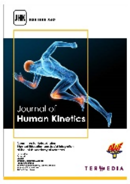

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Section III – Sports and Physical Activity

Fast by Training or by Skill? Key Performance Predictors of 100-m Breaststroke Success in Short-Course Swimming

by
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This study aimed to identify the key technical and training-related factors that differentiated among performance levels in short-course (25 m) 100-m breaststroke swimmers. Sixteen male athletes were divided into two groups: Level 3 (682.3 ± 42.3 FINA points) and Level 4 (574.4 ± 28.7 FINA points). Anthropometry, muscle force characteristics, stroke efficiency, and underwater performance were assessed under competition conditions. A Bayesian regression model revealed that Level 3 swimmers achieved significantly faster 100-m times than Level 4 swimmers ($\beta = 1.16$, SE = 0.36, 95% CI [0.43, 1.87]). No significant between-group differences were observed in maximum voluntary force (F_{max}), the rate of force development (RFD), or basic anthropometric variables, suggesting that strength and body size alone did not explain performance disparities. In contrast, Level-3 swimmers demonstrated a superior stroke index in the first half of the race, as well as significantly greater start-dive velocity and turn-dive length. Bayesian regression confirmed a decisive interaction between turn-dive length and start-dive velocity ($\beta = -0.41$, SE = 0.09, 95% CI [−0.59, −0.23]), underscoring the importance of efficient underwater transitions. These findings suggest that beyond a certain threshold, additional strength may not translate into faster race times, whereas technical skill, neuromuscular coordination, and efficient glide mechanics are decisive in short-course performance. Future studies should integrate fat-free mass and drag coefficient measures for a more comprehensive profile of performance determinants, and examine whether the dominance of underwater phases persists in long-course (50 m) pools, where stroke efficiency and in-swim propulsion may play a greater role.

Keywords: *turn-dive; start-dive; Bayesian regression; underwater performance; stroke efficiency; short-course swimming*

Introduction

Swimming performance is governed by a complex interaction of physiological, biomechanical, and technical variables (Barbosa et al., 2013). Among the four competitive strokes, breaststroke stands out due to its distinct technique, characterized by simultaneous arm and leg actions, pronounced glide phases, and the highest intra-cycle velocity variation (Chollet et al., 1996). Unlike freestyle and backstroke, which emphasize continuous propulsion, breaststroke relies on a cyclical pattern of propulsion and deceleration, making it particularly sensitive to drag, timing, and stroke coordination. Optimal performance in the 100-m breaststroke requires not only well-developed aerobic and anaerobic capacities, but also refined stroke mechanics, efficient underwater transitions, and effective force production (Seifert et al., 2007b). While anthropometric and strength-related factors, such as body height, the arm span, and muscular force, have been positively associated with performance (Alves et al., 2022; Hawley et al., 1992), other studies suggest that elite-level swimmers succeed primarily by optimizing stroke efficiency and

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underwater phases (Morais et al., 2019). Allometric models further identify several morphological and biomechanical predictors of performance, including career length, upper-body circumference, and hand breadth, whereas waist circumference and subscapular skinfold thickness show negative associations (Rejman et al., 2023).

The influence of these variables becomes particularly nuanced in short-course (25 m) competitions, where the frequency and quality of turns and underwater phases have a disproportionately large impact on race outcomes (Gonjo and Olstad, 2021a; Keskinen et al., 1996). In breaststroke, each turn is followed by an underwater pull-out, which, when executed with optimal velocity and minimal resistance, can significantly enhance overall performance (Morais et al., 2019). Studies show that elite swimmers often travel over 10 m underwater before surfacing (Seifert et al., 2007b). Swimmers also tend to remain longer in the underwater phase and delay the breakout to the surface in 200-m events (~14.5 m) compared with 100-m (~13 m) and 50-m events (11.5 m) (Gonjo and Olstad, 2021b), suggesting that underwater proficiency is not merely a tactical option, but a defining feature of high-level performance. However, evidence also indicates that faster swimmers may prioritize high underwater velocity over maximum underwater distance (Sánchez et al., 2021), highlighting gliding skill and coordination as potential innate differentiators (Cuenca-Fernández et al., 2022).

Beyond underwater phases, stroke efficiency remains a fundamental element in minimizing resistance and maintaining velocity throughout the race. The stroke index (SI), defined as the product of stroke length and swimming velocity, is widely used to assess swimming efficiency (Maglischo, 2003). However, the SI is more suited to monitoring changes in efficiency of an individual swimmer over time than to comparing different swimmers, due to interindividual anthropometric and sex-related differences (Nicol et al., 2022). Elite breaststrokers typically exhibit higher SI values, allowing them to cover greater distances per stroke without compromising speed (Chollet et al., 1997). Nevertheless, the optimal balance between stroke length (SL) and the stroke rate (SR) is highly individualized: excessive gliding can disrupt momentum, whereas an overly high SR may increase drag. Consequently, swimmers may achieve success using differing strategies, with some emphasizing longer, well-timed strokes, and others favoring a higher SR (Thompson et al., 2000). Moreover, stroke efficiency varies throughout the race as swimmers dynamically adjust the SR and technique to manage fatigue (Seifert et al., 2007a). In parallel, the ability to generate powerful, and well-coordinated movements, particularly at the start and during turns, plays a crucial role in breaststroke performance. Previous research has highlighted the importance of maximum force (F_{max}) and the rate of force development (RFD), especially in the lower limbs and trunk musculature, for enhancing propulsion during critical race phases (Dopsaj et al., 1999; Zatsiorsky and Kraemer, 2006). While higher absolute strength has been associated with short-distance swimming performance (Amara et al., 2025), propulsion must always be balanced against hydrodynamic drag, as increases in force production may also lead to suboptimal stroke mechanics and greater resistance (Alberty et al., 2005).

Despite these insights, many training programs continue to prioritize surface stroke mechanics, potentially underestimating the impact of underwater phases and gliding skill in short-course races (Gonjo and Olstad, 2021a; Sánchez et al., 2021). Furthermore, both stroke efficiency and force application fluctuate throughout the race as athletes respond to fatigue and tactical adjustments (Arellano at al., 2022; Gonjo et al., 2025). Consequently, although elite swimmers may succeed through a multifaceted optimization of physical and technical qualities, it remains unclear which specific attributes, particularly gliding skill versus trained power, most reliably differentiate between competitive performance levels in the short-course 100-m breaststroke.

Therefore, the present study aimed to identify the key kinematic and performance-related variables that distinguish between higher- and lower-level swimmers in short-course (25 m) 100-m breaststroke events. By examining muscle force characteristics, stroke efficiency, and underwater performance, we sought to determine whether success in this context would be better predicted by trainable attributes such as strength and stroke mechanics, or by more innate technical abilities such as gliding efficiency. In doing so, this research addresses a long-standing question in swimming performance analysis: are fast breaststrokers primarily developed through training or are they defined by superior technical skill?

