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The road to 21 seconds: A case report of a 2016 Olympic swimming sprinter

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Abstract

This study aimed to describe training characteristics as well as physical, technical and morphological changes of an elite Olympic swimming sprinter throughout his road to 21 s in the 50 m freestyle. Over a ~2.5-year period, the following assessments were obtained: external training load, competitive performance, instantaneous swimming speed, tethered force, dry-land maximal dynamic strength in bench press, pull-up and back squat and body composition. From 2014 to 2016, the athlete dropped 3.3% of his initial best time by reducing total swimming time (i.e. the total time minus 15-m start time – from 17.07 s to 16.21 s) and improving the stroke length (from 1.83 m to 2.00 m). Dry-land strength (bench press: 27.3%, pull-up: 9.1% and back squat: 37.5%) and tethered force (impulse: 30.5%) increased. Competitive performance was associated to average ($r = -0.82$, $p = 0.001$) and peak speeds ($r = -0.71$; $p = 0.009$) and to lean body mass ($r = -0.55$; $p = 0.03$), which increased in the first year and remained stable thereafter. External training load presented a polarized pattern in all training seasons. This swimmer reached the sub-22 s mark by reducing total swimming time, which was effected by a longer stroke length. He also considerably improved his dry-land strength and tethered force levels likely due to a combination of neural and morphological adaptations.

Keywords

Biomechanics, performance, sport, strength, tethered swimming, training

Introduction

The 50 m freestyle is the fastest event in competitive swimming and was introduced into the Olympic Games in Seoul 1988, when Matt Biondi set the new World Record with 22.14 s. Two years later, Tom Jager became the first man to swim this event under 22 s (21.98 s) and until December of 2017 a total of only 76 swimmers reached this mark. The ability to swim the 50 m freestyle under 22 s amongst men has become imperative to succeed in international events; therefore, effort has been put into better describing the determinant factors of a successful performance in this race.

Recently, several studies verified the influence of isolated factors on sprint swimming performance, such as race analysis,[1,2] swim kinematics,[3] tethered force,[4] dry-land strength and power,[5–7] training load distribution,[8] body composition[9,10] and inter-arm coordination.[11] To some extent, these findings have provided a stronger basis for planning sprinters' training programs. However, the competitive level of the swimmers tested

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in some of these studies may hinder the application of these experimental findings for elite athletes.[12]

Studies comprising elite swimmers typically present cross-sectional data[13–15] and/or do not focus on the integration of the different aspects of an athlete's preparation. Differently, Slominski and Nowacka[16] described in detail the external training load planned and implemented within a four-year cycle that led one swimmer to European, World and Olympic medals. Similarly, Hellard et al.[8] quantified the external training load of the last 11 weeks leading to the main competitions of 20 seasons (from 1991 to 2012) in 138 elite swimmers, modelled its relationship to swimming performance and provided useful insights for planning sprint, middle-distance and distance training programs.

Indeed, the description and the interpretation of long-term data of elite athletes can help to understand key features of swimming performance. However, to date, there is no study concerning elite sprinters' training load and its effects on sprint performance-related variables, such as swim kinematics, tethered force, dry-land strength and body composition. Considering the small number of swimmers who have been able to swim the 50 m freestyle under 22 s and the lack of documented technical and physical modifications along this way to 21 s, the aim of this study was to describe training characteristics and physical, technical and morphological changes of an elite Olympic sprinter throughout his road to 21 s in 50 m freestyle.

Methods

Participant

The male swimmer in this investigation (age: 25 years, height: 1.80 m, arm span: 1.80 m) has been ranked in the top 50 in the World since 2014 and achieved his best ranking in 2016 (14th) with his first sub-22 s mark (21.82 s, 880 FINA points). He joined our training program in 2014, when his best time was 22.57 s (795 FINA Points) obtained in 2011. He had been involved in systematic training for 10 years and did not present any injuries during the studied period. He provided verbal and written consent to participate in this study and procedures received approval of Campinas State University's Ethics Committee.

Study design

This case study had a retrospective longitudinal observational design and was carried out from January 2014 to September 2016. The following assessments were obtained to monitor the athlete's training responses (Figure 1): external training load, competitive performance, instantaneous swimming speed, tethered force, dry-land maximal dynamic strength and body composition. Due to logistical restrictions in 2016, the second tethered force measure was obtained in February 2017.

External training load

The training load prescribed by the coach was analysed and the in-water training volume was divided into three intended intensity zones[17]: zone 1 – low lactate zone: intensity below the first ventilatory threshold, typically blood lactate below $<2\,\text{mmol}\cdot\text{L}^{-1}$; zone 2 – lactate accommodation zone: from the first to the second ventilatory threshold, typically blood lactate between 2 and $4\,\text{mmol}\cdot\text{L}^{-1}$; and zone 3 – lactate accumulation zone: above the second ventilatory threshold, where blood lactate production exceeds maximum clearance rates, typically blood lactate above $4\,\text{mmol}\cdot\text{L}^{-1}$. The training loads executed during the week of the main competition were not computed. Dry-land strength training load complied with American College of Sports Medicine (ACSM) guidelines[18] (Table 2).

Competitive performance

The competitive performance was evaluated by electronic timing in 50 m freestyle long course official competitions. The first 2014 National Championship was used as baseline (athlete's first major competition after joining our squad) whereas the first, the second and the third 2015 National Championships, the first 2016 National Championship and the 2016 Olympic Games (heats) were used to follow up his competitive performance (Figure 1).

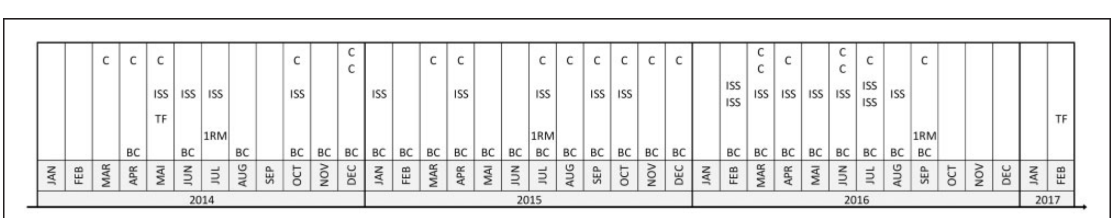

Figure 1. Timeline of experimental procedures.
C: competitive performance; ISS: instantaneous swimming speed; TF: tethered force; 1RM = maximal strength; BC: body composition.

Due to organizational limitations of the competitions, only one camera was used to video record the races. It was placed at the 25 m mark on a tripod and an operator rotated it to follow the swimmer's displacement. The acquisition frequencies were 30 (in 2014, in the first and second 2015 National Championships, and in the 2016 Olympic Games – video provided by the Brazilian biomechanist in Rio 2016) and 60 Hz (in the third 2015 National Championship and in the first 2016 National Championship – cameras were upgraded). Digital lines were superimposed onto the videos at 15, 25 and 35 m on Kinovea (v.0.8.24, Paris, France) using gold-standard references positioned on both sides of the pool.

