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Section: Case study

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Long-term changes in the speed curve of a world-class butterfly swimmer

Running Title: Elite butterfly performance

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Abstract

BACKGROUND: This study described the changes in selected points of the speed curve, stroke rate (SR), and stroke length (SL) of an elite butterfly swimmer and examined their relationship with average speed (AS) and competitive performance.

METHODS: Over eight years, the male swimmer (50 and 100 m: 22.70 and 51.47 s) underwent 18 tests to assess AS, SR, SL, intracyclic speed variation (ISV), and eight selected points of the speed curve. $Peak_1$ is the maximum speed in the upward kick executed during the arm recovery. $Peak_2$ is the maximum speed in the first downward kick after the arm entry into the water. $Peak_3$ is the maximum speed during the arm pull. $Peak_4$ is the maximum speed during the arm push combined with the second downward kick. Min_1, Min_2, Min_3, Min_4 corresponds to the minimum speeds found respectively before each peak speed. Official competitive results in 50 (50BF) and 100 m (100BF) within three weeks of the speed tests were registered.

RESULTS: SR (r = .736), ISV (r = -.493), $Peak_1$ (r = .555), Min_2 (r = .558), and Min_3 (r = .539) correlated with AS. 50BF correlated with AS (r = -.658) and $Peak_1$ (r = -.820), whereas 100BF with AS (r = -.676), SR (r = -.571), $Peak_1$ (r = -.758), and $Peak_2$ (r = -.594).

CONCLUSIONS: AS increased by improving SR, $Peak_1$ and $Peak_3$. Increases in Min_2 and Min_3 indicate better transitions from resistive to propulsive phases. Selected points of the speed curve may predict butterfly performance.

Keywords: biomechanics, training, performance, testing, analysis

Introduction

International swimming competitions comprise the 50, 100 and 200 m butterfly events and the final performance depends on the speeds in the underwater kicking during the start and turns, and on the swimming strokes executed on the water surface. The butterfly technique involves coordinating two simultaneous leg kicks with one complete arm cycle (right and left arms together) and with a full-body wave action [1,2]. This movement pattern impairs propulsive continuity [3] and causes intracyclic speed fluctuations within the stroke cycle [4], which are associated with a greater energy cost [5].

A typical speed curve of one butterfly cycle has four peaks [6,7]. The first relates to the upward kick executed during the arm recovery. The second corresponds to the downward kick that occurs immediately after the arms enter into the water. The third peak refers to the arm pull combined with the second upward kick, whereas the fourth relates to the arms push combined with the second downward kick. These peak speeds are preceded by minimum points, which correspond to the transitions from predominantly resistive to propulsive phases. The long-term changes of these speed references in elite butterfly swimmers can provide useful insights regarding how they improve technique, average speed, and achieve world-class performance over time.

Previous studies have covered other critical aspects of elite swimmers' performance, such as training organization [8–10], biomechanical [11] and physiological profiles [9,12,13], and provided a greater comprehension of their performance development. However, the long-term effects of training on the butterfly speed curve remain underexploited, especially at the elite level.

From 2011 to 2018, we monitored a butterfly swimmer who evolved to the top 15 in the annual world ranking in 50 and 100 m butterfly. The aim of this study was to describe the long-term changes in selected points of his hip speed curve, stroke rate and stroke length, and to examine their relationships with performance, measured as average speed during experimental conditions and time in 50 and 100 m butterfly competitions.

Case Report

Participant: The male swimmer analysed (age in 2018: 26 years, height: 1.80 m, body mass: 72 kg, and arm span: 1.83 m) holds the 6^{th} and 41^{st} all-time long-course marks in the 50 (22.70 s) and 100m butterfly (51.47 s), respectively (searched in April 2020 in www.fina.org – more competitive results shown in Table 1). His best positions in the annual world ranking in these races were 2^{nd} and 14^{th}. He won gold medals in the World University Games, Military World Games, and was finalist in the 2016 Olympic Games and in the 2017 World Championships. He had been involved in systematic training for fourteen years in 2018 and did not present any injuries during the studied period. The athlete provided verbal and written informed consent to participate in this study. Procedures complied with the Declaration of Helsinki and were approved by the University's Ethics Committee (Process: 74965917.5.0000.5404).