Methods

Participants

An a priori power analysis was conducted using G*Power 3.1 (Faul et al., 2007) to determine the minimum required sample size. The analysis specified a fixed-effects, one-way ANOVA with two groups, assuming an alpha level of $\alpha = 0.05$, a statistical power $(1 - \beta) = 0.80$, and a large expected effect size $(f = 1.00)$. The resulting estimate indicated that a total sample size of 12 swimmers $(n = 6$ per group; critical $F = 4.96$, $\lambda = 12.00)$ would be sufficient to achieve adequate power. Accordingly, the sample comprised 16 male competitive 100-m breaststroke swimmers (mean age: 19.14 ± 2.97 years; FINA points: 628.3 ± 65.7) who voluntarily participated in this study. All swimmers had qualified for the senior short-course national championships in the 100-m breaststroke event, ensuring a high-performance sample representative of national-level competition. Participants were divided into two performance-based groups according to recent classification criteria proposed by Ruiz-Navarro et al. (2023). The Level 3 group included the top eight swimmers based on championship results (mean age: 19.50 ± 2.77 years; FINA points: 682.25 ± 42.27), while the Level 4 group consisted of swimmers ranked from the 9th to the 16th place (mean age: 18.78 ± 3.31 years; FINA points: 574.38 ± 28.68). Prior to participation, all swimmers received detailed information regarding the study's objectives, procedures, potential risks, and benefits. Written informed consent was obtained from all participants, and for those under 18 years of age, additional consent was obtained from a parent or a legal guardian. The study protocol was approved by the Institutional Review Board of the Faculty of Sport and Physical Education, University of Niš, Niš, Serbia (approval no. 04-73/2; approval date: 24 January 2024) and was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. Testing procedures were designed to minimize the risk of injury or undue fatigue, and participants were instructed to maintain their habitual training and nutritional routines throughout the study period to ensure consistency in performance assessment.

Study Design

This observational, cross-sectional study was conducted during the senior Serbian short-course national championships in the 100-m breaststroke event. All coaches approved the study protocol and all athletes agreed to participate. Participants were instructed to maintain their habitual training and dietary routines throughout the study. All procedures were conducted on the same day under standardized indoor conditions (22–24°C), using consistent equipment and a standardized warm-up. Following the qualifying races, anthropometric measurements and muscle-force assessments were conducted in the laboratory during the morning session. The force-testing protocol consisted of two maximal isometric efforts for each of the three exercises (six trials in total), with 2-min rest intervals between trials. Given the low testing volume and sufficient recovery periods, residual fatigue affecting afternoon performance was unlikely, in line with evidence demonstrating rapid neuromuscular recovery following brief, high-intensity exercise (Carroll et al., 2017). In the afternoon, kinematic data were collected during the 100-m finals in the indoor short-course (25 m) pool, enabling performance analysis under real competition conditions. All testing procedures were conducted at the indoor short-course pool and the adjacent gym within the competition venue, ensuring minimal transition time and consistent environmental conditions between laboratory assessments and in-competition performance.

Anthropometric Measurements

Body mass, height, and the arm span were measured by experienced researchers following the guidelines of the International Biological Program (IBP). Body height and the arm span were assessed using a Martin anthropometer (GPM 101, GPM GmbH, Switzerland), and body mass was measured with a digital scale (Tanita HD-351, Tanita Corp., Tokyo, Japan). All procedures adhered to established anthropometric protocols to ensure accuracy and reproducibility (ISAK, 2019). Table 1 presents the physical characteristics of both groups (age, body height, body mass, the arm span and the body mass index [BMI]). No significant differences were observed between Level-3 and

Level-4 swimmers ($p > 0.05$), indicating comparable anthropometric profiles between groups.

Muscle Force Testing

Isometric muscle force was assessed using a tensiometric dynamometer (IMADA Z2H-1100, Japan) equipped with a 5000-N load cell and sensitivity of 1.25 N. Force-time data were sampled at 1 kHz and recorded using a hardware-software interface (WinWedge 3.4, TAL Technologies, Philadelphia, PA, USA). Tests targeted three muscle groups relevant to swimming performance: knee extensors, back extensors, and shoulder flexors. Following a standardized warm-up, each participant performed two 5-s maximal voluntary isometric contractions (MVICs) per muscle group, with 2-min rest intervals between attempts. All measurements were conducted in a fully equipped laboratory located within the competition venue. Swimmers were organized into four testing groups, allowing sufficient recovery while other participants were assessed, which enabled completion of all 16 participants within approximately 50 min. For each muscle group, the highest force value recorded was used for subsequent analysis. Testing protocols followed previously validated procedures (Majstorović et al., 2020; McGuigan and Winchester, 2008), and participants were instructed to exert maximum force while avoiding any lateral or forward body movement. The testing positions were as follows:

- Knee extensors: Standing on a platform in a semi-squat position (~120° knee angle), with arms and the back straight; the dynamometer was anchored behind the participant.

- Back extensors: Standing with knees fully extended and the trunk flexed ~30° at the hips; the dynamometer was positioned at the mid-thigh level in front of the participant.
- Shoulder flexors: Seated at a lat machine with the arms extended forward at 90° of shoulder flexion; the dynamometer was attached in front of the machine.

Performance Variables

Kinetic Variables

Muscle force characteristics were assessed for the knee extensors, back extensors, and shoulder flexors (Majstorović et al., 2020), with two variables recorded: maximum voluntary force (F_{max}, in Newtons) and the rate of force development (RFD, in $N \cdot s^{-1}$). The RFD was calculated using the formula:

$$RFD = \frac{Fmax}{tFmax} \times 1000$$

where:
$-\ Fmax$ represents the maximum isometric force (N)
$-\ tFmax$ represents the time (ms) required to reach F_{max}.
This calculation was applied to all three muscle groups.

Race Analysis

Two transverse high-speed video cameras (Casio FX300; 60 frame/s and Sony HDD, DCR-SR353E) were used to capture the kinematic aspects of 100-m breaststroke races. The cameras were positioned perpendicularly to the pool's longitudinal axis at the 12.5-m mark to ensure optimal coverage of swimmers' movements. Lane buoys served as fixed reference markers for distance calibration, and additional reference cones were placed on the pool deck at a distance of 5, 10, 12.5, 15, and 20 m from the pool edge. Race analysis was performed using SwimWatch Race Analyzer Standard (Version 4.0).

Swimming Performance Variables

Official race results were used to determine total 100-m race time (T100). The race was divided into four 25-m segments, to allow detailed phase-specific analysis.

Stroke efficiency was assessed using the stroke index (SI), calculated according to Maglischo (2003):

$$SI = StrokeLength(0.01m) \\ \times SwimmingSpeed(m/s)$$

The stroke index was computed separately for each race segment, denoted as SI1-25, SI2-25, SI3-25, and SI4-25.