Start time was considered from the start signal (i.e. the light emitted by the official start system that was visible by the camera) to the instant in which the swimmer crossed the digital line at the 15-m mark.[1] Split times were attained from 0–25 m and 25–50 m, respectively, whereas clean swimming was measured between 15 m and 35 m. The centre of the swimmer's head was the reference for the assessments at 15, 25 and 35 m. Stroke rate was obtained from the time to complete eight cycles, whereas stroke length was calculated as the ratio between swimming speed and stroke rate,[1] both between 15 and 35 m. Stroke count corresponded to the total of strokes performed during the race. Total swimming time was obtained by subtracting the start time from the final time.

The perspective error was accounted in a pilot study which compared this one-camera approach to another with three fixed cameras, positioned at ~10 m (camera 1 = 15 m's view), 25 m (camera 2 = 25 m's view) and ~40 m (camera 3 = 35 m's view). Seven swimmers performed one 50 m maximal swim, so the times at the 15, 25 and 35-m marks could be obtained. Comparison between both methods indicated low typical errors of measurement (15 m = 0.02 s, 25 m = 0.01 s and 35 m = 0.01 s), low coefficient of variations (CVs; 15 m = 0.3%, 25 m = 0.1% and 35 m = 0.2%) and very high intra-class correlation coefficients (ICCs; 15 m = 0.95, confidence interval (CI) 95% = 0.70–0.99, $F = 39.796$, $p = 0.0002$; 25 m = 0.99, CI 95% = 0.93–1.00, $F = 191.414$, $p < 0.0001$; 35 m = 0.96, CI 95% = 0.77–0.99, $F = 54.407$, $p = 0.0001$).

In a second experiment, we also estimated the intra-examiner reliability of the one-camera approach, which was considered excellent for start (0–15 m: typical error of measurement = 0.01 s, CV = 0.2%, ICC = 0.94, CI 95% = 0.71–0.99, $F = 34.480$, $p = 0.0001$), split (0–25 m: typical error of measurement = 0.01 s, CV = 0.1%, ICC: 0.99, CI 95% = 0.94–1.00, $F = 174.323$, $p < 0.0001$ and 25–50 m: typical error of measurement = 0.01 s, CV = 0.1%, ICC = 1.00, CI 95% = 0.98–1.00, $F = 496.935$, $p < 0.0001$) and clean swimming times (15–35 m: typical error of measurement = 0.03 s, CV = 0.3%; ICC = 0.95, CI 95% = 0.76–0.99, $F = 43.970$, $p < 0.0001$).

Instantaneous swimming speed

Instantaneous speed was measured (Figure 1) with a speedometer[19] (CEFISE, Nova Odessa, Brazil) attached to the swimmer's hips during one push-off 20–25 m maximal sprint with breath held and self-selected stroke rate. An analogic underwater camera attached to a monopod recorded the trial from the 15-m mark (the operator rotated it to follow the swimmer's displacement). A custom-designed software received and synchronized both filtered speed (50–240 Hz – system's sampling capacity was improved over time) and video data (30 Hz). Video and speed data were synchronized by interpolation.

The first two strokes after the break-out were discarded to attenuate push off effects. Main points (Figure 2) were obtained in six consecutive complete cycles (i.e. the interval between two successive lowest points in the velocity–time curve) for the assessment of peak speed (the highest speed value between two consecutive minimum speed values, CV = 0.42%), minimum speed (the minimum speed value found immediately after hand's entry in the water – CV = 0.14%) and average speed (the average of all speed values within a cycle – CV = 0.03%). The average of six cycles of each variable was retained for analysis. Results from the tests that occurred within three weeks of any competition were used for correlation analysis.

Tethered force

A fully tethered swimming system (200 Hz; CEFISE, Nova Odessa, Brazil) evaluated the tethered force on June 2014 and February 2017 (Figure 1). The test consisted of a 10-s maximal swimming with breath held and self-selected stroke rate. All testing procedures complied with previous investigation.[20] Peak force (CV = 3.4%), average force (CV = 8.4%), impulse (CV = 0.2%), rate of force development (RFD, CV = 2.6%) and stroke duration (CV = 8.9%) were assessed during cycles (i.e. the interval between two successive lowest points in the force-time curve), as used previously.[20] Main points used for analysis are shown in Figure 3. Variables from the trial with the highest impulse were retained for analysis.

Dry-land maximal dynamic strength

Absolute maximal dynamic strength was assessed with 1RM for pull-up, bench press and back squat in the same testing session, interspaced by 10 min. All these

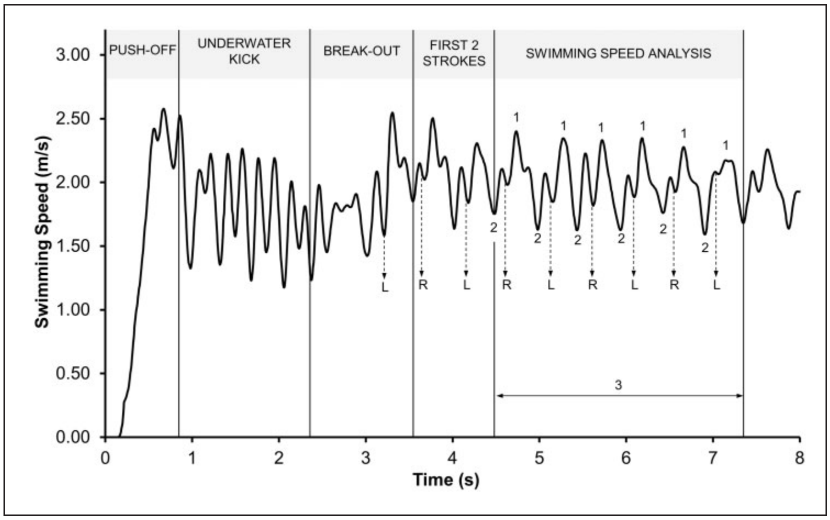

Figure 2. Typical speed–time curve. 1: peak speed points; 2: minimum speed points; 3: average speed range; L: entry of left hand in the water; R: entry of right hand in the water.

