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RESEARCH ARTICLE



Race level comparison and variability analysis of 100 m freestyle sprinters competing in the 2019 European championships

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ABSTRACT

This study aimed to (i) compare the race performance of the swimmers with better performances and poorer performances during all sections of a 100 m freestyle event and (ii) compare stroke kinematics variables between tiers and analyse their stability in each tier. The sample was composed of 88 swimmers that participated in the 100 m Freestyle event at the 2019 LEN European Junior Championships. Speed achieved the largest difference between tiers in section (S) 50-15 m of lap #1 (mean difference = -0.109 s, $p < 0.001$). During the clean swim and finish phases, the stroke length and stroke index presented significant differences ($p < 0.05$) between tiers in all sections of the race (stroke frequency did not). Significant variances were noted for both tiers in all variables in both laps. Swimmers in tier #1 were significantly faster than swimmers in tier #2 especially in sections related to the push-off against a solid (block or wall), and finish. A significant variance was noted by both tiers during the race with a moderate-to-high normative stability. Coaches are advised to analyse and understand the swimmers' within-lap stability, which can give deeper details about their swimmers' behaviour during the 100 m freestyle race.

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KEYWORDS

Swimming; race analysis; performance; stability; strategy

Introduction

Race analysis in sports performance always played an important role (Abbiss & Laursen, 2008), but nowadays it is more pre-eminent than ever (López-Belmonte et al., 2022; T. M. Barbosa et al., 2021a). Researchers, coaches, athletes, and support staff work together aiming to improve performance. The researchers' goal is to answer questions addressed by coaches, athletes, and support staff (Buchheit, 2016). They must define and provide objective feedback to athletes and coaches using different technologies and statistical analyses (T. M. Barbosa et al., 2021a).

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In the sport of swimming, race analysis consists of conducting qualitative and quantitative analyses of the swim strokes, start, turn, and finish (A. C. Barbosa et al., 2021b; T. M. Barbosa et al., 2021a; Marinho et al., 2021). There are studies reporting data about race analysis in several swim events (i.e. strokes and distances; Born et al., 2021; Olstad et al., 2022; Sánchez et al., 2021). Notwithstanding, the freestyle events (i.e. front-crawl stroke) are the ones getting more attention in all main events because it is the fastest stroke (Lipińska et al., 2016; Mauger et al., 2012; Morais et al., 2022). From all the race segments (i.e. start, clean swim, turn, and finish), the clean swim and finish are the ones given more attention since it is where swimmers perform the swim stroke (Morais et al., 2021; Simbaña-Escobar et al., 2018). The clean swim is considered as the time spent to displace in the distance of the swimming pool not taking into consideration the effect of the start and turns, i.e. the distance between the 15 m mark until the 45 m mark of each lap in a long course pool (Morais et al., 2021). The finish is the last 5 m of the race (Morais et al., 2022). It was claimed that for short-distance events (50 m and 100 m) analysis could be more detailed within the clean swim phase (i.e. 15 m to 45 m) by using sub-sections (intermediate distances; R. D. Arellano et al., 2018; Morais et al., 2022; Simbaña-Escobar et al., 2018). As these are the shortest events, every added information would be extremely useful helping swimmers to excel and understand what differs them (i.e. “best” vs “worst” performers) in each section of the clean swim phase.

This topic can be addressed by two main approaches: (i) comparing the swimmers with better (i.e. fastest) and poorer (i.e. worst) performances in each section of the race and (ii) analysing the within lap variability (i.e. stability analysis; Morais et al., 2022). The former will allow to understand the magnitude of the difference between swimmers in each section of the race. This will help to understand how much and where the swimmers with poorer performances have room for improvement. The latter will give substantial information about the variances of each group of swimmers during each lap section allowing to understand the magnitude of the difference between such sections. Moreover, stability studies about this topic analyse the stability between laps and not the stability within laps (i.e. between intermediate sections of the swimming pool – clean swim phase and finish). It was argued that to achieve better performances, swimmers must design and employ a race strategy in each phase of the race that better suits their characteristics (Gonjo & Olstad, 2021).

Therefore, this study aimed to (i) compare the race performance (i.e. speed) of the swimmers with better performances (tier #1) and poorer performances (tier #2) during all sections of the 100 m freestyle event during the 2019 European Junior Championship and (ii) compare stroke kinematics variables between tiers in the clean swim and finish phases and analyse their stability in each tier. It was hypothesised that (i) swimmers in tier #1 (better performances) are significantly faster than their poorer performance (tier #2) counterparts specially during lap #2 and (ii) swimmers in tier #1 present better stroke kinematics than counterparts included in tier #2, and also a higher stability.

