Spor Bilimleri Araştırmaları Dergisi
Journal of Sport Sciences Research
Vol: 11, Issue: 1, 2026
E-ISSN: 2548-0723
URL: http://www.dergipark.org.tr/jssr

Swimming Efficiency of Male Swimmers According to Phases in Short Distance Backstroke Race

Benil KISTAK ALTAN[1*], Ali ÖZÜAK[2]

[1] Halic University, Faculty of Sport Sciences, Istanbul.
[2] Marmara University, Faculty of Sport Sciences, Istanbul.

Research Article **DOI: 10.25307/jssr.1739398**
Received: 10.07.2025 Accepted: 23.01.2026 Online Published: 28.02.2026

Abstract

The aim of this study was to investigate the swimming efficiency of youth swimmers in the start, swimming, finish phases of short distance (50 meter) backstroke races. A total of 152 male swimmers who participated in the Long Course National Development Project races held in Istanbul, voluntarily participated in the study. One Canon camera with 25 fps was positioned to see the whole race. The 50-meter distance was analyzed in three sections: a) the start phase, which was the first 15-meter b) the swim phase between 15-meter, and 35-meter c) the finish phase, which was the last 15-meter. The swimmers' time, speed, stroke count, stroke rate, stroke length, stroke index, and SWOLF-Index were determined in these three phases. In the start phase, the distance and time (underwater distance and underwater time) obtained by the swimmers during their kicks between the start and underwater were not included. Data were analyzed by Repeated Measures ANOVA and Bonferroni post-hoc test in JASP 0.19.3 program. There were significant differences in the performance parameters of swimmers according to the start, swimming and finish phases of the 50-meter event ($p<0.05$). Large effect sizes were observed for time, speed, stroke count, stroke rate, swim index, and SWOLF-Index values. In the short-distance backstroke race for male swimmers, significant differences in performance were observed according to different phases of the race. It was determined that after the first 15 meter, in addition to speed and time parameters, stroke mechanics, swimming index, and SWOLF-Index value also had a performance-determining effect.
Keywords: Swimming, Backstroke, Stroke mechanics, Performance

[*] **Corresponding Author:** Asst. Prof. Benil Kıstak Altan, **E-mail**: benilkistak@halic.edu.tr

INTRODUCTION

Swimming uses arm and leg motions on the water's surface to cover a specific distance in the shortest amount of time (Seifert & Carmigniani, 2023). Freestyle, backstroke, breaststroke, and butterfly are the four swimming strokes. The study of swimming biomechanics examines the physical characteristics of swimming and the interactions between the human body and water (Bulgan-Ercin, 2023). The start, swim, turn, and finish are the four elements that are used to analyse swimmers' competition performances (Olstad et al., 2020; Pérez-Tejero et al., 2017). Swimming biomechanics can be divided into three subgroups: performance, kinetics, and kinematics. Performance, kinetics, and kinematics are the three subgroups of swimming biomechanics. The performance subgroup includes stroke count, stroke rate, stroke length, lap time, and finish time (Daly et al., 2003; Feitosa et al., 2022; Mooney et al., 2015).

Technique, endurance, strength, and hydrodynamics are all important in swimming. Coaches can learn about swimmers' upper extremity technical skills from stroke mechanics parameters (Barbosa et al., 2011). Stroke mechanics directly affect swimming performance, and this relationship has been extensively discussed from biomechanical and hydrodynamic perspectives in the literature (Barbosa et al., 2021; Marinho et al., 2011). Coaches and sports scientists often use these variables to assess and improve swimmers' technique and endurance. The magnitude of propulsive force depends on the assessment method used, stroke mechanics, the number of body limbs involved and gender (Santos et al., 2024). The dynamic interaction between these parameters determines swimming success. Improving only one parameter may not lead to optimal performance (Morais et al., 2023). Integrated approaches that monitor all these parameters simultaneously enable swimmers to maximise propulsion, minimise fatigue and maintain speed (McCabe et al., 2015). Elite swimmers often prioritise a greater stroke length to maximise swimming efficiency, since a higher stroke frequency increases friction and energy costs (Barbosa et al., 2021). By decreasing the cross-sectional area of water flow, the ideal stroke length improves propulsion efficiency, according to a computational fluid dynamics study (Takagi et al., 2023). Compared to long-distance competitions, swimmers attain a greater stroke frequency in sprint distance events. Increased drag and variations in speed may cause this frequency and swimming speed to drop (Morais et al., 2010; Seifert et al., 2007b).

