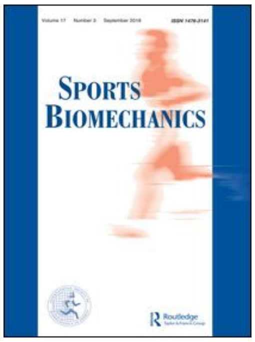

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Stability analysis and prediction of pacing in elite 1500 m freestyle male swimmers

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ABSTRACT

This study aimed to analyse the stability of elite male long-distance swimmers (1500 m), and to identify the main predictors related to the pace. The performance of 16 elite male swimmers (22.59 ± 2.10 years-old) participating in the 1500 m event at the 2016 (London) and 2018 (Glasgow) LEN European Aquatic Championships were analysed. The lap performance, clean swim performance, turn performance, and a set of stroke mechanics variables were assessed. The lap performance presented a significant and moderate variation with all laps included ($p < 0.001$) and deleting the first and last lap ($p = 0.002$). Swimmers were significantly faster in the first half in comparison of the second. The total turn also presented a significant and moderate variation. The hierarchical linear modelling retained the time (estimate = 0.0019, $p = 0.007$), stroke frequency (estimate = −27.49, $p < 0.001$) and stroke length (estimate = −6.55, $p < 0.001$) as the main predictors of the clean swim performance. By contrast to the analysis based on the lap performance, clean swim performance presented a non-significant variation. Coaches should be aware that stroke length maintenance could negatively affect the clean swim performance, whereas a small increase of stroke frequency may present a meaningful enhancement of the total race time.

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Swimming; stroke mechanics; competition; performance

Introduction

Excellent performance in sports is the major aim for every athlete and coach. Researchers and coaches try to innovate training methods based on the performance determinants, and understand how these determinants might be monitored helping athletes to improve (Skorski & Abbiss, 2017). The best way to learn how elite athletes behave is by analysing their performance. Video analysis of major events is an essential tool for all the support around athletes responsible for the athlete's performance (O´Donoghue, 2006). Moreover, this information will clearly be important and useful to athletes and coaches that will take part in similar competitions.

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In swimming, there are studies that video-analysed the swimmers' performances in major events such as the Olympic Games (e.g., Arellano et al., 2001; Hellard et al., 2008), World Championships (e.g., Simbaña-Escobar et al., 2018a; Veiga & Roig, 2016), and European Championships (e.g., Morais et al., 2019a). In a swimming race the performance includes the start, clean swim, turn(s), and finish (Hay & Guimaraes, 1983). Nonetheless, such studies based on video-analysis only analysed short- (50 m and 100 m), and/or middle-distance events (200 m and 400 m) (e.g., Arellano et al., 1994; Mauger et al., 2012). It cannot be found in the literature substantial information about long-distance events (such as the 800 m and 1500 m). Nonetheless, the information that is possible to retrieve from this kind of analysis is of substantial importance for athletes, coaches, and sport analysts.

Studies can be found in the literature about pacing in 800 m freestyle events (Lipinska et al., 2016a; Morais et al., 2019a), and 1500 m freestyle events (Lipinska et al., 2016b; Lipinska & Erdmann, 2009; Oliveira et al., 2019). Overall, they showed that parabolic pacing is generally used in freestyle events of 800 m and 1500 m, with the highest swimming speed at the beginning and end of the race. Nonetheless, best classified swimmers may exhibit a speed ascending pattern; while remaining ones presented a descending profile (Lipinska & Erdmann, 2009). However, these studies are only based on the lap times (time between the start and the touch in the wall, and so on until the finish), and not on kinematic variables.

Pacing is considered as the distribution of work, or pattern of energy expenditure where during competitions athletes must regulate their rate of work output optimising their overall performance (Abbiss & Laursen, 2008). In swimming, pacing profiles are typically characterised by plotting split times or speed over each lap of the event. However, this approch may not be suitable for swimming performance since external factors (e.g., the presence of an opponent) may interfere with a swimmer's pacing strategy (McGibbon et al., 2018). Additionally, pacing behaviour is associated with the different biomechanical and physiological limitations of each athlete (Menting et al., 2019). However, pacing analysis is usually performed based on the wall-to-wall time as mentioned earlier. Thus, one can argue if the pacing analysis in swimming should rely on the lap performance since the clean swim and turn phases are mixed togheter.

For instance, in all swimming races the first lap is conditioned by the start (Morais et al., 2019a). Therefore, the first lap should be analysed with some caution because the corresponding lap time will be positively affected by the start, and not only by the swimmer's clean swim performance (Lipinska et al., 2016b). Consequently, after each turn the clean swim performance (during the initial strokes) will also be positively affected by the swimmer's wall push-off while performing the turn. As in the 1500 m freestyle events swimmers spent almost all the race time performing the clean swim and turn phases, one might claim that the pacing analysis should be more precise. That is, not based on the lap performance, but in the two phases that characterise each lap: (i) the clean swim performance, and; (ii) the turn(s). The clean swim performance is considered as the swim speed that is not influenced by the turn (i.e., swim speed/time achieved in the intermediate length of the swimming pool without the advantage of the wall push-off) (Hay & Guimaraes, 1983). The turn is assumed as the sum of the last 5 m of the previous lap, and the first 15 m of the current lap (Morais et al., 2019a). Indeed, it was indicated that slight improvements in turn's performances affect final performance (Mason & Portus, 2005).

Literature reports few studies about stroke kinematics in elite long-distance swimmers (e.g., Craig et al., 1985; Jesus et al., 2011; Rushall et al., 1994). For instance, the studies of Craig et al. (1985) and Rushall et al. (1994) could be seen as outdated, since it shows performances from more than thirty and twenty years ago, respectively. Indeed, swimming performance has evolved based on swimmers' nature (Charles & Bejan, 2009), and nurture (Hellard et al., 2005). The study by Jesus et al. (2011) reported the stroke mechanics of elite swimmers racing the 1500 m freestyle event but based on the lap performance (wall to wall time). Thus, it seems that literature is lacking of substantial information about elite long-distance swimmers' stroke kinematics. A recent study highlighted that other variables (such as technical and/or biomechanical determinants) should be used (Oliveira et al., 2019).

Additionally, stability assessment (i.e., analysis of the variation) is a feasible way to gather insights about swimmer's performance over time (Costa et al., 2011). This indicates if swimmers significantly change (i.e., intra-swimmer variation) their performance or other variables over the race distance (i.e., laps). To the best of our knowledge only one study reported this kind of data in elite long-distance swimmers, but for the 800 m event (Morais et al., 2019a). It was highlighted that despite being an endurance race, that is characterised by the ability of maintaining a inherent movement or pattern, the swimmers presented a low stability (i.e., significant variaiton) of the stroke mechanics variables (Morais et al., 2019a). In this sense, one can claim that 1500 m swimmers might present a similar pattern.

Hence, the aims of this study were to: (i) analyse the stability of the lap performance, and a set of clean swim performance and turn variables of elite male long-distance swimmers during a 1500 m freestyle race, and; (ii) identify the main predictors of the clean swim performance. It was hypothesised that a non-significant variability would be verified for the lap performance, clean swim performance, and turn performance. Additionally, that the stroke length would be the main predictor of the clean swim performance.

Methods

Participants

Sixteen elite male swimmers (all event finalists: 22.59 ± 2.10 years-old at the time of each event) participating in the 1500 m event at the 2016 (London) and 2018 (Glasgow) LEN European Aquatic Championships (LCM-long course metre, 50 m swimming pool) were assessed. The swimmers' performance, obtained in this event, corresponded to 97.62% of the world record time (871.04 s) at the time of the Championships (FINA points: 834.56 ± 28.50 in the 1500 m freestyle event).

