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Research article

Race Analysis and Determination of Stroke Frequency – Stroke Length Combinations during the 50-M Freestyle Event

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Abstract

The aims of this study were to: (1) analyze and compare the stroke kinematics between junior and senior elite male swimmers in every section of the race during the 50-m freestyle event, and; (2) identify stroke frequency (SF)–stroke length (SL) combinations on swim speed independently for junior and senior swimmers in each section of the 50-m freestyle event. Eighty-six junior swimmers (2019) and 95 seniors (2021) competing in the 50-m long course meter LEN Championships were analyzed. The t-test independent samples ($p \leq 0.05$) were used to compare juniors and seniors. The SF and SL combinations on swim speed were explored using three-way ANOVAs. Senior swimmers were significantly faster in the 50-m race than juniors ($p < 0.001$). Speed presented the largest significant difference ($p < 0.001$) in section S0-15 m (start until the 15th meter mark) being seniors fastest. Both junior and senior swimmers revealed a significant categorization ($p < 0.001$) by stroke length and stroke frequency in each race section. It was possible to model several SF–SL combinations for seniors and juniors in each section. The fastest swim speed in each section, for seniors and juniors independently, was achieved by a SF–SL combination that may not be the fastest SF or the longest SL. Coaches and swimmers must be aware that despite the 50-m event being an all-out bout, several SF–SL combinations were observed (independently for juniors and seniors), and they differ between race sections.

Key words: Analysis; biomechanics; competition; performance.

Introduction

Sports performance is a multifactorial phenomenon where researchers and support staff from several scientific domains work together to improve performance (Houtmeyers et al., 2021). From all those domains (e.g., physiology, biomechanics, psychology, nutrition, etc.), the role of race analysis in sports performance is becoming of paramount importance for coaches and athletes. It consists in an expert analyzing the total race or breaking down the race into sections and extracting objective biomechanical information about the athlete's performance (Barbosa et al., 2021a).

Race analysis in the sports of swimming focuses on stroke kinematics during the clean swim phase (the distance between the 15th meter mark until the 45th meter mark of each lap in a long course pool), or other kinematic parameters related to the start, turns, and finish (Gonjo and Olstad, 2020; Marinho et al., 2020). Out of all swim events, freestyle is under more attention because it is the fastest stroke (Kennedy et al., 1990). Literature reports several studies on freestyle in all distances at main competition (100-m: Simbaña-Escobar et al., 2018; 200-m: Morais et al., 2021; 400-m: Mauger et al., 2012; 800-m: Lipińska et al., 2016; 1500-m: Neuloh et al., 2020). Interestingly, less is known on the 50-m event, where far fewer studies can be found in the literature (Morais et al., 2022a; Simbaña-Escobar et al., 2018). Indeed, one article review noted that the body of knowledge on this sprint event is scarce (Gonjo and Olstad, 2021).

In the past, stroke kinematics analysis over a race was mainly focused on assessing the swimmers' split times or the swimmers' behavior during the entire lap (Robertson et al., 2009; Thompson et al., 2000). This may explain why there are much less studies on the 50-m events: only one lap is performed in long-course swimming. More recently, it was claimed that race analysis could be more detailed not only for short sprints such as the 50-m, but also in remaining events (Arellano et al., 2018; Morais et al., 2021). This can be done by analyzing the swimmers' kinematic profile in each intermediate section of the swimming pool (between the 15th and the 45th mark) taking into consideration the pool's marks: (i) between the 15th and 25th meter; (ii) between the 25th and 35th meter; (iii) between the 35th and 45th meter, and; (iv) between the 45th and 50th meter (Morais et al., 2022a).

Studies analyzed differences in performance and kinematics between best and worst swimmers in experimental (Seifert et al., 2007) or observational designs (Simbaña-Escobar et al., 2018) in freestyle event. Overall, such studies noted that swimmers with better performances also presented better kinematic scores, namely fastest stroke frequency (SF) and longer stroke length (SL). More specifically, in the males' 50-m freestyle event (i.e., official competition context), it was recently shown that the better performers were significantly faster in all section of the race, mainly due to a longer SL (Morais et al., 2022b). That is, a decrease in SF still occurs, but swimmers who can maintain (or at least diminish the SL decrease) are more likely to achieve faster swim speeds. However, there is no information about the comparison of the performance and stroke kinematics between junior and senior swimmers in any swimming event. As swimming is a multifactorial phenomenon, anthropometrics, stroke kinematics, strength and power, and physiological variables may also play an important role in this competitive level transition (Barbosa et

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al., 2013). For instance, it was indicated that swimmers with a greater physiological capacity would be able to maintain or diminish less their energetics and hence their swim speed (Pyne and Sharp, 2014). Additionally, it was also noted that elite swimmers (national squad) showed greater lower limbs' strength and power characteristics than their less experienced counterparts (talent identification squad) (Jones et al., 2018). However, it's difficult to obtain anthropometric, strength and power, and physiological data from high-level swimmers in a competition context. By contrast, data retrieved from race analysis allows to have insights about the swimmers' stroke kinematic profile (Morais et al., 2021). Indeed, it was experimentally reported that 50-m freestyle performance was very largely associated with average and peak swim speeds (staying longer at the upper part of the speed curve), but not with minimum speed and speed fluctuation (Barbosa et al., 2021b). Thus, based on the importance of stroke kinematics to performance and on the information that it is possible to retrieve from race analysis, it seems important to understand the magnitude of difference between juniors and seniors. This will allow to understand how much juniors must improve to succeed later in their careers.