Stroke rate, i.e., the frequency of strokes in one minute, indicates how quick swimmers do their strokes. While stroke length and frequency reflect efficiency of work, a higher frequency does not necessarily equate with a higher speed (Garland-Fritzdorf et al. 2009). Stroke length, in contrast, refers to the distance traveled over one cycle of a stroke (Seifert et al., 2007a). The enhancement of stroke length decreased the stroke rate and energy cost, thus improving endurance (Craig and Pendergast, 1979; Figueiredo et al., 2016). Swimming index is calculated by multiplying swimming speed by stroke length and is used to assess the effectiveness of the swim stroke of a swimmer (Maglischo, 2003).

The efficiency of swimming performance is highly dependent on technical factors, such as stroke mechanics. The main measures used to analyse swimming technique and performance are stroke count (total strokes per distance), swim index (a measure of efficiency combining speed and stroke length), stroke length (distance covered per stroke), and stroke rate (strokes per minute) (Morais et al., 2023; Seifert et al., 2014). Descriptive or comparative studies examining the stroke mechanics and swimming performance of different age groups have been conducted in the literature (Delgado-Gonzalo et al., 2016; Kaya, 2012; Kıstak-Altan & Odabas, 2023; Nicol et al., 2022; Şenel & Baykal, 2017). According to one study, while it was stated that stroke rate and stroke count should be evaluated together, it was found that there was a moderately significant positive relationship between stroke count and both stroke rate (r=0.325) and race time (r=0.587) (Şimşek, 2024). This significant positive relationship shows that, as the stroke count increases, so does race time. This has a negative effect on swimming performance (Garland-Fritzdorf et al., 2009). In addition, a moderate negative correlation (r=-0.587) was found between stroke length and 50-meter race time, while a very strong negative correlation (r=-0.991) was found between stroke length and stroke count (Şimşek, 2024). The optimum balance between stroke speed and length should be determined for everyone, with the focus being on achieving a high stroke length through a high stroke speed (Ruiz-Navarro et al., 2025). Consistent with these findings, a negative correlation was observed between stroke length (1.38±0.18 m/stroke) and performance time (81.57±9.82 s) in the 100 m freestyle competition among male swimmers (r=-0.708) (Şenel & Baykal, 2017). Seifert and Carmigniani (2023) emphasised in their study that swimmers should train not only swimming speed but also stroke speed for a given speed. Furthermore, coaches should be encouraged to design training programmes that enhance the ratio of stroke speed to stroke length

The aim of this study was to address a gap in the literature by comparing stroke-related parameters of male athletes competing in short-distance backstroke swimming events, categorised by race phase. The study investigated the swimming efficiency of young swimmers in the start, swimming and finishing phases of short-distance backstroke swimming races. The study hypothesises that there are differences in stroke mechanics and performance parameters in the start, swim, and finish phases of short-distance backstroke swimming races.

METHOD

Research Model

This study was designed according to the quantitative research method.

Research Groups

G-Power analysis (G*Power 3.1) determined the sample size of the study to be 152, with an effect size (d) of 0.50, a power value of 92%, and a type I error rate of 5%. The inclusion criteria were living in Istanbul; being in the 11–12 age group; being an active, licensed athlete in a private club for at least two years; and participating in backstroke-style competitions. A total of 152 athletes (mean age = 11.45 ± 0.50 years; mean height = 152.85 ± 7.69 cm; mean body weight = 44.48 ± 8.41 kg), 12-year-old (n=69) and 11-year-old boys (n=83), participated in the study voluntarily. Swimmers who completed the backstroke competition in under 50 seconds were included in the study (mean time = 40.72 ± 4.42 s). The study was conducted with the approval of the Halic University Non-Interventional Clinical Research Ethics

Committee, which was granted on 27 February 2025 (number 279). The study was conducted in accordance with the principles of the Declaration of Helsinki; written and verbal consent was obtained from the swimmers' parents since they were under 18 years of age. Swimmers whose parents did not give consent (n = 30) were excluded from the study.