Methods

Participants

Ninety-six swimmers participated in the 100 m Freestyle event at the 2019 long course metre LEN European Junior Championships. Eight individual races (semi-final #2) were excluded from the study because it was not possible to analyse the entire race (from start

to finish) due to technical issues. Thus, the 100 m performance of 88 swimmers included in this research delivered $91.08 \pm 2.66\%$ and $91.84 \pm 2.68\%$ of the 100 m Freestyle World Record and Junior World Record, respectively.

Data analysis

The official race times, block times and split times (i.e. 50 m lap) were retrieved from the official competition website (http://ejc2019.microplustiming.com/indexEJC2019_web.php). All video clips were provided in high-definition video ($f = 50$ Hz). The setup system was based on a real-time multi-angle recording (10 pan-tilt-zoom cameras, AXIS v5915, Lund, Sweden). Each swimmer was recorded by one camera (i.e. one camera per lane), enabling it to analyse the start, turn, and finish individually. The start strobe lights were synchronised with the official timing system and were visible by all cameras. The start strobe light was used as reference to set the timestamp on the race analysis software (Morais et al., 2018). Two expert race analysts perform each race analysis (with a very-high agreement; IntraClass Correlation Coefficient – ICC = 0.992).

All sections of the race were converted into speed for further analysis. In laps #1 and #2, the following sections were used: (i) S0–15 m; (ii) S15–25 m; (iii) S25–35 m; (iv) S35–45 m, and; (v) S45–50 m. For lap #1, all the following kinematic variables were measured after the 15 m mark until the 45 m mark in these sections (i) S15–25 m: time between the 15 m and 25 m; (ii) S25–35 m: time between the 25 m and 35 m; (iii) S35–45 m: time between the 35 m and 45 m. For lap #2, the same sections were used and added the section S45–50 m (time between the 45 m and 50 m – finish; Morais et al., 2022). The clean swim speed (in $\text{m}\cdot\text{s}^{-1}$), stroke frequency (SF, in Hz), stroke length (SL, in m), and stroke index (SI, in $\text{m}^2\cdot\text{s}^{-1}$) were measured in these sections. The clean swim speed was calculated as $v = d/t$, where 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 (during four consecutive strokes). The SL was calculated as $SL = v / SF$ (Craig & Pendergast, 1979), and the SI as $SI = v \cdot SL$ (Costill et al., 1985). The finish time and speed started to be measured when the swimmer's head reached the 45 m mark and stopped when the swimmer's hand touched the end wall. Therefore, a time and speed correction were made 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 Levene tests were used to assess the normality and homoscedasticity assumptions, respectively. Data revealed to be normally distributed ($p > 0.05$) and equal variances were assumed ($p > 0.05$). The mean \pm one standard deviation (SD) was computed for all variables. The dataset was split-up into two tiers: (i) tier #1 – swimmers with better performances; (ii) tier #2 – swimmers with poorer performances (each group with 44 swimmers). The t-test independent samples ($p \leq 0.05$) were used to compare tiers. 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 $0 \leq |d| \leq 0.2$; medium effect size if $0.2 < |d| \leq 0.5$ and; large effect size if $|d| > 0.5$ (Cohen, 1988).

Between-subject worthwhile changes were computed to examine the smallest meaningful improvement. This helps determine the true change eliciting a meaningful change in performance, rather than just typical variation in the test. Worthwhile changes were calculated by having $d = 0.20$ as the smallest standardised effect size in sports performance (Buchheit, 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 tiers being compared.

The swimmer's stability was assessed based on mean and normative stability (Morais et al., 2021). Mean stability refers to the persistence of the magnitude of change over the race of a given variable. This was assessed by the ANOVA repeated measures (i.e. variance between sections), followed-up by Bonferroni post-hoc test to verify significant differences between each pairwise ($p < 0.05$). The effect size index (eta square – η^2) was computed and interpreted as follows: (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. Cohen's d was selected as standardised effect size as aforementioned. 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 by IntraClass Correlation Coefficient between each pairwise. As a rule of thumb, it was deemed that the stability was as follows: (i) low if $r < 0.30$; (ii) moderate if $0.30 \leq r < 0.60$; (iii) high if $r \geq 0.60$ (Malina, 2001). Both mean and normative stability were only measured during the clean swim phase (lap #1: S15–25 m, S25–35 m, S35–45 m; lap #2: S15–25 m, S25–35 m, S35–45 m, S45–50 m). This was done to avoid effects from the turn (last five metres of lap #1 – S45–50 m, and first 15 m of lap #2).