Study Design: This is an exploratory and retrospective case study. From October 2011 to March 2018 the swimmer underwent 18 tests for technical analysis using instantaneous speed synchronized with video recording. The speedometer [8] (CEFISE, Nova Odessa, Brazil – the sampling frequency improved over time, so it varied from 50 to 240 Hz) was attached to the hip during one or more ~25 m maximal sprints with self-selected stroke rate from an in-water push-off. The fastest trial was retained for analysis. The swimmer consistently broke the water surface near to the 10 m. Therefore, a favourable perspective of the stroke could be captured in the first cycles. An underwater cabled camera was attached to either a trolley or to a monopod and recorded the trial at 30 Hz in real-time. The trolley was pulled alongside the pool at the same speed as the swimmer, whereas the monopod was positioned at the 15-m mark and was rotated by the operator to follow the swimmer's displacement. A custom-designed software (Forward®, Meazure Sport Sciences, Brazil) synchronized both speed and video data by interpolation. A fourth-order Butterworth low-pass digital filter with a cut-off frequency of 8 Hz smoothed the speed data.

The break-out and the first cycle were omitted to attenuate both push-off and underwater kicking effects. The three next cycles were used to calculate the average speed, stroke rate ([3 · 60] / time of the 3 cycles), stroke length (= average speed / stroke rate), and intracyclic speed variation as represented by the coefficient of variation of hip speed. Additionally, the selected speed points shown in shown Figure 1 were marked in each of the three cycles and provided following variables:

- $Peak_1$: the maximum speed point found in the upward kick, which happens during the arm recovery
- Min_1: the minimum speed point immediately before $Peak_1$
- $Peak_2$: the maximum speed point found in the first downward kick, which happens after the arm entry into the water
- Min_2: the minimum speed point immediately before $Peak_2$
- $Peak_3$: the maximum speed point found in the arm pull, which happens combined with the second upward kick
- Min_3: the minimum speed point immediately before $Peak_3$
- $Peak_4$: the maximum speed point found in the arm push combined with the second downward kick
- Min_4: the minimum speed point immediately before $Peak_4$.

Minimum and peak speed points represent important actions and/or positions within the stroke [6,7,14]. In each trial, the average value of these variables was retained for analysis. The upward kick and the pull curves, respectively represented from Min_1 to Min_2 and from

Min_3 to Min_4, were not detected in all strokes, so the average of the found values was considered for $Peak_1$, Min_2, $Peak_3$, and Min_4, whereas their occurrence is reported in Table 1. In ten tests, the athlete performed two or more trials, so we could calculate the CV and the typical error of measurement, which were 0.8% and 0.02 $m \cdot s^{-1}$ for average speed, 3.1% and 2.1 $c \cdot min^{-1}$ for stroke rate, 2.8% and 0.06 m for stroke length, 5.6% and 1.6% for intracyclic speed variation, 3.8% and 0.09 $m \cdot s^{-1}$ for $Peak_1$, 4.9% and 0.11 $m \cdot s^{-1}$ for $Peak_2$, 3.4% and 0.09 $m \cdot s^{-1}$ for $Peak_3$, 2.2% and 0.06 $m \cdot s^{-1}$ for $Peak_4$, 4.6% and 0.07 $m \cdot s^{-1}$ for Min_1, 6.1% and 0.09 $m \cdot s^{-1}$ for Min_2, 7.3% and 0.09 $m \cdot s^{-1}$ for Min_3, and 4.1% and 0.10 $m \cdot s^{-1}$ for Min_4, respectively.

Competitive performances in 50 and 100 m long course butterfly within three weeks of the measurement were registered. The best official time out of the heat, semi-final or final was retained. The time difference in days in-between each measurement and the main competition of the respective season was also computed. The starting dates of the three annual national championships and the Rio 2016 Olympic Games were the references.