Data Collection Tools

Height: Athletes were measured with a soft tape measure fixed vertically on the wall with bare feet and body in an upright position.

Body Weight: Athletes were measured with an electronic scale with bare feet and body in an upright position.

Camera: One Canon camera with 25 frames per second (fps) was placed in the bleachers to follow the whole competition.

Kinovea Analysis Program: The latest version of Kinovea-2023.1.2. (https://www.kinovea.org) video analysis program was used in the study. The images taken during the race were transferred to the computer in mp4 format and analyzed in .avi format. Forward-backward, pause and stopwatch features of this free analysis program were used (Aprilo et al., 2025).

Stroke Mechanics and Performance: The 50-meter backstroke race distance of the athletes was examined in three phases: a) the start phase, which is the first 15-meter b) the swimming phase between 15-meter and 35-meter c) the finish phase, which is the last 15-meter (Gonjo and Olstad, 2021). In these three phases, swimmers' time, speed, stroke count, stroke rate, stroke length, swim index, and swim golf index were determined or calculated. The parameters determined in the analysis of the start, swimming, and finish phases of the athletes are explained in detail below.

Time: Starts with the start command and ends when the person touches the finish wall (s).
Speed: A distance divided by time (m/s).
Stroke count: The number of arms thrown at a distance (number).
Stroke rate: The number of strokes in 1 min (stroke/min).
Stroke length: A distance divided by the number of arms thrown over that distance (m/stroke).
Stroke index: It is obtained by multiplying stroke length and speed [m^2/(stroke x s)] (Kıstak-Altan & Odabas, 2023).
SWOLF-Index (Swim Golf index): The sum of time and stroke count in swimming performance is called a quantitative index, swim golf index or SWOLF-Index (Madou et al., 2023).

In the start phase, the distance and time (underwater distance and underwater time) obtained by the swimmers during their kicks between the start and underwater were not included. For this reason, the values of the swimmers in the start phase of the study are calculated based only on the time or distance they swam above water (Özüak, 2023). Underwater distance and time were subtracted from the start phase.

Ethics Approval

The Non-Interventional Clinical Research Ethics Committee at Halic University granted approval for the study on 27 February 2025 (approval number: 279). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Collection of Data

This study was conducted during a swimming competition (long course) within the National Development League in Istanbul, Turkey. Male athletes aged between 11 and 12 years participating in the 50-meter backstroke race were first measured for height and body weight, which are descriptive physical characteristics. In the 50-meter backstroke race, a Canon camera with 25 frames per second (fps) was placed in the bleachers to follow the whole competition. The images obtained in MP4 format during the race were transferred to the computer and analysed using the Kinovea-2023.1.2 programme, which utilises the .avi format. The 50-meter distance was analysed in three phases: (a) the initial 15-meter segment, (b) the subsequent 15-meter segment, and (c) the concluding 15-meter segment. The time, speed, stroke count, stroke rate, stroke length, swim index and swim golf index of the swimmers were determined or calculated in these three phases.

Analysis of Data

The data collected for the study was entered into the JASP 0.19.3 analysis program. In the present study, the suitability of the data for normal distribution was determined by Skewness and Kurtosis values. It was determined that these values were within the range of ± 1. As posited by Hair et al., the prevailing consensus was that the data demonstrated a normal distribution (Hair et al., 2013). Given the assumption of normality of data distribution, paired comparisons of stroke mechanics and performance parameters across three phases were analysed by Repeated Measures ANOVA. The Bonferroni post-hoc test was used to identify pairwise differences among the swimming phases. The effect sizes were categorized as small (~0.01), medium (~0.06) and large (~0.14) through analysis of the partial eta squared coefficient ($\eta^2 p$) from the Repeated Measures ANOVA test (Cohen,1988). The confidence interval was accepted as $p<0.05$.