Data collection

Spiideo (https://www.spiideo.com) was responsible for the footage. The Championships organisation (Ligue Européenne de Natation) made available all the videos for the race analysis on a dedicated network. The video system included high-definition cameras (f = 50 Hz), and real-time multi-angle recordings. Each lane had a pan-tilt-zoom camera (AXIS v5915, Lund, Sweden) tracking back and forth the correspondent swimmer. Two extra cameras (AXIS q1635, Lund, Sweden) were fixed at the ends of the swimming pool. This enabled the single recording of the start and the turns. An in-house customised software for swimming was used to perform each race analysis (Morais et al., 2019b). The starting lights were synchronised with the official timer, which were visible by all cameras, and were used as reference to set the time-stamp on the race analysis software. Each race analysis (including all start, clean swim, turn, and finish variables) is performed based on time and distance variables, being each one analised by two expert analysts. The Intra-Class Correlation Coefficient (ICC, with 95% confidence interval—95 CI) was used to assess the agreement between the measures related to time (ICC = 0.994; 95 CI: 0.992;0.995), and distance (ICC = 0.992; 95 CI: 0.991;0.994).

Lap performance

The swimmers' official times (the final race time and each 50 m split time) was retrieved from the official website of each the event (2016: www.london2016.microplustimming.com; 2018: www.europeanchampionships.com).

Clean swim performance and stroke mechanics/efficiency

For this LCM 1500 m event 30 laps were analysed. In each lap, the clean swim performance was considered as time spent to travel the distance between the 15th and 45th metre (Morais et al., 2019a). This is done to avoid hypothetical advantages from the previous turn and spatial-temporal adjustments to the next one. Thus, in each lap the following pace variables were analysed: (i) the clean swim performance (s); (ii) the clean swim speed (v, m/s); (iii) the stroke frequency (SF, Hz); (iv) the stroke length (SL, m), and; (v) the stroke index (SI, m^2/s). Afterwards, the mean of all complete strokes, during such middle 30 m was used for analysis. The v was calculated as: v = d/t, where d is the distance and t the time swum. The SF was assessed in the race analysis software. It was obtained by computing the period of the time spent to complete a full stroke cycle (during the intermediate 30 m), having as reference always the hand closest to the camera. The SL was calculated as SL = v/SF (Craig & Pendergast, 1979), and the SI as SI = v · SL (Costill et al., 1985).

Turn

In the LCM 1500 m freestyle event, 29 turns are performed (and hence analysed). In each one, the following turning variables were assessed: (i) the 5 m-in (s); (ii) the water break time (s); (iii) the water break distance (m); (iv) the underwater speed (m/s); (v) the 15 m-out (s) and; (vi) the total turn (s, selected as the turn main outcome) (Morais et al., 2019a). The distance variable (i.e., water break distance) was estimated based on the pool's marks (5 m and 15 m marks in the swim lanes) (Morais et al., 2019a, 2019b).

Statistical analysis

The normality of the distribution was assessed with the Shapiro-Wilk test, and the Levene test was used to analyse the homoscedasticity. The descriptive statistics included the mean ± 1 standard deviation (SD), the 95% confidence interval (95CI), and the difference between pairwise (Δ, in %). The paired-samples t-test ($p \leq 0.05$) was used to verify differences between the first and the second half of the race. The Cohen's d was computed to verify the magnitude of the effect size, and it was interpreted as: (i) small if $0 \leq |d| \leq 0.2$; (ii) medium if $0.2 < |d| \leq 0.5$ and; (iii) large if $|d| > 0.5$ (Cohen, 1988).

The stability was assessed with the ANOVA repeated measures measuring the variation lap per lap. The effect size index (eta square—η^2) was computed and interpreted as: (i) without effect if $0 < \eta^2 \leq 0.04$; (ii) minimum if $0.04 < \eta^2 \leq 0.25$; (iii) moderate if $0.25 < \eta^2 \leq 0.64$ and; (iv) strong if $\eta^2 > 0.64$ (Ferguson, 2009). The Bonferroni post-hoc test was used to verify significant differences between each pairwise ($p < 0.05$) (Morais et al., 2019a). The coefficient of variation (CV, in %) was used to measure the clean swim variation along the race. It was calculated from lap to lap, and the mean of the total race was used for analysis.

Since repeated data could be considered hierarchical (repeated measures are nested in individuals) the hierarchical linear model (HLM) was used to verify the clean swim performance predictors. This method handles with variables that change over time. Therefore, the model may include predictors for the trajectories of each swimmer. The clean swim speed was not included in the model to avoid a multicollinearity phenomenon, since it was computed based on the clean swim performance. Only one level was used (i.e., trajectories), and the model was computed without the first and last laps. The final model only retained significant predictors. Maximum likelihood estimation was calculated with HLM7 software (Raudenbush et al., 2011).

Results

Lap performance

Table 1 presents the descriptive statistics (mean ± one standard deviation) and 95 CI for the lap performance during the total race. In the total race, the lap performance was 0.78 ± 1.19% faster in the first half of the race (T0-750 m: 444.41 ± 3.13 s) in comparison to the second (T750-1500 m: 447.98 ± 7.32 s). Deleting the first and last lap the first half of the race was still faster in comparison to the second (Δ = 0.66 ± 1.14%; T0-750 m: 416.71 ± 3.24 s; T750-1500 m: 419.53 ± 6.73 s) (Table 2 and Figure 1).

Table 1. Descriptive statistics (mean, one standard deviation and 95% confidence interval) for the performance, pace and turn variables.