Statistical Analysis: Absolute data presented the time effects. Shapiro-Wilk test checked the assumptions of normally-distributed samples, whereas the presence of outliers was identified by the outlier labelling rule [15]. Pearson or Spearman (either when normality was not confirmed or outliers were identified) correlation coefficients assessed the relationships between variables and, when significant, were interpreted as: >0.30: small, 0.31-0.49: moderate, 0.50-0.69: large, 0.70-0.89: very large, and 0.90-1.00: nearly perfect [16]. The significance level was set at $p \leq .05$. The analyses were conducted using IBM SPSS for Windows (Version 25.0, Armonk, NY, USA).

Results

Data from the speed curves analysed from 2011 to 2018 are in Table I. Figure 2 exemplifies the speed points and their respective stroke positions at the beginning (#3) and end (#18) of the analysed period. These tests used the trolley and provided a better view of the stroke positions. A total of nine and 13 official competitive performances occurred within three weeks of the speed tests for the 50 and 100 m, respectively. The correlations between variables and average speed and 50 and 100 m competitive performances are in Table II.

[Figure 1 near here]

[Table I near here]

[Table II near here]

[Figure 2 near here]

Discussion

This is the first study to analyse the long-term changes in the hip speed curve of an elite butterfly swimmer, and our main findings were: 1) over time, the average speed measured by the speedometer has increased ~5% from the first to the last assessment and the swimmer tended to swim faster closer to the main competitions; 2) higher speeds are related to a reduced intracyclic speed variation; 3) the stroke rate increased and considerably influenced average speed; 4) changes in the upward kick ($Peak_1$), in the pull phase ($Peak_3$), and in the transitions from resistive to propulsive phases (i.e., Min_2 and Min_3) correlated with the average speed; and finally, 5) average speed and $Peak_1$ correlated with both 50- and 100-m results, whereas $Peak_2$ and stroke rate correlated only with the 100-m results. These variables may then predict competitive performances.

Swimming speed is the product of stroke rate and stroke length. For the current swimmer, the speed improvements were very largely related to the increase of the stroke rate ($r = .736$, $p < .0001$). For instance, the comparison between the 4 slowest (#4, #6, #8 and #11) and the 4 fastest assessments (#13, #14, #17 and #18 - Table I) indicates a 10.7%

increase in average swimming speed (1.69 ± 0.04 *vs.* 1.87 ± 0.02 $m \cdot s^{-1}$), accompanied by a 13.9% augment in stroke rate (52.7 ± 4.6 *vs.* 60.0 ± 3.7 $c \cdot min^{-1}$), and only a 2.9% reduction in stroke length (1.93 ± 0.13 m vs. 1.87 ± 0.10 m). These results are not in line with some previous studies, which verified the increase in stroke length as the regular path for swimmers to improve speed [8,17]. In other words, elite athletes and their staffs may find individualized solutions for performance development that differ from the patterns and trends reported in the literature.

The moderate and negative correlation between the average speed and the time for the main competition of the season ($r = -.462$, $p = .054$) indicates that the swimmer tended to swim faster closer to the main competitions. This tendency may be affected during intensified training periods when athletes experience accumulated fatigue and eventually a reduction in performance [18,19]. This might be the case of the assessment #16, in which the average speed reached 95.2% of his personal best speed result at that time (i.e., #13 in 2016), whereas the other three were above 98.5%. It is noteworthy that all tests in 2017 were part of the same cycle.

According to previous studies, the intracyclic speed variation in men may range from 9.1 to ~30% in all-out paces [4,5,20,21]. The lower value is considerably different from our results, which varied from 20.4 to 29.1%. The intracyclic speed variation is a consequence of the butterfly technique [3] and can be an indirect measure of swimming efficiency as Barbosa et al. [5] verified that the energy cost is strongly associated with the speed fluctuation of the centre of mass in the butterfly stroke ($r = .807$, $p < .001$). Herein, there was a moderate and inverse correlation between speed fluctuations and average swimming speed. Based on prior studies [4,21], it is conceivable that higher stroke rates and, therefore, higher segmental velocities have shifted the stroke technique towards a greater propulsive continuity and reduced speed fluctuations.