Stroke length (SL) and the stroke rate (SR) were obtained for each 25-m segment using the method proposed by Maglischo (2003). The SL was determined using the equation:

$$SL = \frac{D - d1}{N}$$

where:
- D represented the swimming distance
- $d1$ was the underwater glide distance
- N was the number of strokes taken.

The SL was calculated separately for each race segment: SL1-25, SL2-25, SL3-25, and SL4-25.

The SR was computed using the formula:

$$SR = \frac{N}{T - t1} \times 60$$

where:
- T represented the total swimming time
- $t1$ was the underwater phase duration
- N was the number of strokes taken.

The SR was determined for each race segment: SR1-25, SR2-25, SR3-25, and SR4-25.

Underwater Performance Variables

The underwater phase was assessed using four key variables calculated according to Thanopoulos et al. (2012):
- Start Dive Length (SDL): distance traveled from the starting signal until the swimmer's head broke the water surface and entered the swimming phase.
- Start Dive Velocity (SDV): average velocity during the underwater phase following the start, serving as indirect indicator of start effectiveness.
- Turn Dive Length (TDL): distance traveled from the wall push-off to head resurface after each turn. TDL was calculated separately for each turn (TDL1, TDL2, and TDL3).
- Turn Dive Velocity (TDV): average velocity during the underwater phase follwing each turn, serving as a surrogate measure of turn efficiency (TDV1, TDV2, and TDV3).

Statistical Analyses

All analyses were conducted in RStudio (v4.2.0, RStudio/2024.12.0+467). Data were reported as mean ± SD. The Levene's test assessed homogeneity of variance; variables meeting this assumption ($p \geq 0.05$) were analyzed with one-way ANOVA, otherwise the Welch's F-test was used. Residual normality was verified via the Shapiro-Wilk test. To control for multiple comparisons across 34 variables, p-values were adjusted using the Benjamini-Hochberg false discovery rate (q = 0.05). Effect sizes were calculated as Hedges' g with 95% confidence intervals, interpreted using sport science thresholds (trivial < 0.2, small 0.2–0.59, moderate 0.60–1.19, large 1.20–1.99, very large ≥ 2.0; Batterham and Hopkins, 2006). In addition, Spearman correlations examined associations between 100-m time and key kinematic, kinetic, and strength variables. Based on these results, a Bayesian regression model was applied to assess predictors of 100-m performance. Bayesian methods were chosen for their ability to model complex data and provide direct probability estimates of effects. Predictors included start-dive velocity, the stroke index, turn dive length, and turn dive velocity, with the group level as a factor. Turn variables were structurally missing at the first segment (no turn post-start), thus the mi() function in brms, was used to impute missing values within the Bayesian framework, preserving model integrity. Posterior estimates were reported as means with 95% credible intervals (CIs), which represented the range within which the true effect lay with 95% probability, offering a more intuitive interpretation than classical p-values. A Bayesian assurance analysis was also conducted to assess the reproducibility of the key interaction (start-dive velocity × turn dive length). Using the fitted model, we simulated 1,000 new datasets (n = 8 per group × 4 segments). The interaction's 95% CI excluded zero in 18.3% of replicates (assurance = 0.183 ± 0.02, Monte Carlo SE), indicating that a similar study would detect the effect roughly 1 in 5 times.

Results

Table 1 presents the descriptive anthropometric characteristics of the participants. No significant between-group differences were observed for age, body height, body mass, the BMI, or the arm span ($p > 0.05$).

No significant differences were observed between Level-3 and Level-4 swimmers in maximum voluntary force (F_{max}) and the rate of force development (RFD) of the knee extensors, back extensors, or shoulder flexors, indicating comparable strength profiles between groups (Table 2). Kinematic analyses revealed that Level-3 swimmers completed the 100-m breaststroke significantly faster than Level-4 swimmers ($F = 34.1$, $p < 0.001$, $g = -2.76$). Stroke length differed only in the second 25-m segment, where Level-3 swimmers exhibited longer stroke lengths ($F = 8.33$, $p = 0.045$, $g = 1.36$); no differences were observed in the remaining segments ($p \geq 0.05$). The stroke rate remained comparable across all race segments ($p \geq 0.05$). The stroke index was significantly higher in Level-3 swimmers during the first (F = 25.60, $p < 0.001$, g = 2.39) and second (F = 34.30, $p < 0.001$, g = 2.77) segments, but not in the final two segments ($p > 0.05$). Start and turn mechanics further distinguished between the two groups. Although start-dive length did not differ significantly between groups ($p = 0.116$), Level-3 swimmers exhibited higher start-dive velocity (F = 19.00, $p = 0.003$, g = 2.06). Turn performance was markedly better in Level-3 swimmers, who maintained significantly longer underwater distances following each wall push-off (all F ≥ 44.00, $p < 0.001$, g = 3.14–3.90). Turn-dive velocity was significantly greater only in the 25–50 m segment (F = 14.60, $p = 0.008$, g = 1.80), with no differences observed thereafter ($p > 0.05$) (Table 3).

Table 1. Physical characteristics of the swimmers (Mean ± SD).

Variables	Level-3 group	Level-4 group	F	*p* (adj.)	Hedges g
Age (years)	19.50 ± 2.77	18.78 ± 3.31	0.226	0.840	0.22 [−0.71–1.15]
Body height (cm)	183.62 ± 3.92	182.77 ± 3.01	0.237	0.884	0.17 [−0.76–0.09]
Body mass (kg)	77.00 ± 4.50	75.26 ± 3.77	0.703	0.840	0.23 [−0.70–1.16]
Arm span (cm)	188.50 ± 5.70	187.62 ± 4.13	0.126	0.673	0.40 [−0.55–0.33]
BMI (kg/m^2)	22.80 ± 0.99	22.50 ± 0.81	0.460	0.510	0.32 [−0.31–0.33]

Note. Values are arithmetic mean ± standard deviation (M ± SD); BMI = body mass index; F = one-way analysis-of-variance statistic comparing Level-3 and Level-4 swimmers for each variable; p (adj.) = false-discovery-rate–adjusted p-value obtained with the Benjamini-Hochberg procedure; Hedges g = bias-corrected standardized mean difference. Bracketed numbers are the 95% confidence limits for Hedges g

Table 2. Different muscle force characteristics of the 100-m breaststroke swimmers.