	Lap Performance (s)	Clean swim performance (s)	Clean swim velocity (m/s)	Stroke frequency (Hz)	Stroke length (m)	Stroke index (m^2/s)		Total turn (s)	5 m-in (s)	Water break time (s)	Water break distance (m)	Underwater velocity [m/s]	15 m-out (s)
Total race							Total race						
T1500 m	29.75 ± 0.33	18.24 ± 0.19	1.64 ± 0.01	0.64 ± 0.06	2.60 ± 0.24	4.28 ± 0.39	Turn 1–29	11.39 ± 0.13	3.36 ± 0.07	2.15 ± 0.38	5.48 ± 0.87	2.61 ± 0.16	8.03 ± 0.12
	29.09;30.40	17;8718.61	1.62;1.67	0.52;0.75	2.14;3.07	3.51;5.04		11.13;11.65	3.23;3.49	1.40;2.90	3.77;7.18	2.30;2.92	7.80;8.25
Race 1st half							Race 1st half						
T0-750 m	29.63 ± 0.22	18.19 ± 0.14	1.65 ± 0.01	0.63 ± 0.06	2.64 ± 0.24	4.35 ± 0.38	Turn 1–15	11.35 ± 0.09	3.34 ± 0.06	2.21 ± 0.41	5.61 ± 0.91	2.61 ± 0.17	8.01 ± 0.10
	29.19;30.06	17.91;18.48	1.62;1.68	0.51;0.75	2.17;3.11	3.60;5.11		11.16;11.53	3.22;3.46	1.41;3.00	3.83;7.40	2.28;2.93	7.82;8.20
Race 2nd half							Race 2nd half						
T750-1500 m	29.87 ± 0.49	18.28 ± 0.28	1.64 ± 0.03	0.65 ± 0.06	2.56 ± 0.24	4.21 ± 0.40	Turn 15–29	11.43 ± 0.18	3.39 ± 0.08	2.09 ± 0.36	5.33 ± 0.84	2.62 ± 0.16	8.04 ± 0.15
	28.91;30.82	17.74;18.83	1.59;1.69	0.53;0.76	2.10;3.02	3.41;5.00		11.07;11.79	3.23;3.55	1.38;2.79	3.69;6.97	2.32;2.92	7.75;8.33
Lap							Turn						
T0-50 m	27.71 ± 0.27	17.51 ± 0.36	1.71 ± 0.04	0.64 ± 0.06	2.69 ± 0.20	4.60 ± 0.31	Turn 1	11.23 ± 0.17	3.26 ± 0.25	2.35 ± 0.47	6.07 ± 1.16	2.61 ± 0.36	7.97 ± 0.26
	27.18;28.23	16.81;18.22	1.64;1.78	0.53;0.75	2.29;3.08	3.99;5.21		10.89;11.57	2.78;3.75	1.42;3.27	3.80;8.33	1.92;3.31	7.45;8.49
T50-100 m	29.58 ± 0.19	18.16 ± 0.17	1.65 ± 0.02	0.62 ± 0.05	2.69 ± 0.20	4.45 ± 0.32	Turn 2	11.34 ± 0.15	3.37 ± 0.32	2.18 ± 0.51	5.60 ± 0.91	2.66 ± 0.58	7.96 ± 0.40
	29.21;29.95	17.83;18.48	1.62;1.68	0.52;0.71	2.30;3.09	3.82;5.08		11.04;11.64	2.74;4.00	1.19;3.17	3.81;7.40	1.51;3.80	7.18;8.75
T100-150 m	29.59 ± 0.26	18.23 ± 0.21	1.65 ± 0.02	0.63 ± 0.05	2.64 ± 0.21	4.35 ± 0.32	Turn 3	11.25 ± 0.15	3.28 ± 0.59	2.24 ± 0.66	5.80 ± 1.00	2.53 ± 0.41	7.97 ± 0.65
	29.09;30.10	17.82;18.64	1.61;1.68	0.52;0.73	2.24;3.05	3.72;4.98		10.96;11.55	2.12;4.45	0.94;3.55	3.84;7.76	1.72;3.34	6.69;9.25
T150-200 m	29.60 ± 0.30	18.14 ± 0.25	1.65 ± 0.02	0.63 ± 0.06	2.65 ± 0.24	4.39 ± 0.39	Turn 4	11.34 ± 0.12	3.37 ± 0.75	2.30 ± 0.62	5.59 ± 0.96	2.51 ± 0.41	7.98 ± 0.77
	29.00;30.19	17.65;18.63	1.61;1.70	0.51;0.75	2.19;3.12	3.63;5.15		11.11;11.58	1.90;4.83	1.10;3.51	3.71;7.46	1.70;3.32	6.46;9.49
T200-250 m	29.63 ± 0.21	18.18 ± 0.21	1.65 ± 0.02	0.63 ± 0.06	2.62 ± 0.24	4.33 ± 0.38	Turn 5	11.27 ± 0.19	3.31 ± 0.10	2.24 ± 0.41	5.76 ± 1.02	2.64 ± 0.18	8.18 ± 0.74
	29.22;30.04	17.77;18.59	1.61;1.69	0.52;0.75	2.16;3.09	3.59;5.07		10.90;11.63	3.13;3.50	1.43;3.05	3.76;7.75	2.29;2.99	6.73;9.62
T250-300 m	29.72 ± 0.32	18.20 ± 0.27	1.65 ± 0.02	0.63 ± 0.06	2.64 ± 0.26	4.35 ± 0.43	Turn 6	11.36 ± 0.10	3.56 ± 0.76	2.16 ± 0.38	5.55 ± 0.90	2.61 ± 0.15	8.00 ± 0.10
	29.09;30.05	17.67;18.74	1.60;1.70	0.51;0.75	2.14;3.14	3.51;5.19		11.17;11.56	2.07;5.05	1.42;2.89	3.79;7.30	2.31;2.91	7.80;8.19
T300-350 m	29.72 ± 0.22	18.23 ± 0.24	1.65 ± 0.02	0.63 ± 0.06	2.64 ± 0.25	4.35 ± 0.39	Turn 7	11.27 ± 0.14	3.51 ± 0.93	2.44 ± 0.89	5.66 ± 0.97	2.59 ± 0.19	8.00 ± 0.13
	29.28;30.15	17.76;18.69	1.60;1.69	0.50;0.75	2.16;3.13	3.58;5.12		10.99;11.54	1.68;5.34	0.70;4.18	3.75;7.56	2.22;2.96	7.74;8.25
T350-400 m	29.77 ± 0.25	18.23 ± 0.19	1.65 ± 0.02	0.63 ± 0.07	2.64 ± 0.26	4.34 ± 0.41	Turn 8	11.39 ± 0.09	3.37 ± 0.11	2.13 ± 0.41	5.43 ± 0.84	2.60 ± 0.14	8.02 ± 0.09
	29.28;30.27	17.86;18.60	1.61;1.68	0.50;0.76	2.14;3.14	3.54;5.15		11.21;11.57	3.16;3.59	1.34;2.93	3.79;7.07	2.33;2.88	7.85;8.19
T400-450 m	29.82 ± 0.23	18.31 ± 0.21	1.64 ± 0.02	0.63 ± 0.07	2.63 ± 0.26	4.30 ± 0.40	Turn 9	11.49 ± 0.32	3.36 ± 0.11	2.25 ± 0.42	5.89 ± 1.23	2.66 ± 0.45	8.12 ± 0.32
	29.36;30.27	17.90;18.72	1.60;1.68	0.50;0.76	2.13;3.13	3.52;5.08		10.92;12.06	3.15;3.58	1.43;3.07	3.47;8.30	1.78;3.53	7.49;8.76
T450-500 m	29.93 ± 0.32	18.22 ± 0.38	1.65 ± 0.04	0.63 ± 0.07	2.66 ± 0.28	4.38 ± 0.48	Turn 10	11.41 ± 0.13	3.37 ± 0.09	2.16 ± 0.43	5.46 ± 0.86	2.61 ± 0.22	8.05 ± 0.11
	29.29;30.56	17.47;18.97	1.58;1.72	0.50;0.76	2.11;3.20	3.44;5.32		11.15;11.67	3.20;3.54	1.32;3.01	3.78;7.14	2.18;3.03	7.83;8.26
T500-550 m	29.88 ± 0.27	18.34 ± 0.24	1.64 ± 0.02	0.63 ± 0.07	2.62 ± 0.26	4.28 ± 0.41	Turn 11	11.37 ± 0.16	3.31 ± 0.10	2.22 ± 0.40	5.60 ± 0.92	2.60 ± 0.17	8.06 ± 0.12
	29.34;30.42	17.87;18.81	1.59;1.68	0.50;0.76	2.10;3.13	3.47;5.09		11.06;11.67	3.12;3.50	1.43;3.00	3.79;7.42	2.26;2.94	7.81;8.30
T550-600 m	29.92 ± 0.34	18.34 ± 0.22	1.64 ± 0.02	0.63 ± 0.07	2.63 ± 0.27	4.30 ± 0.44	Turn 12	11.42 ± 0.14	3.38 ± 0.11	2.14 ± 0.43	5.40 ± 0.82	2.60 ± 0.20	8.04 ± 0.10
	29.26;30.58	17.91;18.76	1.60;1.68	0.50;0.76	2.10;3.15	3.44;5.15		11.14;11.70	3.17;3.58	1.29;2.99	3.80;7.01	2.20;3.00	7.84;8.24
T600-650 m	29.85 ± 0.30	18.29 ± 0.21	1.64 ± 0.02	0.63 ± 0.07	2.62 ± 0.27	4.30 ± 0.43	Turn 13	11.34 ± 0.15	3.33 ± 0.09	2.18 ± 0.41	5.62 ± 0.93	2.63 ± 0.14	8.01 ± 0.11
	29.27;30.43	17.88;18.70	1.60;1.68	0.50;0.77	2.09;3.15	3.45;5.15		11.05;11.63	3.16;3.51	1.38;2.97	3.79;7.44	2.36;2.91	7.80;8.22

(*Continued*)

Table 1. (Continued).