FINDINGS

Table 1. Mean and standard deviation values of swimmers' performance parameters according to phases

	11 age (n=83)			12 age (n=69)			11-12 age (n=152)		
	Start 0-15 m $\bar{X}\pm S$	Swimming 15-35 m $\bar{X}\pm S$	Finish 35-50 m $\bar{X}\pm S$	Start 0-15 m $\bar{X}\pm S$	Swimming 15-35 m $\bar{X}\pm S$	Finish 35-50 m $\bar{X}\pm S$	Start 0-15 m $\bar{X}\pm S$	Swimming 15-35 m $\bar{X}\pm S$	Finish 35-50 m $\bar{X}\pm S$
Time (s)	11.13±1.02	16.82±1.72	13.53±1.36	10.70±1.23	16.18±2.03	12.97±1.68	10.94±1.14	16.53±1.89	13.28±1.54
Speed (m/s)	1.28±0.17	1.20±0.12	1.12±0.11	1.41±0.31	1.25±0.14	1.17±0.14	1.34±0.25	1.22±0.13	1.14±0.13
Stroke Count (number)	5.92±1.53	13.28±1.55	9.68±1.14	5.30±1.76	12.78±1.66	9.30±1.27	5.63±1.66	13.05±1.62	9.51±1.21
Stroke Rate (stroke/min)	51.11±6.82	47.54±4.55	43.00±3.69	49.43±6.97	47.65±5.58	43.30±5.18	50.35±6.92	47.59±5.03	43.14±4.42
Stroke Length (m/stroke)	1.52±0.22	1.53±0.17	1.57±0.18	1.65±0.29	1.59±0.20	1.64±0.21	1.58±0.26	1.55±0.19	1.60±0.20
Swim Index (m^2/(stroke x s))	1.97±0.46	1.84±0.33	1.77±0.33	2.34±0.64	2.01±0.42	1.94±0.42	2.14±0.58	1.92±0.38	1.85±0.38
SWOLF-Index	12.97±3.35	30.10±2.94	23.21±2.31	11.84±3.94	28.96±3.29	22.27±2.64	12.46±3.66	29.58±3.14	22.79±2.51

The mean ($\bar{X}$) and standard deviation (S) values of swimmers' performance parameters according to the start, swimming and finish phases are given in Table 1.

Table 2. Comparison of 11-year-old swimmers' performance parameters according to phases

				Start vs Swimming			Start vs Finish			Swimming vs Finish		
	F	p	n^2	%95 Lower	%95 Upper	post-hoc	%95 Lower	%95 Upper	post-hoc	%95 Lower	%95 Upper	post-hoc
Time (s)	1906.663	**<.001**	0.959	-5.937	-5.425	**<.001**	-2.629	-2.165	**<.001**	3.101	3.468	**<.001**
Speed (m/s)	112.676	**<.001**	0.579	0.052	0.112	**<.001**	0.131	0.197	**<.001**	0.070	0.094	**<.001**
Stroke Count (number)	1456.239	**<.001**	0.947	-7.779	-6.956	**<.001**	-4.117	-3.413	**<.001**	3.401	3.804	**<.001**
Stroke Rate (stroke/min)	109.106	**<.001**	0.571	2.123	5.020	**<.001**	6.472	9.751	**<.001**	3.738	5.342	**<.001**
Stroke Length (m/stroke)	5.047	0.018*	0.058	-0.047	0.041	1.000	-0.100	0.004	0.076	-0.069	-0.021	**<.001**
Swim Index (m^2/(stroke x s))	22.534	**<.001**	0.216	0.046	0.210	**<.001**	0.108	0.295	**<.001**	0.040	0.106	**<.001**
SWOLF-Index	2623.966	**<.001**	0.970	-17.818	-16.431	**<.001**	-10.905	-9.570	**<.001**	6.590	7.183	**<.001**

***p<0.05**

Table 2 presents the comparison of performance parameters according to phases in 11-year-old swimmers. According to the table, statistically significant differences with large effect sizes were observed according to phases for all performance parameters except stroke length (effect size small to medium). Statistically significant differences were identified in the time, speed, stroke count, stroke rate, swim index, and SWOLF-Index values of the swimmers between the phases. A statistically significant difference was identified between the start vs swimming, start vs finish and swimming vs finish phases ($p<0.05$). Also, a statistically significant difference in stroke length was found between the swimming and finish phases ($p<0.01$).