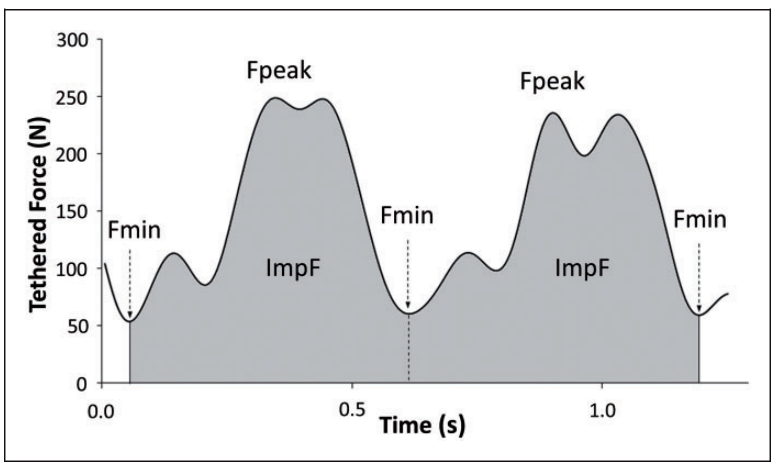

Figure 3. Example of two consecutive cycles of front-crawl force-time curve and the main points used for analysis. Fpeak: peak force; ImpF: Impulse; Fmin: minimum force.

exercises were mentioned in previous investigations, as reported by a recent review about resistance training in swimming.[21] Relative maximal dynamic strength was obtained by dividing the total load lifted by the swimmer's body mass. After a standard warm-up performed prior to each exercise (eight repetitions with 60% 1RM + four repetitions with 80% 1RM with 3 min of rest), the athlete performed up to five attempts with 3 min of rest. The load was progressively increased until a failed attempt terminated the test. Tests were performed once a year: (1) July 2014, (2) July 2015 and (3) September 2016 (Figure 1). In 2016, the staff decided to test the athlete in September (i.e. after the Olympic Games) because he spent a relative long time competing in Europe in June, when the training schedule and loads had to be adjusted. So, July was strategic for improving his strength and conditioning towards the Olympic Games.

Body composition

Body composition was measured (Figure 1) by the same researcher in the mornings. Body mass was obtained using an electronic scale (Toledo, Model 2096-PP, Sao Paulo, Brazil). Seven-site skinfolds (chest, abdominal, thigh, triceps, sub-scapular, supra iliac and mid axillary) were measured with a plicometer (Lange, *Cambridge Scientific Instruments*, Cambridge, MD) following ACSM's[22] guidelines. Test–retest ICC of all skinfolds exceeded 0.90. Afterwards, body density[23] and fat percentage[24] were estimated. Lean body mass (LBM) was determined by subtracting absolute body

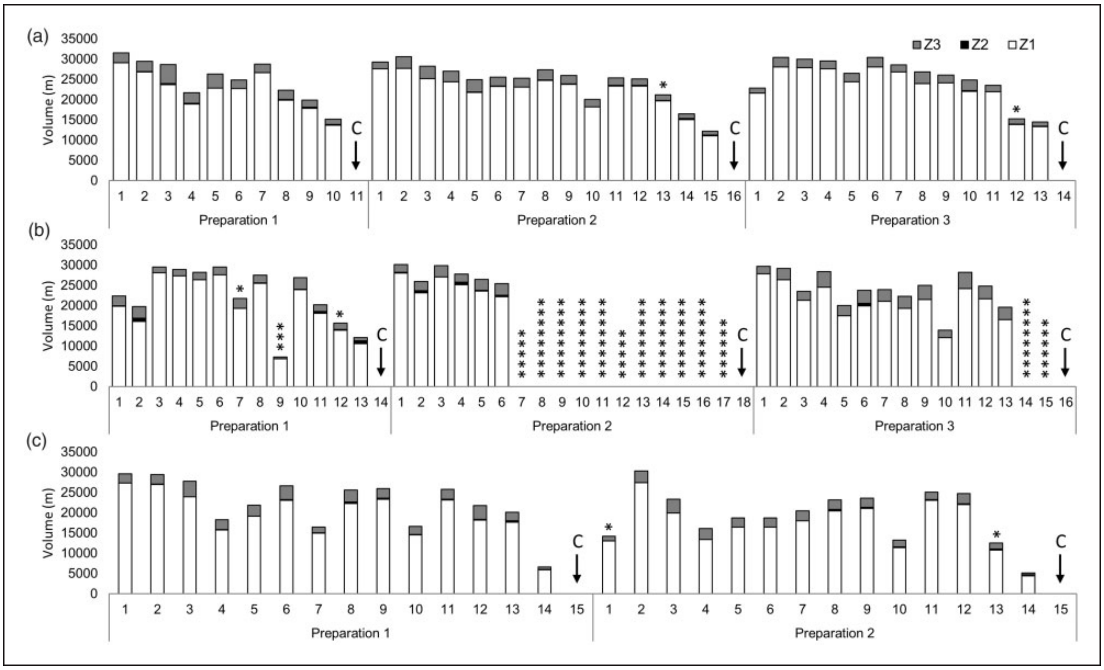

Figure 4. Weekly volume in Z1, Z2 and Z3 in (a) 2014, (b) 2015 and (c) 2016.
C: main competition; *Number of unquantified sessions.

fat from total body mass. The swimmer received nutritional guidance throughout the study period and the whole process was regularly monitored and adjusted by a certified nutritionist. However, dietary intake was not registered.

Statistical analysis

Absolute data and percent changes were used to present time effects. Shapiro-Wilk was used to test data normality. The relationship between competitive performance and body composition variables was assessed through Pearson coefficient correlation, interpreted as: 0 to 0.30 = small, 0.31 to 0.49 = moderate, 0.50 to 0.69 = large, 0.70 to 0.89 = very large and 0.90 to 1.00 = nearly perfect.[25] Regression analyses were performed between competitive performance and peak, minimum and average swimming speed. Significance level was set at $p < 0.05$. Analyses were conducted using SPSS for Windows (Version 16.0).

Results

External training load

The years were divided into 2 (2016) or 3 preparations (2014 and 2015), according to Brazilian's main competitions. The preparations ranged from 10 to 17 weeks (13.9 ± 2.0 weeks). The regular weekly training routine comprised 8 to 11 sessions, which consisted of 6 to 8 in-water (40–120 min) and 2 to 3 dry-land sessions (30–120 min). The external training load of 715 in-water training sessions out of 818 performed by the swimmer (i.e. 87.4%; 289 in 2014, 232 in 2015 and 194 in 2016) was quantified (Table 1 and Figure 4). Due to technical problems, some training sessions did not get registered, especially in the second preparation of 2015 (Table 1 and Figure 4). In general, the average session volume was 3272 ± 773 m, in which Z1, Z2 and Z3 corresponded to 89.7 ± 2.9%, 0.6 ± 1.0% and 9.7 ± 2.8%, respectively. Weekly volumes in Z1, Z2 and Z3 are shown in Figure 4.

A typical dry-land cycle lasted 15 weeks (Table 2) and was divided into three mesocycles plus two weeks of taper. All sessions were supervised by a strength and conditioning professional to ensure appropriate technique and loads.

Competitive performance

The swimmer raced the 50 m freestyle 21 times during the study (Figure 5), obtained four personal bests (−1.4%, −0.5%, −0.3% and −1.2%, respectively) and dropped 3.3% of his initial best time, from 22.57 s to 21.82 s. After approximately 2.5 years of training, he first swam under 22 s in Olympic trials (April 2016, 21.82 s), and again in the heats of the Olympic Games (August 2016, 21.96 s). Results from race analysis in 2014, 2015 and 2016 are shown in Table 3.

Table 1. Weekly volume and training intensity distribution of each preparation analyzed.

