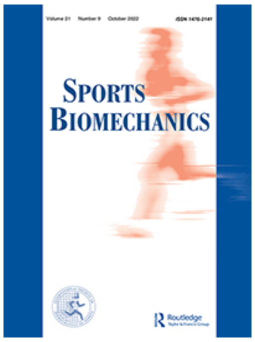

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Race analysis of the men's 50 m events at the 2021 LEN European Championships

Jorge E Morais[a,b], Tiago M Barbosa[a,b], Tiago Lopes[c], David Simbaña-Escobar[d] and Daniel a Marinho[b,c]

[a]Department of Sport Sciences, Instituto Politécnico de Bragança, Bragança, Portugal; [b]Research Centre in Sports, Health and Human Development (CIDESD), Covilhã, Portugal; [c]Department of Sport Sciences, University of Beira Interior, Covilhã, Portugal; [d]Center for the Study and the Transformation of Physical Activities (CETAPS), Faculty of Sport Sciences, University of Rouen Normandie, Mont Saint Aignan, UNIROUEN, Rouen, France

ABSTRACT

The aim of this study was to: (i) characterise the stroke kinematics' stability of the male swimmers competing in the four 50 m events at the 2021 European Championships, and; (ii) understand the speed–time relationship in the four race events. All male swimmers who participated in the 50 m events (backstroke: 78 swimmers; breaststroke: 79 swimmers; butterfly: 89 swimmers; freestyle: 95 swimmers) were evaluated. In each swimming stroke swimmers were split in two groups (better and poorer performances). Significant variances ($p < 0.05$) were observed in both groups in all variables and for all swimming strokes. Swimming speed was the variable with the highest variance in both groups and strokes. Overall, better swimmers presented a low to high normative stability, and poorer swimmers a moderate-to-high. Speed–time curve fitting for all swimming strokes and groups suggested a cubic relationship. It can be considered that elite male swimmers racing 50 m sprint events at major competitions present an all-out trend. The present data provide coaches with substantial information about the main trend in the 50 m sprint events, specifically in each section of the race.

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Analysis; biomechanics; performance; training

Introduction

In sports performance, the athlete's improvement is based on the interaction of several domains (Phillips et al., 2010). Race analysis is becoming more important than ever as it provides insights on the performance itself and its underlying factors (Barbosa et al., 2021). Race analysts must provide coaches and athletes with detailed information about what happens during the race. In competitive swimming, race analysis can provide information about the start (Born et al., 2021), turn(s) (Veiga et al., 2016), clean swimming and finish (Morais et al., 2022). The clean swimming phase is the one in which swimmers spend the greatest

CONTACT Jorge E Morais morais.jorgestrela@gmail.com

amount of time, thus even more crucial to coaches and swimmers (Morais et al., 2022; Simbaña-Escobar et al., 2018).

Most research conducted in race analysis focused on freestyle events, distances of 100 m or longer (Huot-Marchand et al., 2005; Mauger et al., 2012; McGibbon, Pyne, Heidenreich, & Pla, 2021). Less information is provided regarding the other swimming strokes (i.e., backstroke, breaststroke, and butterfly). Nonetheless, Veiga et al. (2016) analysed the time that swimmers spent performing the underwater phase after the start and turn(s) in all four swimming strokes. Others investigated the temporal patterns of elite breaststroke swimmers in 100 and 200 m events (Nicol et al., 2021). Regardless of the swimming stroke, even less information is available on distances shorter than 100 m, i.e., the 50 m sprint events. Notwithstanding, this fact was observed in a review study on all swimming events (McGibbon et al., 2018). Nevertheless, two studies can be found on the 50 m sprint event in a race analysis context, although freestyle (Morais et al., 2022; Simbaña-Escobar et al., 2018). One can argue that missing evidence on one of the most popular races in swimming, the 50 m distance events, may occur because is a non-Olympic event. Nevertheless, the information that can be retrieved from such analyses may be paramount for swimmers and coaches.

Studies usually analyse the swimmers' pacing by stability analysis (i.e., variance) based on lap-to-lap performance and stroke kinematics (Morais et al., 2021; Robertson et al., 2009). As the 50 m events in long-course metre (swimming pool with 50 m of length) consist of only one lap, lap-to-lap stability (i.e., variance) cannot be performed. Yet, studies suggested that 50 m events can also be analysed by stability analysis to understand the swimmers' behaviour throughout the race (Morais et al., 2022; Simbaña-Escobar et al., 2018). In such short sprints of one single lap, it is feasible to perform within lap stability (i.e., intra-lap variance) having as reference the swimming pool marks (i.e., 15 m, 25 m, 35 m, and 45 m). This allows for a more detailed understanding of the magnitude of the difference between the lap sections and a better insight of the swimmers' profiles and their variance during the race (Mauger et al., 2012). Moreover, it was suggested that 50 m sprinters perform a rapid acceleration at the start by taking advantage of the dive effect, followed by a gradual decay of swimming speed throughout the race as fatigue sets in (Morais et al., 2022). Hence, 50 m events seem to present a positive profile, considering that there is a decrease in the swimming speed throughout the race (McGibbon et al., 2018). In tandem to this assertion, two studies reported such trend in the 50 m freestyle, where the speed–time curve revealed a cubic relationship (Morais et al., 2022; Simbaña-Escobar et al., 2018). However, there is no evidence on this topic in the remaining swimming strokes, as well, as for the stroke kinematics' stability.

Therefore, this study aimed to: (i) characterise the stroke kinematics' stability of the male swimmers competing in the four 50 m events at the 2021 European Championships, and; (ii) understand the speed-time relationship in the four race events. It was hypothesised that: (i) a low kinematics' stability (i.e., significant differences during the race specially in swim speed) will be observed, and; (ii) swimmers will present a cubic speed–time relationship.

Methods

Participants

An a priori power analysis was conducted using G*Power (Faul et al., 2007). Eighty-four participants (42 in each group) were required to detect a large effect size (d = 0.80) with 95% power (α = 0.05, two-tailed test) for a 'Difference between two independent means (two groups)' statistical test. Participants were all male swimmers who competed in the 50 m events (i.e., heats, semi-finals, and final) at the 2021 LEN European Championships held in Budapest (backstroke: 78 swimmers; breaststroke: 79 swimmers; butterfly: 89 swimmers; freestyle: 95 swimmers). Only swimmers with official race times were analysed (i.e., disqualifications were not considered). Whenever swimmers qualified for semi-finals or finals, multiple analyses for each swimmer were conducted. The 50 m backstroke performance reached 93.51 ± 3.09% the World Record, the 50 m breaststroke 93.59 ± 3.04%, the 50 m butterfly 93.24 ± 2.81%, and the 50 m freestyle 92.39 ± 3.56%. All procedures were in accordance with the Declaration of Helsinki regarding human research, and the Polytechnic Ethics Board approved the research design (N.º 73/2022).