Table 3. Comparison of 12-year-old swimmers' performance parameters according to phases

				Start vs Swimming			Start vs Finish			Swimming vs Finish		
	F	p	n^2	%95 Lower	%95 Upper	post-hoc	%95 Lower	%95 Upper	post-hoc	%95 Lower	%95 Upper	post-hoc
Time (s)	1166.17	**<.001**	.945	-5.820	-5.137	**<.001**	-2.560	-1.976	**<.001**	3.028	3.392	**<.001**
Speed (m/s)	42.963	**<.001**	.387	.077	.229	**<.001**	.156	.309	**<.001**	.067	.092	**<.001**
Stroke Count (number)	912.862	**<.001**	.931	-7.991	-6.966	**<.001**	-4.507	-3.508	**<.001**	3.265	3.677	**<.001**
Stroke Rate (stroke/min)	47.853	**<.001**	.413	.043	3.521	.043*	4.166	8.087	**<.001**	3.548	5.141	**<.001**
Stroke Length (m/stroke)	2.078	.129	.030	-.031	.153	.319	-.085	.108	1.000	.074	-.025	**<.001**
Swim Index (m^2/(stroke x s))	26.774	**<.001**	.283	0.160	.503	**<.001**	.223	.575	**<.001**	.034	.102	**<.001**
SWOLF-Index	1550.42	**<.001**	.958	-18.010	-16.219	**<.001**	-11.348	-9.518	**<.001**	6.372	6.991	**<.001**

***p<0.05**

Table 3 presents the comparison of performance parameters according to phases in 12-year-old swimmers. According to the table, statistically significant differences with large effect sizes were observed according to phases for all performance parameters except stroke length. Statistically significant differences were identified in the time, speed, stroke count, stroke rate, swim index, and SWOLF-Index values of the swimmers between the phases. A statistically significant difference was identified between the start vs swimming, start vs finish and swimming vs finish phases (p<0.05).

Table 4. Comparison of 11-12 years old swimmers' performance parameters according to phases

				Start vs Swimming			Start vs Finish			Swimming vs Finish		
	F	p	n^2	%95 Lower	%95 Upper	post-hoc	%95 Lower	%95 Upper	post-hoc	%95 Lower	%95 Upper	post-hoc
Time (s)	3017.966	**<.001**	.952	-5.796	-5.382	**<.001**	-2.519	-2.157	**<.001**	3.123	3.379	**<.001**
Speed (m/s)	110.404	**<.001**	.422	.076	.152	**<.001**	.156	.234	**<.001**	.072	.089	**<.001**
Stroke Count (number)	2323.562	**<.001**	.939	-7.737	-7.099	**<.001**	-4.169	-3.581	**<.001**	3.400	3.686	**<.001**
Stroke Rate (stroke/min)	148.211	**<.001**	.495	1.645	3.874	**<.001**	5.952	8.469	**<.001**	3.891	5.011	**<.001**
Stroke Length (m/stroke)	3.740	.025*	.024	-.022	.074	.558	-.072	.031	0.988	-.064	-.030	**<.001**
Swim Index (m²/(stroke x s))	45.474	**<.001**	.231	.130	.311	**<.001**	.196	.386	**<.001**	.047	.094	**<.001**
SWOLF-Index	4078.150	**<.001**	.964	-17.667	-16.573	**<.001**	-10.871	-9.782	**<.001**	6.581	7.006	**<.001**

***p<0.05**

Table 4 presents the comparison of performance parameters according to phases in 11-12 years old swimmers. According to the table, statistically significant differences with large effect sizes were observed according to phases for all performance parameters except stroke length (effect size small to medium). Statistically significant differences were identified in the time, speed, stroke count, stroke rate, swim index, and SWOLF-Index values of the swimmers between the phases. A statistically significant difference was found between the start vs swimming, start vs finish and swimming vs finish phases (p<0.05). Also, a statistically significant difference in stroke length was found between the swimming and finish phases (p<0.01).