The mean swimming velocity depends on SF and SL: v = SF · SL, where v is the mean swim velocity ($m \cdot s^{-1}$), SF is the stroke frequency (Hz), and SL is the stroke length (m) (Craig and Pendergast, 1979). Thus, it can be enhanced by increasing SF, SL, or both concurrently. Swimmers may often attempt to select an adequate SF–SL combination to yield maximal velocity according to their technical characteristics in such context (Maglischo, 2003). The seminal study by Craig and Pendergast (1979) noted that swimmers must find an adequate SF–SL combination in all race distances. Afterwards, others still reported that understanding such combinations could be of paramount importance to understand how to improve swim speed (Barden and Kell, 2009; Simbaña-Escobar et al., 2020). However, literature does not provide insights on SF–SL combinations in 50-m events, either selecting experimental or observational research designs. Studies about 50-m events focused on understanding the speed-time curve of the race and it was learned that these are all-out sprints (Morais et al., 2022a; 2022b; Simbaña-Escobar et al., 2018). Moreover, it was noted a trend SF to decrease and SL to increase over the race (Morais et al., 2022a). Nonetheless, swimmers may adopt different SF–SL combinations in each section of the race depending on their level or experience (junior or senior). As aforementioned, a significant group effect was noted by swimmers of the same competitive level competing in the 50-m freestyle event (Morais et al., 2022a; 2022b). Thus, it would of major importance for coaches and swimmers to verify and understand the SF–SL combinations that the best and worst performers within each competitive level (i.e., juniors or seniors) may present. Moreover, one can argue that understanding the SF–SL combinations can be the hinge to setup more effective race strategies.

The aims of this study were to: (1) analyze and compare the stroke kinematics between swimmers of different competitive levels (juniors vs. seniors) in every section of the race during the 50-m freestyle event, and; (2) identify SF–SL combinations on swim speed independently for junior and senior swimmers in each section of the 50-m freestyle event. This was performed by dividing both juniors and seniors into two groups (juniors: best vs. worst performers; seniors: best vs. worst performers). It was hypothesized that senior swimmers would be faster in every section of the race, but with a larger effect size at the end of the race. Moreover, as a tendency for a SF decrease would be verified during the race, junior and senior swimmers would present different combinations of SF–SL to diminish the swim speed decrease in each section of the race.

Methods

Participants

Participants were 95 elite junior male swimmers participated in the 50-m Freestyle event at the 2019 long course meter LEN European Junior Championships, and 95 elite senior male swimmers participated in the 50-m Freestyle event at the 2021 LEN European Championships. At the Junior Championships, nine individual races were excluded from the study because it was not possible to analyze the entire race (from start to finish) due to technical issues. Thus, the 50-m performance of the junior swimmers analyzed (86 swimmers) reached on average 91.93 ± 3.02% and 88.38 ± 2.90% of the 50-m Freestyle junior world record and senior world record, respectively. The 50-m performance of the senior level swimmers reached on average 92.39 ± 3.56% of the senior world record performance. The University's Ethic Board approved the study design (N. 73/2022).

Race analysis

The official race times, block times and split times (i.e., 50-m lap) were retrieved from the official competition website (junior: http://ejc2019.microplustiming.com/indexEJC2019_web.php; senior: http://budapest2020.microplustiming.com/indexBudapest2021_web.php). In both the junior and senior championships all video clips were provided in high-definition video (*f* = 50Hz) and the setup system was based on a real-time multi-angle recording (10 pan-tilt zoom cameras). Each swimmer was tracked and recorded by one camera (one camera per lane) enabling to analyze the start, clean swim, and finish phases. In both championships, the start strobe lights were synchronized 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). Each race was analyzed by two experts in race analysis. The race analysis is done based on the times it takes swimmers to reach a certain distance based on the pool's marks. Afterwards, swim speed is calculated based on such times (t) and distances (d): v = d / t. The following race sections were used: (1) S0-15 (start phase); (2) S15-25 (clean swim phase); (3) S25-35 (clean swim phase); (4) S35-45 (clean swim phase), and; (5) S45-50 (finish phase). All these sections were converted into speed for level comparison. To assess the inter-evaluator reliability, the Intra-Class Correlation Coefficient (ICC) was used. The "two-way mixed effects" model and the "absolute agreement" definition for the inter-evaluator reliability were chosen as suggested by Koo and Li (2016). For all race sections the ICC for the speed measurement revealed a very-high agreement (S0-15: ICC = 0.999; S15-25: ICC = 0.998; S25-35: ICC = 0.998; S35-45: ICC = 0.995; S45-50: ICC = 0.995).