Year	Preparation (duration)	Sessions P/Q	Volume (m/wk)	Z1		Z2		Z3	
				m/wk	%	m/wk	%	m/wk	%
2014	1 (10 wks)	77/77	24,704 ± 5463	22,109 ± 5022	89.5 ± 3.1%	95 ± 96	0.4 ± 0.4%	2500 ± 964	10.1 ± 2.9%
	2 (15 wks)	114/113	24,339 ± 4917	22,185 ± 4499	91.2 ± 1.6%	80 ± 77	0.4 ± 0.5%	2073 ± 652	8.4 ± 1.7%
	3 (13 wks)	100/99	25,344 ± 5281	23,393 ± 4951	92.2 ± 1.8%	31 ± 63	0.2 ± 0.3%	1921 ± 564	7.6 ± 1.6%
2015	1 (13 wks)	96/91	22,298 ± 7167	20,283 ± 6958	90.6 ± 3.8%	188 ± 282	1.1 ± 1.9%	1826 ± 736	8.3 ± 2.9%
	2 (17 wks)	126/46	27,608 ± 2015	24,875 ± 2325	90.0 ± 2.0%	300 ± 224	1.1 ± 0.8%	2433 ± 415	8.9 ± 1.8%
	3 (15 wks)	109/95	24,032 ± 4454	21,092 ± 4237	87.6 ± 2.8%	46 ± 166	0.2 ± 0.7%	2894 ± 698	12.2 ± 2.6%
2016	1 (14 wks)	100/100	22,489 ± 5966	19,893 ± 5434	88.4 ± 2.5%	143 ± 122	0.7 ± 0.6%	2453 ± 821	10.9 ± 2.5%
	2 (14 wks)	96/94	21,317 ± 6890	18,795 ± 6176	88.0 ± 2.2%	129 ± 138	0.9 ± 1.2%	2393 ± 951	11.1 ± 2.5%

P: prescribed sessions; Q: quantified sessions.

Table 2. Description of the dry-land strength training.

Mesocycle	Objective	Training load
I (2–4 weeks)	Morphological adaptation	3 sets x 10-8RM with 60 s rest and slow velocity (1s concentric / 3s eccentric) Exercises: 5 per session comprising chest, shoulder, legs, back (2x). Example: dumbbell bench press, shoulder press, back squat, low pulley row, pull up.
II (4–6 weeks)	a) Maximal strength and power	a) 3-4 sets x 6RM + 4(first 2 weeks); 3-4 sets x 3(1RM*) + 4-10 Movement velocity on the first part was slow due to the high resistance. Athlete was instructed to try to move the weight as fast as possible though. Rest: 120-180 s. †Power exercises: low resistance and high velocity, executed at the end of each set. *Assisted repetitions: the strength coach provided help or resistance to keep movement velocity constant and slow (duration: ~5s per repetition), ensuring maximal voluntary muscle actions in each repetition (i.e. considering the force-length curve of each exercise). Exercises: 5 per session comprising chest, shoulder, legs and back (2x). Examples: bar bench press + push up, leg press + box jump, hang clean, pull up + pulley pull down, medicine ball throws (e.g. shoulder extension, shoulder horizontal adduction, shoulder abduction).
	b) Power (strength endurance)	b) 3 circuits, each with 5 exercises, 3 sets x 6-10, all with high concentric velocity, Rest: 30-60 s. All exercises in the circuit were done in sequence; thus the rest was only after all repetitions of each exercise was performed. Rest between circuits was 3 minutes. Circuit example: pulley pullover (shoulder extension) + pull up + burpees + medicine ball (shoulder extension) throw + pulley pull down (shoulder extension + scapula adduction/downward rotation).
III (3 weeks)	Maintenance	Usually one session of each mesocycle per week. Session choice was based on the athlete's body composition, fatigue level, in-water performance and psychological factors. When mesocycle 1: modified to 3 sets of 6RM. When mesocycle 2: a or b.
IV (2 weeks)	Taper	First week: 2 short sessions (~30 minutes) 72 hours apart. 4 exercises in each session. 2 sets x 6-12 (low resistance, high velocity). Rest: 120 s rest. Exercise examples: unilateral or bilateral box jump, medicine ball throws (e.g. shoulder extension, shoulder horizontal adduction, shoulder abduction), push-ups, pulley pull down, pull-ups.

Note: In all mesocycles there were 2 strength sessions (2 sessions/week, ~90-120 minutes, interspaced by 72 hours) and a third session focusing on trunk strength and preventative/postural exercises (1 session with 30-60 minutes, each with 2-3 sets of 6-10 repetitions and 60-90s of rest, 6 exercises, e.g., shoulder internal and external rotation, trunk extension and flexion - isometric and dynamic, hip flexion, scapula posterior tilt and planks).

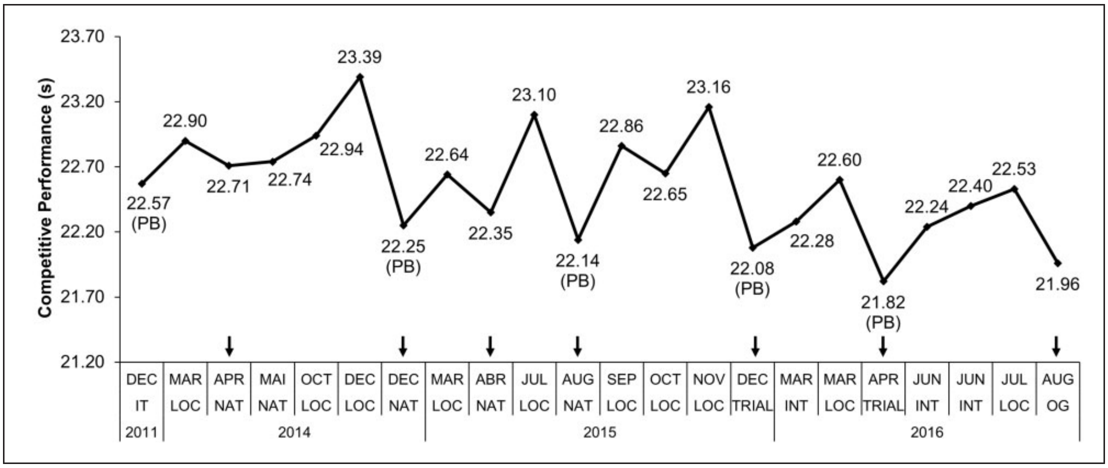

Figure 5. Competitive performance in 50 m freestyle.
IT: initial best time; PB: personal best; LOC: local event; NAT: national event; TRIAL: Brazilian Olympic Trial; INT: international event; OG: Olympic Games. Arrows indicate the main competitions.

Table 3. Comparison between race analysis in 2014, 2015 and 2016 and percent changes from April 2014 to April 2016.