Data analysis

The official race times and block times were retrieved from the official competition website (http://budapest2020.microplustiming.com/indexBudapest2021_web.php). All video clips were provided in high-definition video ($f = 50$ Hz) by the Ligue Européenne de Natation (LEN). The setup system delivered 10 pan-tilt-zoom cameras. Each swimmer was recorded by one camera (i.e., one camera per lane) allowing the analysis of the start and finish individually. Pool calibration was set before every session. Clamps were placed in the lane ropes to stop the counters from moving and then, pictures were taken at 5 m, 15 m, 25 m, 35 m, and 45 m to identify exactly where these distance points were. The start strobe lights were synchronised with the official timing system and were visible by all cameras. The start strobe light was used as a reference to set the timestamp on the race analysis software (Morais et al., 2019). Two expert race analysts performed each race analysis. The agreement between both analysts was assessed with the Intraclass Correlation Coefficient (ICC). This revealed a very-high agreement (ICC = 0.999).

The start (i.e., the time lag between the starting signal and the 15 m mark) was converted into speed. This was section S0–15 m (i.e., time between 0 and 15 m). The remaining sections were: (i) S15–25 m (time between the 15^{th} and the 25^{th} metre); (ii) S25–35 m (time between the 25^{th} and the 35^{th} metre); (iii) S35–45 m (time between the 35^{th} and the 45^{th} metre), and; (iv) S45–50 m (time between the 45^{th} and the 50^{th} metre—finish) (Morais et al., 2022). All kinematic variables were measured after the S0–15 m section. In each of the next sections the following variables were measured: (i) the clean swimming speed (in m/s); (ii) the stroke frequency (SF, in Hz); (iii) the stroke length (SL, in m), and; (iv) the stroke index (SI, in m^2/s). The clean swimming speed was calculated as $v = d/t$, in which d is the distance (in m) and t is the time (in seconds). The SF was obtained by computing the period of the time spent to complete a full stroke cycle ($SF = 1/P$, where P is the period). In each section (besides the start—S0–15 m), the average SF was calculated based on the number of strokes that were performed in that same section. The SL was calculated as $SL = v/SF$ (Craig & Pendergast, 1979), and the SI as $SI = v * SL$

(Costill et al., 1985). The finish time and speed started to be measured when the swimmer's head reached the 45th metre mark and stopped when the swimmer's hand touched the end wall. For each swimmer, it was measured the distance between the head and the end wall. This was done to perform a speed correction based on the time that the swimmer's head would take to complete the remaining distance (Thompson et al., 2000).

Statistical analysis

The Kolmogorov-Smirnov and the Levene tests were used to assess the normality and homoscedasticity, respectively. The mean plus one standard deviation were computed as descriptive statistics. For each race event, the dataset was split into two halves: (i) fastest swimmers; (ii) slowest swimmers (significant differences were observed between groups in the swimming speed). The independent samples *t*-test ($p \leq 0.05$) was used to compare groups (fastest vs slowest swimmers). The mean difference and 95% confidence intervals (95 CI) of the mean difference were also calculated. Cohen's d was selected as standardised effect size, and interpreted as small effect size if $0 \leq |d| \leq 0.2$; medium if $0.2 < |d| \leq 0.5$ and; large effect size if $|d| > 0.5$ (Cohen, 1988).

Between-participants worthwhile changes were computed to examine the smallest meaningful improvement. This allows to determine the true change that elicits a meaningful improvement in performance, rather than just typical variation in the test. Worthwhile changes were calculated by having $d = 0.2$ as the smallest standardised effect size in sports performance (Bucheit, 2016). Afterwards, each worthwhile change was converted into smallest partial improvement to be expected. This was performed having as reference the mean value of the fastest group of the two being compared.

The swimmer's stability was assessed based on mean and normative stability (Morais et al., 2021). This refers to the persistence of the magnitude of change of a given variable over the race. The ANOVA repeated measures (i.e., variance between sections), followed by the Bonferroni post-hoc were used to verify differences between each pairwise ($p \leq 0.05$). 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 coefficient of variation (CV, in %) was calculated for each pairwise. The normative stability focuses on the stability of inter-individual differences in intra-individual changes. It refers to the maintenance of the relative position of the swimmers within a group assessed over the race. This was assessed with the IntraClass Correlation Coefficient (ICC) between each pairwise. As a rule of thumb, it was defined that the stability was: (i) low if $r < 0.30$; (ii) moderate if $0.30 \leq r < 0.60$; (iii) high if $r \geq 0.60$ (Malina, 2001).

For each race event (i.e., backstroke, breaststroke, butterfly, and freestyle), the curve fitting was used to model the speed-time data spread by assigning the 'best fit' function through the entire race (Morais et al., 2022). It was performed based on the five main sections defined beforehand: (i) S0–15 m; (ii) S15–25 m; (iii) S25–35 m; (iv) S35–45 m, and; (v) S45–50 m. Linear, quadratic, and cubic fits were tested. Trendline, 95 CI, 95% of prediction interval (95PI), and standard error of estimation (SEE) were calculated. The SEE was used as a goodness-of-fit indicator to compare the models (i.e., linear, quadratic, and cubic) (Siegel, 2016). It demonstrates how precise model predictions are by using the units of the dependent variable (i.e., it indicates how far the data points are from the regression line on average). Lower SEE values indicate that the distances between the data points and the fitted values are narrower. Statistical computations were performed using a statistical analysis program (SPSS, Version 26.0; Chicago, IL).

Results

Descriptive data of all sections of the race, and comparison between groups, is presented in Table 1. Clean swimming (i.e., sections between the 15th and the 45th metre marks) and finish (i.e., last section, S45-50 m) mean stability of both groups are depicted in Figure 1 and Table 2 Significant variances were found for both groups in all variables and swimming strokes. Moreover, for all swimming strokes, the swimming speed was the variable with the highest variance in both groups.

Table 2 also presents the normative stability. Overall, swimmers of both groups showed a moderate-to-high normative stability in backstroke (except swimmers in the fastest group regarding speed between S35–45 m and S45–50 m). In breaststroke, a moderate-to-high normative stability was observed for all variables and groups. However, the swimming speed for the fastest swimmers had a low to high normative stability. Butterfly revealed a low to high normative stability for all variables and groups. Same trend was noticed for freestyle swimmers in the fastest group, although their counterparts in the slowest group had a moderate-to-high normative stability. Altogether, fastest swimmers are more likely to change their relative position during the race than their slower counterparts, especially in butterfly and freestyle.

Figure 2 depicts the speed-time curve fitting in the 50 m events. For all swimming strokes and groups, the curve fitting suggested a cubic relationship (based on lower SEE) in comparison to linear and quadratic models (backstroke—fastest group: SEE = 0.053; slowest group: SEE = 0.082; breaststroke—fastest group: SEE = 0.061; slowest group: SEE = 0.068; butterfly—fastest group: SEE = 0.050; slowest group: SEE = 0.085; freestyle—fastest group: SEE = 0.043; slowest group: SEE = 0.092).