The following kinematic variables were measured in all sections described previously, except in section (S0-15, i.e., start): (1) clean swim speed ($m \cdot s^{-1}$); (2) stroke frequency (SF, Hz); (3) stroke length (SL, m), and; (4) stroke index (SI, $m^2 \cdot s^{-1}$). As aforementioned, the clean swim speed was calculated as $v = d / t$, where d is the distance (m) and t is the time (seconds). The SF was obtained by computing the period of the time spent to complete a full stroke cycle. In each race section, only complete stroke cycles were considered for the SF calculation. Afterwards, the average of that set of stroke cycles was used for further analysis. In section S15-25, an average of 3.75 ± 0.52 cycles was measured, in S25-35 an average of 3.58 ± 0.57 cycles, in S35-45 an average of 3.63 ± 0.56 cycles, and in S45-50 an average 1.60 ± 0.49 cycles. The inter-evaluator ICC for the SF measurement revealed a very-high agreement in all race sections (S15-25: ICC = 0.988; S25-35; ICC = 0.991; S35-45: ICC = 0.991; S45-50: ICC = 0.990). The SL was calculated as $SL = v / SF$ (Craig and 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^{th} meter mark and stopped when the swimmer's hand touched the end wall (Morais et al., 2022a; 2022b). As for the previous race sections, swim speed was based on the swimmer's head, a speed correction was performed. For each swimmer, it was measured the distance between the head and the end wall. This was done to calculate the amount of time 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. The mean ± one standard deviation (SD) was computed for all variables. The t-test independent samples ($p \leq 0.05$) were used to compare junior and senior swimmers. The mean difference and 95% confidence intervals (95CI) of the mean difference were also calculated. Cohen's d was selected as standardized effect size, and interpreted as: (1) small effect size $0 \leq |d| \leq 0.2$; (2) medium effect size if $0.2 < |d| \leq 0.5$, and; (3) large effect size if $|d| > 0.5$ (Cohen, 1988).

Between-subjects 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 standardized 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 being compared (i.e., senior swimmers, except speed, SL, and SI in section S45-50 m in which the junior swimmers presented better performances).

To identify the SF and SL combinations on swim speed as the dependent variable in each competitive level (juniors and seniors), exploratory associations between SF categorized ("rounded") and SL categorized ("rounded") on swim speed were explored using three-way ANOVAs (SF round, SL round, and group effect: best vs. worst performers). "Rounding" means making a number simpler but keeping its value close to what it was (Al-Hashami, 2022). We converted continuous variables (SF and SL) into categories by rounding these variables into the nearest tenth of meter for SL and tenth of Hz for SF (see Figure 1). Main effects being SF categorized, SL categorized and a group effect (i.e., best vs. worst performers), independently for junior and senior swimmers. Swim speed was entered as the dependent variable with both SF and SL categorized ("rounded") plus the group effect as independent variables. To analyze the group effect (best vs. worst performers), each dataset (juniors and seniors independently) was split-up into two groups: (1) group #1–swimmers with better performances; (2) group #2–swimmers with worst performances. Non-estimable means were not plotted. Eta square (η^2) was used as an effect size index and interpreted as: (1) without effect if $0 < \eta^2 \leq 0.04$; (2) minimum if $0.04 < \eta^2 \leq 0.25$; (3) moderate if $0.25 < \eta^2 \leq 0.64$ and; (4) strong if $\eta^2 > 0.64$ (Ferguson, 2009). Coefficient of determination (R^2) was used to describe to what extent the swim speed could be explained by the three factors in the ANOVA. As rule of thumb and qualitative interpretation, the relationship was defined as: (1) very weak if $R^2 < 0.04$; (2) weak if $0.04 \leq R^2 < 0.16$; (3) moderate if $0.16 \leq R^2 < 0.49$; (4) high if $0.49 \leq R^2 < 0.81$ and; (5) very high if $0.81 \leq R^2 < 1.0$ (Barbosa et al., 2015).

Results

Kinematics comparison between juniors and senior swimmers

Table 1 presents the descriptive statistics (mean ± one standard deviation) and comparison between junior and senior swimmers in the 50-m freestyle event in each section of the race. Senior swimmers were significantly faster in the 50-m freestyle event than junior swimmers ($p < 0.001$). Speed presented the largest significant difference in section S0-15 (start) (mean difference: -0.125; 95CI: -0.161 to -0.089; $t_{(1,178)} = -6.920$; $p < 0.001$; d = 1.00) being senior swimmers fastest. This trend was kept until section S45-50 (finish). In this section (finish), junior swimmers were significantly faster than their senior counterparts (mean difference: 0.038; 95CI: 0.015 to 0.060; $t_{(1,179)} = 3.326$; $p = 0.001$; d = 0.40). Remaining variables showed a similar trend. That is, senior swimmers presented a significantly faster SF, longer SL, and greater SI until section S35-45 (except SL in section S35-45 which was non-significant). In section S45-50 (finish) senior swimmers still presented a faster and significant SF in comparison to junior counterparts. However, as it happened with speed, junior swimmers had a significantly longer SL (mean difference: 0.081; 95CI: 0.038 to 0.125; $t_{(1,179)} = 3.712$; $p < 0.001$; d = 0.47), and higher SI (mean difference: 0.225; 95CI: 0.116 to 0.333; $t_{(1,179)} = 4.082$; $p < 0.001$; d = 0.59).

