85 ± 0.15 m vs. 2.13 ± 0.05 m), BA (2.18 ± 0.15 m vs. 2.23 ± 0.11 m), BR (2.01 ± 0.24 m vs. 2.19 ± 0.13 m), and FR (2.18 ± 0.17 m vs. 2.28 ± 0.12 m), respectively (Hellard et al., 2008). Yet, future studies may identify potentials for further development in IM swimming performance by comparing section elements of IM to single stroke events of the corresponding distance.

Previous studies provided unique insights into 100 m short-course BU and BR races and various types of turns in controlled laboratory studies (Gonjo and Olstad, 2020b; Nicol et al., 2021; Olstad et al., 2020). In accordance with these articles and previously reported breakout distances at about 10 m (Morais et al., 2019; Veiga and Roig, 2016), in the present study turn performances were assess up to 10 m after wall contact despite the regulatory limit of the underwater phase at 15 m (FINA, 2021). Additionally, the final 5 m before wall are commonly included in the turn performance as well to account for the body rotation in BA and FR and adjustments of stroke mechanics when anticipating the pool wall. Previous studies used individualized distance measurements to isolate turn performance more accurately from the free-swimming section (Veiga et al., 2014; Veiga et al., 2013). This is of particular importance for swimmers with underwater phases beyond 10 m after wall contact as swimming velocities underwater and shortly after the breakout are faster than mean free-swimming velocity (Tor et al., 2015; Veiga and Roig, 2016; Veiga and Roig, 2017). Despite the advantages of individualized distance measurements for scientific purposes, the first aim of the present study was to establish practically relevant benchmarks for coaches and swimmers. Fixed distance measures are still the method of choice for most coaches, to evaluate performance progression of start and turn times during daily training routines with minimal equipment necessary, i.e. stop watch. Therefore, benchmarks were established with fixed markers 5 m before and 10 m after wall contact.

Conclusion

Based on the largest percent contribution to race time and the largest effect in the regression model, which explained 97 - 100% of race time, stepwise regression analysis revealed turn performance as distinguishing factor. As turn times and swim velocities only differed between fastest and slowest male swimmers in the second half of the race, pacing and fatigue resistance seem to be important performance indicators for 400 m IM. With largest contribution to race time, slowest swim velocities, and missing difference between fastest and slowest 100 m IM swimmers, BR may provide largest potential for future development in IM race times. Correlation analyses revealed that DPS rather than SR is a performance indicator and may be used by coaches and performance analysts to evaluate stroke mechanics despite its more complex assessment. Performance analysts, coaches, and swimmers may use normative data from the present study regarding start, turn, and swim performance of 100 m, 200 m, and 400 m short-course IM events, to establish minimal and maximal requirements for European Championship participation and to create specific drills in practice.

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Key points

- Turn performance, in addition to swim velocity, was revealed as distinguishing factor of international swim races.
- Coaches and performance analysts should use benchmarks and normative data provided here to establish minimal and maximal requirements for European Championship participation and to create specific drills in practice.
- Breaststroke may provide potential for future development of Individual Medley race times.
- Distance per stroke rather than stroke rate should be used to evaluate stroke mechanics, despite its more complex assessment.

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