	Lap Performance (s)	Clean swim performance (s)	Clean swim velocity (m/s)	Stroke frequency (Hz)	Stroke length (m)	Stroke index (m^2/s)		Total turn (s)	5 m-in (s)	Water break time (s)	Water break distance (m)	Underwater velocity [m/s]	15 m-out (s)
T650-700 m	29.84 ± 0.37	18.21 ± 0.22	1.65 ± 0.02	0.63 ± 0.06	2.63 ± 0.26	4.34 ± 0.42	Turn 14	11.42 ± 0.16	3.40 ± 0.09	2.14 ± 0.40	5.37 ± 0.86	2.58 ± 0.15	8.02 ± 0.12
	29.13;30.56	17.79;18.64	1.61;1.69	0.51;0.76	2.13;3.14	3.51;5.16		11.12;11.73	3.23;3.58	1.37;2.92	3.69;7.05	2.28;2.87	7.79;8.25
T700-750 m	29.87 ± 0.40	18.33 ± 0.27	1.64 ± 0.02	0.64 ± 0.07	2.60 ± 0.26	4.25 ± 0.43	Turn 15	11.34 ± 0.15	3.33 ± 0.09	2.15 ± 0.37	5.43 ± 0.94	2.60 ± 0.18	8.01 ± 0.11
	29.09;30.65	17.80;18.85	1.59;1.68	0.51;0.77	2.08;3.11	3.42;5.08		11.06;11.63	3.15;3.51	1.43;2.86	3.58;7.28	2.25;2.96	7.79;8.23
T750-800 m	29.86 ± 0.34	18.27 ± 0.21	1.64 ± 0.02	0.63 ± 0.06	2.61 ± 0.27	4.29 ± 0.45	Turn 16	11.45 ± 0.19	3.39 ± 0.10	2.11 ± 0.38	5.31 ± 0.84	2.59 ± 0.16	8.06 ± 0.18
	29.19;30.53	17.87;18.68	1.61;1.68	0.51;0.76	2.09;3.14	3.41;5.17		11.07;11.83	3.20;3.58	1.36;2.85	3.67;6.96	2.28;2.89	7.71;8.40
T800-850 m	29.84 ± 0.39	18.24 ± 0.31	1.64 ± 0.03	0.64 ± 0.07	2.59 ± 0.25	4.26 ± 0.41	Turn 17	11.35 ± 0.16	3.32 ± 0.08	2.10 ± 0.36	5.45 ± 0.85	2.65 ± 0.18	8.03 ± 0.15
	29.07;30.60	17.63;18.86	1.59;1.70	0.51;0.77	2.10;3.09	3.46;5.06		11.03;11.67	3.16;3.48	1.40;2.80	3.78;7.12	2.30;3.01	7.74;8.32
T850-900 m	29.91 ± 0.47	18.30 ± 0.31	1.64 ± 0.03	0.64 ± 0.06	2.60 ± 0.25	4.27 ± 0.42	Turn 18	11.43 ± 0.22	3.38 ± 0.10	2.06 ± 0.38	5.30 ± 0.71	2.64 ± 0.27	8.05 ± 0.17
	29.00;30.82	17.70;18.90	1.59;1.69	0.51;0.76	2.11;3.09	3.45;5.08		11.00;11.86	3.18;3.58	1.32;2.80	3.91;6.70	2.12;3.16	7.72;8.38
T900-950 m	29.89 ± 0.42	18.36 ± 0.28	1.63 ± 0.03	0.64 ± 0.06	2.59 ± 0.23	4.23 ± 0.38	Turn 19	11.41 ± 0.18	3.40 ± 0.26	2.07 ± 0.42	5.35 ± 0.86	2.74 ± 0.48	8.00 ± 0.30
	29.06;30.72	17.80;18.91	1.58;1.68	0.52;0.75	2.13;3.04	3.48;4.98		11.06;11.75	2.89;3.91	1.24;2.89	3.66;7.05	1.81;3.68	7.42;8.59
T950-1000 m	29.99 ± 0.46	18.29 ± 0.28	1.64 ± 0.03	0.64 ± 0.06	2.59 ± 0.24	4.25 ± 0.40	Turn 20	11.44 ± 0.19	3.40 ± 0.09	2.06 ± 0.37	5.29 ± 0.78	2.62 ± 0.18	8.04 ± 0.16
	29.09;30.89	17.74;18.85	1.59;1.69	0.52;0.75	2.13;3.06	3.48;5.03		11.07;11.81	3.23;3.57	1.34;2.79	3.76;6.82	2.27;2.98	7.73;8.36
T1000-1050 m	29.90 ± 0.43	18.37 ± 0.26	1.63 ± 0.02	0.64 ± 0.06	2.56 ± 0.25	4.19 ± 0.42	Turn 21	11.40 ± 0.15	3.35 ± 0.09	2.13 ± 0.38	5.45 ± 0.93	2.59 ± 0.13	8.04 ± 0.13
	29.05;30.75	17.87;18.87	1.59;1.68	0.52;0.76	2.08;3.05	0.37;5.01		11.11;11.69	3.18;3.52	1.40;2.87	3.62;7.28	2.35;2.84	7.78;8.31
T1050-1100 m	30.00 ± 0.52	18.34 ± 0.31	1.64 ± 0.03	0.65 ± 0.06	2.56 ± 0.24	4.18 ± 0.43	Turn 22	11.48 ± 0.21	3.41 ± 0.11	2.07 ± 0.35	5.22 ± 0.78	2.58 ± 0.15	8.07 ± 0.16
	28.99;31.01	17.73;18.95	1.58;1.69	0.53;0.76	2.08;3.03	3.35;5.02		11.08;11.89	3.20;3.62	1.39;2.75	3.68;6.75	2.29;2.88	7.75;8.40
T1100-1150 m	30.04 ± 0.58	18.41 ± 0.38	1.63 ± 0.03	0.64 ± 0.06	2.56 ± 0.25	4.17 ± 0.44	Turn 23	11.42 ± 0.19	3.36 ± 0.11	2.10 ± 0.39	5.39 ± 0.94	2.61 ± 0.18	8.06 ± 0.13
	28.92;31.17	17.66;19.15	1.56;1.70	0.53;0.76	2.07;3.04	3.31;5.03		11.05;11.79	3.14;3.59	1.34;2.86	3.55;7.22	2.26;2.95	7.80;8.32
T1150-1200 m	30.05 ± 0.57	18.37 ± 0.38	1.63 ± 0.03	0.64 ± 0.06	2.59 ± 0.25	4.24 ± 0.45	Turn 24	11.52 ± 0.27	3.43 ± 0.13	2.06 ± 0.36	5.31 ± 0.97	2.63 ± 0.22	8.09 ± 0.18
	28.94;31.16	17.63;19.10	1.57;1.70	0.52;0.76	2.09;3.09	3.36;5.11		10.99;12.06	3.17;3.70	1.35;2.77	3.42;7.20	2.19;3.06	7.74;8.44
T1200-1250 m	30.16 ± 0.62	18.53 ± 0.44	1.62 ± 0.04	0.64 ± 0.06	2.55 ± 0.25	4.13 ± 0.44	Turn 25	11.46 ± 0.32	3.39 ± 0.11	2.12 ± 0.37	5.44 ± 0.87	2.61 ± 0.17	8.06 ± 0.25
	28.95;31.37	17.67;19.39	1.54;1.69	0.52;0.76	2.07;3.03	3.28;4.99		10.84;12.08	3.18;3.61	1.40;2.83	3.74;7.13	2.27;2.95	7.57;8.56
T1250-1300 m	30.13 ± 0.62	18.43 ± 0.32	1.63 ± 0.03	0.64 ± 0.06	2.56 ± 0.26	4.17 ± 0.45	Turn 26	11.57 ± 0.21	3.48 ± 0.11	2.06 ± 0.36	5.23 ± 0.81	2.59 ± 0.16	8.09 ± 0.14
	28.92;31.35	17.80;19.06	1.57;1.68	0.52;0.76	2.06;3.07	3.28;5.07		11.17;11.97	3.26;3.70	1.34;2.77	3.65;6.81	2.27;2.92	7.81;8.37
T1300-1350 m	30.07 ± 0.58	18.40 ± 0.40	1.63 ± 0.04	0.65 ± 0.06	2.55 ± 0.23	4.16 ± 0.41	Turn 27	11.51 ± 0.24	3.41 ± 0.19	2.09 ± 0.35	5.28 ± 0.85	2.54 ± 0.21	8.10 ± 0.19
	28.93;31.22	17.60;19.19	1.56;1.70	0.53;0.76	2.09;3.01	3.36;4.96		11.03;11.99	3.03;3.79	1.41;2.77	3.61;6.94	2.13;2.94	7.73;8.47
T1350-1400 m	30.05 ± 0.66	18.32 ± 0.37	1.64 ± 0.03	0.65 ± 0.07	2.56 ± 0.26	4.20 ± 0.46	Turn 28	11.45 ± 0.21	3.44 ± 0.11	2.05 ± 0.38	5.32 ± 0.91	2.61 ± 0.16	8.01 ± 0.19
	28.76;31.34	17.59;19.04	1.57;1.70	0.52;0.77	2.05;3.08	3.30;5.10		11.04;11.86	3.21;3.67	1.30;2.80	3.53;7.11	2.28;2.93	7.64;8.38
T1400-1450 m	29.63 ± 0.70	18.08 ± 0.50	1.66 ± 0.05	0.67 ± 0.05	2.51 ± 0.21	4.17 ± 0.41	Turn 29	11.21 ± 0.35	3.35 ± 0.17	2.08 ± 0.45	5.30 ± 1.06	2.62 ± 0.18	7.86 ± 0.25
	28.25;31.01	17.10;19.05	1.57;1.75	0.56;0.77	2.09;2.92	3.37;4.97		10.53;11.89	3.02;3.67	1.20;2.97	3.23;7.38	2.27;2.98	7.38;8.35
T1450-1500 m	28.45 ± 0.70	17.54 ± 0.43	1.71 ± 0.04	0.70 ± 0.05	2.46 ± 0.18	4.21 ± 0.33							
	27.08;29.81	16.69;18.38	1.63;1.80	0.60;0.80	2.10;2.82	3.56;4.87							