Certain speed points also correlated to the average speed. As they refer to specific actions and/or positions within the stroke [6,7,14], their changes can provide insight about technique and its effect on average speed. The large association between the upward kick executed during the arm recovery ($Peak_1$) and average speed, 50 and 100 m performances indicates that this leg movement contributes to a faster stroke in both experimental and competitive conditions. The importance of the upward phase for underwater kick performance was previously demonstrated [22], and its effectiveness seems related to the kinetic energy transferred from the swimmer to the water and vice versa, resulting in body acceleration. Ungerechts et al. [23] suggested that the generation of vortices can be improved by "emphasizing the reversal action of the kick using, as much as possible, whip-like action" (p. 6). Swimmers should then strive to increase effectiveness by combining a good upward kick while maintaining the hips close to the water surface, that is, a more horizontal body position. Importantly, this action should be coordinated with other movements in the stroke and in repeated cycles [24], so the kinetic energy from the body undulation can be properly transmitted caudally [1,2]. Keeping the hip close to the water surface during the upward kick was one of the main technical modifications this swimmer incorporated over the years, which is the transition from Min_1 to $Peak_1$ in Figure 2. Future studies on how to execute the up kick effectively during the butterfly stroke are encouraged.

The large association between the first downward kick after the arm entry ($Peak_2$) with 100 m butterfly performance demonstrates that its augmentation has a positive influence on the whole stroke swimming speed in competition. Despite non-significant, the moderate and large correlations between $Peak_2$ and the average speed and 50 m butterfly performance, respectively, may reinforce the practical importance of this leg kick action for this swimmer's performance, especially considering his competitive level, in which medals are decided by marginal differences. It is important though that either dry-land or in-water strategies to increase the lower limbs' power do not shift knees and hips towards excessive flexions, as these changes may also increase drag and eventually compromise a more horizontal body position and the caudal transmission of energy [1]. Besides, directing the head and arms to the bottom as shown by $Peak_2$ changes in Figure 2, and keeping the arms apart beyond the width of the shoulders may also hamper this peak speed value. These actions combined or not have the potential to expand the frontal projected area and therefore compete with the downward propulsive kick by increasing drag.

Keeping the head between the arms instead of directing it to the bottom was an important technical change of this swimmer, which is shown in the transition from Min_2 to $Peak_2$ in Figure 2. Besides reducing the drag, this action/position favours the connection between arms and trunk during the arm-catch phase (i.e., Min_3) and provides a stronger pull (i.e., $Peak_3$). In other words, when the head is not directed towards the bottom, the elbows get below the shoulders more quickly, which is a more mechanically advantageous position for the pull [25]. In addition, the pull phase can be more useful to move the body forward instead of upwards [7]. It is then suggested that this technical change may also have contributed to increase Min_3 and $Peak_3$ over time. This is represented by the changes in Min_3 and $Peak_3$ in Figure 2. In fact, the correlation analysis revealed a positive and large relationship between the average speed and these speed points (r = .539 and .506 for Min_3 and $Peak_3$, respectively).

The minimum points represent the transitions from predominantly resistive to propulsive phases. In general, the positive correlations of Min_2 and Min_3 with the average speed and their increase over time highlight their importance for the butterfly stroke. Similarly, [26] verified that the faster breaststrokers tend to extend the arms' glide and yet present higher minimum speed values, and suggested this non-propulsive phase as a key factor for performance. In the front crawl though, Barbosa et al. [8] found that the performance changes of an elite swimmer were more associated with increases in the highest points of the speed-curve. Then, changing the lower points of the curve in elite swimmers may be more relevant for butterfly and breaststroke, in which there is propulsive discontinuity.

Average speed, $Peak_1$ and $Peak_2$ presented large to very large correlations with 50 and 100 m butterfly performances ($Peak_2$ only for the 100 m). These results suggest that the changes in the speed curve transferred to competition, which is more complex and requires high levels of physical, psychological, and technical skills together. Besides, the fact that stroke rate and these speed curve points can predict competitive performances for this swimmer is of practical relevance during training routines as it is possible to analyse the impact of the training load through a 25-m sprint.

