





















## 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 ( $2.96 \pm 0.14$  m/s) that were beyond free-swimming speed ( $1.41 \pm 0.06$  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 utilize 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 ( $1.85 \pm 0.15$  m vs.  $2.13 \pm 0.05$  m), BA ( $2.18 \pm 0.15$  m vs.  $2.23 \pm 0.11$  m), BR ( $2.01 \pm 0.24$  m vs.  $2.19 \pm 0.13$  m), and FR ( $2.18 \pm 0.17$  m vs.  $2.28 \pm 0.12$  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 assessed 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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