Discussion and Implications

This study aimed to: (i) characterise the stroke kinematics' stability of the male swimmers competing in the four 50 m sprint events at the 2021 European Championships, and; (ii) understand the speed-time relationship in the four race events. In all swimming strokes, a low mean stability was found in the swimming speed in both groups, suggesting a positive pacing profile during the race. Overall, the same trend was observed in the remaining variables. Conversely, fastest swimmers in all strokes presented a low to high normative stability, and slowest swimmers a moderate-to-high normative stability. The best fitting for both groups in all swimming strokes was a cubic speed-time relationship. Thus, it can be considered that elite swimmers in the four swimming strokes presented an all-out trend with two evident key-moments (section S0–15 m—start; section S45–50 m—finish) in both groups.

Table 1. Descriptive statistics (mean ± one standard deviation) and comparison between the fastest and slowest swimmers in the 50 m backstroke, breaststroke, butterfly, and freestyle events during 2021 LEN European Championships.

	50 m backstroke						
	Mean±1SD (Fastest group)	Mean±1SD (Slowest group)	Mean difference (95%CI)	t	p	d [descriptor]	Worthwhile change [% of tier #1]
			S0-15 m				
Speed [m/s]	2.45±0.07	2.31±0.15	-0.133 (-0.186 to -0.078)	-4.886	<0.001	1.20 [large]	0.01 [0.57%]
			S15-25 m				
Speed [m/s]	1.91±0.04	1.82±0.08	-0.089 (-0.116 to -0.061)	-6.460	<0.001	1.42 [large]	0.01 [0.42%]
SF [Hz]	0.96±0.05	0.95±0.07	-0.012 (-0.038 to 0.014)	-0.919	0.361	0.16 [small]	0.01 [1.04%]
SL [m]	1.99±0.10	1.93±0.14	-0.065 (-0.119 to -0.012)	-2.452	0.017	0.49 [medium]	0.02 [1.01%]
SI [m^2/s]	3.80±0.21	3.51±0.31	-0.290 (-0.411 to -0.169)	-4.791	<0.001	1.10 [large]	0.04 [1.11%]
			S25-35 m				
Speed [m/s]	1.87±0.04	1.79±0.06	-0.079 (-0.102 to -0.057)	-6.970	<0.001	1.57 [large]	0.01 [0.43%]
SF [Hz]	0.94±0.05	0.91±0.08	-0.028 (-0.059 to 0.002)	-1.857	0.067	0.45 [medium]	0.01 [1.06%]
SL [m]	2.00±0.11	1.98±0.16	-0.016 (-0.078 to 0.045)	-0.523	0.603	0.15 [small]	0.02 [1.10%]
SI [m^2/s]	3.75±0.23	3.55±0.28	-0.192 (-0.308 to -0.075)	-3.274	0.002	0.78 [large]	0.05 [1.23%]
			S35-45 m				
Speed [m/s]	1.83±0.05	1.76±0.06	-0.073 (-0.098 to -0.048)	-5.828	<0.001	1.27 [large]	0.01 [0.55%]
SF [Hz]	0.91±0.05	0.89±0.07	-0.023 (-0.045 to 0.004)	-1.673	0.099	0.33 [medium]	0.01 [1.10%]
SL [m]	2.02±0.11	1.99±0.14	-0.026 (-0.082 to 0.031)	-0.913	0.364	0.24 [medium]	0.02 [1.09%]
SI [m^2/s]	3.69±0.26	3.49±0.27	-0.195 (-0.313 to -0.078)	-3.301	0.001	0.75 [large]	0.05 [1.41%]
			S45-50 m				
Speed [m/s]	1.68±0.06	1.60±0.08	-0.075 (-0.106 to -0.043)	-4.713	<0.001	1.13 [large]	0.01 [0.71%]
SF [Hz]	0.89±0.05	0.88±0.07	-0.006 (-0.034 to 0.022)	-0.433	0.666	0.16 [small]	0.01 [1.12%]
SL [m]	1.90±0.14	1.83±0.16	-0.067 (-0.135 to 0.001)	-1.976	0.052	0.47 [medium]	0.03 [1.47%]
SI [m^2/s]	3.19±0.33	2.94±0.35	-0.250 (-0.405 to -0.096)	-3.227	0.002	0.73 [large]	0.07 [2.07%]
	50 m breaststroke						
	Mean±1SD (Fastest group)	Mean±1SD (Slowest group)	Mean difference (95%CI)	t	p	d [descriptor]	Worthwhile change [% of tier #1]
			S0-15 m				
Speed [m/s]	2.36±0.09	2.26±0.09	-0.106 (-0.147 to -0.065)	-5.185	<0.001	1.11 [large]	0.02 [0.76]
			S15-25 m				
Speed [m/s]	1.69±0.04	1.62±0.05	-0.070 (-0.092 to -0.048)	-6.384	<0.001	1.55 [large]	0.01 [0.47]
SF [Hz]	1.09±0.07	1.04±0.09	-0.050 (-0.086 to -0.014)	-2.788	0.007	0.62 [large]	0.01 [1.28]
SL [m]	1.56±0.10	1.57±0.14	0.012 (-0.044 to 0.067)	0.422	0.674	0.08 [small]	0.02 [1.28]
SI [m^2/s]	2.63±0.20	2.54±0.26	-0.089 (-0.193 to 0.0145)	-1.708	0.092	0.39 [medium]	0.04 [1.52]
			S25-35 m				
Speed [m/s]	1.69±0.03	1.61±0.06	-0.081 (-0.102 to -0.060)	-7.824	<0.001	1.69 [large]	0.01 [0.36]
SF [Hz]	1.08±0.08	1.02±0.07	-0.060 (-0.093 to -0.026)	-3.568	0.001	0.80 [large]	0.02 [1.48]

(*Continued*)

Table 1. (Continued).

SL [m]	1.58±0.10	1.59±0.13	0.014 (-0.039 to 0.067)	0.524	0.602	0.09 [small]	0.02 [1.27]
SI [m^2/s]	2.67±0.18	2.57±0.26	-0.101 (-0.201 to -0.0001)	-1.994	0.050	0.45 [medium]	0.04 [1.35]
			S35-45 m				
Speed [m/s]	1.66±0.03	1.58±0.06	-0.083 (-0.103 to -0.062)	-7.988	<0.001	1.69 [large]	0.01 [0.36]
SF [Hz]	1.06±0.08	1.01±0.06	-0.053 (-0.085 to -0.020)	-3.205	0.002	1.05 [large]	0.02 [1.51]
SL [m]	1.57±0.12	1.57±0.13	-0.003 (-0.057 to 0.051)	-0.124	0.901	0.00 [small]	0.02 [1.53]
SI [m^2/s]	2.61±0.10	2.48±0.26	-0.132 (-0.234 to -0.029)	-2.563	0.012	0.66 [large]	0.02 [0.77]
			S45-50 m				
Speed [m/s]	1.57±0.06	1.50±0.07	-0.064 (-0.093 to -0.036)	-4.490	<0.001	1.07 [large]	0.01 [0.76]
SF [Hz]	1.04±0.08	1.00±0.09	-0.044 (-0.082 to -0.007)	-2.349	0.021	0.47 [medium]	0.02 [1.54]
SL [m]	1.51±0.12	1.51±0.15	0.007 (-0.054 to 0.067)	0.222	0.825	0.00 [small]	0.02 [1.59]
SI [m^2/s]	2.36±0.23	2.28±0.28	-0.086 (-0.202 to 0.030)	-1.472	0.145	0.31 [medium]	0.05 [1.95]