The large correlation between the stroke rate and the 100-m performance is also of interest. Detecting that a higher stroke rate is beneficial for the swimming speed during tests should be followed by a serious training process so that the swimmer can support it during 100 m in competition. Notably, the test results herein relate specifically to the clean swimming stroke in a non-fatigued condition, as the short duration of the testing procedure (~10-12 s) prevents the occurrence of a high level of acidosis [27]. The competition is unequivocally more demanding. Also, improving other features such as the dive, the underwater kick, the water break-out, the finish, and the turn, may be paths for the progression of the competitive results.

Finally, some limitations may be raised: 1) our results apply for the swimmer analysed and different aspects may be determinant to other swimmers with distinct physical, technical and anthropometric characteristics; 2) more speed assessments would provide a better view of his within-year changes; 3) although very practical to combine with athletes' training routines, the hip does not correctly represent the speed variations of the centre of mass [6,28] and 4) the use of different suits throughout the assessments may have influenced the speed curve. Tests with competitive suits became more accessible due to a sponsorship and were an attempt to assess the stroke closer to the competitive condition. Nevertheless, our results expand our understanding of elite performance development and can be useful for both sports scientists and practitioners.

Conclusion

This butterfly swimmer improved his swimming speed by increasing the stroke rate and the peak speeds in the upward kick executed during arm recovery and in the arm-pull phase. He also increased two minimum speed points, indicating better transitions from resistive to propulsive phases. Finally, parameters extracted from the speed curve are related to 50 and 100 m competitive times and may predict performance.

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NOTES

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Table I. Butterfly speed curve and matching 50 and 100m butterfly competitive performances

Year	2011	2012	2013		2014	2015			2016					2017				2018
Test	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16	#17	#18
$T_{Competition}$ (days)	48	5	41	82	34	69	33	91	59	7	31	18	11	75	48	27	14	18
Type of suit	T	T	T	T	T	T	T	T	T	T	S	T	S	S	S	T	S	S
AS ($m \cdot s^{-1}$)	1.79	1.79	1.77	1.65	1.75	1.65	1.73	1.73	1.75	1.71	1.83	1.81	1.87	1.85	1.84	1.78	1.87	1.89
SR ($c \cdot min^{-1}$)	55.6	51.6	53.2	49.7	52.6	50.7	59.5	58.1	54.6	50.7	55.8	58.1	58.1	59.6	60.0	56.4	56.8	65.3
SL (m)	1.93	2.08	1.99	1.99	1.99	1.96	1.75	1.79	1.93	2.02	1.97	1.86	1.93	1.86	1.84	1.89	1.97	1.73
ISV (%)	20.4	27.6	28.4	24.5	26.5	25.4	26.2	26.1	22.6	25.3	22.9	21.9	22.6	22.6	21.9	29.1	22.0	21.7
Min_1 ($m \cdot s^{-1}$)	1.17	0.85	1.06	1.08	1.00	1.21	1.06	1.05	1.29	1.35	1.35	1.18	1.17	1.20	1.25	1.06	1.33	1.07
$Peak_1$ ($m \cdot s^{-1}$)	1.65	1.84	1.45	1.47	1.76	1.72	1.68	1.76	1.75	1.82	1.86	1.67	1.99	1.64	1.90	1.92	1.91	1.93
Min_2 ($m \cdot s^{-1}$)	1.46	1.74	1.17	1.22	1.57	1.09	1.24	1.34	1.19	1.03	1.34	1.41	1.35	1.47	1.41	1.12	1.30	1.82
$Peak_2$ ($m \cdot s^{-1}$)	2.07	2.10	2.46	2.08	1.94	2.07	2.29	2.23	2.27	2.33	2.46	2.36	2.28	2.43	2.32	2.60	2.36	2.30
Min_3 ($m \cdot s^{-1}$)	1.43	1.21	1.30	1.08	1.26	0.89	0.96	1.14	1.21	0.96	1.05	1.21	1.24	1.17	1.26	0.78	1.21	1.48
$Peak_3$ ($m \cdot s^{-1}$)	2.14	2.43	1.99	2.16	-	2.29	2.43	2.17	2.17	2.00	2.36	2.29	2.48	2.50	2.30	2.43	2.56	2.27
Min_4 ($m \cdot s^{-1}$)	1.82	1.78	1.91	1.91	-	1.82	2.06	1.32	1.48	1.87	1.92	1.85	1.81	1.94	2.08	1.84	1.73	1.98
$Occ_{Peak1+Min2}$ (%)	100%	33%	33%	100%	67%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	33%
$Occ_{Peak3+Min4}$ (%)	100%	100%	100%	100%	0%	67%	67%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
$Peak_4$ (m/s)	2.57	2.64	2.61	2.31	2.71	2.23	2.32	2.76	2.64	2.62	2.51	2.49	2.61	2.50	2.54	2.54	2.55	2.56
50 m (s)	24.49	24.07	-	-	-	-	24.19	23.68	-	-	23.63	-	-	-	23.73	23.54	22.98	23.12
$Diff_{50m}$ (days)	8	10	-	-	-	-	2	2	-	-	1	-	-	-	1	1	14	8
100 m (s)	53.02	53.97	-	54.84	-	-	53.56	52.73	52.59	52.71	53.10	-	52.42	-	52.70	52.23	51.57	52.04
$Diff_{100m}$ (days)	8	5	-	7	-	-	2	2	16	7	1	-	11	-	1	1	14	8