Variables	Level-3 group	Level-4 group	F	*p* (adj.)	Hedges g
F_{max} knee extensors (N)	1349.10 ± 190.81	1386.72 ± 183.92	0.161	0.922	0.13 [−0.80–1.06]
F_{max} back extensors (N)	1639.77 ± 304.87	1600.28 ± 266.48	0.076	0.874	−0.19 [−1.12–0.74]
F_{max} shoulder flexors (N)	436.70 ± 54.86	405.33 ± 81.37	0.817	0.648	0.43 [−0.52–1.36]
RFD_{knee} (N·s^{-1})	2339.32 ± 712.70	2369.13 ± 495.95	0.009	0.943	0.10 [−0.83–1.03]
RFD_{back} (N·s^{-1})	2809.39 ± 703.64	2736.17 ± 650.45	0.047	1.000	−0.05 [−0.97–0.88]
$RFD_{shoulder}$ (N·s^{-1})	743.08 ± 146.27	690.12 ± 179.93	0.417	0.922	0.13 [−0.80–1.06]

Note. Values are arithmetic mean ± standard deviation (M ± SD); F_{max} = Maximal force; RFD = Rate force development; F = one-way analysis-of-variance statistic comparing Level-3 and Level-4 swimmers for each variable; p (adj.) = false-discovery-rate–adjusted p-value obtained with the Benjamini-Hochberg procedure; Hedges g = bias-corrected standardized mean difference. Bracketed numbers are the 95% confidence limits for Hedges g

Table 3. Kinematical characteristics of the 100-m breaststroke swimmers (Mean ± SD).

Variables	Level-3 group	Level-4 group	F	*p* (adj.)	Hedges g
Time for 100 m (s)	62.83 ± 1.28	66.51 ± 1.09	34.1	<0.001	−2.76 [−4.11–−1.37]
Stroke length 1–25 m (m)	1.76 ± 0.13	1.57 ± 0.20	4.95	0.116	1.05 [0.03–2.04]
Stroke length 2–25 m (m)	2.09 ± 0.17	1.79 ± 0.24	8.33	0.045	1.36 [0.29–2.40]
Stroke length 3–25 m (m)	1.68 ± 0.16	1.60 ± 0.17	0.89	0.645	0.45 [−0.50–1.38]
Stroke length 4–25 m (m)	1.75 ± 0.10	1.63 ± 0.16	3.31	0.204	0.86 [−0.13–1.83]
Stroke Rate 1–25 m (stroke/min)	52.96 ± 4.17	50.15 ± 6.49	1.06	0.605	0.49 [−0.46–1.42]
Stroke Rate 2–25 m (stroke/min)	45.09 ± 4.57	43.39 ± 6.13	0.396	0.764	0.30 [−0.64–1.22]
Stroke Rate 3–25 m (stroke/min)	49.46 ± 4.17	46.65 ± 6.49	1.06	0.605	0.49 [−0.46–1.42]
Stroke Rate 4–25 m (stroke/min)	48.00 ± 3.85	46.44 ± 5.17	0.469	0.764	0.32 [−0.62–1.25]
Stroke Index 1–25 m	2.73 ± 0.24	2.04 ± 0.30	25.60	<0.001	2.39 [1.09–3.64]
Stroke Index 2–25 m	3.27 ± 0.25	2.49 ± 0.28	34.30	<0.001	2.77 [1.37–4.12]
Stroke Index 3–25 m	2.58 ± 0.40	2.11 ± 0.30	7.05	0.058	1.26 [0.20–2.27]
Stroke Index 4–25 m	2.50 ± 0.32	2.11 ± 0.26	7.14	0.058	1.26 [0.21–2.28]
Start Dive length (m)	13.81 ± 0.92	12.97 ± 0.56	4.87	0.116	1.04 [0.03–2.03]
Turn Dive length 2–25 m (m)	11.60 ± 1.05	8.72 ± 0.57	46.60	<0.001	3.23 [1.70–4.71]
Turn Dive length 3–25 m (m)	11.97 ± 0.87	9.13 ± 0.74	44.00	<0.001	3.14 [1.64–4.59]
Turn Dive length 4–25 m (m)	12.01 ± 0.81	9.45 ± 0.34	68.20	<0.001	3.90 [2.18–5.59]
Start Dive Velocity (m/s)	2.60 ± 0.17	2.30 ± 0.10	19.00	0.003	2.06 [0.84–3.24]
Turn Dive Velocity 2–25 m (m)	2.03 ± 0.18	1.76 ± 0.09	14.60	0.008	1.80 [0.64–2.92]
Turn Dive Velocity 3–25 m (m)	1.93 ± 0.46	1.65 ± 0.09	2.85	0.281	0.80 [−0.19–1.76]
Turn Dive Velocity 4–25 m (m)	1.89 ± 0.12	1.71 ± 0.23	3.70	0.182	0.91 [−0.09–1.88]

Note. Values are arithmetic mean ± standard deviation (M ± SD); F = one-way analysis-of-variance statistic comparing Level-3 and Level-4 swimmers for each variable; p (adj.) = false-discovery-rate–adjusted p-value obtained with the Benjamini-Hochberg procedure; Hedges g = bias-corrected standardized mean difference. Bracketed numbers are the 95% confidence limits for Hedges g

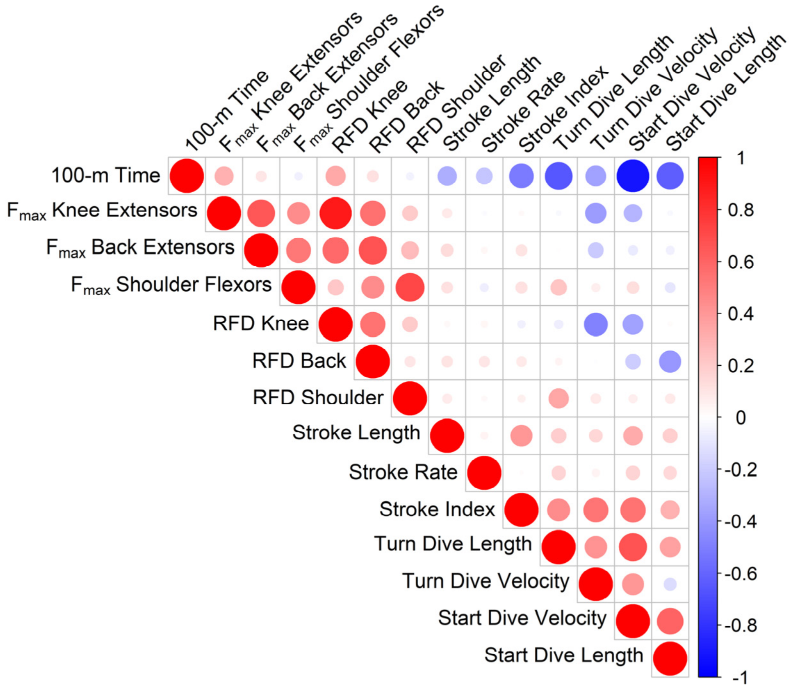

Figure 1. Spearman correlation matrix of key kinematic and kinetic variables with 100-m performance time. Negative (blue shades) and positive correlations (red shades) are shown, with darker shades indicating stronger associations. For clarity, only the upper triangle is shown.