Results

Descriptive statistics and comparison between swimmers in all sections are presented in Table 1. Regarding the swim speed, the largest difference between tiers was noted in section S0–15 m of lap #1 (start) (mean difference = -0.109 s, $t = -6.089$, $p < 0.001$, $d = 1.36$). During the clean swim and finish phases the SL and SI presented significant differences (small to large effects) between tiers in all sections of the race. On the other hand, the SF did not present significant differences in any section (Table 1).

Figure 1 and Table 2 depict the mean stability in both tiers of the clean swim and finish phases (i.e. lap #1: between the 15 m and 45 m marks; lap #2: between the 15 m and 50 m marks). Overall, significant variances (i.e. low mean stability) were noted for both tiers in all variables. In lap #1, the SF was the variable showing the highest variance (i.e. less stability) (tier #1: $F = 101.48$, $p < 0.001$, $\eta^2 = 0.71$; tier #2: $F = 97.33$, $p < 0.001$, $\eta^2 = 0.69$). Both tiers presented the largest differences in pairwise S15–25 m vs S35–45 m (tier #1: $CV = 2.72$, $d = 0.83$, $p < 0.05$; tier #2: $CV = 2.61$, $d = 0.67$, $p < 0.05$). In lap #2, speed presented the highest variance (i.e. less stability) in swimmers included in tier #1 ($F = 68.58$, $p < 0.001$, $\eta^2 = 0.62$). As for swimmers in tier #2, the highest variance (i.e. less stability) was noted by the SI ($F = 75.05$, $p < 0.001$, $\eta^2 = 0.64$). This shows that swimmers in tier #1 presented a different approach to race than their tier #2 counterparts.

Table 1. Descriptive statistics (mean \pm one standard deviation) and comparison between male swimmers in tier #1 and tier #2 in the 100 m freestyle event during 2019 LEN European Junior Championships.