	APR 2014	APR 2015	AUG 2015	DEC 2015	APR 2016	SEP 2016	% 2014 vs. 2016
Official time (s)	22.71	22.35	22.14	22.08	21.82	21.96	−3.9%
Start time 0–15 m (s)	5.64	5.81	5.60	5.65	5.61	5.64	−0.5%
Split times (s)							
0–25 m	10.37	10.51	10.16	10.27	10.10	10.14	−2.6%
25–50 m	12.34	11.84	11.98	11.81	11.72	11.82	−5.0%
Total swimming time (s)	17.07	16.54	16.54	16.43	16.21	16.32	−5.0%
Clean swimming time (s)	9.64	9.40	9.24	9.31	9.09	9.17	−5.7%
Stroke rate (c/min)	67.9	64.3	65.7	65.9	66.1	66.6	−2.6%
Stroke length (m)	1.83	1.99	1.98	1.95	2.00	1.97	+8.9%
Stroke count (n)	42	38	39	40	39	39	−7.1%

Table 4. Matching competitive performance (CP), average (ASS), minimum (MSS) and peak (PSS) swimming speeds in all testing sessions.

Year	2014						2015			2016								
Month	May	Jun	Jul	Oct	Jan	Apr	Jul	Sep	Oct	Feb	Feb[a]	Mar	Apr	May	Jun	Jul	Jul	Aug[a]
CP (s)	22.74	–	–	22.94	–	–	23.10	22.86	22.65	22.28	–	22.60	21.82	22.24	22.40	22.53	–	21.96
ASS (m/s)	1.90	1.94	1.85	1.87	1.90	1.88	1.91	1.87	1.89	1.92	1.92	1.93	2.01	1.93	1.98	1.97	2.04	2.03
MSS (m/s)	1.61	1.70	1.60	1.50	1.53	1.56	1.65	1.56	1.63	1.64	1.67	1.56	1.66	1.53	1.60	1.54	1.64	1.60
PSS (m/s)	2.15	2.21	2.11	2.19	2.20	2.13	2.23	2.22	2.21	2.27	2.25	2.29	2.31	2.27	2.32	2.28	2.38	2.32

[a]Swimmer stopped before completing six strokes, so only four were considered.

Instantaneous swimming speed

Data from all 18 assessments performed over the study period are shown in Table 4. The swimmer used regular trunks in the first 13 assessments and a competition suit in the last 5. This may have influenced his speed and is assumed as a limitation. Twelve speed tests were performed close to competitions and were used for

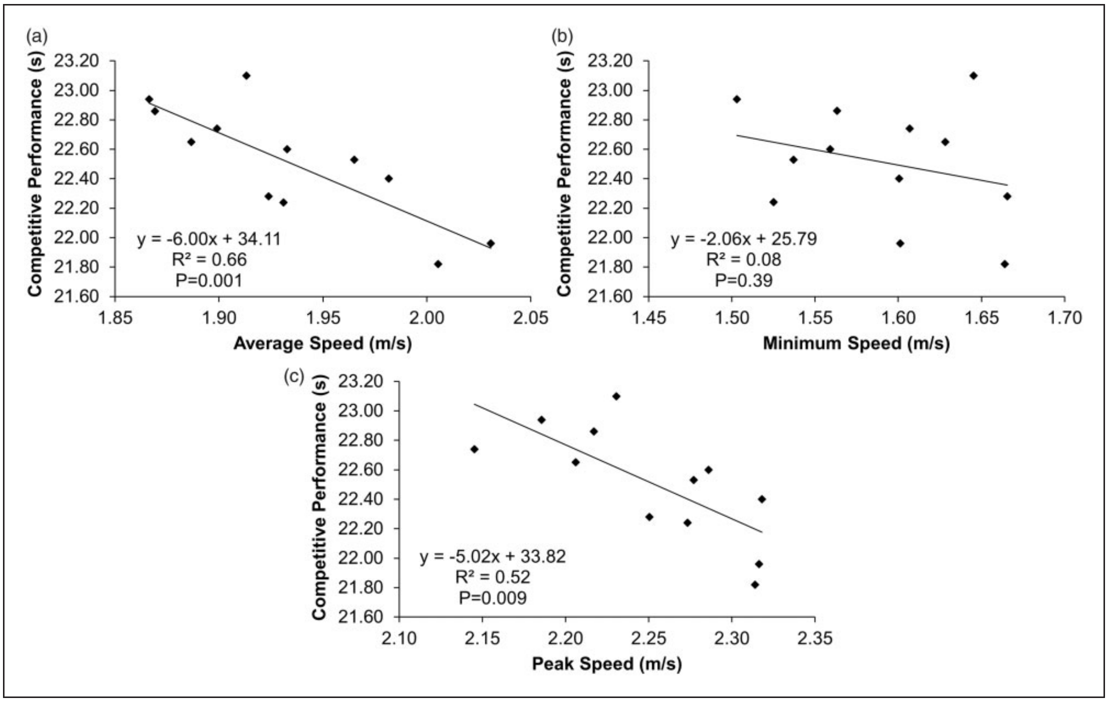

Figure 6. Regression analyses between competitive performance and (a) average, (b) minimum and (c) peak speeds.

regression analysis (Figure 6). Very large correlations were found between competitive performance and speedometer average (r = −0.82, CI 95%: −0.95/−0.46; p = 0.001) and peak speeds (r = −0.71; CI 95%: −0.91/−0.23; p = 0.009), whereas no relationship was detected for minimum speed (r = −0.28; CI 95%: −0.73/0.35; p = 0.39).

Tethered force

Results concerning tethered force are shown in Table 5. All tethered swimming test variables considerably increased from 2014 to 2017, indicating that the training was effective for improving specific strength.

Dry-land maximal dynamic strength

Absolute maximal strength increased in all exercises (Figure 7(a)). From 2014 to 2015, the percent changes were 2.8% for pull-up, 6.4% for bench press and 8.3% for back squat. Improvements from 2015 to 2016 were 6.2%, 19.7% and 26.9%, for pull-up, bench-press and back squat, respectively, greater than those from 2014 to 2015. The same pattern was observed for relative strength (Figure 7(b)) which increased 0.5% for pull-up, 4.0% for bench press and 5.9% for back squat from 2014 to 2015, and 5.1%, 18.4% and 25.6% from 2015 to 2016, respectively.

Table 5. Tethered force variables.

	Jun 2014	Feb 2017	Δ%
Peak force (N)	211.1	245.9	+16.5%
Average force (N)	133.7	149.2	+11.6%
RFD (N/s)	611.9	711.0	+16.2%
Duration (ms)	463	552	+19.2%
Impulse (N·s)	62.4	81.5	+30.6%

RFD: rate of force development.

Body composition

Body composition data are shown in Figure 8. The CV for body mass, % fat, LBM and fat mass (considering all measurements throughout the study period) were 1.1%, 12.8%, 1.5% and 13.2%, respectively. When the swimmer reached the sub-22 s mark (i.e. April and August 2016), his body mass, % fat, LBM, fat mass values were 77.0 and 77.3 kg, 8.4 and 7.1%, 70.5 and 71.8 kg and 6.5 and 5.5 kg, respectively. Fifteen measures matched competitions dates (Figure 8) and were used for correlation analysis. LBM correlated moderately to competitive performance (r = −0.55; CI 95% = −0.83/−0.06; p = 0.03), whereas no relationship was detected for the other body composition variables.