Table 2. Intra-swimmer variability for the lap performance, clean swim performance, and turn performance including and excluding the first and last lap. Comparison between the first and second half of the race for all the variables assessed (including and excluding the first and last lap).

	Lap and clean swim performance											
	Total race						Excluding first and last lap					
	Intra-swimmer variability				T0-750 m vs T750-1500 m		Intra-swimmer variability				T50-750 m vs T750-1450 m	
	F	p	η2	CV	Δ (d)	t (p)	F	p	η2	CV	Δ (d)	t (p)
Lap performance [s]	46.64	<0.001	0.76	1.85	0.78 ± 1.19% (0.63)	−2.67 (0.017)	5.86	0.002	0.28	0.96	0.66 ± 1.14% (0.53)	−2.33 (0.034)
Clean swim performance [s]	9.41	<0.001	0.44	1.71	0.84 ± 3.60% (0.42)	−0.99 (0.340)	1.72	0.158	0.12	1.31	0.88 ± 3.78% (0.41)	−1.00 (0.330)
Clean swim velocity [m/s]	9.68	<0.001	0.44	1.75	−0.08 ± 2.95% (0.25)	0.11 (0.915)	1.82	0.135	0.13	1.32	−0.07 ± 3.17% (0.00)	0.00 (1.000)
Stroke frequency [Hz]	12.69	<0.001	0.46	3.12	2.50 ± 2.35% (0.33)	−4.10 (0.001)	6.84	<0.001	0.32	2.38	2.06 ± 2.16% (0.17)	−4.57 (<0.001)
Stroke length [m]	6.47	<0.001	0.35	2.78	−2.67 ± 4.23% (0.28)	2.62 (0.019)	5.24	<0.001	0.30	2.45	−2.23 ± 4.30% (0.19)	2.17 (0.047)
Stroke index [m^2/s]	5.66	<0.001	0.32	5.23	−3.17 ± 4.26% (0.31)	3.16 (0.006)	4.13	0.002	0.26	3.08	−2.73 ± 4.33% (0.26)	2.67 (0.018)
	Turn											
	Total race						Excluding first and last turn					
	Intra-swimmer variability				T0-750 m vs T750-1500 m		Intra-swimmer variability				T50-750 m vs T750-1450 m	
	F	p	η2	CV	Δ (d)	t (p)	F	p	η2	CV	Δ (d)	t (p)
5 m-in [s]	3.56	0.010	0.24	2.83	2.58 ± 2.78% (0.83)	−3.45 (0.004)	3.28	0.017	0.23	2.68	2.60 ± 2.60% (0.88)	−3.35 (0.005)
Water break time [s]	4.01	0.004	0.29	6.38	−13.70 ± 7.59% (0.71)	6.21 (<0.001)	3.09	0.018	0.24	5.89	−13.63 ± 7.39% (0.72)	6.33 (<0.001)
Water break distance [m]	7.36	<0.001	0.33	5.83	−5.29 ± 4.07% (0.32)	5.13 (<0.001)	5.97	<0.001	0.28	5.29	−4.63 ± 3.81% (0.29)	4.85 (<0.001)
Underwater velocity [m/s]	0.90	0.467	0.08	4.69	−0.19 ± 4.12% (0.06)	0.05 (0.962)	0.89	0.474	0.08	4.64	−0.31 ± 4.62% (0.06)	0.21 (0.838)
15 m-out [s]	2.58	0.033	0.18	1.41	0.82 ± 1.95% (0.41)	−1.61 (0.132)	1.75	0.142	0.13	1.31	0.98 ± 2.01% (0.46)	−1.84 (0.088)
Total turn [s]	4.23	0.002	0.28	1.36	1.67 ± 2.73% (0.77)	−2.29 (0.040)	3.67	0.005	0.25	1.25	1.82 ± 2.85% (0.81)	−2.38 (0.033)

F- F-ratio value; p—significance value; η^2—eta square (effect size); CV—coefficient of variation (%); Δ—relative difference (%); d—Cohen's d (effect size); t—t-test value.