$T_{Competition}$: remaining time for the main competition of the season; **T:** regular trunks; **S:** competitive suit, **AS:** average speed, **SR:** stroke rate, **SL:** stroke length, **ISV:** intracyclic speed variation, **Min_1:** minimum speed before the upward kick during arm recovery, **$Peak_1$:** peak speed of the upward kick during arm recovery, **Min_2:** minimum speed before the first downward kick after the arm entry, **$Peak_2$:** peak speed of the first downward kick after the arm entry, **Min_3:** minimum speed before the arm pull combined with the second upward kick, **$Peak_3$:** peak speed during the arm pull combined with the second upward kick, **Min_4:** minimum speed before the arm push combined with the second downward kick, **$Peak_4$:** peak speed during the arm push combined with the second downward kick, **$Occ_{Peak1+Min2}$**: percentual occurrence of the upward kick curve (i.e., $Peak_1$ and Min_2) considering the 3 cycles analyzed, **$Occ_{Peak3+Min4}$**: percentual occurrence of the arm pull curve (i.e., $Peak_3$ and Min_4) considering the 3 cycles analyzed, **50m:** official time for the 50 m butterfly; **100m:** official time for the 100 m butterfly, **$Diff_{50m}$:** number of days between the assessment and 50m result, **$Diff_{100m}$:** number of days between the assessment and 100m result.

Table II. Correlations between speed variables, average speed and 50 and 100 m butterfly performances - Significant correlations are in bold.

	Average Speed			50m Butterfly			100m Butterfly		
	r	*p*	Interpretation	*r*	*p*	Interpretation	*r*	*p*	Interpretation
$T_{Competition}$	**-.462**	**.054**	**Moderate**	-	-	-	-	-	-
Average Speed	-	-	-	**-.658**	**.054**	**Large**	**-.676**	**.011**	**Large**
Stroke Rate	**.736**	**< .0001**	**Very Large**	-.445	.231	-	**-.571**	**.041**	**Large**
Stroke Length	-.282	.258	-	.147	.705	-	.308	.305	-
ISV	**-.493**	**.038**	**Moderate**	.122	.754	-	.287	.342	-
Min_1	.150	.552	-	-.347	.360	-	-.443	.130	-
$Peak_1$	**.555**	**.017**	**Large**	**-.820**	**.007**	**Very Large**	**-.758**	**.003**	**Very Large**
Min_2	**.558**	**.016**	**Large**	-.044	.910	-	.014	.963	-
$Peak_2$	.449	.062	-	-.557	.119	-	**-.594**	**.032**	**Large**
Min_3	**.539**	**.021**	**Large**	-.033	.934	-	-.177	.564	-
$Peak_3$	**.506**	**.038**	**Large**	-.388	.302	-	-.249	.413	-
Min_4	.163 #	.532	-	.093	.812	-	.176 #	.566	-
$Peak_4$	.056 #	.826	-	.033 #	.932	-	-.492	.088	-