Overall, seniors racing the 50-m freestyle event are significantly faster than juniors in all sections of the race. On the other hand, juniors were significantly faster with a moderate effect size in the finish section (S45-50).

Categorization of SF and SL, and group effect

Table 2 presents the three-way ANOVAs investigating swim speed by SL round, SF round, group effect and their interaction in each race section. Both junior and senior swimmers revealed a significant "rounding" ($p < 0.001$), i.e., categorization by SL and SF in each race section. This means that it was possible to categorize all the SF's and SL's observed into groups rounded to the tenths. Overall, a significant group effect was noted in junior and senior swimmers in all race sections (except for senior swimmers in S45-50–finish). Regarding interactions, mixed findings were noted for the SF*SL interaction, where significant and non-significant interactions were found in junior and senior swimmers. A significant SF*Group interaction was noted in senior swimmers in race section S25-35. The R^2 of senior swimmers ranged between 0.792 (S25-35 m) and 0.849 (S35-45); whereas the junior swimmers R^2 ranged from 0.746 (S45-50 m) to 0.835 (S25-35). This indicates that the amount of variance in swim speed that can be combined by the three factors ranged between high to very high.

Identification of the SF–SL combinations in each section of the race

Figure 1 depicts the SF–SL combinations in each section of the clean swim phase and finish in junior and senior swimmers split by groups (better vs worst performers).

Section S15-25 – senior swimmers (both groups) achieved the fastest speed performing SF at 1.00 Hz, and with a SL of 1.90-m. Junior swimmers in group #1 also achieved the fastest swim speed at a SF of 1.00 Hz, and with a 2.30-m SL. Junior swimmers in group #2 achieved the fastest speed at 1.10 Hz and 2.00-m.

Section S25-35 – senior swimmers (both groups) achieved the fastest speed with a SF of 1.10 Hz, and with a SL of 2.10-m. Junior swimmers in group #1 achieved the fastest speed at a SF of 1.00 Hz, and at a SL of 2.20-m. Junior swimmers in group #2 achieved the fastest speed at a SF of 0.80 Hz, and at a SL of 2.40-m.

Section S35-45 – senior swimmers in group #1achieved the fastest speed with a SF of 1.10 Hz, and a SL of 1.90-m. In group #2, senior swimmers, achieved the fastest speed with a SF of 1.00 Hz, and a SL of 2.10-m. Junior swimmers (both groups) achieved the fastest speed at a SF of 0.90 Hz, and a SL of 2.20 and 2.30-m (group #1), and SL of 2.20-m (group #2).

Section S45-50 – In the last section (finish), senior swimmers in group #1 achieved the fastest speed with a SF of 1.00 Hz, and a SL of 2.00-m. In group #2, senior swimmers achieved the fastest speed at a SF of 1.10 Hz, and a SL of 1.80-m. Junior swimmers in group #1 achieved the fastest speed at a SF of 0.90 Hz, and a SL of 2.30-m. In group #2, junior swimmers achieved the fastest speed also at a SF of 0.90 Hz, and a SL of 2.20-m. In summary, these results point out that depending on the race sections, and being junior or senior (competition level), swimmers tend to present different SF–SL combinations to maximize swim speed.

Table 1. Descriptive statistics (mean ± one standard deviation) and comparison between seniors and juniors in the 50 m freestyle event.