	50 m butterfly						
	Mean±1SD (Fastest group)	**Mean±1SD (Slowest group)**	**Mean difference (95%CI)**	**t**	**p**	**d [descriptor]**	**Worthwhile change [% of tier #1]**
			S0-15 m				
Speed [m/s]	2.74±0.08	2.60±0.13	-0.146 (-0.194 to -0.099)	-6.117	<0.001	1.30 [large]	0.02 [0.58%]
			S15-25 m				
Speed [m/s]	2.00±0.04	1.91±0.06	-0.083 (-0.104 to -0.062)	-8.024	<0.001	1.77 [large]	0.01 [0.40%]
SF [Hz]	1.06±0.07	1.05±0.06	-0.011 (-0.037 to 0.016)	-0.786	0.434	0.15 [small]	0.01 [1.32%]
SL [m]	1.86±0.14	1.82±0.11	-0.065 (-0.116 to -0.013)	-2.510	0.014	0.32 [medium]	0.03 [1.51%]
SI [m^2/s]	3.77±0.29	3.49±0.25	-0.280 (-0.393 to -0.166)	-4.889	<0.001	1.03 [large]	0.06 [1.54%]
			S25-35 m				
Speed [m/s]	1.96±0.03	1.88±0.05	-0.082 (-0.098 to -0.067)	-10.526	<0.001	1.94 [large]	0.01 [0.31%]
SF [Hz]	1.05±0.06	1.03±0.06	-0.027 (-0.052 to -0.002)	-2.135	0.036	0.33 [medium]	0.01 [1.14%]
SL [m]	1.87±0.11	1.84±0.12	-0.029 (-0.077 to 0.018)	-1.225	0.224	0.26 [medium]	0.02 [1.18%]
SI [m^2/s]	3.66±0.21	3.45±0.25	-0.206 (-0.305 to -0.108)	-4.166	<0.001	0.91 [large]	0.04 [1.15%]
			S35-45 m				
Speed [m/s]	1.93±0.04	1.87±0.07	-0.056 (-0.081 to -0.031)	-4.487	<0.001	1.05 [large]	0.01 [0.41%]
SF [Hz]	1.03±0.05	1.00±0.06	-0.024 (-0.047 to -0.0003)	-2.012	0.047	0.54 [large]	0.01 [0.97%]
SL [m]	1.87±0.12	1.86±0.13	-0.010 (-0.062 to 0.042)	-0.368	0.714	0.08 [small]	0.02 [1.28%]
SI [m^2/s]]	3.61±0.27	3.49±0.34	-0.122 (-0.252 to 0.008)	-1.862	0.066	0.39 [medium]	0.05 [1.50%]
			S45-50 m				
Speed [m/s]	1.72±0.04	1.65±0.08	-0.079 (-0.107 to -0.050)	-5.498	<0.001	1.11 [large]	0.01 [0.47%]
SF [Hz]	0.99±0.06	0.98±0.05	-0.017 (-0.041 to 0.006)	-1.481	0.142	0.18 [small]	0.01 [1.21%]
SL [m]	1.74±0.11	1.69±0.11	-0.051 (-0.097 to -0.006)	-2.228	0.028	0.45 [medium]	0.02 [1.26%]
SI [m^2/s]	3.00±0.22	2.78±0.28	-0.217 (-0.323 to -0.111)	-4.069	<0.001	0.87 [large]	0.04 [1.47%]

(*Continued*)

Table 1. (Continued).

	50 m freestyle						
	Mean±1SD (Fastest group)	**Mean±1SD (Slowest group)**	**Mean difference (95%CI)**	**t**	**p**	**d [descriptor]**	**Worthwhile change [% of tier #1]**
			S0-15 m				
Speed [m/s]	2.76±0.06	2.57±0.12	-0.187 (-0.224 to -0.149)	-9.862	<0.001	2.00 [large]	0.01 [0.43%]
			S15-25 m				
Speed [m/s]	2.17±0.04	2.05±0.08	-0.113 (-0.138 to -0.087)	-8.714	<0.001	1.90 [large]	0.01 [0.37%]
SF [Hz]	1.04±0.04	1.03±0.05	-0.012 (-0.032 to 0.0076)	-1.226	0.223	0.22 [medium]	0.01 [0.77%]
SL [m]	2.09±0.08	2.00±0.13	-0.083 (-0.127 to -0.039)	-3.743	<0.001	0.83 [large]	0.02 [0.77%]
SI [m^2/s]	4.53±0.21	4.12±0.37	-0.406 (-0.529 to -0.283)	-6.551	<0.001	1.36 [large]	0.04 [0.93%]
			S25-35 m				
Speed [m/s]	2.12±0.03	2.02±0.08	-0.102 (-0.127 to -0.077)	-8.164	<0.001	1.66 [large]	0.01 [0.28%]
SF [Hz]	1.02±0.04	1.00±0.06	-0.012 (-0.032 to 0.009)	-1.110	0.270	0.39 [medium]	0.01 [0.78%]
SL [m]	2.09±0.09	2.01±0.12	-0.075 (-0.118 to -0.031)	-3.395	0.001	0.75 [large]	0.02 [0.86%]
SI [m^2/s]	4.42±0.22	4.06±0.34	-0.358 (-0.475 to -0.241)	-6.067	<0.001	1.26 [large]	0.04 [1.00%]
			S35-45 m				
Speed [m/s]	2.06±0.03	1.96±0.10	-0.097 (-0.127 to -0.068)	-6.575	<0.001	1.35 [large]	0.01 [0.29%]
SF [Hz]	0.98±0.07	0.97±0.05	-0.016 (-0.042 to 0.010)	-1.202	0.232	0.16 [small]	0.01 [1.43%]
SL [m]	2.11±0.20	2.03±0.15	-0.074 (-0.145 to -0.002)	-2.054	0.043	0.45 [medium]	0.04 [1.90%]
SI [m^2/s]	4.34±0.43	4.00±0.42	-0.344 (-0.517 to -0.172)	-3.960	<0.001	0.80 [large]	0.09 [1.98%]
			S45-50 m				
Speed [m/s]	1.87±0.05	1.78±0.08	-0.086 (-0.113 to -0.058)	-6.214	<0.001	1.35 [large]	0.01 [0.53%]
SF [Hz]	0.97±0.06	0.94±0.07	-0.035 (-0.062 to -0.009)	-2.639	0.010	0.46 [medium]	0.01 [1.24%]
SL [m]	1.93±0.13	1.92±0.16	-0.016 (-0.076 to 0.043)	-0.547	0.586	0.07 [small]	0.03 [1.35%]
SI [m^2/s]	3.62±0.30	3.42±0.39	-0.192 (-0.332 to -0.051)	-2.708	0.008	0.57 [large]	0.06 [1.66%]