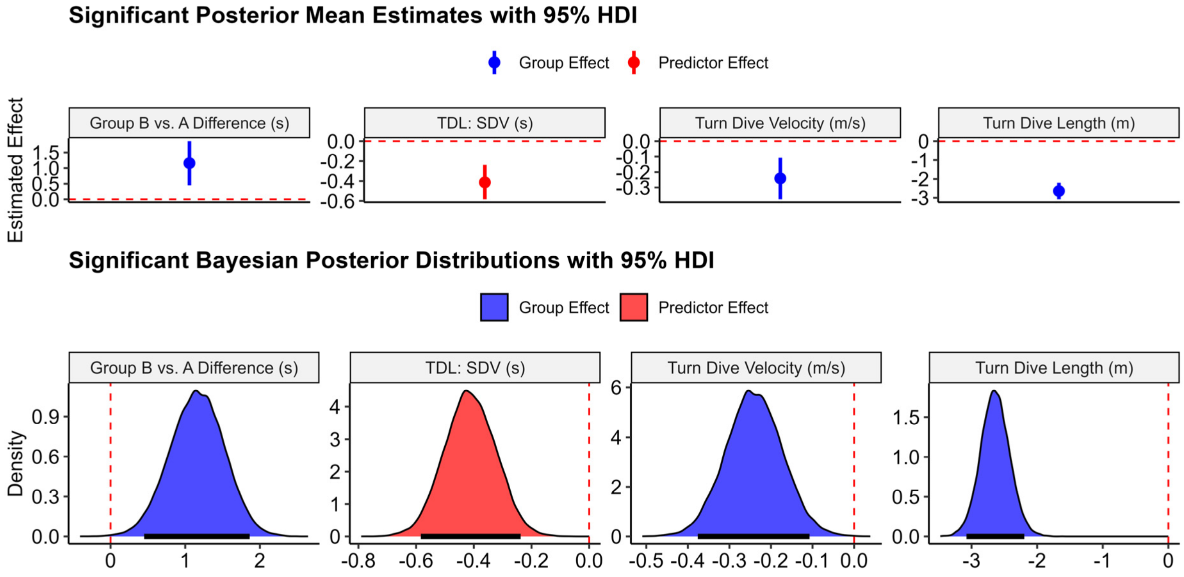

Figure 2. Estimated effects and posterior density plots from the Bayesian regression model for 100-m performance time. Red represents direct performance predictors, such as turn dive length: start dive velocity interaction effect (TDL: SDV), while blue indicates group-based comparisons (Level-3 vs. Level-4 differences). The estimated effects plot displays posterior means and 95% credible intervals, while the density plots illustrate the distribution of posterior estimates for each variable.

Spearman rank-order correlation analyses (Figure 1) revealed strong negative associations between 100-m race time and start-dive velocity ($r = -0.91$, $p < 0.001$) as well as turn-dive length ($r = -0.65$, $p < 0.001$). Start-dive velocity and turn-dive length were also strongly and positively associated ($r = 0.67$, $p < 0.001$). Moderate negative correlations were observed between race time and the stroke index ($r = -0.51$, $p < 0.001$), and between race time and start-dive length ($r = -0.63$, $p < 0.001$). Turn-dive velocity showed a weak and non-significant association with race performance ($r = -0.36$, $p = 0.693$). No significant correlations were found between 100-m race time and F_{max} or RFD variables. The Bayesian regression model confirmed a significant performance-level ($\beta = 1.16$, SE = 0.36, 95% CI [0.43, 1.87]) between Level-3 and Level-4 swimmers. Turn-dive length ($\beta = -2.64$, SE = 0.22) and turn-dive velocity ($\beta = -0.24$, SE = 0.07) were significantly lower in Level-4 swimmers; however, neither variable showed a direct main effect on overall race performance. A significant interaction between turn-dive length and start-dive velocity ($\beta = -0.41$, SE = 0.09) indicated that the performance impact of turn length depended on start velocity. Turn-related variables were structurally missing at the first race segment (no turn following the start) and were handled using Bayesian estimation, avoiding data deletion bias. Residual performance variance was lower in Level-3 swimmers ($\beta = -0.91$, SE = 0.21), indicating more consistent performance. The stroke index and its interaction with start-dive velocity were not significant predictors. Full model results are presented in Figure 2.

Discussion

This study examined key performance predictors distinguishing between Level-3 and Level-4 male swimmers in the 100-m breaststroke during a short-course (25 m) championship. Specifically, stroke efficiency, muscle force characteristics, and underwater performance were evaluated. Level-3 swimmers demonstrated faster race times, longer stroke lengths in specific race segments, higher stroke efficiency, and superior underwater performance metrics. A notable interaction between turn-dive length and start-dive velocity indicated that swimmers entering turns with higher initial velocity derived greater performance benefits from longer underwater phases, highlighting a synergistic relationship between start and turn dynamics. In contrast, no between-group differences were observed in F_{max} or RFD, suggesting that technical execution and race-specific skill may play a more decisive role than absolute strength in short-course breaststroke performance.

Anthropometric variables (body height, body mass, and the arm span) did not differ significantly between groups, suggesting that, between Levels 3 and 4, body dimensions alone do not explain the performance differences. Although larger physiques may confer biomechanical advantages through longer levers, allowing propulsive surfaces such as the hands and forearms to remain submerged longer and generate force more effectively, greater body size may also be disadvantageous by increasing hydrodynamic resistance and energy expenditure (Alves et al., 2022). In addition, previous research has shown that body composition, flexibility variables and the somatotype play important roles in swimming performance, as they influence physiological responses and energetic demands (Jagomägi and Jürimäe, 2005; Siders et al., 1993). In this context, fat-free mass is a particular relevant variable, as it reflects the amount of active contractile tissue directly contributing to force production and propulsion. Although fat-free mass was not assessed in the present study, future research should incorporate this variable to provide a more comprehensive understanding of the anthropometric and physiological determinants of breaststroke performance. Nevertheless, the present findings are consistent with the recommendations of Thompson et al. (2000), suggesting that when swimmers are closely matched in body size, technical efficiency becomes a more critical determinant of competitive success.