	50 m freestyle						
	Mean±1SD (Senior)	**Mean±1SD (Junior)**	**Mean difference (95%CI)**	**t (df)**	**p**	**d [descriptor]**	**Worthwhile change [% of elite swimmers]**
50 m race [s]	22.67±0.92	23.68±0.78	1.016 (0.765 to 1.268)	7.962 (1,179)	<0.001	1.18 [large]	0.18 [0.81%]
	S0-15 m						
Speed [m·s⁻¹]	2.66±0.13	2.54±0.11	-0.125 (-0.161 to -0.089)	-6.920 (1,178)	<0.001	1.00 [large]	0.03 [0.98%]
	S15-25 m						
Speed [m·s⁻¹]	2.11±0.08	1.99±0.07	-0.116 (-0.139 to -0.094)	-10.138 (1,179)	<0.001	1.60 [large]	0.02 [0.76%]
SF [Hz]	1.03±0.05	1.01±0.07	-0.020 (-0.038 to -0.002)	-2.182 (1,150)	0.028	0.33 [moderate]	0.01 [0.97%]
SL [m]	2.04±0.12	1.98±0.15	-0.069 (-0.108 to -0.023)	-3.415 (1,158)	0.001	0.44 [moderate]	0.02 [1.18%]
SI [m²·s⁻¹]	4.32±0.36	3.95±0.39	-0.374 (-0.484 to -0.264)	-6.705 (1,179)	<0.001	0.99 [large]	0.07 [1.67%]
	S25-35 m						
Speed [m·s⁻¹]	2.07±0.08	1.95±0.06	-0.117 (-0.138 to -0.096)	-10.882 (1,179)	<0.001	1.70 [large]	0.02 [0.77%]
SF [Hz]	1.01±0.05	0.98±0.07	-0.026 (-0.044 to -0.009)	-2.893 (1,157)	0.004	0.49 [moderate]	0.01 [0.99%]
SL [m]	2.05±0.11	1.99±0.15	-0.060 (-0.099 to -0.020)	-2.944 (1,154)	0.003	0.46 [moderate]	0.02 [1.07%]
SI [m²·s⁻¹]	4.24±0.34	3.88±0.37	-0.359 (-0.463 to -0.254)	-6.786 (1,179)	<0.001	1.01 [large]	0.07 [1.60%]
	S35-45 m						
Speed [m·s⁻¹]	2.01±0.09	1.93±0.06	-0.080 (-0.103 to -0.058)	-7.064 (1,179)	<0.001	1.05 [large]	0.02 [0.90%]
SF [Hz]	0.98±0.06	0.95±0.06	-0.023 (-0.042 to -0.004)	-2.392 (1,179)	0.018	0.50 [large]	0.01 [1.22%]
SL [m]	2.07±0.18	2.03±0.16	-0.035 (-0.085 to 0.015)	-1.400 (1,179)	0.163	0.23 [moderate]	0.04 [1.74%]
SI [m²·s⁻¹]	4.17±0.46	3.93±0.39	-0.240 (-0.364 to -0.115)	-3.790 (1,179)	<0.001	0.56 [large]	0.04 [0.86%]
	S45-50 m						
Speed [m·s⁻¹]	1.83±0.08	1.86±0.07	0.038 (0.015 to 0.060)	3.326 (1,179)	0.001	0.40 [moderate]	0.01 [0.75%]
SF [Hz]	0.95±0.07	0.93±0.05	-0.020 (-0.039 to -0.002)	-2.234 (1,179)	0.027	0.33 [moderate]	0.02 [1.47%]
SL [m]	1.93±0.15	2.00±0.15	0.081 (0.038 to 0.125)	3.712 (1,179)	<0.001	0.47 [moderate]	0.03 [1.50%]
SI [m²·s⁻¹]	3.52±0.36	3.74±0.38	0.225 (0.116 to 0.333)	4.082 (1,179)	<0.001	0.59 [large]	0.08 [2.03%]

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

Table 2. The senior and junior three-way ANOVAs investigating swim speed by SL round, SF round, group, and their interactions (see Figure 1).

	Senior			Junior		
S15-25 m						
Swim speed	**F-ratio (df)**	**p**	**η²**	**F-ratio (df)**	**p**	**η²**
SL round	22.133 (6,77)	<0.001	0.63	9.345 (6,62)	<0.001	0.48
SF round	24.714 (3,77)	<0.001	0.49	19.672 (3,62)	<0.001	0.28
Group effect	10.475 (1,77)	0.002	0.12	8.774 (1,62)	0.004	0.12
SL*SF round	1.794 (1,77)	0.184	0.02	2.623 (4,62)	0.043	0.15
SF*Group	n/a	n/a	0.00	0.518 (2,62)	0.598	0.01
SL*Group	0.952 (2,77)	0.391	0.03	1.932 (4,62)	0.116	0.11
R^2	0.844			0.815		
S25-35 m						
Swim speed	**F-ratio (df)**	**p**	**η²**	**F-ratio (df)**	**p**	**η²**
SL round	19.019 (5,76)	<0.001	0.56	10.478 (6,67)	<0.001	0.49
SF round	28.425 (3,76)	<0.001	0.53	28.570 (2,67)	<0.001	0.46
Group effect	8.660 (1,76)	0.004	0.10	19.451 (1,67)	<0.001	0.23
SL*SF round	3.858 (4,76)	0.007	0.17	3.898 (1,67)	0.052	0.05
SF*Group	4.006 (1,76)	0.049	0.05	n/a	n/a	0.00
SL*Group	0.316 (3,76)	0.814	0.02	0.968 (2,67)	0.385	0.03
R^2	0.792			0.835		
S35-45 m						
Swim speed	**F-ratio (df)**	**p**	**η²**	**F-ratio (df)**	**p**	**η²**
SL round	21.717 (7,72)	<0.001	0.68	5.920 (8,65)	<0.001	0.42
SF round	19.606 (2,72)	<0.001	0.35	9.994 (3,65)	<0.001	0.32
Group effect	14.395 (1,72)	<0.001	0.16	25.327 (1,65)	<0.001	0.28
SL*SF round	1.715 (5,72)	0.142	0.11	n/a	n/a	0.00
SF*Group	0.446 (2,72)	0.642	0.01	n/a	n/a	0.00
SL*Group	0.956 (3,72)	0.418	0.04	1.091 (3,65)	0.359	0.05
R^2	0.849			0.811		
S45-50 m						
Swim speed	**F-ratio (df)**	**p**	**η²**	**F-ratio (df)**	**p**	**η²**
SL round	19.954 (7,70)	<0.001	0.67	10.024 (6,66)	<0.001	0.48
SF round	26.883 (3,70)	<0.001	0.54	16.495 (2,66)	<0.001	0.33
Group effect	0.095 (1,70)	0.758	0.00	18.830 (1,66)	<0.001	0.22
SL*SF round	2.267 (5,70)	0.057	0.14	0.870 (3,66)	0.461	0.03
SF*Group	2.654 (1,70)	0.108	0.04	0.241 (1,66)	0.625	0.00
SL*Group	1.952 (4,70)	0.111	0.10	1.296 (4,66)	0.281	0.07
R^2	0.823			0.746		