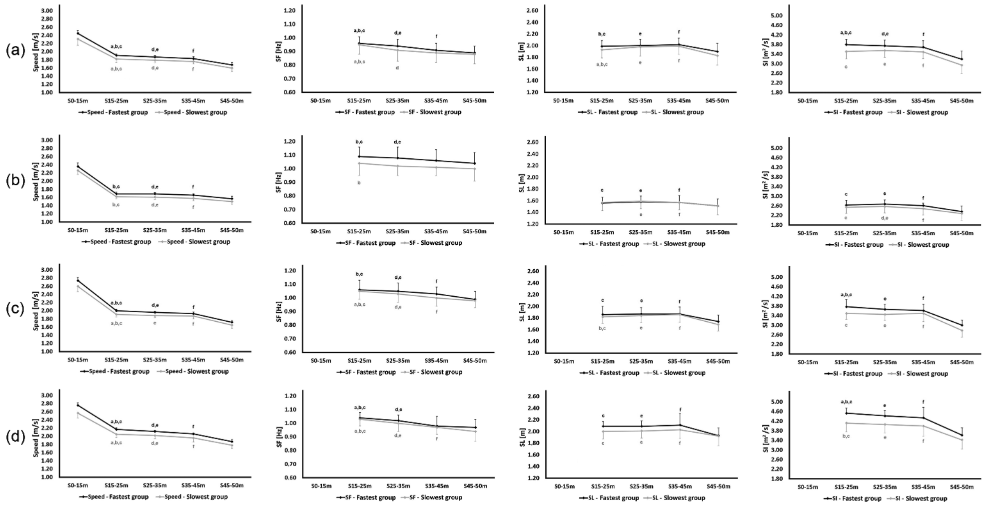

Figure 1. Average data of the variables analyzed during the stroke cycle. Within-lap stability for the stroke kinematics (from the 15th to 50th meter, i.e., clean swim and finish) by the fastest and slowest swimmers in the 50 m male events during the 2021 LEN European Championships. Panel A – backstroke; Panel B – breaststroke; Panel C – butterfly; Panel D – freestyle. SF – stroke frequency; SL – stroke length; SI – stroke index. Significant differences ($p \leq 0.05$) between sections: a – S15-25 m vs S25-35 m; b – S15-25 m vs S35-45 m; c – S15-25 m vs S45-50 m; d – S25-35 m vs S35-45 m; e – S25-35 m vs S45-50 m; f – S35-45 m vs S45-50 m.

A low stability throughout the race was noted for all variables in the four events and both groups. It was suggested that swimmers of the same competitive level might have the same stability profile while racing (Morais et al., 2022). However, until now there was no evidence on this matter. Differences (with small to large effect size) were observed in speed from the S15–25 m onwards (clean swimming and finish phases). That is, a drop in speed over the race was observed in all sprint events. This has also been noted before at junior (Morais et al., 2022) and elite levels (Simbaña-Escobar et al., 2018), but only in freestyle sprinting. Altogether, our research confirms that a swimming speed decay over the race also happens in all sprint events.

Likewise, SF decreased over the 50 m race in events and groups. Conversely, SL increased at the beginning of the clean swim (S15–25 m to S35–45 m) to decrease later (S35–45 m to S45–50 m) in all events and groups. It was argued that in sprint events, swimmers 'control' their pace through SF (Costill et al., 1985; Simbaña-Escobar et al., 2020). Swimming speed is changed by mainly increasing and decreasing the SF rather than the SL. Thus, the speed decay observed here is largely due to a decrease in SF. In sprint events it seems that swimmers do not undergo a pacing strategy, but rather an all-out trend is employed. The drop in SF at the end of the race can be due to an impairment of the energetics pathways (Pyne & Sharp, 2014). Swimmers tend to trade-off SF and SL, i.e., whenever SF decreases, often SL increases (Craig & Pendergast, 1979). However, from sections S35–45 m to S45–50 m, decreases in SF were coupled with SL decreases. Swimmers may not be able to produce the same amount of in-water force and the leading energetic pathway unable to deliver the same power at the end of a maximal bout (Pyne & Sharp, 2014). It was claimed that a shorter SL could be associated with a lower capability to generate sufficient propulsive