$T_{Competition}$: remaining time for the main competition of the season; **ISV:** intracyclic speed variation, **Min_1:** minimum speed before the upward kick during arm recovery, **$Peak_1$:** peak speed of the upward kick during arm recovery, **Min_2:** minimum speed before the first downward kick after the arm entry, **$Peak_2$:** peak speed of the first downward kick after the arm entry, **Min_3:** minimum speed before the arm pull combined with the second upward kick, **$Peak_3$:** peak speed during the arm pull combined with the second upward kick, **Min_4:** minimum speed before the arm push combined with the second downward kick, **$Peak_4$:** peak speed during the arm push combined with the second downward kick, # Spearman correlation coefficient.

FIGURE CAPTIONS

Figure 1. A typical speed curve in butterfly swimming. The eight speed points and their respective stroke positions.

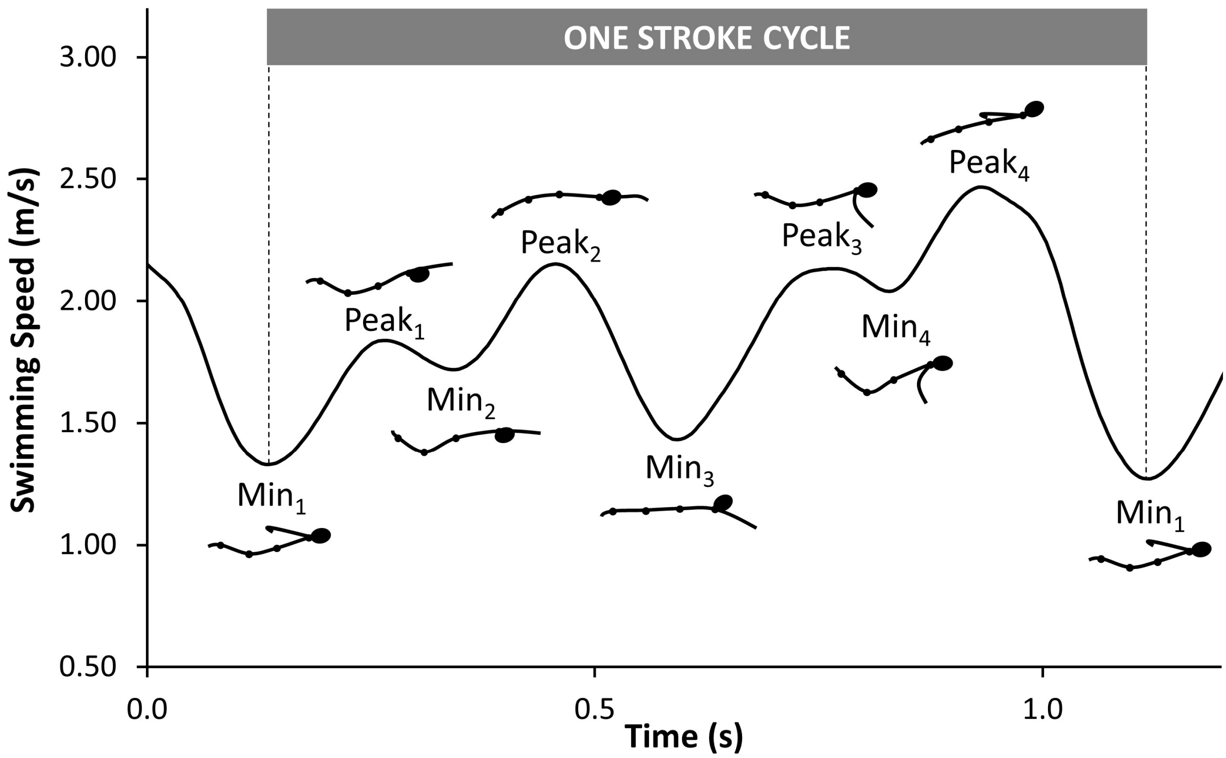

Figure 2. Comparison between the speed points and their respective stroke positions at the beginning (2013, test #3) and end (2018, test #18) of the analysed period. These tests used a trolley and provided a better view of the stroke positions.