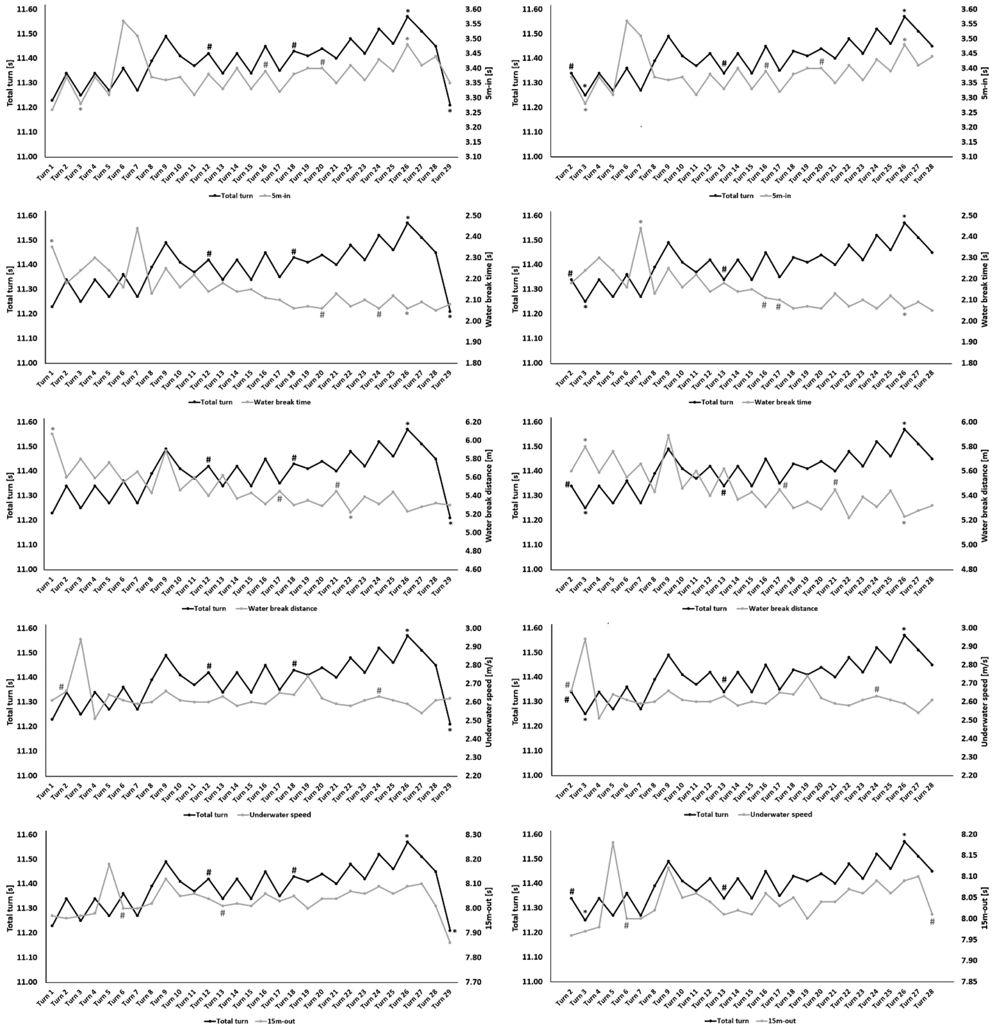

Figure 1. Intra-swimmer variation of the turning variables assessed. Left panels include all turns, and right panels exclude the first and last turn. For the variables that presented a significant intra-swimmer variation: *—highest and significant differences ($p \leq 0.05$) between pairwise; #—lowest and non-significant differences ($p > 0.05$) between pairwise.

Table 2 presents the data variation for the total race and deleting the first and last lap. In the total race a significant and strong variation was verified in the lap performance ($F = 46.64$, $p < 0.001$, $\eta^2 = 0.76$). Deleting the first and last lap, a significant and moderate variation was verified ($F = 5.86$, $p < 0.001$, $\eta^2 = 0.28$). The CV presented a variation of 1.85% for the total race, and 0.96% after deleting the first and last laps (Table 2).

Clean swim performance

Table 1 presents the descriptive statistics (mean ± one standard deviation) and 95 CI for the clean swim performance and stroke kinematics during the total race.The clean swim (intermediate 30 m in each lap) account 60.93 ± 0.89% of the total race time. In the total race time, between the first and second half of the race, the mean clean swim time increased but not significantly (T0-750 m: 18.04 ± 0.42 s; T750-1500 m: 18.21 ± 0.38 s; Δ = 0.84 ± 3.60%; t = −0.99; p = 0.340; d = 0.42), consequently the v decreased (Table 2 and Figure 1). Deleting the first and last lap, the trend was the same for the time (T0-750 m: 18.08 ± 0.44 s; T750-1500 m: 18.25 ± 0.39 s; Δ = 0.88 ± 3.78%, t = −1.00, p = 0.330, d = 0.41) (Table 2 and Figure 1).

Table 2 presents the data variation for all the clean swim performance variables assessed, for the total race and deleting the first and last lap. In the total race a significant and moderate variation was verified for the clean swim performance (F = 9.41, p < 0.001, η^2 = 0.44), and all the remaining variables assessed (Table 2). Moreover, non-significant differences were observed between the first and last lap (p = 1.000). Deleting the first and last lap, a non-significant and minimum variation (F = 1.72, p = 0.158, η^2 = 0.12) was verified for the clean swim performance (Table 2). The CV presented a variation of 1.71% for the total race, and 1.31% after deleting the first and last laps (Table 2).

Turn

Table 1 presents the descriptive statistics (mean ± one standar deviation) and 95 CI for the turn performance during the total race.The turn main outcome (total turn time) accounts 36.87 ± 0.61% of the total race time. Including all turns (29 turns in the total race), swimmers were significantly faster (with moderate effect) in the first half of the race in comparison to the second (Turn 1–15: 11.24 ± 0.30 s; Turn 16–29: 11.43 ± 0.18 s; Δ = 1.67 ± 2.73%; t = −2.29; p = 0.040; d = 0.77) (Table 2 and Figure 2). Deleting the first and last turn, the trend was the same (Turn 2–15: 11.24 ± 0.32 s; Turn 16–28: 11.45 ± 0.18 s; Δ = 1.82 ± 2.85%; t = −2.38; p = 0.033; d = 0.81).

The data variation for the turn variables assessed is presented in Table 2. The total turn presented a significant and moderate variation in the total race (F = 4.23, p = 0.002, η^2 = 0.28). Remaining turn variables presented a similar trend, except the underwater speed (Table 2). Excluding the first and last turn, the total turn also presented a significant and moderate variation (F = 3.67, p = 0.005, η^2 = 0.25). Remaining turn variables presented a similar trend, except the underwater speed and the 15 m-out (Table 2). The CV presented a variation of 1.36% for the total race, and 1.25% after deleting the first and last laps (Table 2).

Clean swim performance predictors

The HLM retained as clean swim performance predictors the time, i.e., lap (estimate = 0.0019, 95 CI: 0.0009;0.0029, p = 0.007), the SF (estimate = −27.49, 95 CI: −28.68;-26.29, p < 0.001), and the SL (estimate = −6.55, 95 CI: −6.90;-6.20, p < 0.001) (Table 3). The prediction equation is as follows:

$$\text{Clean swim performance} = 52.81 + (0.0019 * \text{Lap}) - (27.49 * \text{SF}) - (6.55 * \text{SL}) \quad (1)$$

Where clean swim performance is the time spent between the 15th and 45th metre of the swimming pool (s), Lap is the lap number (ordinal), SF is the stroke frequency (Hz), and SL is the stroke length (m).