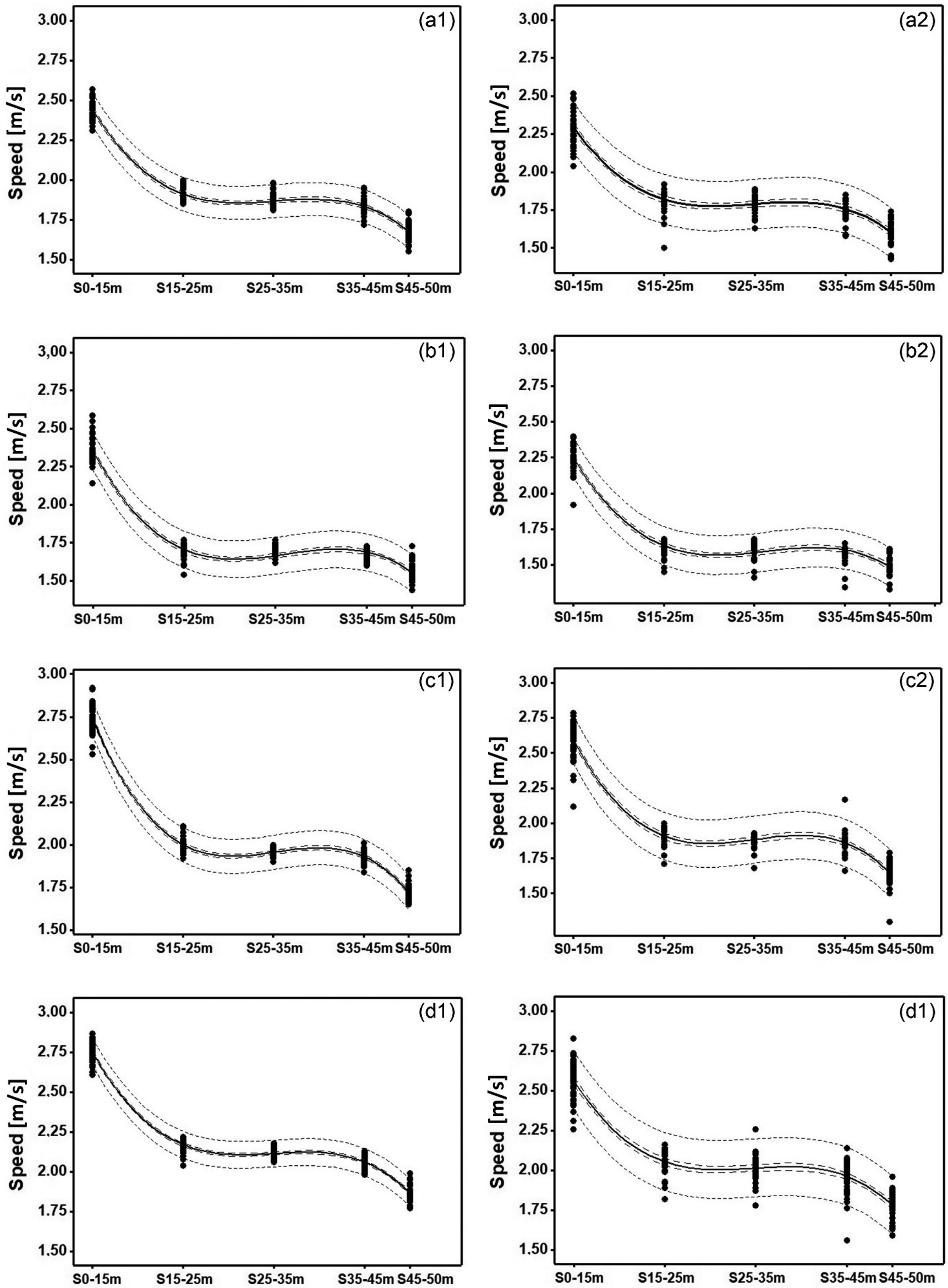

Figure 2. Cubic curve fitting of the swim speed in the 50 m events during 2021 LEN European Championships. Solid line denotes the mean, dashed line the 95CI, and dotted line the 95PI. Panel A – backstroke; Panel B – breaststroke; Panel C – butterfly; Panel D – freestyle. In each panel, 1 and 2 after each letter corresponds to the fastest and slowest swimmers' groups, respectively.

Table 2. Mean and normative stability between each swim section for the fastest and slowest swimmers in the 50 m events (i.e., backstroke, breaststroke, butterfly, and freestyle) during 2021 LEN European Championships.

	F	p	η²	S15-25m vs S25-35m	S15-25m vs S35-45m	S15-25m vs S45-50m	S25-35m vs S35-45m	S25-35m vs S45-50m	S35-45m vs S45-50m
50 m backstroke									
Fastest group									
Speed [m/s]	301.71	<0.001	0.89	r=0.888; p<0.001 CV=0.93; d=1.00	r=0.885; p<0.001 CV=1.71; d=1.77	r=0.230; p=0.212 CV=4.78; d=4.51	r=0.885; p<0.001 CV=1.16; d=0.88	r=0.403; p=0.058 CV=4.62; d=3.73	r=0.324; p=0.116 CV=4.28; d=2.72
SF [Hz]	119.72	<0.001	0.76	r=0.982; p<0.001 CV=1.14; d=0.40	r=0.971; p<0.001 CV=2.18; d=1.00	r=0.887; p<0.001 CV=2.91; d=1.40	r=0.983; p<0.001 CV=1.53; d=0.60	r=0.875; p<0.001 CV=2.20; d=1.00	r=0.880; p<0.001 CV=1.15; d=0.40
SL [m]	34.96	<0.001	0.48	r=0.962; p<0.001 CV=0.23; d=0.10	r=0.953; p<0.001 CV=0.49; d=0.29	r=0.760; p<0.001 CV=2.40; d=0.74	r=0.965; p<0.001 CV=0.36; d=0.18	r=0.787; p<0.001 CV=2.72; d=0.79	r=0.754; p<0.001 CV=3.08; d=0.95
SI [m^2/s]	121.19	<0.001	0.76	r=0.938; p<0.001 CV=0.70; d=0.23	r=0.929; p<0.001 CV=1.21; d=0.47	r=0.613; p=0.002 CV=6.78; d=2.21	r=0.932; p<0.001 CV=0.78; d=0.24	r=0.665; p=0.001 CV=7.09; d=1.97	r=0.604; p=0.003 CV=7.28; d=1.68
Slowest group									
	F	**p**	**η²**	**S15-25m vs S25-35m**	**S15-25m vs S35-45m**	**S15-25m vs S45-50m**	**S25-35m vs S35-45m**	**S25-35m vs S45-50m**	**S35-45m vs S45-50m**
Speed [m/s]	206.46	<0.001	0.84	r=0.863; p<0.001 CV=0.72; d=0.42	r=0.862; p<0.001 CV=1.44; d=0.85	r=0.585; p=0.004 CV=4.78; d=2.75	r=0.935; p=0.004 CV=1.03; d=0.50	r=0.711; p<0.001 CV=4.76; d=2.69	r=0.723; p<0.001 CV=4.53; d=2.26
SF [Hz]	17.53	<0.001	0.32	r=0.870; p<0.001 CV=2.04; d=0.53	r=0.962; p<0.001 CV=2.73; d=0.86	r=0.622; p=0.002 CV=2.83; d=1.00	r=0.905; p<0.001 CV=1.26; d=0.27	r=0.573; p=0.005 CV=1.31; d=0.40	r=0.609; p=0.002 CV=0.23; d=0.14
SL [m]	21.43	<0.001	0.36	r=0.786; p<0.001 CV=1.45; d=0.34	r=0.945; p<0.001 CV=1.43; d=0.44	r=0.568; p=0.006 CV=3.36; d=0.69	r=0.807; p<0.001 CV=0.15; d=0.07	r=0.492; p<0.001 CV=3.38; d=0.94	r=0.516; p=0.014 CV=4.24; d=1.06
SI [m^2/s]	74.50	<0.001	0.66	r=0.803; p<0.001 CV=0.65; d=0.14	r=0.916; p<0.001 CV=0.73; d=0.07	r=0.545; p=0.009 CV=7.50; d=1.72	r=0.795; p<0.001 CV=0.86; d=0.22	r=0.531; p=0.011 CV=8.35; d=1.92	r=0.526; p=0.012 CV=8.66; d=1.76
50 m breaststroke									
Fastest group									
	F	**p**	**η²**	**S15-25m vs S25-35m**	**S15-25m vs S35-45m**	**S15-25m vs S45-50m**	**S25-35m vs S35-45m**	**S25-35m vs S45-50m**	**S35-45m vs S45-50m**
Speed [m/s]	98.39	<0.001	0.72	r=0.780; p<0.001 CV=0.19; d=0.19	r=0.757; p<0.001 CV=1.08; d=0.74	r=0.324; p=0.116 CV=3.23; d=0.2.41	r=0.786; p<0.001 CV=1.04; d=0.56	r=0.234; p=0.207 CV=3.28; d=2.23	r=0.122; p=0.345 CV=2.87; d=1.67
SF [Hz]	15.38	<0.001	0.29	r=0.971; p<0.001 CV=0.50; d=0.13	r=0.922; p<0.001 CV=0.96; d=0.38	r=0.838; p<0.001 CV=1.32; d=0.50	r=0.959; p<0.001 CV=0.68; d=0.25	r=0.889; p<0.001 CV=1.01; d=0.38	r=0.891; p<0.001 CV=0.56; d=0.13

(*Continued*)

Table 2. (Continued).