	Mean \pm 1SD Tier #1	Mean \pm 1SD Tier #2	Mean difference (95%CI)	t	p	d [descriptor]	Worthwhile change [% of swimmers in tier #1]
Lap #1 – S0–15 m (start)							
Speed [m·s ⁻¹]	2.54 \pm 0.07	2.43 \pm 0.09	-0.109 (-0.144 to -0.073)	-6.089	<0.001	1.36	0.01 [0.55%]
Lap #1 – S15–25 m (clean swim)							
Speed [m·s ⁻¹]	1.98 \pm 0.04	1.90 \pm 0.06	-0.074 (-0.093 to -0.054)	-7.459	<0.001	1.57	0.01 [0.40%]
SF [Hz]	0.84 \pm 0.06	0.87 \pm 0.08	0.025 (-0.006 to 0.055)	1.591	0.115	0.42	0.01 [1.43%]
SL [m]	2.35 \pm 0.17	2.21 \pm 0.20	-0.144 (-0.224 to -0.065)	-3.618	<0.001	0.75	0.03 [1.45%]
SI [m ² ·s ⁻¹]	4.64 \pm 0.34	4.20 \pm 0.40	-0.446 (-0.604 to -0.288)	-5.610	<0.001	1.19	0.07 [1.47%]
Lap #1 – S25–35 m (clean swim)							
Speed [m·s ⁻¹]	1.93 \pm 0.03	1.87 \pm 0.06	-0.060 (-0.082 to -0.038)	-5.464	<0.001	1.26	0.01 [0.31%]
SF [Hz]	0.81 \pm 0.06	0.84 \pm 0.07	0.028 (-0.0002 to 0.056)	1.974	0.052	0.46	0.01 [1.48%]
SL [m]	2.40 \pm 0.17	2.25 \pm 0.20	-0.148 (-0.227 to -0.069)	-3.729	<0.001	0.81	0.03 [1.42%]
SI [m ² ·s ⁻¹]	4.62 \pm 0.33	4.20 \pm 0.42	-0.417 (-0.576 to -0.258)	-5.209	<0.001	1.11	0.07 [1.43%]
Lap #1 – S35–45 m (clean swim)							
Speed [m·s ⁻¹]	1.92 \pm 0.03	1.85 \pm 0.06	-0.064 (-0.083 to -0.044)	-6.431	<0.001	1.48	0.01 [0.31%]
SF [Hz]	0.79 \pm 0.06	0.82 \pm 0.07	0.025 (-0.002 to 0.051)	1.846	0.068	0.46	0.01 [1.52%]
SL [m]	2.43 \pm 0.17	2.29 \pm 0.19	-0.147 (-0.225 to -0.070)	-3.795	<0.001	0.78	0.03 [1.40%]
SI [m ² ·s ⁻¹]	4.66 \pm 0.32	4.23 \pm 0.39	-0.425 (-0.578 to -0.272)	-5.533	<0.001	1.21	0.06 [1.37%]
Lap #1 – S45–50 m (turn 5 m-in)							
Speed [m·s ⁻¹]	1.73 \pm 0.05	1.65 \pm 0.06	-0.077 (-0.101 to -0.054)	-6.514	<0.001	1.45	0.01 [0.58%]
Lap #2 – S0–15 m (turn 15 m-out)							
Speed [m·s ⁻¹]	2.12 \pm 0.05	2.02 \pm 0.05	-0.102 (-0.123 to -0.081)	-9.561	<0.001	2.00	0.01 [0.47%]
Lap #2 – S15–25 m (clean swim)							
Speed [m·s ⁻¹]	1.85 \pm 0.03	1.76 \pm 0.04	-0.091 (-0.107 to -0.075)	-11.593	<0.001	2.55	0.01 [0.32%]
SF [Hz]	0.81 \pm 0.05	0.82 \pm 0.07	0.002 (-0.023 to 0.027)	0.145	0.885	0.19	0.01 [1.23%]
SL [m]	2.28 \pm 0.16	2.17 \pm 0.18	-0.112 (-0.184 to -0.041)	-3.108	0.003	0.65	0.03 [1.40%]
SI [m ² ·s ⁻¹]	4.23 \pm 0.32	3.82 \pm 0.35	-0.405 (-0.546 to -0.263)	-5.670	<0.001	1.22	0.06 [1.51%]
Lap #2 – S25–35 m (clean swim)							
Speed [m·s ⁻¹]	1.82 \pm 0.03	1.72 \pm 0.04	-0.094 (-0.110 to -0.078)	-11.668	<0.001	2.83	0.01 [0.33%]
SF [Hz]	0.81 \pm 0.05	0.80 \pm 0.07	-0.0007 (-0.026 to 0.024)	-0.054	0.957	0.16	0.01 [1.23%]
SL [m]	2.27 \pm 0.15	2.16 \pm 0.19	-0.109 (-0.181 to -0.037)	-3.006	0.003	0.64	0.03 [1.32%]
SI [m ² ·s ⁻¹]	4.12 \pm 0.29	3.72 \pm 0.36	-0.400 (-0.539 to -0.261)	-5.711	<0.001	1.22	0.06 [1.41%]
Lap #2 – S35–45 m (clean swim)							
Speed [m·s ⁻¹]	1.81 \pm 0.04	1.71 \pm 0.05	-0.093 (-0.112 to -0.074)	-9.855	<0.001	2.21	0.01 [0.44%]

(Continued)

Table 1. (Continued).

	Mean±1SD Tier #1	Mean±1SD Tier #2	Mean difference (95%CI)	t	p	d [descriptor]	Worthwhile change [% of swimmers in tier #1]
SF [Hz]	0.80 ± 0.06	0.79 ± 0.06	−0.006 (−0.031 to 0.019)	−0.489	0.626	0.17	0.01 [1.50%]
SL [m]	2.27 ± 0.17	2.17 ± 0.18	−0.098 (−0.173 to −0.023)	−2.610	0.011	0.57	0.03 [1.50%]
SI [m ² ·s ^{−1}]	4.09 ± 0.32	3.72 ± 0.37	−0.376 (−0.524 to −0.227)	−5.033	<0.001	1.07	0.06 [1.56%]
Lap #2 – S45–50 m (finish)							
Speed [m·s ^{−1}]	1.76 ± 0.06	1.65 ± 0.08	−0.107 (−0.138 to −0.075)	−6.803	<0.001	1.56	0.01 [0.68%]
SF [Hz]	0.80 ± 0.07	0.81 ± 0.07	0.005 (−0.024 to 0.034)	0.348	0.728	0.14	0.01 [1.75%]
SL [m]	2.20 ± 0.19	2.05 ± 0.18	−0.146 (−0.224 to −0.067)	−3.686	<0.001	0.81	0.04 [1.73%]
SI [m ² ·s ^{−1}]	3.87 ± 0.37	3.40 ± 0.39	−0.472 (−0.633 to −0.311)	−5.825	<0.001	1.24	0.07 [1.91%]

S – race section; SF – stroke frequency; SL – stroke length; SI – stroke index. t – t-test comparison; p – significance level; d – Cohen's d (effect size).