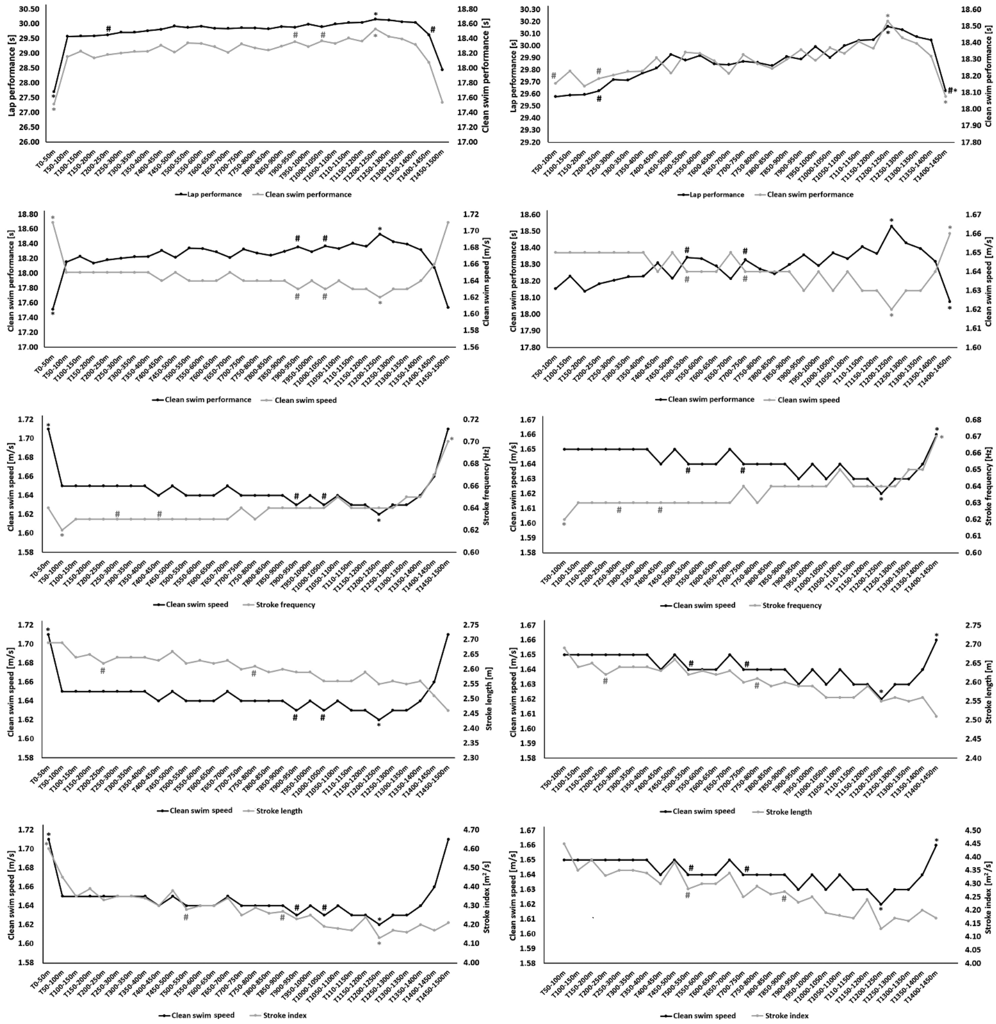

Figure 2. Intra-swimmer variation of the lap performance, clean swim performance, clean swim speed, and all independent variables assessed. Left panels include all laps, and right panels exclude the first and last lap. For the variables that presented a significant intra-swimmer variation: *—highest and significant differences ($p \leq 0.05$) between pairwise; #—lowest and non-significant differences ($p > 0.05$) between pairwise.

Table 3. Fixed effects of the clean swim performance model computed with standard errors (SE) and 95% confidence intervals (95 CI).

Fixed Effect	Estimate (SE)	95 CI	p value
Clean swim performance			
Intercept	52.81 (0.44)	51.95;53.67	<0.001
Time	0.0019 (0.0005)	0.0009;0.0029	0.007
Stroke frequency	−27.49 (0.61)	−28.68;-26.29	<0.001
Stroke length	−6.55 (0.18)	−6.90;-6.20	<0.001

Discussion and implications

The aims of this study were to: (i) analyse the stability of the lap performance, and a set of clean swim performance and turn variables of male elite long-distance swimmers during a 1500 m freestyle race, and; (ii) verify the main predictors responsible for the clean swim performance. For the total race time, a significant and strong variation was verified for the lap performance, and a significant and moderate variation for the clean swim performance. In the turning performance, the total turn presented a significant and moderate variation in the total race, and excluding the first and last lap. The clean swim model included the SF and the SL main predictors.

Lap performance

Lap performance revealed a significant and strong variation in the total race, and a significant and moderate variation after excluding the first and last laps (Table 2). The first lap is highly influenced by the start, and the last lap by a strong enhancement in the swimming speed to finish the race (Lipinska et al., 2016a). Our data shows this phenomenon as the variation decreased (Table 2). Nevertheless, after excluding the first and last laps, a significant variation (moderate effect) was still verified. In both cases, a positive pacing strategy was shown, i.e., the first half of the race is faster than the second one (Table 2 and Figure 1). This pacing strategy is characterised by a gradual decline of the athlete's speed throughout the race distance (Abbiss & Laursen, 2008). This is a common race strategy among male long-distance athletes in other sports like running (Díaz et al., 2019), and cycling (Abbiss & Laursen, 2008). Despite it cannot be found in the literature up-to-date information about elite 1500 m race stability, it was indicated that if swimmers could change their lap profile (reducing their lap variation) their performance could be improved (Lipinska et al., 2016b). This was also noticed in shorter distance as the 200 m (Simbaña-Escobar et al., 2018a).

Clean swim performance

In swimming, pacing analysis should be performed in a deeper approach rather than based only in the official laps. The lap performance includes several variables related to the race (Morais et al., 2019a). Hence, the clean swim performance should be differentiated from lap performance. Indeed, our data show that when both trends are overlapped, they do not exactly correspond (Figure 1). This is even highlighted when the first and last lap are excluded from the analysis. Indeed, while the lap performance presented a significant and moderate variation, the clean swim performance presented a non-significant and minimum variation (Table 2 and Figure 1).

For instance, between T400-450 m and T450-500 m the lap performance increased (lower performance), and the clean swim improved (higher performance). An opposite trend was verified between T850-900 m and T900-950 m, where the lap performance decreased (higher performance), and the clean swim declined (lower performance). This indicates that clean swim analysis should not be assessed based on lap time performance, since different trends may be verified. Even when the trend is similar the proportion of increase/decrease may not always be equivalent (Figure 1). Studies that assessed the pacing effect in long-distance swimmers (800 m or 1500 m freestyle) used the lap times as a pace indicator (Lipinska et al., 2016a, 2016b). Therefore, based in such differences it should be suggested that these two concepts should not be analysed as one. At least for 200 m races this rational is reinforced by the studies of Simbaña-Escobar et al. (2018a) and Simbaña-Escobar et al. (2018b). These authors showed that besides an inter-lap variation, an intra-lap variation also occurs. That is, swimmers changed their stroke kinematics not only between laps, but also within the same lap.

After excluding the first and last lap, the remaining variables (SF, SL, and SI) presented a significant variation. Indeed, these variables responsible for the stroke mechanics presented a sinusoidal profile (increases and decreases) (Figure 1). With this kind of data, only one study can be found about long-distance elite swimmers (800 m), where a significant variation was also verified (Morais et al., 2019a). The authors indicated that swimmers racing long-distance events presented a significant lap effect (high variation between laps) (Morais et al., 2019a). By contrast to other long-distance sports, such as cycling (Ansley & Cangley, 2009) and running (Díaz et al., 2019), elite long-distance swimmers do not maintain a similar stroke mechanics pattern (with non-significant differences) during the clean swim performance (pace). Moreover, a J-shape was observed in the second half of the race, specifically between T1050-1100 m and T1450-1500 m (Figure 1).