	F	p	η^2	S15-25m vs S25-35m	S15-25m vs S35-45m	S15-25m vs S45-50m	S25-35m vs S35-45m	S25-35m vs S45-50m	S35-45m vs S45-50m
SL [m]	11.31	<0.001	0.23	r=0.935; p<0.001 CV=0.27; d=0.08	r=0.858; p<0.001 CV=0.30; d=0.08	r=0.704; p<0.001 CV=2.10; d=0.64	r=0.932; p<0.001 CV=0.35; d=0.16	r=0.760; p<0.001 CV=2.33; d=0.75	r=0.759; p<0.001 CV=2.30; d=0.56
SI [m^2/s]	39.24	<0.001	0.51	r=0.880; p<0.001 CV=0.08; d=0.00	r=0.803; p<0.001 CV=1.25; d=0.23	r=0.515; p=0.014 CV=5.21; d=1.24	r=0.895; p<0.001 CV=1.37; d=0.24	r=0.538; p=0.010 CV=5.54; d=1.27	r=0.535; p=0.010 CV=5.17; d=1.00
						Slowest group			
	F	**p**	**η^2**	**S15-25m vs S25-35m**	**S15-25m vs S35-45m**	**S15-25m vs S45-50m**	**S25-35m vs S35-45m**	**S25-35m vs S45-50m**	**S35-45m vs S45-50m**
Speed [m/s]	112.25	<0.001	0.74	r=0.878; p<0.001 CV=0.19; d=0.00	r=0.849; p<0.001 CV=0.89; d=0.66	r=0.739; p<0.001 CV=2.82; d=1.99	r=0.901; p<0.001 CV=1.03; d=0.66	r=0.853; p<0.001 CV=2.99; d=2.16	r=0.683; p<0.001 CV=2.55; d=1.59
SF [Hz]	5.27	0.002	0.12	r=0.937; p<0.001 CV=0.54; d=0.13	r=0.859; p<0.001 CV=1.14; d=0.40	r=0.667; p<0.001 CV=1.56; d=0.47	r=0.942; p<0.001 CV=0.84; d=0.27	r=0.729; p<0.001 CV=1.23; d=0.35	r=0.795; p<0.001 CV=0.66; d=0.12
SL [m]	7.41	<0.001	0.16	r=0.936; p<0.001 CV=0.71; d=0.17	r=0.892; p<0.001 CV=0.60; d=0.09	r=0.629; p=0.001 CV=1.53; d=0.31	r=0.958; p<0.001 CV=0.21; d=0.09	r=0.708; p<0.001 CV=1.76; d=0.48	r=0.758; p<0.001 CV=1.77; d=0.40
SI [m^2/s]	32.18	<0.001	0.45	r=0.916; p<0.001 CV=0.90; d=0.21	r=0.895; p<0.001 CV=1.04; d=0.10	r=0.632; p=0.001 CV=4.16; d=0.99	r=0.954; p<0.001 CV=1.23; d=0.32	r=0.744; p<0.001 CV=4.65; d=1.19	r=0.722; p<0.001 CV=4.27; d=0.92
						50 m butterfly			
						Fastest group			
	F	**p**	**η^2**	**S15-25m vs S25-35m**	**S15-25m vs S35-45m**	**S15-25m vs S45-50m**	**S25-35m vs S35-45m**	**S25-35m vs S45-50m**	**S35-45m vs S45-50m**
Speed [m/s]	511.51	<0.001	0.92	r=0.599; p=0.002 CV=0.95; d=1.13	r=0.423; p=0.037 CV=1.46; d=1.75	r=-0.472; p=0.896 CV=5.56; d=7.00	r=0.275; p=0.148 CV=0.84; d=0.85	r=0.106; p=0.358 CV=5.57; d=6.79	r=-0.096; p=0.618 CV=5.56; d=5.25
SF [Hz]	31.07	<0.001	0.42	r=0.815; p<0.001 CV=0.52; d=0.15	r=0.828; p<0.001 CV=1.28; d=0.49	r=0.598; p=0.002 CV=2.56; d=1.07	r=0.970; p<0.001 CV=1.03; d=0.36	r=0.680; p<0.001 CV=2.36; d=1.00	r=0.676; p<0.001 CV=1.84; d=0.72
SL [m]	35.16	<0.001	0.45	r=0.710; p<0.001 CV=0.51; d=0.16	r=0.764; p<0.001 CV=0.42; d=0.15	r=0.598; p=0.002 CV=3.22; d=1.19	r=0.961; p<0.001 CV=0.18; d=0.00	r=0.679; p<0.001 CV=3.38; d=1.18	r=0.582; p=0.003 CV=3.72; d=1.13
SI [m^2/s]	160.66	<0.001	0.79	r=0.641; p=0.001 CV=1.47; d=0.43	r=0.720; p<0.001 CV=1.76; d=0.57	r=0.469; p=0.020 CV=8.53; d=2.99	r=0.891; p<0.001 CV=0.62; d=0.21	r=0.577; p=0.003 CV=8.77; d=3.07	r=0.398; p=0.050 CV=9.27; d=2.48

(*Continued*)

Table 2. (Continued).