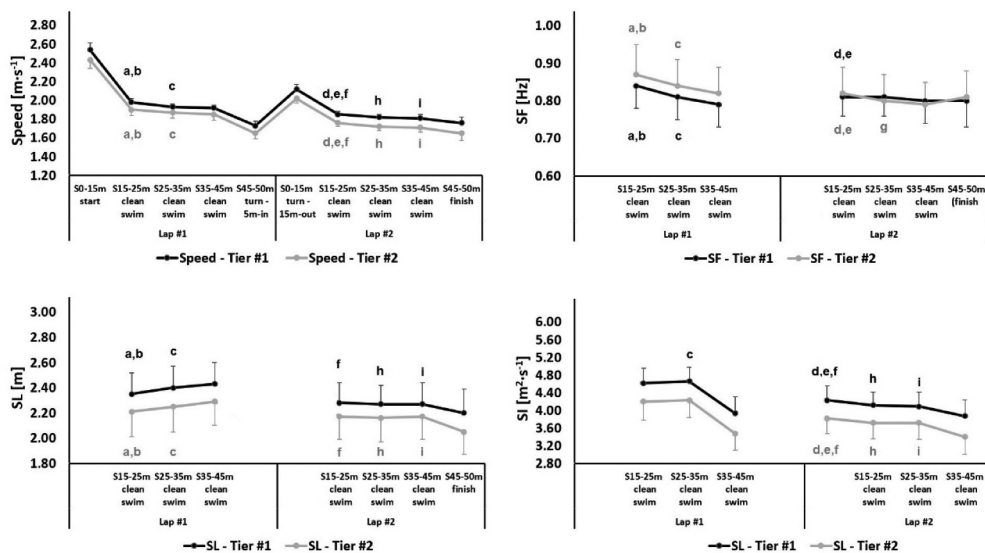


Figure 1. Within-lap stability for the stroke kinematics during the clean swim phase (lap #1: from the 15 m to the 45 m; lap #2: from the 15 m to the 50 m) by swimmers in tier #1 (better performances) and tier #2 (poorer performances). SF – stroke frequency; SL – stroke length; SI – stroke index. Black line depicts swimmers in tier #1, and grey line the swimmers in tier #2. Significant differences ($p < 0.05$) between sections in lap #1: a – S15–25 m vs S25–35 m; b – S15–25 m vs S35–45 m; c – S25–35 m vs S35–45 m. Significant differences ($p < 0.05$) between sections in lap #2: d – S15–25 m vs S25–35 m; e – S15–25 m vs S35–45 m; f – S15–25 m vs S45–50 m; g – S25–35 m vs S35–45 m; h – S25–35 m vs S45–50 m; i – S35–45 m vs S45–50 m.

Table 2. Mean and normative stability between each swim section for swimmers in tier #1 and tier #2 in the 100 m Freestyle event during the 2019 LEN Junior European Championships.