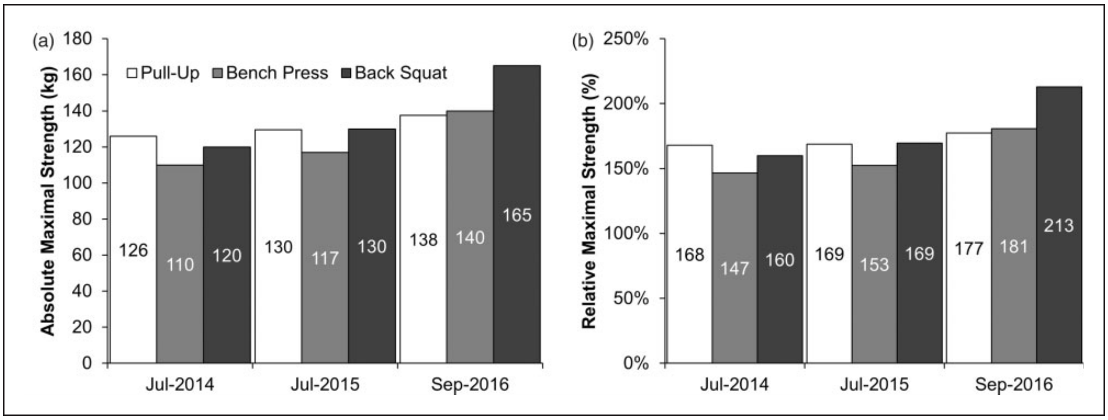

Figure 7. Progression of maximal absolute and relative strength in all three exercises.

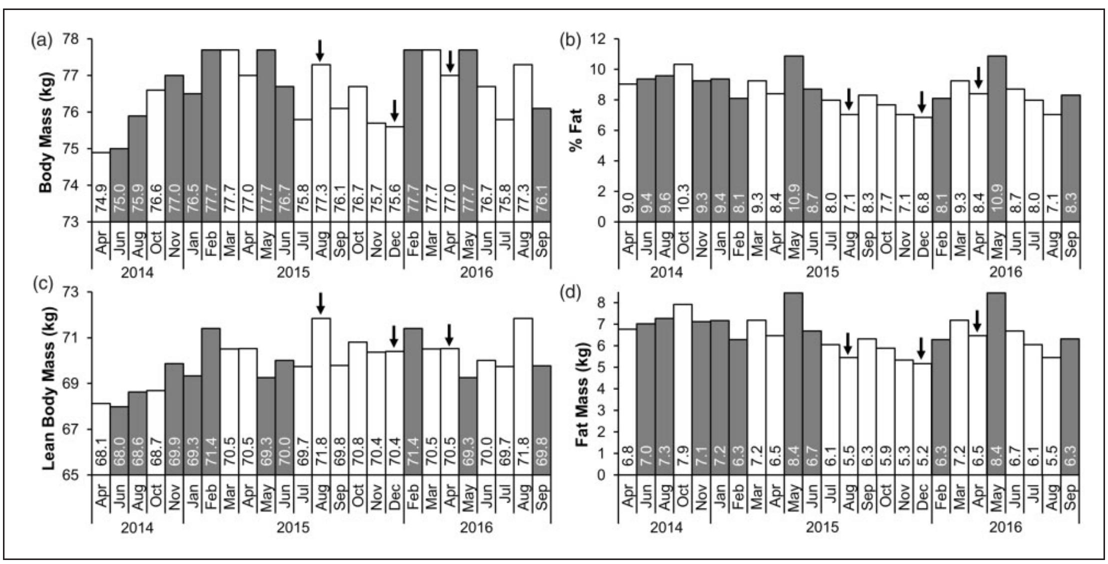

Figure 8. Body mass (a), % fat (b), lean body mass (c) and fat mass (d). White bars indicate assessments in both body composition and competitive performance. Arrow points correspond to athlete's personal best times.

Discussion

Elite athletes' data are seldom published for several reasons including the time-consuming task of paper writing and submission, the gap between researchers and practitioners and/or the team's policy of maintaining data secret for competitive reasons. This is the first study to describe training characteristics and long-term changes in physical and technical variables of an elite 50 m freestyle swimmer, and our main findings were as follows: (1) the external training load presented a polarized distribution in all training cycles; (2) competitive performance improved mainly by reducing total swimming time; (3) clean swimming time (15–35 m) improved due to a longer stroke length; (4) dry-land strength and tethered force considerably increased; (5) competitive performance correlated with average and peak speed during testing and (6) LBM increased in the first year, remained stable thereafter and was inversely correlated to competitive performance.

The sprinter's training was mostly performed in Z1 (89.7%), followed by Z3 (9.7%), and very little in Z2 (0.6%), which is similar to the polarized intensity distribution model. The polarized model consists of significant proportions of training at both high (15%–20%) and low intensities (75%–80%), and only a small proportion of threshold training (5%–10%).[26,27] This pattern has been utilized by coaches from different sports as a way to benefit from high intensity training effects without using high volumes, which could lead to overreaching or overtraining.[28] Although it is unclear whether there is an optimal training load distribution for swimming sprinters, we observed that this pattern succeeded in improving athlete's performance herein. Nevertheless, the current "90-0.5-9.5" distribution across the three zones is considerably different from those verified earlier for high-trained endurance athletes (e.g. "75-5-20"[17] and "80-0-20"[27]) and for 100- and 200-m elite swimmers ("77-12-11"[29]), indicating that distribution across the three zones should be adjusted according to athletes' competitive requirements.

It is also interesting that the ~9.5% of the volume performed in the high-intensity zone is ~10% lower than that reported previously.[17] Considering that during the 50-m race a large amount of energy is rapidly required (anaerobic contribution estimated at 96%: ATP-PCr = 38% and glycolytic = 58%),[30] an increase in zone 3 volume could be expected to further develop the metabolic and neuromuscular mechanisms involved in this task. However, the short duration of the race also prevents the occurrence of high level of acidosis,[30] so in order to succeed the swimmer should be able to generate and maintain the highest speed level as possible. Such characteristic is different from endurance sports[17,27] in which a relatively high intensity (not maximum) should be maintained during long distances and thus could explain the difference between the "90-0.5-9.5" and the typical "75-5-20" polarized patterns. Therefore, we suggest that the current balance between zone 1 and zone 3 may allow swimmers to reach competitive speed more frequently in training without getting chronically fatigued throughout the season and improve long-term adaptations by enhancing training specificity.

The athlete obtained four personal best performances and dropped 3.3% of his initial best time (22.57 s) during the study period. Despite reaching the sub-22 s mark in Rio 2016, he was slower compared to the Olympic trials (21.96 s vs. 21.82 s). Although both cycles presented similar training intensity distributions, weekly volume was lower in the preparation immediately before the Olympics (~22 km vs. ~21 km), especially in Z3 (~60 m per week). The reduction of 60 m per week over 14 weeks equals 840 m, which represent 1/3 of the volume performed in a week. This volume also corresponds to 2.5% of the total volume swam in Z3. Although we cannot be sure about this volume's effect, we believe it may be relevant and may have influenced his performance as this intensity is more specific for 50 m race. Accordingly, Hellard et al.[8] showed that an increase in high intensity training load is important for 50-m sprinters' performance in the last 10 weeks prior the main competition. In addition, it also likely that psychosocial pressure of competing at home during the Olympics Games may have impacted his performance, especially in the semi-finals, when there may have been a greater public expectation.