This J-shape pattern refers to athletes' tendency to decrease effort during a physical task, followed by an increase of their effort back again, leading to an end-spurt (swim speed) (Abbiss & Laursen, 2008; Edwards & Polman, 2013). Indeed, it was reported that elite swimmers manage their stroking profile within and between laps to functionally adapt themselves to the environmental constraints (Seifert et al., 2014). In the case of elite long-distance swimmers this management seems to be related mainly to energetic constraints. That is, along the race, swimmers tend to dose the amount of energy they have in order to maintain their ideal pacing throughout the use of the SL or SF (Barden & Kell, 2009). This was notably verified in the second half of the race, where their energetic indexes naturally might decrease. During a long-distance race the oxygen uptake, ventilation, and phosphocreatine levels decrease, and lactate levels increase (Zamparo et al., 2005). A study that evaluated the presence of the slow-component in elite male long-distance swimmers during a 6 × 500 m series revealed that during the first interval (6 x 300 m) performed at the lactic threshold rate showed a slow component allowing them to reach ~92% of the peak of maximum oxygen consumption (Hellard et al., 2010). By contrast, the high percentage of VO_2 sustained during the 6 × 500 m interval can be interpreted as being related to an increase in the cost of ventilation, which has been shown to contribute approximately 20% to the slow-component (Demarie et al., 2001).

Turn

All turning variables presented a sinusoidal profile (increases and decreases), and a significant and minimum-moderate variation, except the underwater speed (Table 2 and Figure 2). To the best of our knowledge only one study assessed the turning stability of elite long-distance swimmers, but for the 800 m freestyle (Morais et al., 2019a). It was possible to note that during the race swimmers tend to increase their total turn time. The same trend was verified in our study. As the turn includes surface and underwater phases, and accounted by nearly 37% of the total race time, it can be suggested that fatigue not only affect the clean swim but also the turn (Lomax et al., 2019). Indeed, the 5 m-in and 15 m-out (surface phase) did increase along the race. Moreover, swimmers did not take any advantage from the underwater break time and distance to probably save themselves energy as it happens with their sprinter and middle-distance counterparts (Marinho et al., 2020). That is, swimmers decreased their water break time and distance along the race, and hence started the swim stroke sooner. There is delicate balance between physiological and hydrodynamic responses (Mullen, 2018; Zamparo et al., 2008). If swimmers maintain themselves underwater during a longer period of time, the wave drag decreases. If they break the water earlier, they can oxygenate sooner. However, there is there is no evidence about which one will be more important and should be preferred. In our data this particular case swimmers did choose to break the water sooner in order to hypothetically oxygenate themselves. Despite no information exists for long-distance races, this trend was also verified in 200 m elite freestyle swimmers from the first to the last turn (Veiga & Roig, 2016). This could be related to energetic constarint as aforementioned for the clean swim (Hellard et al., 2010; Zamparo et al., 2005).

Indeed, swimmers are submitted to inspiratory muscle fatigue while swimming which might induce a deficit in their energetics (Hellard et al., 2010; Lomax et al., 2019). On the other hand, it was shown that an increase in the race distance (between 100 m and 400 m freestyle), did not significantly influenced the degree of inspiratory muscle fatigue (Brown & Kilding, 2011). Thus, one might claim that if long-distance swimmers do not have a precocious need to ventilate, they could take some advantage from the impulse performed on the turning wall. This will lead to a higher break distance, and hence less time spent on swim stroke. Training focused on the control of frequency breathing appeared to prevent inspiratory muscle fatigue (Burtch et al., 2017). Additionally, it was indicated that endurance training with a reduced breathing frequency improved the toleration to CO_2, and hence the necessity to breath (Kapus et al., 2013). Therefore, based on the short under water distance that swimmers covered in comparison to shorter race distance (Marinho et al., 2020), one can suggest that swimmers may exercise this type of drills which could help them in saving energy for the swim stroke.

Clean swim performance predictors

The HLM retained as main predictors the SF and the SL (Table 3). The SL showed a positive effect to the pace, i.e., an increase in one unit by the SL imposed a decrease by 6.55 s in the clean swim performance. The SL is seen as the practical outcome of the force exerted by the swimmer. That is, increasing the amount of force applied by the swimmer, he/she will increase their SL, and hence performing fewer strokes per length of the pool (Barden & Kell, 2009). However, it could be suggested that in long-distance races swimmers may not be capable of maintaining their strength indexes during an entire race, and hence their SL (Ikuta et al., 2010). Indeed, Figure 1 shows that the SL started decreasing from the 750 m onwards. On the other hand, our data showed that an increase in one unit (Hz) by the SF, decreased the clean swim time in 27.49 s (converting to cycles per minute: an increase in one cycle per minute imposed a 0.46 s decrease in the clean swim time, i.e., better performance). Therefore, in 28 laps (without the first and last lap) a swimmer may reduce his/her final race time in 12.88 s. Indeed, the relationship between the SL and SF management in long-distance swimming races could be related to inter-lap constraints (Seifert et al., 2014).

There are two basic strategies for increasing speed: or increasing stroke length or increasing stroke frequency (or both combined) (Craig & Pendergast, 1979). Long-distance events depend heavily on swimming savings (more energy cost, lower performance). It is known that increases in speed due to the increase in stroke frequency induce sharp increases in energy costs. On the other hand, increases in the stroke length lead to lower increases in energy costs (Barbosa et al., 2008). Therefore, it was expected that SL would be a better predictor of performance because it allows speed increases with lower energy costs. However, was pointed out that long-distance elite athletes such as cyclists (as a cyclic and closed sport like swimming) seem to privilege the SF over the SL (Abbiss et al., 2009). It was highlighted that elite cyclists that maintained a higher cadence increased their power output based on a high mechanical efficiency and maximal aerobic capacity (Reed et al., 2016). Our data seems to also suggest this rational for long-distance swimmers. In this sense, studies about the energy cost of long-distance swimming comparing both strategies (i.e., focus on SL or SF) are required to understand if swimmers can improve their performances based on the SF strategy.

This research highlights that coaches should be advised about this SF/SL relationship in long-distance races. A study indicated that the SF maintenance was the key-factor in preventing the swim speed to decrease in a higher magnitude (Ikuta et al., 2010). Indeed, it was noted that the fastest swimmer from this sample was the one presenting the highest SF. If swimmers could maintain the mean SL showed until this distance (without the first lap: 50–750 m) and increase the SF by one cycle per minute until the 1400–1450 m lap (excluding the last lap effect as previously argued), they could increase their clean swim performance in 7.05% (less 16.90 s to cover the distance). It can be suggested: (1) the analysis of elite female swimmers to understand if the trend is similar (or not) to their male counterparts; (2) perform a stroke per stroke variation to give deeper insights about swimmers' stroke mechanics variation; (3) registering the number of breaths by each swimmer during the clean swim performance could give an insight about the reasoning for the decrease of time spent in the turn underwater phase, and; (4) use a much larger sample to classify (by cluster analysis per example) the different types of pacing and relate them to performance and technical parameters.

Conclusion

Elite long-distance male swimmers exhibit a positive pacing strategy where the first half of the race was faster than the second. The lap performance and clean swim performance showed a significant variation (i.e., low stability), but this was lower in the clean swim performance. This highlights that long-distance swim pace analysis may present different results depending on the conceptualisation used. The total turn presented a significant variation (i.e., low stability). The SF was the main factor responsible for the clean swim performance.

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