	Slowest group								
	F	**p**	**η²**	**S15-25m vs S25-35m**	**S15-25m vs S35-45m**	**S15-25m vs S45-50m**	**S25-35m vs S35-45m**	**S25-35m vs S45-50m**	**S35-45m vs S45-50m**
Speed [m/s]	202.55	<0.001	0.82	r=0.854; p<0.001 CV=0.95; d=0.54	r=0.728; p<0.001 CV=0.99; d=0.61	r=0.251; p=0.171 CV=5.81; d=3.68	r=0.706; p<0.001 CV=0.17; d=0.16	r=0.332; p=0.092 CV=6.01; d=3.45	r=-0.577; p=0.993 CV=6.43; d=2.93
SF [Hz]	44.62	<0.001	0.50	r=0.908; p<0.001 CV=1.33; d=0.33	r=0.836; p<0.001 CV=1.82; d=0.67	r=0.725; p<0.001 CV=2.73; d=1.27	r=0.902; p<0.001 CV=0.89; d=0.33	r=0.787; p<0.001 CV=2.01; d=0.91	r=0.672; p<0.001 CV=1.56; d=0.54
SL [m]	51.84	<0.001	0.54	r=0.870; p<0.001 CV=0.43; d=0.18	r=0.768; p<0.001 CV=0.93; d=0.34	r=0.653; p<0.001 CV=3.75; d=1.24	r=0.831; p<0.001 CV=0.70; d=0.16	r=0.774; p<0.001 CV=4.29; d=1.30	r=0.588; p=0.002 CV=4.93; d=1.41
SI [m²/s]	121.88	<0.001	0.73	r=0.847; p<0.001 CV=0.53; d=0.16	r=0.717; p<0.001 CV=0.52; d=0.00	r=0.472; p=0.018 CV=9.11; d=2.67	r=0.748; p<0.001 CV=0.58; d=0.13	r=0.629; p=0.001 CV=10.03; d=2.52	r=0.203; p=0.227 CV=11.30; d=2.28
	50 m freestyle								
	Fastest group								
	F	**p**	**η²**	**S15-25m vs S25-35m**	**S15-25m vs S35-45m**	**S15-25m vs S45-50m**	**S25-35m vs S35-45m**	**S25-35m vs S45-50m**	**S35-45m vs S45-50m**
Speed [m/s]	622.82	<0.001	0.93	r=0.528; p=0.006 CV=1.21; d=1.41	r=0.591; p=0.002 CV=2.08; d=3.11	r=0.186; p=0.244 CV=5.52; d=6.63	r=0.581; p=0.002 CV=1.34; d=2.00	r=-0.458; p=0.898 CV=5.27; d=6.06	r=-0.385; p=0.863 CV=4.88; d=4.61
SF [Hz]	30.65	<0.001	0.40	r=0.898; p<0.001 CV=1.20; d=0.50	r=0.622; p=0.001 CV=2.26; d=1.05	r=0.681; p<0.001 CV=2.73; d=1.37	r=0.687; p<0.001 CV=1.56; d=0.70	r=0.707; p<0.001 CV=1.93; d=0.98	r=0.499; p=0.010 CV=0.74; d=0.15
SL [m]	26.30	<0.001	0.36	r=0.897; p<0.001 CV=0.01; d=0.00	r=0.456; p=0.021 CV=0.45; d=0.13	r=0.675; p<0.001 CV=3.40; d=1.48	r=0.583; p=0.002 CV=0.48; d=0.13	r=0.622; p=0.001 CV=3.79; d=1.43	r=0.208; p=0.216 CV=4.29; d=1.07
SI [m²/s]	127.84	<0.001	0.74	r=0.830; p<0.001 CV=1.21; d=0.51	r=0.471; p=0.016 CV=1.70; d=0.56	r=0.618; p=0.001 CV=8.47; d=3.51	r=0.615; p=0.001 CV=0.86; d=0.23	r=0.458; p=0.020 CV=8.76; d=3.04	r=0.053; p=0.427 CV=9.13; d=1.94
	Slowest group								
Speed [m/s]	248.91	<0.001	0.84	r=0.806; p<0.001 CV=0.97; d=0.38	r=0.861; p<0.001 CV=1.87; d=0.99	r=0.801; p<0.001 CV=5.32; d=3.38	r=0.477; p=0.014 CV=1.32; d=0.66	r=0.685; p<0.001 CV=5.18; d=3.00	r=0.855; p<0.001 CV=4.80; d=1.99
SF [Hz]	79.38	<0.001	0.63	r=0.854; p<0.001 CV=1.18; d=0.54	r=0.890; p<0.001 CV=2.45; d=1.20	r=0.663; p<0.001 CV=3.60; d=1.48	r=0.866; p<0.001 CV=1.81; d=0.54	r=0.912; p<0.001 CV=2.92; d=0.92	r=0.839; p<0.001 CV=1.77; d=0.49
SL [m]	19.24	<0.001	0.20	r=0.796; p<0.001 CV=0.22; d=0.08	r=0.837; p<0.001 CV=0.60; d=0.21	r=0.707; p<0.001 CV=2.22; d=0.55	r=0.715; p<0.001 CV=0.50; d=0.15	r=0.833; p<0.001 CV=2.53; d=0.64	r=0.860; p<0.001 CV=2.92; d=0.71
SI [m²/s]	93.15	<0.001	0.66	r=0.752; p<0.001 CV=0.76; d=0.17	r=0.882; p<0.001 CV=1.24; d=0.30	r=0.753; p<0.001 CV=7.14; d=1.84	r=0.577; p=0.002 CV=0.76; d=0.16	r=0.752; p<0.001 CV=7.47; d=1.75	r=0.850; p<0.001 CV=7.73; d=1.43

force needed to overcome drag (Craig et al., 1985). In summary, SF and SL suggest that swimmers indeed adopt an all-out trend when they swim 50 m sprints.

Sprinters showed a moderate-to-high normative stability of both SF and SL in all events and groups. Hence, they kept their relative position, i.e., those with higher SF or SL at the start of the race were likely to still have higher SF or SL in the middle and end of the race. On the other hand, speed stability showed that fastest swimmers had a low to high stability; whereas slowest swimmers, a moderate-to-high stability. Thus, swimmers with better performances are likely to change their relative position over the race more often than low group counterparts. Literature reports that elite swimmers are inclined to explore the race context optimising their technique with their individual strengths, at least in longer distances than 50 m (Bideault et al., 2013). Maybe the same is happening in short sprints as the 50 m. Swimmers have stronger and weaker points in different phases of the race, leading to relative changes in their relative positions.

If an all-out race is considered, then sprinting events should yield linear relationships instead. However, the present data reveal that the best fit is non-linear (i.e., cubic fit). Studies have shown that both elite (Simbaña-Escobar et al., 2018) and junior (Morais et al., 2022) 50 m sprinters in freestyle stroke denoted a cubic speed–time curve. However, there was no available evidence yet on the remaining sprint events. In this cubic relationship, the first key-moment point happened in the start (S0-15 m) and the second key-moment in the finish (S45–50 m). As such, the start is indeed a key phase in freestyle (Marinho et al., 2021), breaststroke (Sánchez et al., 2021), backstroke (Barkwell & Dickey, 2018), and butterfly (Gonjo & Olstad, 2020) sprint events. Same assertion is true for the finish. Studies in freestyle sprinting events reported that swimmers tend to significantly slowdown in the finish (Arellano et al., 2018; Morais et al., 2022; Simbaña-Escobar et al., 2018). However, a study on the 100 m breaststroke showed that the finish (last 5 m of the race) did not have a significant association with the final race time (Olstad et al., 2020). Still, our swimmers clearly shown a sharp decay in speed in the finish. Thus, swimmers who do not slowdown as much at the end of the race may deliver better performance times (Morais et al., 2022).

Overall, coaches should be aware that a speed decay happens over short sprints even though an all-out trend is set. The decay is mostly due to a decrease in SF due to energetic and strength parameters decline that limit or cap the production of propulsive force. The changes in the relative position among competitors over the race is related to different swimmers presenting strong and weak points in different phases of the race. Thus, each one should keep their own race trend avoiding changes over the course of such short sprint. The start and finish are steppingstones to be worked out as were noted as key-moments of the 50 m race.

Conclusion

The mean stability of elite male swimmers of both groups in all 50 m sprint events had a significant variance during the race. Fastest swimmers presented a low to high normative stability, whereas slowest swimmers a moderate-to-high. Hence, the best performers in all sprint events change their relative positions more often throughout the race. Speed-time curve fitting yielded a cubic relationship, in which the start and finish are key moments of the race. Elite male swimmers who race the 50 m sprint events at major competitions adopt an all-out trend.

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ORCID

Jorge E Morais http://orcid.org/0000-0002-6885-0648
Tiago M Barbosa http://orcid.org/0000-0001-7071-2116
Daniel a Marinho http://orcid.org/0000-0003-2351-3047

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