SL – stroke length; SF – stroke frequency; Group – group of swimmers (group #1 – better performers; group #2 – worst performers) at the 50 m race time for elite and junior swimmers); * - interaction; n/a – not applicable; df – degree of freedom; R^2 – determination coefficient; p – significance value; η^2 – eta square (effect size index)

Identification of the SF–SL combinations of the fastest eight swimmers (seniors and juniors)

Figure 1 also presents the combinations of the fastest eight swimmers (i.e., best final race times) in each section of the race. The number of swimmers that performed at a given combination is also shown.

Juniors – The majority (N = 6) of the fastest eight junior swimmers presented an SF–SL combination of 1.10 Hz and 2.10-m in the section S15-25. In section S25-35, four presented an SF–SL combination of 1.00 Hz and 2.10-m. In section S35-45, three presented an SF–SL combination of 1.00 Hz and 2.10-m. And in the last section (finish–S45-50), four presented an SF–SL combination of 1.00 Hz and 1.80-m.

Seniors – In section S15-25, three of the fastest eight, presented an SF–SL combination of 1.10 Hz and 2.00-m. In section S25-35, three swimmers presented an SF–SL combination of 1.00 Hz and 2.20-m. In section S35-45, three swimmers presented an SF–SL combination of 0.90 Hz and 2.20-m. And in the finish section (S45-50): (i) two swimmers presented and SF–SL combination of 1.00 Hz and 1.90-m; (ii) other two a combination of 0.90 Hz and 2.20-m, and; (iii) other two a combination of 0.90 Hz and 2.30-m. In summary, even the fastest eight swimmers per competitive level, presented several SF–SL combinations. This highlights the variability presented by the best performers in each competitive to maximize their swimming speed.

Discussion

This study aimed to analyze and compare the stroke kinematics between junior and senior elite swimmers in every section of the race during the 50-m freestyle event and identify the SF–SL combinations on swim speed independently for junior and senior swimmers in each section of the 50-m freestyle event. Altogether, senior swimmers were faster in every section of the race and presented better kinematics, except in the finish (S45-50). Junior and senior swimmers presented different SF–SL combinations in each section of the race. A significant group effect was noted in junior swimmers in all sections of the race. Senior swimmers presented the same trend, except in the finish (S45-50) where a non-significant group effect was noted. This