Unexpectedly, no significant differences were observed in F_{max} or RFD across the major swimming muscle groups. This finding appears to contrast with previous evidence suggesting that greater muscular strength is associated with enhanced swimming performance in freestyle (Chen et al., 2026; Dominguez-Castells et al., 2013; Dopsaj et al., 1999). One possible explanation may relate to the training strategies emphasized by these swimmers. In breaststroke (and often butterfly), coaches may deliberately limit the use of resistance-based equipment such as paddles, parachutes, or drag devices, as athletes frequently report that such methods negatively affect their "feeling" for the water. As a result, gains in gym-based strength may not be optimally transferred to stroke-specific propulsion. Although strength is undoubtedly required for propulsion, increases in force production do not necessarily translate into faster performance, particularly in breaststroke, which is associated with the highest energetic cost among the four competitive strokes (Barbosa et al., 2006). Instead, the present findings support the notion that neuromuscular coordination, technical execution, and training specificity may compensate for, or even outweigh, maximal strength or rapid force production in generating effective propulsion (Oliveira, 2019; Ruiz-Navarro et al., 2022). The absence of between-group differences in RFD further reinforces this interpretation. RFD is often considered a key determinant of performance in explosive actions such as starts and turns (Zatsiorsky and Kraemer, 2006), however, the present results indicate that Level-3 swimmers did not necessarily exhibit superior RFD despite their faster race performances. In this sense, according to Knihs et al. (2025), force magnitude (i.e., impulse) shows more consistent relationships with 100-m performance, whereas explosive qualities (i.e., RFD) become more relevant over shorter distances. Beyond training-related factors, swimmer experience may also play a decisive role in the ability to apply force effectively in the aquatic environment. Finally, it should be acknowledged that the isometric testing protocols employed in this study may not fully capture the dynamic, fluid-specific muscle actions characteristics of swimming propulsion (Gonjo and Olstad, 2021b). Future research should address this limitation by incorporating more ecologically valid, sport-specific assessments.

Stroke efficiency emerged as the most distinguishing factor between performance levels. Level-3 swimmers exhibited a significantly higher stroke index (SI) during the first half of the race, reflecting more effective propulsion and suggesting reduced drag. Although no direct drag coefficient was assessed in the present study, the SI has been proposed as a practical proxy of swimming efficiency, as it indirectly reflects the balance between propulsion output and hydrodynamic resistance (Nicol et al., 2022). Since breaststroke relies heavily on the coordination of the kick-glide cycle, efficient execution of this sequence is essential to minimize the pronounced intra-cycle velocity fluctuations characteristic of this stroke (Strzała et al., 2012). These findings are consistent with previous research identifying efficiency as a key determinant of swimming performance, particularly in strokes characterized by long propulsive phases and limited recovery periods, such as breaststroke (Chollet et al., 1996; Morais et al., 2019).

Stroke length (SL) was significantly greater in Level-3 swimmers only during the second 25-m segment, with no differences observed in the remaining segments. This suggests that Level-3 swimmers are able to maintain superior efficiency early in the race, likely due to more effective propulsion mechanics and optimized energy conservation strategies. Interestingly, the stroke rate (SR) did not differ between groups, indicating that performance advantages were driven by stroke quality rather than stroke frequency. This interpretation is supported by previous findings showing that improved efficiency is achieved through optimized glide phases rather than an increased stroke rate (Alberty et al., 2011; Seifert et al., 2007a). The higher SI values observed in Level-3 swimmers further confirm their ability to optimize stroke mechanics and energy management during the early race phases. These results are in agreement with Seifert et al. (2007a) who reported lower SI values in regional-level swimmers compared with national-level swimmers, reinforcing the role of technical efficiency in discriminating between competitive performance levels. Similar conclusions have recently been reported in elite backstroke contexts (Papadimitriou et al., 2025).

Start and turn phases emerged as critical discriminators of performance based on posterior estimates derived from the Bayesian regression analysis. Level-3 swimmers demonstrated superior start-dive velocity as well as greater turn-dive velocity and length compared with Level-4 swimmers, supporting the notion that more skilled swimmers are able to maintain higher underwater velocities, which in turn contribute to faster overall race times (Gonjo and Olstad, 2021a; Sánchez et al., 2021). Because breaststroke includes a distinctive underwater pull-out phase, optimizing glide distance while minimizing hydrodynamic resistance appears to confer a decisive competitive advantage. Further support for the importance of these phases comes from analyses of reaction, turn, and finish performance across multiple race distances, which have consistently highlighted the contribution of start and turn optimization to competitive success (Marinho et al., 2020). Recent evidence has also emphasized the role of dryland training components in start performance. For instance, Chen et al. (2026) reported that horizontal and vertical vector resistance training improved swim-start performance in collegiate swimmers, underscoring the relevance of lower-limb explosive strength and its transfer to start efficiency. Nevertheless, despite the established association between jump ability and start performance, the present findings suggest that technical competence in executing underwater transitions, particularly in short-course breaststroke, remains a key determinant of race success, beyond strength-related capacities alone (Marinho et al., 2020; Sánchez et al., 2021).

The strong negative correlation between turn-dive length and 100-m time (r = –0.91) reinforces the importance of turn efficiency. Although turn-dive velocity differed significantly between groups in only one race segment, the consistent advantage in underwater distance suggests that Level-3 swimmers prioritize maintaining momentum through longer underwater travel rather than relying on higher peak velocity alone. Similar findings were reported by Seifert et al. (2007b) who observed that high-level swimmers covered greater larger underwater distances after turns compared with lower-ranked competitors. Comparable results were also described by Veiga and Roig (2017) who showed that longer underwater phases and smoother transitions contributed to faster race times by reducing drag and sustaining higher velocity. These findings support the notion that effective underwater gliding can outperform surface swimming in maintaining the race pace, provided that the swimmer possesses sufficient technical proficiency (Cuenca-Fernández et al., 2022; Veiga and Roig, 2017). Although start-dive velocity and turn-dive length were positively correlated, the negative interaction term observed in the present model indicates a synergistic effect on performance. In this context, the negative coefficient reflects enhanced performance, meaning that swimmers who achieve high start velocities and subsequently maintain longer underwater distances after the turn tend to record faster overall race times. In breaststroke, both the start and turn phases are technically demanding and require precise optimization of glide mechanics, breakout timing, and stroke integration. A high start velocity provides substantial initial momentum, and an extended turn-dive distance, when combined with that momentum, allows swimmers to sustain speed while minimizing hydrodynamic resistance before resuming surface stroking. The critical factor is the ability to execute both elements without excessive deceleration or disruption of the stroke rhythm, thereby ensuring an efficient transition that preserves the advantages gained in each phase. When both components are performed at a high technical level, their combined effect appears to confer a sustained competitive advantage throughout the race, highlighting the importance of training these elements in an integrated and holistic manner.

The main limitation of this study was the relatively small sample size (n = 16), which may limit the generalizability and replicability of the findings. Although Bayesian regression allowed for robust inference under conditions of limited data, the assurance analysis indicated that the key interaction effect would be expected to replicate in approximately ~18% of studies with a similar design. Additionally, physiological variables such as aerobic capacity (e.g., VO_2), blood lactate responses, or muscle fiber characteristics were not assessed and may provide further insight into inter-individual differences in performance. Despite these limitations, the study also presents several important strengths. Notably, it is among the few investigations to apply Bayesian regression modeling to the analysis of competitive swimming performance. Compared with traditional frequentist approaches, Bayesian methods offer several advantages, including the incorporation of prior information, greater flexibility when working with smaller sample sizes, and the estimation of full posterior probability distributions for model parameters, resulting in more informative and interpretable inferences. This analytical framework is particularly well suited to sports science research, where sample sizes are often limited and relationships between variables may be complex and non-linear. Importantly, the present approach enabled the identification of subtle interaction effects between key performance determinants, such as start-dive velocity and turn-dive length, which may remain undetected using conventional statistical models. Furthermore, the findings provide practical insights for coaches and swimmers by emphasizing the importance of specific technical factors, rather than traditional descriptive strength measures alone, in determining short-course breaststroke performance.