Lap #1									
Tier #1									
Speed [m·s ⁻¹]	F	p	η ²	S15–25 m		S15–25 m		S25–35 m	
				vs		vs		vs	
				S25–35 m		S35–45 m		S35–45 m	
	96.33	<0.001	0.69	r = 0.848, p < 0.001 CV = 1.21, d = 1.41	r = 0.648, p < 0.001 CV = 1.34, d = 1.98	r = 0.750, p < 0.001 CV = 0.35, d = 0.57			
SF [Hz]	101.48	<0.001	0.71	r = 0.958, p < 0.001 CV = 2.10, d = 0.50	r = 0.926, p < 0.001 CV = 2.72, d = 0.83	r = 0.974, p < 0.001 CV = 1.16, d = 0.33			
SL [m]	39.90	<0.001	0.48	r = 0.958, p < 0.001 CV = 0.92, d = 0.29	r = 0.955, p < 0.001 CV = 1.39, d = 0.47	r = 0.990, p < 0.001 CV = 0.79, d = 0.18			
SI [m ² ·s ⁻¹]	2.10	<0.001	0.05	r = 0.945, p < 0.001 CV = 0.27, d = 0.06	r = 0.951, p < 0.001 CV = 0.36, d = 0.06	r = 0.980, p < 0.001 CV = 0.44, d = 0.12			
Tier #2									
Speed [m·s ⁻¹]	F	p	η ²	S15–25 m		S15–25 m		S25–35 m	
				vs		vs		vs	
				S25–35 m		S35–45 m		S35–45 m	
	34.41	<0.001	0.44	r = 0.801, p < 0.001 CV = 0.89, d = 0.50	r = 0.901, p < 0.001 CV = 1.12, d = 0.83	r = 0.878, p < 0.001 CV = 0.46, d = 0.33			
SF [Hz]	97.33	<0.001	0.69	r = 0.976, p < 0.001 CV = 1.84, d = 0.40	r = 0.956, p < 0.001 CV = 2.61, d = 0.67	r = 0.977, p < 0.001 CV = 1.33, d = 0.29			
SL [m]	29.58	<0.001	0.41	r = 0.968, p < 0.001 CV = 0.90, d = 0.20	r = 0.968, p < 0.001 CV = 1.43, d = 0.41	r = 0.973, p < 0.001 CV = 0.85, d = 0.21			
SI [m ² ·s ⁻¹]	0.92	0.403	0.02	r = 0.917, p < 0.001 CV = 0.04, d = 0.00	r = 0.959, p < 0.001 CV = 0.38, d = 0.08	r = 0.944, p < 0.001 CV = 0.38, d = 0.07			
Lap #2									
Tier #1									
Speed [m·s ⁻¹]	F	p	η ²	S15–25 m		S15–25 m		S25–35 m	
				vs		vs		vs	
				S25–35 m		S35–45 m		S35–45 m	
	68.58	<0.001	0.62	r = 0.889, p < 0.001 CV = 0.88, d = 1.00	r = 0.750, p < 0.001 CV = 1.02, d = 1.13	r = 0.498, p < 0.001 CV = 1.81, d = 1.90	r = 0.801, p < 0.001 CV = 0.32, d = 0.28	S25–35 m vs S45–50 m	S35–45 m vs S45–50 m
SF [Hz]	1.83	0.178	0.04	r = 0.968, p < 0.001 CV = 0.49, d = 0.00	r = 0.955, p < 0.001 CV = 0.65, d = 0.18	r = 0.755, p < 0.001 CV = 0.57, d = 0.16	r = 0.976, p < 0.001 CV = 0.30, d = 0.18	r = 0.803, p < 0.001 CV = 0.26, d = 0.16	r = 1.33, d = 0.98 CV = 1.33, d = 0.98 r = 0.824, p < 0.001 CV = 0.24, d = 0.00

(Continued)

Lap #1
Tier #1

	F	p	η^2	S15–25 m vs S25–35 m	S15–25 m vs S35–45 m	S25–35 m vs S35–45 m	r = 0.806, p < 0.001 CV = 1.43, d = 0.46 r = 0.801, p < 0.001 CV = 3.18, d = 1.04	r = 0.847, p < 0.001 CV = 0.03, d = 0.00 r = 0.947, p < 0.001 CV = 0.29, d = 0.10	r = 0.843, p < 0.001 CV = 1.51, d = 0.39 r = 0.824, p < 0.001 CV = 2.82, d = 0.64
Tier #2				S15–25 m vs S25–35 m	S15–25 m vs S35–45 m	S15–25 m vs S35–45 m			
SL [m]	12.03	<0.001	0.22	r = 0.978, p < 0.001 CV = 0.40, d = 0.06	r = 0.964, p < 0.001 CV = 0.36, d = 0.06	r = 0.806, p < 0.001 CV = 1.43, d = 0.46	r = 0.975, p < 0.001 CV = 0.03, d = 0.00	r = 0.847, p < 0.001 CV = 1.40, d = 0.41	r = 0.843, p < 0.001 CV = 1.51, d = 0.39
SI [$\text{m}^2 \cdot \text{s}^{-1}$]	44.01	<0.001	0.51	r = 0.968, p < 0.001 CV = 1.28, d = 0.36	r = 0.939, p < 0.001 CV = 1.37, d = 0.44	r = 0.801, p < 0.001 CV = 3.18, d = 1.04	r = 0.947, p < 0.001 CV = 0.29, d = 0.10	r = 0.841, p < 0.001 CV = 2.78, d = 0.75	r = 0.824, p < 0.001 CV = 2.82, d = 0.64
				S15–25 m vs S25–35 m	S15–25 m vs S35–45 m	S15–25 m vs S35–45 m	S25–35 m vs S35–45 m	S25–35 m vs S35–45 m	S35–45 m vs S45–50 m
Speed [$\text{m} \cdot \text{s}^{-1}$]	55.91	<0.001	0.57	r = 0.916, p < 0.001 CV = 1.02, d = 1.00	r = 0.798, p < 0.001 CV = 1.13, d = 1.10	r = 0.474, p < 0.001 CV = 2.25, d = 1.74	r = 0.834, p < 0.001 CV = 0.31, d = 0.22	r = 0.547, p < 0.001 CV = 1.86, d = 1.11	r = 0.757, p < 0.001 CV = 1.81, d = 0.90
SF [Hz]	3.71	0.050	0.08	r = 0.984, p < 0.001 CV = 0.65, d = 0.29	r = 0.937, p < 0.001 CV = 1.05, d = 0.46	r = 0.723, p < 0.001 CV = 0.94, d = 0.14	r = 0.967, p < 0.001 CV = 0.64, d = 0.15	r = 0.782, p < 0.001 CV = 0.78, d = 0.14	r = 0.877, p < 0.001 CV = 0.94, d = 0.31
SL [m]	30.42	<0.001	0.41	r = 0.979, p < 0.001 CV = 0.34, d = 0.05	r = 0.956, p < 0.001 CV = 0.30, d = 0.00	r = 0.851, p < 0.001 CV = 2.28, d = 0.67	r = 0.975, p < 0.001 CV = 0.29, d = 0.05	r = 0.873, p < 0.001 CV = 2.42, d = 0.59	r = 0.915, p < 0.001 CV = 2.72, d = 0.67
SI [$\text{m}^2 \cdot \text{s}^{-1}$]	75.05	<0.001	0.64	r = 0.971, p < 0.001 CV = 1.36, d = 0.28	r = 0.956, p < 0.001 CV = 1.28, d = 0.28	r = 0.871, p < 0.001 CV = 4.35, d = 1.13	r = 0.964, p < 0.001 CV = 0.00, d = 0.00	r = 0.870, p < 0.001 CV = 4.20, d = 0.85	r = 0.894, p < 0.001 CV = 4.52, d = 0.84