Race analysis revealed that performance enhancement occurred mainly due to a progressive reduction in total swimming time over time (17.07 s in 2014 vs. 16.21 s in 2016), which reached 5.0% in 2016. Swimming speed is the combination of stroke rate and stroke length, and despite a 2.6% decrease in stroke rate, stroke length increased 8.9% at the end. These results are in accordance with previous findings that faster swimmers achieve greater distances per stroke.[31] Additionally, such increase in stroke length was likely related to his increased ability to produce force in the tethered swim test. The greater impulse observed in 2017 was a consequence of increased peak force, RFD and stroke duration. We acknowledge that the second tethered swimming test was considerably far from the athlete's best competitive performance and that these variables may change over time, but we consider conceivable that increased tethered force contributed to performance enhancement as it has been shown to be sensitive to identify training-induced adaptations in swimming.[32]

Tethered swimming performance depends on the force applied to the water, which is influenced by both technique and the neuromuscular ability to produce strength, assessed herein through 1RM test. Increases in maximal strength were detected for all exercises and likely had an impact on both tethered force and stroke length. Interestingly, changes in maximal strength of back squat and bench press were larger than the improvements of tethered force variables, whereas the pull-up maximal strength modification was slightly lower. Force transference is still a challenging topic in sports, even more in swimming due to the great influence of technique on force application. It is becoming clear though that factors such as body position, type of muscle action and pattern of neural activation utilized in training affect transference to specific motor tasks,[33] such as arm stroke and leg kicking. Although it is not possible to determine the contribution of strength gains in each exercise to the increase in tethered force variables, it is conceivable higher transference from pull-up due to its kinesiologic similarity to the arm stroke. Accordingly, Perez-Olea et al.[7] verified strong correlations between 50 m freestyle performance and different mechanical variables of the pull-up in both 1RM and maximum number of repetition tests.

Regarding strength gains, they possibly resulted from a combination of morphological and neural adaptations. Although a direct measure of muscle morphology was not available (e.g. cross-sectional area and/or pennation angle), hypertrophy may be inferred by the ~2 kg increase in LBM from 2014 to 2015. Changes in muscle mass may not be directly related to strength gains,[34] but may allow greater strength production after a period of training to induce neural changes.[35]

Accordingly, all maximal strength levels kept increasing from 2015 to 2016 despite no relevant changes in LBM.

Interestingly, the strength gains were greater from 2015 to 2016 than from 2014 to 2015. Although dry-land training was designed to improve strength and power in all cycles, it progressed carefully at the beginning to avoid injuries. Over time, training intensity was further increased and led to this greater strength improvement from 2015 to 2016.

LBM moderately correlated with competitive performance, suggesting that its increase may lead to a lower time in competition. This seems reasonable since increased LBM is attained mainly by augmenting muscle mass, which is responsible for producing strength and power. However, this result should be carefully interpreted as LBM increased in the first year and remained relatively stable thereafter, whereas competitive performance continued improving. Additionally, there was a considerable variation of competitive performance (from 23.2 s to 21.8 s) for similar LBM values (~70.5 kg).

Body mass varied slightly over time. The difference between the highest and the lowest values is ~5% and the CV was 1.1%, indicating that it remained stable during both preparatory and competitive periods, and that the swimmer trained and competed in very similar conditions. Of note, his top five competitive performances were obtained with %fat around 8% (8.4%, 7.1%, 6.8%, 7.1% and 8.7%). Keeping body fat within certain limits is important as it enlarges body surface and may ultimately increase drag and reduce swimming speed.[36] Moreover, fat mass always increased after main competitions possibly due to a week off from training for recovery to the next preparation.

Data also revealed that speedometer average and peak speeds can predict competitive performance. Peak speed is attained when propulsion is greater than drag at the maximum level within an arm-stroke. Therefore, to swim faster, one should find the best body position throughout the stroke cycle (i.e. drag reduction) and increase the ability to produce power (i.e. neuromuscular capacity and technique). Our results are reasonable as this swimmer improved performance mainly by reducing total swimming time (−0.86 s) with a smaller change in start time (−0.03 s). The athlete reached the sub-22 s mark when peak speed reached ~2.30 m/s, suggesting that swimmers should attempt to approximate or be better than this "threshold." Conversely, minimum speed is reached at the end of entry phase (i.e. the beginning of hand's backward movement)[11] and lower values are likely associated to non-favourable body and/or arm positions that may increase drag and/or propulsive discontinuity. Although minimum speed may differentiate regular and elite sprinters, it seems to not have major influence on the current swimmer's average speed or competitive performance. Future studies on elite-level swimmers are encouraged to investigate whether such rationale is individual-specific or can be applied to this population.

As much as these speed parameters may provide world-class references, the data presented herein were attained under rested conditions and may better represent the first half of the race, whereas the 50 m performance also depends on the second 25-m split. For instance, the current swimmer had a greater time improvement in the second half of the race (−5.0%) compared to the first one (−2.6%). Therefore, the swimmer should be able to achieve such minimum and/or maximum values references and also keep them in great levels under a more fatigued condition.

Finally, this study has inherent limitations of case study designs. As only one swimmer was analysed, conclusions may vary according to individual's strong and weak physical and technical characteristics. Although his competitive performance improved mainly due to reduced total swimming time, other swimmers may improve more by improving their starts, as it corresponds to 30% of the total race distance. We also acknowledge that more assessments of maximal strength, tethered force and race analysis would provide a better understanding of the mechanisms underlying his road to 21 s. Additionally, internal training load was not analysed and could have provided more information about physiological effects of training.[37] Nevertheless, our results can be useful and revealing since average data are not always capable of explaining elite "outlier" performances.

Practical applications

This study has important practical applications as it provides long-term training, testing and competitive data of a world-class 50 m freestyle swimmer. Data reported herein may be used as reference for setting training characteristics as well as physical and technical goals for teams and/or individuals. Additionally, this study not only highlights the usefulness of simple, inexpensive and practical assessments such as anthropometry and maximal strength for monitoring elite athletes' progression but also points to the important role of technology (e.g. speedometer, tethered swimming and video analysis) on providing access to more complex variables required within high-performance sports context.

In line with previous studies on swimming biomechanics, our data also highlight the importance of increasing stroke length to improve swimming performance, which was likely achieved through an increased ability to produce dry-land and in-water force levels.

Our results also suggest that reaching adequate levels of LBM is important, especially within competitive periods, as this variable may influence both drag and propulsive force. Hence, such multifactorial and complex nature of 50 m swimming performance should be taken into account by the coaching staff when planning individual athlete's training and testing programs.

Conclusions

This swimmer reached the sub-22 s mark mainly by reducing total swimming time, which was effected by a longer stroke length. He also considerably improved his dry-land strength and in-water tethered force levels, likely due to a combination of neural and morphological adaptations.