Conclusions and Implications for Training

This study highlights that technical skill, particularly in starts, turns, and stroke efficiency, plays a more decisive role in short-course 100-m breaststroke performance than raw physical strength. Despite comparable muscle force characteristics (F_{max} and RFD), faster swimmers (Level-3) consistently outperformed their peers in stroke efficiency, turn-dive length, and underwater velocity. These findings suggest that, beyond a certain threshold, further increases in strength may not translate into faster race times. Instead, optimized technique and efficient application of propulsive forces appear to be the primary performance differentiators. Accordingly, conditioning programs should prioritize skill acquisition and technical refinement, ensuring that stroke length is maximized without increasing hydrodynamic drag or compromising propulsion. The significant interaction between start-dive velocity and turn-dive length further reinforces the need for a coordinated training approach that simultaneously develops explosive power, glide efficiency, and transition control. Coaches are therefore encouraged to implement targeted drills aimed at improving push-off mechanics, streamlined body posture, and breath control during underwater phases (Papic et al., 2024). In addition, resistance training emphasizing explosive lower-limb actions, combined with resisted or drag-assisted swimming drills, may further enhance underwater performance. Future research should investigate the longitudinal effects of such training interventions and determine whether these performance predictors remain consistent in long-course competitions. While the present findings are specific to the short-course context, where turns and underwater phases exert a proportionally greater influence, studies conducted in long-course (50 m) pools may reveal different performance hierarchies, with greater relative contribution of stroke efficiency and in-swim propulsion. Longitudinal and cross-format comparisons would therefore provide valuable insight into how technical and strength-related factors interact to shape breaststroke performance.

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References

Alberty, M., Sidney, M., Huot-Marchand, F., Hespel, J. M., & Pelayo, P. (2005). Intracyclic velocity variations and arm coordination during exhaustive exercise in front crawl stroke. *International Journal of Sports Medicine, 26*(6), 471–475. https://doi.org/10.1055/s-2004-821110

Alves, M., Carvalho, D. D., Fernandes, R. J., & Vilas-Boas, J. P. (2022). How anthropometrics of young and adolescent swimmers influence stroking parameters and performance? A systematic review. *International Journal of Environmental Research and Public Health*, *19*(5), 2543. https://doi.org/10.3390/ijerph19052543

Amara, S., Bouassida, A., & van den Tillaar, R. (2025). Relative contributions of upper-body muscular power and repeated sprint ability to 50-m freestyle swimming performance in competitive swimmers. *Frontiers in Sports and Active Living*, *7*, 1751687. https://doi.org/10.3389/fspor.2025.1751687

Arellano, R., Ruiz-Navarro, J. J., Barbosa, T. M., López-Contreras, G., Morales-Ortíz, E., Gay, A., ... & Cuenca-Fernández, F. (2022). Are the 50 m race segments changed from heats to finals at the 2021 European swimming championships?. *Frontiers in Physiology*, *13*, 797367. https://doi.org/10.3389/fphys.2022.797367

Barbosa, T. M., Costa, M., & Marinho, D. A. (2013). Proposal of a deterministic model to explain swimming performance. *International Journal of Sports Physiology and Performance, 2*(1), 1–54. http://hdl.handle.net/10314/3184

Barbosa, T. M., Fernandes, R., Keskinen, K. L., Colašo, P., Cardoso, C., Silva, J., & Vilas-Boas, J. P. (2006). Evaluation of the energy expenditure in competitive swimming strokes. *International Journal of Sports Medicine*, *27*(11), 894–899. https://doi.org/10.1055/s-2006-923776

Batterham, A. M., & Hopkins, W. G. (2006). Making meaningful inferences about magnitudes. *International Journal of Sports Physiology and Performance, 1*(1), 50–57. https://doi.org/10.1123/ijspp.1.1.50

Carroll, T. J., Taylor, J. L., & Gandevia, S. C. (2017). Recovery of central and peripheral neuromuscular fatigue after exercise. *Journal of Applied Physiology*, *122*(5), 1068–1076. https://doi.org/10.1152/japplphysiol.00775.2016

Chollet, D., Pelayo, P., Delaplace, C., Tourny, C., & Sidney, M. (1997). Stroking characteristic variations in the 100-M freestyle for male swimmers of differing skill. *Perceptual and Motor Skills, 85*(1), 167–177. https://doi.org/10.2466/pms.1997.85.1.167

Chollet, D., Pelayo, P., Tourny, C., & Sidney, M. (1996). Comparative analysis of 100 m and 200 m events in the four strokes in top-level swimmers. *Journal of Human Movement Studies, 31*, 25–37.

Cuenca-Fernández, F., Ruiz-Navarro, J. J., Polach, M., Arellano, R., & Born, D. P. (2022). Turn performance variation in European elite short-course swimmers. *International Journal of Environmental Research and Public Health, 19*(9), 5033. https://doi.org/10.3390/ijerph19095033

Chen, X., Lu, Y., Zhang, B. & Shen, Y. (2026). A Correlational Analysis between the Rate of Force Development among the Arm Stroke, the Leg Kick, the Full Stroke and Short Distance Front Crawl Speed in Highly Trained Swimmers. *Journal of Human Kinetics*, Advance online publication. https://doi.org/10.5114/jhk/204780

Dominguez-Castells, R., Izquierdo, M., & Arellano, R. (2013). An updated protocol to assess arm swimming power in front crawl. *International Journal of Sports Medicine*, *34*(04), 324–329. https://doi.org/10.1055/s-0032-1323721

Dopsaj, M., Milosevic, M., Matkovic, I., Arlov, D., & Blagojevic, M. (1999). The relation between sprint ability in free-style swimming and force characteristics of different muscle groups. In L. Keskinen, P. Komi, & P. Hollander (Eds.), *Biomechanics and Medicine in Swimming VIII* (pp. 203–208). University of Jyväskylä.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175–191. https://doi.org/10.3758/BF03193146

Gonjo, T., & Olstad, B. H. (2021a). Differences between elite and sub-elite swimmers in a 100 m breaststroke: A new race analysis approach with time-series velocity data. *Sports Biomechanics, 20*(4), 491–503. https://doi.org/10.1080/14763141.2021.1954238

Gonjo, T., & Olstad, B. H. (2021b). Race analysis in competitive swimming: A narrative review. *International Journal of Environmental Research and Public Health, 18*(1), 69. https://doi.org/10.3390/ijerph18010069

Gonjo, T., Veiga, S., Hermosilla-Perona, F., & Olstad, B. H. (2025). Variabilities in the stroking parameters during short course 50 m time trials in all four competitive swimming strokes. *Scientific Reports*, *15*(1), 23640. https://doi.org/10.1038/s41598-025-08519-9

Hawley, J. A., Williams, M. M., Vickovic, M. M., & Handcock, P. J. (1992). Muscle power predicts freestyle swimming performance. *British Journal of Sports Medicine*, *26*(3), 151–155.