SF – stroke frequency; SL – stroke length; SI – stroke index; F – F-ratio; p – significance value; η^2 – eta square (effect size index); r – IntraClass correlation coefficient; CV – coefficient of variation; d – Cohen's d (effect size index).

Normative stability is shown in [Table 2](#). In lap #1, all variables presented a high normative stability in both tiers. The same trend was verified in lap #2, except for speed. Swimmers in tier #1 presented a moderate normative stability in pairwise S15–25 m vs S45–50 m, S25–35 m vs S45–50 m, and S35–45 vs S45–50 m. Swimmers in tier #2 presented a similar trend as their tier #1 counterparts, except for pairwise S35–45 m vs S45–50 m (high normative stability). Nonetheless, it was noted that normative stability tended to decrease during the race for all variables in both tiers.

Discussion

This study aimed to (i) compare the race performance of the swimmers with better performances (tier #1) and poorer performances (tier #2) during the 100 m freestyle event during the 2019 European Junior Championship and (ii) analyse the swimmers' stability in each tier. Swimmers in tier #1 were significantly faster than swimmers in tier #2 in all sections of the race. Besides the start (lap #1 – S0–15 m) and turn 15 m-out (lap #2 – S0–15 m), the highest mean difference was observed in the finish (lap #2 – S45–50 m). Non-significant differences were observed in the SF between tiers in all sections of the race. Overall, a low mean stability (i.e. significant variance) was noted by both tiers during the race. This indicates a positive pacing where a significant decrease in speed was observed. Conversely, a moderate-to-high normative stability was noted in both tiers. This shows that swimmers tended to maintain their relative position during the race.

Mean data comparison showed that swimmers in tier #1 were significantly faster than swimmers in tier #2 in all sections of the race. The highest mean difference (over than 0.100 s) between tiers was noted in the start (lap #1 – S0–15 m), 15 m-out turn (lap #2 – S0–15 m) and finish (lap #2 – S45–50 m). Two of those three sections were related to a push-off factor, i.e. immediately after the start and after the turn. In both cases, swimmers perform a push-off, and glide with underwater dolphin kicks before they start the swim stroke. Regarding the latter, studies indicated that swimmers who present better scores of parameters related to lower-limbs strength and power are prone on achieving higher underwater speeds (Keiner et al., 2021; Thng et al., 2020). The former (i.e. glide underwater dolphin kicks) showed that swimmers who make undulatory trunk motions by reciprocal activation of the trunk muscles are prone to improving propelling efficiency (Yamakawa et al., 2017). Moreover, numerical simulations noted that peak speed during the underwater dolphin kick occurs at the end of the extension kick while the minimum speed occurs just prior to this kick (Cohen et al., 2012). Thus, swimmers should focus on maximising: (i) their lower-limbs strength and power during the push-off and (ii) the extension phase since it was this which generated most thrust. The remaining section was the finish. It seems that the fastest swimmers can reduce their swim speed in the last section of the race (i.e. lap #2 – S45–50 m).