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References

1. Morais JE, Marinho DA, Arellano R, et al. Start and turn performances of elite sprinters at the 2016 European Championships in swimming. *Sports Biomech* 2018; 1–15. Epub ahead of print 26 March 2018. DOI: 10.1080/14763141.2018.1435713.
2. Veiga S, Roig A and Gomez-Ruano MA. Do faster swimmers spend longer underwater than slower swimmers at World Championships? *Eur J Sports Sci* 2016; 16: 919–926.
3. Craig AB Jr, Skehan PL, Pawelczyk JA, et al. Velocity, stroke rate and distance per stroke during elite swimming competition. *Med Sci Sports Exerc* 1985; 17: 625–634.
4. Morouco P, Keskinen KL, Vilas-Boas JP, et al. Relationship between tethered forces and the four swimming techniques performance. *J Appl Biomech* 2011; 27: 161–169.
5. Loturco I, Barbosa AC, Nocentini RK, et al. A correlational analysis of tethered swimming, swim sprint performance and dry-land power assessments. *Int J Sports Med* 2016; 37: 211–218.
6. Morouco P, Neiva H, Gonzalez-Badillo JJ, et al. Associations between dry land strength and power measurements with swimming performance in elite athletes: a pilot study. *J Hum Kinet* 2011; 29A: 105–112.
7. Perez-Olea JI, Valenzuela PL, Aponte C, et al. Relationship between dryland strength and swimming performance: pull-up mechanics as a predictor of swimming speed. *J Strength Cond Res* 2018; 32: 1637–1642.
8. Hellard P, Scordia C, Avalos M, et al. Modelling of optimal training load patterns during the 11 weeks preceding major competition in elite swimmers. *Appl Physiol Nutr Metab* 2017; 42: 1106–1117.
9. Strzala M, Stanula A, Krezalek P, et al. Influence of morphology and strength on front crawl swimming speed in junior and youth age group swimmers. *J Strength Cond Res*, Epub ahead of print 8 July 2017. DOI: 10.1519/JSC.0000000000002084.
10. Lowensteyn I, Signorile JF and Glitz K. The effect of varying body composition on swimming performance. *J Strength Cond Res* 1994; 8: 149–154.
11. Chollet D, Chalies S and Chatard JC. A new index of coordination for the crawl: description and usefulness. *Int J Sports Med* 2000; 21: 54–59.
12. Pyne DB, Lee H and Swanwick KM. Monitoring the lactate threshold in world-ranked swimmers. *Med Sci Sports Exerc* 2001; 33: 291–297.
13. Olstad BH, Zinner C, Vaz JR, et al. Muscle activation in world-champion, world-class, and national breaststroke swimmers. *Int J Sports Physiol Perform* 2017; 12: 538–547.
14. Toussaint HM and Truijens M. Power requirements for swimming a world-record 50-m front crawl. *Int J Sports Physiol Perform* 2006; 1: 61–64.
15. Seifert L, Vantorre J and Chollet D. Biomechanical analysis of the breaststroke start. *Int J Sports Med* 2007; 28: 970–976.
16. Slominski P and Nowacka A. The structure and volume of training loads in the four-year training cycle of an elite olympic athlete. *Pol J Sport Tourism* 2017; 24: 162–169.
17. Seiler KS and Kjerland GO. Quantifying training intensity distribution in elite endurance athletes: is there evidence for an "optimal" distribution? *Scand J Med Sci Sports* 2006; 16: 49–56.
18. Garber CE, Blissmer B, Deschenes MR, et al. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Med Sci Sports Exerc* 2011; 43: 1334–1359.
19. Barbosa TM, Morouco PG, Jesus S, et al. The interaction between intra-cyclic variation of the velocity and mean swimming velocity in young competitive swimmers. *Int J Sports Med* 2013; 34: 123–130.
20. Barbosa AC, Barroso R and Andries O Jr. Post-activation potentiation in propulsive force after specific swimming strength training. *Int J Sports Med* 2016; 37: 313–317.

21. Crowley E, Harrison AJ and Lyons M. The impact of resistance training on swimming performance: a systematic review. *Sports Med* 2017; 47: 2285–2307.
22. American College of Sports Medicine. *ACSM's guidelines for exercise testing and prescription*, 8th ed. Philadelphia: Lippincott Williams & Wilkins, 2009, p.366.
23. Jackson AS and Pollock ML. Prediction accuracy of body density, lean body weight, and total body volume equations. *Med Sci Sports* 1977; 9: 197–201.
24. Siri WE. Body composition from fluid spaces and density. In: Brozek J and Henschel A (eds) *Techniques for measuring body composition*. Washington: National Academy of Science, 1961, pp.223–244.
25. Hopkins WG, Marshall SW, Batterham AM, et al. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 2009; 41: 3–13.
26. Stoggl T and Sperlich B. Polarized training has greater impact on key endurance variables than threshold, high intensity, or high volume training. *Front Physiol* 2014; 5: 33.
27. Neal CM, Hunter AM, Brennan L, et al. Six weeks of a polarized training-intensity distribution leads to greater physiological and performance adaptations than a threshold model in trained cyclists. *J Appl Physiol (1985)* 2013; 114: 461–471.
28. Hydren JR and Cohen BS. Current scientific evidence for a polarized cardiovascular endurance training model. *J Strength Cond Res* 2015; 29: 3523–3530.
29. Mujika I, Chatard JC, Busso T, et al. Effects of training on performance in competitive swimming. *Can J Appl Physiol* 1995; 20: 395–406.
30. Rodrigues FA and Mader A. Energy system in swimming. In: Seifert L, Chollet D and Mujika I (eds) *World book of swimming: from science to performance*. Hauppauge: Nova Science Publischers, 2010, pp.225–240.
31. Craig AB Jr, Skehan PL, Pawelczyk JA, et al. Velocity, stroke rate and distance per stroke during elite swimming competition. *Med Sci Sports Exerc* 1985; 17: 625–634.
32. Papoti M, Martins LE, Cunha SA, et al. Effects of taper on swimming force and swimmer performance after an experimental ten-week training program. *J Strength Cond Res* 2007; 21: 538–542.
33. Cormie P, McGuigan MR and Newton RU. Developing maximal neuromuscular power: part 2 – training considerations for improving maximal power production. *Sports Med* 2011; 41: 125–146.
34. Buckner SL, Dankel SJ, Mattocks KT, et al. The problem of muscle hypertrophy: revisited. *Muscle Nerve* 2016; 54: 1012–1014.
35. Hakkinen K, Pakarinen A, Alen M, et al. Neuromuscular and hormonal adaptations in athletes to strength training in 2 years. *J Appl Physiol (1985)* 1988; 65: 2406–2412.
36. Toussaint H and Truijens M. Biomechanical aspects of peak performance in human swimming. *Anim Biol* 2005; 55: 17–40.
37. Bourdon PC, Cardinale M, Murray A, et al. Monitoring athlete training loads: consensus statement. *Int J Sports Physiol Perform* 2017; 12: S2161–S2170.