International Society for the Advancement of Kinanthropometry (ISAK). (2019). *International Standards for Anthropometric Assessment*.

Jagomägi, G., & Jürimäe, T. (2005). The influence of anthropometrical and flexibility parameters on the results of breaststroke swimming. *Papers on Anthropology, 14*, 93–102. https://www.jstor.org/stable/29542652

Keskinen, K., Keskinen, O., & Mero, A. (1996). Effect of pool length on biomechanical performance in front crawl swimming. *Biomechanics and Medicine in Swimming VII*, 216–220.

Knihs, D. A., Bishop, C., Guglielmo, L. G. A. & Dal Pupo, J. (2025). Assessing the Relationship between In-Water Kinetic Asymmetries and Performance in Swimming. *Journal of Human Kinetics*, Advance online publication. https://doi.org/10.5114/jhk/211343

Maglischo, E. W. (2003). *Swimming fastest*. Human Kinetics.

McGuigan, M. R., & Winchester, J. B. (2008). The relationship between isometric and dynamic strength in college football players. *Journal of Sports Science & Medicine*, *7*(1), 101.

Majstorović, N., Dopsaj, M., Grbić, V., Savić, Z., Vićentijević, A., Aničić, Z., Zadraznik, M, Toskic, L & Nešić, G. (2020). Isometric strength in volleyball players of different age: A multidimensional model. *Applied Sciences*, *10*(12), 4107. https://doi.org/10.3390/app10124107

Marinho, D. A., Barbosa, T. M., Neiva, H. P., Silva, A. J., & Morais, J. E. (2020). Comparison of the start, turn and finish performance of elite swimmers in 100 m and 200 m races. *Journal of Sports Science & Medicine*, *19*(2), 397.

Morais, J. E., Marinho, D. A., Arellano, R., & Barbosa, T. M. (2019). Start and turn performances of Level-3 sprinters at the 2016 European Championships in swimming. *Sports Biomechanics, 18*(1), 100–114. https://doi.org/10.1080/14763141.2017.1327359

Nicol, E., Pearson, S., Saxby, D., Minahan, C., & Tor, E. (2022). Stroke kinematics, temporal patterns, neuromuscular activity, pacing and kinetics in elite breaststroke swimming: a systematic review. *Sports Medicine-Open*, *8*(1), 75. https://doi.org/10.1186/s40798-022-00467-2

Oliveira, A. R. (2019). History of the Bernoulli principle. In *Advances in Mechanism and Machine Science: Proceedings of the 15th IFToMM World Congress on Mechanism and Machine Science 15* (pp. 1161–1178). Springer International Publishing. https://doi.org/10.1007/978-3-030-20131-9_115

Papadimitriou, K., Zafeiriadis, S., Papadimitriou, N., & Tsalis, G. (2025). Case Report: Impact of dolphin kick implementation during backstroke finishes on swimming performance. From regional to olympic-level swimmers. A comparative case study. *Frontiers in Sports and Active Living*, *7*, 1531427. https://doi.org/10.3389/fspor.2025.1531427

Papic, C., Andersen, J., Naemi, R., Hodierne, R., & Sanders, R. H. (2024). Augmented feedback can change body shape to improve glide efficiency in swimming. *Sports Biomechanics*, *23*(7), 898–917. https://doi.org/10.1080/14763141.2021.1900355

Rejman, M., Nevill, A. M., Garrido, N. D., Rudnik, D., & Morais, J. E. (2023). Identification of key somatic features that are common and the ones that differ between swim strokes through allometric modeling. *Frontiers in Sports and Active Living, 5,* 1308033. https://doi.org/10.3389/fspor.2023.1308033

Ruiz-Navarro, J. J., Andersen, J. T., Cuenca-Fernández, F., López-Contreras, G., Morouço, P. G., & Arellano, R. (2022). Quantification of swimmers' ability to apply force in the water: the potential role of two new variables during tethered swimming. *Sports Biomechanics*, *23*(12), 2533–2545. https://doi.org/10.1080/14763141.2022.2089220

Ruiz-Navarro, J. J., López-Belmonte, Ó., Gay, A., Cuenca-Fernández, F., & Arellano, R. (2023). A new model of performance classification to standardize the research results in swimming. *European Journal of Sport Science*, *23*(4), 478–488. https://doi.org/10.1080/17461391.2022.2046174

Sánchez, L., Arellano, R., & Cuenca-Fernández, F. (2021). Analysis and influence of the underwater phase of breaststroke on short-course 50 and 100m performance. *International Journal of Performance Analysis in Sport, 21*(3), 307–323. https://doi.org/10.1080/24748668.2021.1885838

Seifert, L., Chollet, D., & Rouard, A. (2007a). Swimming constraints and arm coordination. *Human Movement Science, 26*(1), 68–86. https://doi.org/10.1016/j.humov.2006.09.003

Seifert, L., Vantorre, J., & Chollet, D. (2007b). Biomechanical analysis of the breaststroke start. *International Journal of Sports Medicine*, *28*(11), 970–976.

Siders, W. A., Lukaski, H. C., & Bolonchuk, W. W. (1993). Relationships among swimming performance, body composition, and somatotype in competitive collegiate swimmers. *Journal of Sports Medicine and Physical Fitness, 33*(3), 166–171.

Strzała, M., Tyka, A., Krezalek, P., & Gajewski, J. (2012). Swimming speed of the breaststroke kick. *Journal of Human Kinetics, 32*, 53–60. https://doi.org/10.2478/v10078-012-0087-4

Thanopoulos, V., Rozi, G., Okičić, T., Dopsaj, M., Jorgić, B., Madić, D., Velickovic, S., Milanovic, Z., Spanou, F., & Batis, E. (2012). Differences in the efficiency between the grab and track starts for both genders in Greek young swimmers. *Journal of Human Kinetics*, *32*, 43–51. https://doi.org/10.2478/v10078-012-0022-8

Thompson, K. G., Haljand, R., & MacLaren, D. P. (2000). An analysis of selected kinematic variables in national and Level-3 male and female 100-m and 200-m breaststroke swimmers. *Journal of Sports Sciences, 18*(6), 421–431. https://doi.org/10.1080/02640410050074359

Veiga, S., & Roig, A. (2017). Underwater and surface strategies of 200 m world level swimmers. *Journal of Sports Sciences, 35*(8), 748–755. https://doi.org/10.1080/02640414.2015.1069382

Zatsiorsky, V. M., & Kraemer, W. J. (2006). *Science and practice of strength training* (2nd ed.). Human Kinetics.