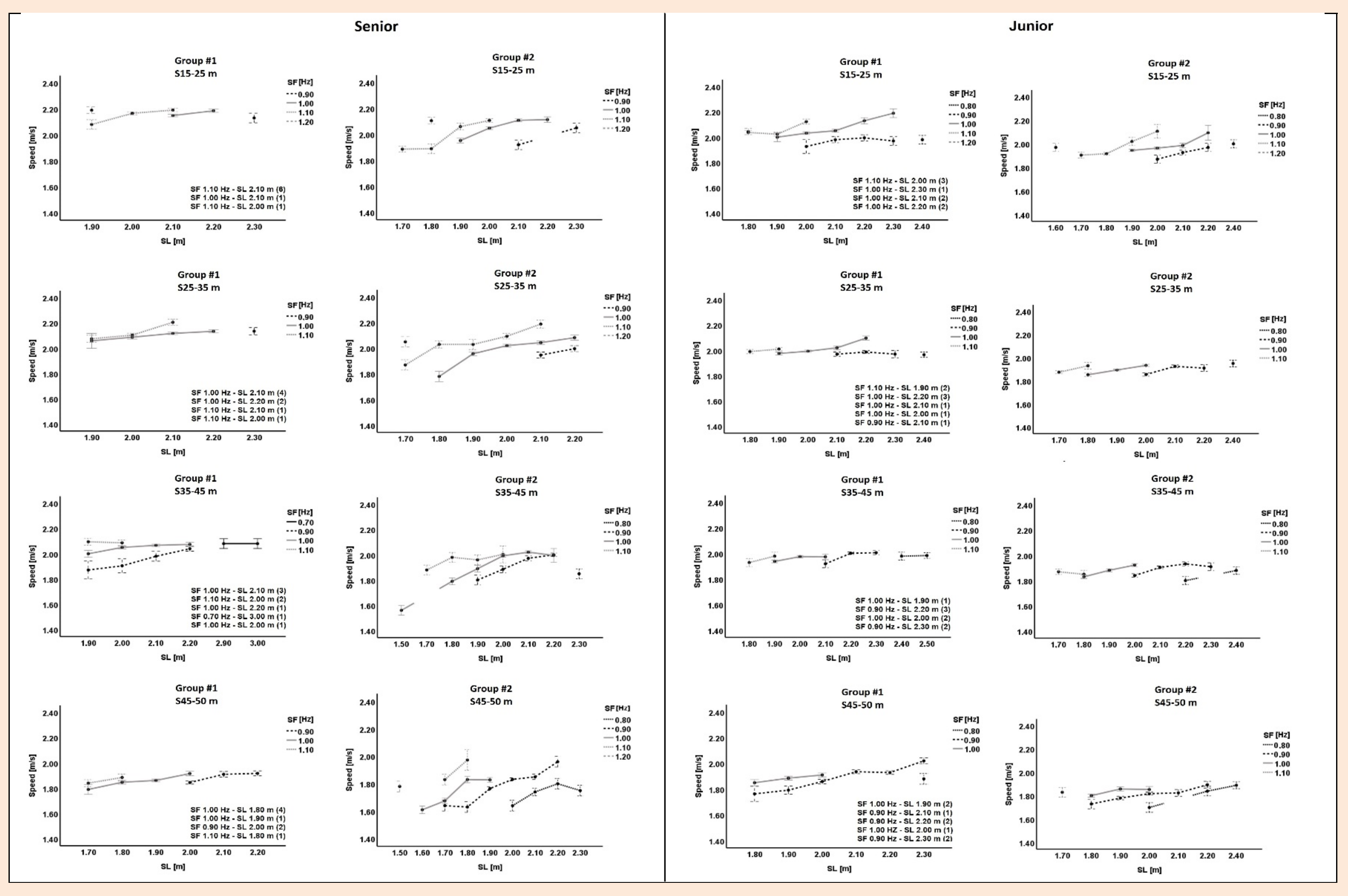

Figure 1. **The SL–SF combinations in each section of the clean swim phase and finish during the 50 m Freestyle event for senior (left panels) and junior swimmers (right panels) for each group (group #1 – better performers; group #2 – worst performers). SL – stroke length; SF – stroke frequency; Group #1 – best performers; Group #2 – worst performers. In the bottom right corner of each race section (group #1: senior and junior), the SF–SL combination of the fastest eight swimmers are presented. The combinations of the fastest eight swimmers (i.e., best final race times) in each section of the race are also shown.**

suggests that, within the junior or senior groups, significant and different SF–SL combinations were adopted.

Studies noted that the 50-m freestyle event raced by elite junior (Morais et al., 2022a) and elite senior swimmers (Morais et al., 2022b; Simbaña-Escobar et al., 2018) is characterized by an all-out pace and with a cubic relationship between speed and time. However, to the best of our knowledge, there is no comparison between elite juniors and elite senior swimmers in such event nor in others. Present data revealed, with no surprise, that senior swimmers were significantly faster in every section of the race until the 45th meter. The highest and significant mean difference was verified in the first section (S0-15; start), and such difference tended to decrease until the 45th meter. The start section (S0-15) is characterized by the block time and push-off, water entry, glide, underwater dolphin kicks (underwater phase), and clean swim (surface phase, which swimmers can perform or not if they choose to break the water surface near the 15th meter mark). It was noted that the fastest swimmers present better scores of parameters related to the block time and push-off (García-Ramos et al., 2015), as well as the underwater phase (Trinidad et al., 2020). Thus, one can argue that senior swimmers may achieve more strength and power with their lower-trunk and adopt a better hydrodynamic position than their junior counterparts in this section.

From the 15th meter and the 45th meter mark, swimmers perform the clean swim phase. During this stretch, seniors were significantly faster and presented higher kinematics and greater efficiency than their junior counterparts. As aforementioned, literature does not share comparisons between junior and senior swimmers in the 50-m freestyle nor other events. However, in the 100-m freestyle, it was claimed that better performers (racing under 50-s) presented a longer SL than worst performers (race time above 50-s) (Pla et al., 2021). Other study about the 100-m freestyle, indicated that faster swimmers presented a significantly faster SF and longer SL, in the fastest lap of the race, than their slower counterparts (Seifert et al., 2007). Thus, SF–SL combination seems to be a key-factor to swim faster. Conversely, junior swimmers were significantly faster in the finish section (S45-50). They presented a significantly slower SF, a significantly longer SL, and consequently a greater efficiency. A study by Morais et al. (2022a), that compared junior swimmers split into two groups, noted that the best performers presented a longer SL and greater SI (non-significant differences were noted in the SF). Based on the present data, and if both seniors and juniors perform an all-out strategy, one can state that junior swimmers present a lower difference between the first and last section of the race (seniors: relative difference = 31.20%; juniors: relative difference = 26.77%).

