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 [$m \cdot s^{-1}$]	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 [$m \cdot s^{-1}$]	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 [$m^2 \cdot s^{-1}$]	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 [$m \cdot s^{-1}$]	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 [$m^2 \cdot s^{-1}$]	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 [$m \cdot s^{-1}$]	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 [$m^2 \cdot s^{-1}$]	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 [$m \cdot s^{-1}$]	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 [$m^2 \cdot s^{-1}$]	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**	**η^2**	**F-ratio (df)**	**p**	**η^2**
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**	**η^2**	**F-ratio (df)**	**p**	**η^2**
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**	**η^2**	**F-ratio (df)**	**p**	**η^2**
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**	**η^2**	**F-ratio (df)**	**p**	**η^2**
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

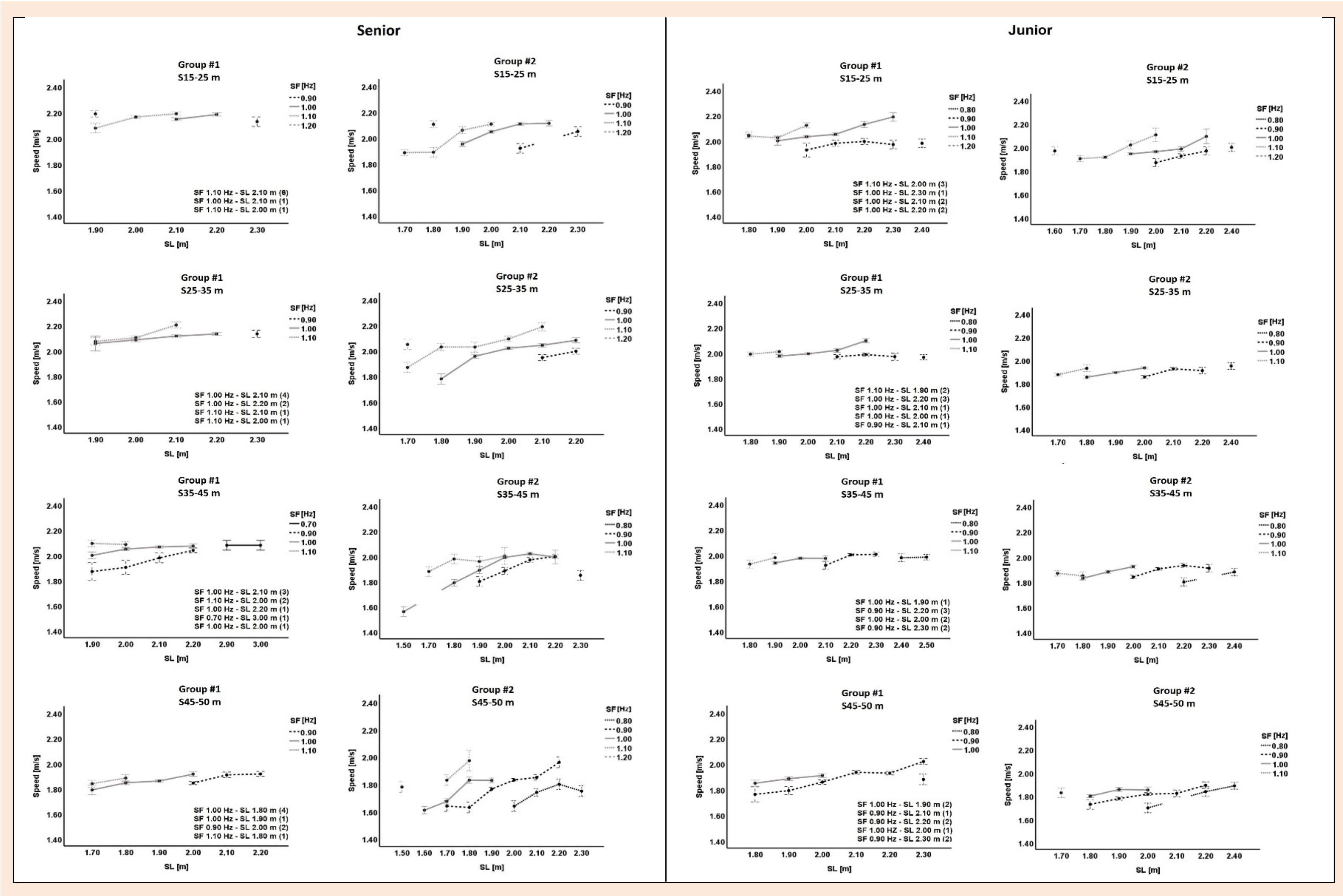

Figure 1. **The SL–SF combinations in each section of the clean swim phase and finish during the 50 m Freestyle event for senior (left panels) and junior swimmers (right panels) for each group (group #1 – better performers; group #2 – worst performers). SL – stroke length; SF – stroke frequency; Group #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.**

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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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