The SL and SI presented a similar trend, i.e. significant differences between tiers in all sections of the race. Conversely, the SF presented non-significant differences between tiers in all sections. Moreover, our data shows that the difference noted by the SF tended to decrease over the race (except between sections S15–25 m and S25–35 m where an increase was noted). Faster SF's are usually related to faster swim speeds (Koga et al., 2020; Samson et al., 2015). Our data also show that sprinters competing the 50 m freestyle in official events presented non-significant differences between the best and worst

performers (Morais et al., 2022). As mentioned earlier, the SL did show significant differences between tiers. Swimmers can increase their swim speed by increasing the SF or SL or both combined (Craig & Pendergast, 1979). Thus, if only significant differences were observed by the SL one can assume that the SL is the key-factor responsible for the differences in sprinters' swim speed. Thus, for a similar SF, swimmers can increase their swim speed by increasing their thrust (i.e. amount of in-water force produced) and consequently their SL.

Regarding mean stability, swimmers in both tiers showed a similar trend in both laps (i.e. significant variance during the race) in all variables. Swim speed during the clean swim significantly decrease in lap #1 and lap #2 (both tiers), and it presented lower values in lap #2 (both tiers). Literature about pacing analysis noted that elite 100 m freestyle sprinters tend to present a positive pacing profile (R. Arellano et al., 1994; Robertson et al., 2009). However, there are no up-to-date references about this topic. Moreover, this kind of analysis is usually performed based on lap times. Our data goes deep further and presented the pacing during the clean swim only, i.e. discarding the push-off's generated in the start and turn. Swimmers in both tiers decreased their SF between laps. This is in accordance with previous literature about 100 m freestyle swimmers (Seifert et al., 2005; Simbaña-Escobar et al., 2018). However, our data showed that swimmers (both tiers) tended to decrease their SF not only between laps but also within each lap. This was also noted by others but in experimental studies (Seifert et al., 2005, 2007) but not in a race analysis context. Nonetheless, swimmers in tier #2 did increase their SF in the last section of the race, and swimmers in tier #1 maintained the decreasing trend. This indicates different kinematic strategies by swimmers in both tiers.

Moreover, whenever an SF increase is noted an SL decrease occurs and vice-versa (R. Arellano et al., 1994; Kennedy et al., 1990). This can be observed in lap #1 (both tiers). However, this trend was not completely observed in lap #2. This may indicate that in this spatial-temporal relationship (SF-SL), other variables related to thrust and drag can play a key-role. Swimmers who are prone to produce higher amount of thrust or less drag may be able to, for the same SF, increase the SL and consequently the swim speed (Toussaint et al., 2000). Once again, the SL seems to be the key-factor determining higher swim speeds in sprinters. Analysing, the swimmers' stability in the mid-section of the swimming pool (rather than lap by lap) can be extremely important for coaches and swimmers to understand the former kinematical behaviour in each section of the race.

In lap #1, swimmers in both tiers presented a high normative stability in all variables. This indicates that swimmers (both tiers) lean towards to maintain their relative position during the clean swim phase of the first lap. A similar profile (i.e. high normative stability) was still noted by the SF, SL, and SI. However, swim speed in lap #2 (both tiers in sections: S15–25 m vs S45–50 m and S25–35 m vs S45–50 m) denoted a lower normative stability than in lap #1 (moderate). One can argue that as the race goes on swimmers are more likely to adapt themselves since several solutions (i.e. SL-SF combinations) are possible based on individual functional role (Bideault et al., 2013). As fatigue instals, swimmers may be “forced” to change or adapt their motor behaviour trying to maintain (or decrease as less as possible) the swim speed (Seifert et al., 2007). Based on our data, it seems this phenomenon (moderate normative stability indicating changes in the swimmers' relative

position) starts from the 15 m of lap #2 onwards. Thus, it can be indicated that 100 m freestyle sprinters maintain the predefined race strategy during lap #1. In lap #2 swimmers may rely more on the energetics they still can use (Pyne & Sharp, 2014).

Conclusion

It can be concluded that swimmers in tier #1 were significantly faster than swimmers in tier #2 in all sections of the race. The highest differences were noted in the sections related to the push-off against a solid (block: lap #1 – S0–15 m; wall: lap #2 – S0–15 m), and finish (lap #2 – S45–50 m). Non-significant differences were observed by the SF between tiers in all sections of the race. Conversely, the SL did show significant differences. This may indicate the SL as the key-factor responsible for the difference speed. A low mean stability (i.e. significant variance) was noted by both tiers during the race, indicating a positive pacing in the clean swim and finish phases. A moderate to high normative stability was noted in both tiers. This shows that swimmers tended to maintain their relative position during the race, especially during lap #1.

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