Regarding the SF–SL combinations, the categorization modelling allowed to identify different possible combinations in seniors and juniors in each section of the race. A significant group effect was also noted in each level of swimmers (junior or senior) for each race section (except for seniors in the finish section–S45-50). However, when rounding the SF by group and SL by group, non-significant differences in the SF–SL combinations were observed in both junior and senior swimmers. There has been interest in conducting experimental research (Dekerle et al., 2005; Toussaint et al., 2006) and observational studies (Arellano et al., 1994; Kennedy et al., 1990) on this topic. This provides important information about the technical development of elite swimmers (Craig and Pendergast, 1979). However, less up-to-date information is known about such relationships in a real competition context and especially in sprinting events. A study by Chen et al. (2007) aimed to identify race patterns based on world class swimmers but in the 400-m freestyle. The authors suggested to monitor elite swimmers' race patterns from the beginning until the end of the race, also considering the intermediate stage. We acknowledge that this approach can be employed in the 50-m by splitting the race into sub-sections. This allowed to understand that both seniors and juniors change their SF–SL combinations during the 50-m event.

Overall, it was noted that best performers can deliver faster swims based on a high cadence and keeping a long SL (Craig and Pendergast, 1979; Dekerle et al., 2005). Interestingly, the main trend verified in S15-25 for both groups of juniors and seniors, was that the fastest speed was not achieved by the highest SF instead of the longest SL. In sections S25-35 (both groups) and S35-45 (group #1), seniors did achieve the fastest swim speed by employing the fastest SF. Conversely, juniors (group #1) in section S45-50 achieved the fastest swim speed with the longest SL. Thus, it seems that depending on the swimmers' level (being junior or senior) different SF–SL combinations can be employed. Nonetheless, it should be highlighted that seniors in group #1, which were the fastest performers, tended to put the focus on maximizing SF rather than SL in intermediate sections (S25-35 and S35-45).

We also observed the SF–SL combinations employed by the fastest eight seniors and juniors. This was to understand if the fastest swimmers would present the same combination as their group #1 counterparts. Main trend for seniors was that the fastest eight swimmers did not follow the same combinations of the entire group #1 (only one swimmer in S25-35; SF: 1.10 Hz–SL: 2.10-m). Juniors presented an opposite trend. In all sections, some of the fastest eight juniors presented the SF–SL combination that denoted the fastest swim speed (S15-25: N = 1; S25-35: N = 3; S35-45: N = 5; S45-50: N = 2). This indicates that seniors have higher variability than juniors. Studies about swimming variability provided evidence that a higher expertise level leads to a larger variability (Seifert et al., 2011). To achieve a world class level swimmers must explore the environment to optimize their individual strengths (Seifert et al., 2011). Thus, based on the present data, one can state that all juniors follow a pre-set strategy, which does not change so much among them. Conversely, seniors seek to find and customize the combination that is more effective for them. Studies find out that changing from junior to senior level can be challenging (Brustio et al., 2021; Yustres et al., 2017). Such studies noted that being successful at a junior level did not guarantee an elite level later in their career as senior swimmers. Senior swimmers, to reach an elite or world class level, must understand how to maximize their performance based on their

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strengths which can be different between swimmers. Coaches and swimmers must be aware that eventually they might not race a given event in the same way in different moments of their swimming career.

As main limitations it can be considered that: (1) in each competitive level (i.e., juniors and seniors), some swimmers (semi-finalists and finalists) were analyzed more than one time. Thus, not only the SF–SL combination that led to a faster swimming speed was analyzed, but also the other one(s). Notwithstanding, this allows to a have an overall perspective about this stroke kinematics topic; (2) transitions between sections were not considered and these may play an important role on swimmers' stroke kinematics (Simbaña-Escobar et al., 2018), and; (3) besides an inter-evaluator agreement, an intra-evaluator agreement can decrease the assumption of manual tracking error. Therefore, future studies should rely on analyzing the within-subjects variance between heats to semis to finals. By doing so, one can get deeper insights about the importance of the SF–SL combinations on swimming speed, and the importance of race sections transitions. Researchers, coaches, and practitioners may also benefit on understanding the SF–SL combinations on other swimming events (i.e., strokes and lengths).

Conclusion

Senior swimmers were faster in every start and clean swim section of the 50-m freestyle than their junior counterparts, presenting also better kinematics. Conversely, juniors presented better scores in the last section (S45-50). Junior and senior swimmers presented different SF–SL combinations in each section of the race. The fastest swim speeds were not achieved the by the faster SF and longer SL concurrently. Seniors fastest speed was underpinned by the fastest SF. On the other hand, juniors used a larger SL. Thus, coaches should be aware that SF–SL combinations change during a 50-m freestyle race, and these may be dependent on the swimmers' characteristics.

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Key points

- The fastest eight seniors did not follow the same combinations of the entire group, and juniors presented an opposite trend.
- This indicates that seniors have higher variability than juniors during the 50-m freestyle event seeking to find and customize the combination that is more effective for them.
- Juniors follow a pre-set strategy, which does not change so much among them.
- Coaches and swimmers must be aware that they might have to adapt themselves since it is not possible to race a given event in the same way in different moments of their swimming career.

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