DISCUSSION and CONCLUSION

The present study was conducted for the purpose of investigating the swimming efficiency of male swimmers in the 11-12 age group in three distinct phases (0-15 m, 15-35 m, 35-50 m) during 50-meter backstroke swimming competitions. In this direction, a comprehensive set of metrics was utilised to assess swimming efficiency, encompassing time, speed, stroke count, stroke rate, stroke length, stroke index, and SWOLF-Index score. These metrics were meticulously calculated for three distinct phases, thereby facilitating a nuanced examination of the temporal dynamics underlying swimming performance. Comparisons of these parameters across phases revealed significant differences in swimmers’ performance parameters during the start, swimming, and finish phases of the 50-m event. Large effect sizes were observed for time, speed, stroke count, stroke rate, swim index, and SWOLF-Index values.

Top swimmers maximise stroke frequency for those stroke lengths (Zamparo et al., 2020). Because stroke count is inversely related to stroke length, swimmers will also want to complete distance using the fewest number of strokes, which means swimmers will want to maximize distance per stroke. If swimmers take less than that, they should avoid 'over gliding' to avoid speed loss (Morais et al., 2023). Evidence suggests that stroke speed, when accelerated without an optimal speed, induces a reduction of stroke length and premature exhaustion in swimmers (McCabe et al., 2015; Seifert et al., 2014). This, in turn, can increase stroke count which is not good for swimming efficiency. In this study, the lowest stroke count and the highest stroke length were obtained in the start phase, while the highest speed value of the swimmers was also found in this phase. We can say that this situation is due to the fast start of the race in sprint distances.

High swimming index values are closely linked to performance, as they reflect both speed and distance covered per stroke (López-Plaza et al., 2024; Morais et al., 2023). Morais et al. (2010) pointed out that the swimming index is a key factor in determining how well a swimmer performs in freestyle, particularly when considering stroke length. Because butterfly and breaststroke are repetitive strokes, swimmers typically use a higher stroke frequency in these styles. But as with other strokes, an excessively high frequency can shorten the stroke and decrease efficiency (Seifert et al., 2007b). Technology has made it possible for swimmers to determine their swimming index in real time while training, enabling them to make quick technical corrections (Seifert et al., 2007a). This study's findings align with existing literature, showing that both the swim index and stroke frequency tend to drop towards the end of a race as speed decreases.

SWOLF-Index point studies are often applied in training with athletes of all age groups. A low SWOLF-Index score indicates athletes' efficiency by reflecting fewer strokes and faster times (Kyriakidou et al., 2024). In a study with 188 university students, it was found that there was a decrease in the SWOLF-Index obtained after swimming training. This index was reported to be suitable for evaluating and predicting swimming performance (Madou et al., 2023). In this study, SWOLF-Index mean values were found to be different according to the phases. We can say that this situation is due to the different distances between the sections (start phase and finish phase 15-meter, swimming phase 20 meter). The SWOLF-Index reached the highest value in the swimming phase, which has the highest distance.

In conclusion, stroke count, stroke length, stroke rate, swim index, and SWOLF-Index are critical biomechanical variables that affect swimming performance. This study showed that there are differences in these parameters according to the phases in short distance sprint backstroke race. In addition, large effect sizes were found not only for time, stroke count, and SWOLF-Index, but also for speed, stroke rate, and swim index. SWOLF-Index obtained with fewer strokes may reflect greater efficiency, especially in developing swimmers. However, in elite swimmers, knowing only the SWOLF-Index will not be sufficient. Therefore, the evaluation of advanced kinematic analyses on stroke mechanics by sports scientists will provide more meaningful and in-depth information. As a result of these evaluations, coaches' knowledge of athlete-specific stroke mechanics will contribute to the athlete's propulsive efficiency and the ability to maintain stable stroke mechanics during fatigue. During practical applications, phase-specific drills may be conducted by coaches. Assessment methods such as SWOLF and swim index are widely used by sports scientists and coaches to monitor the performance development of swimmers. In future research, it is recommended to examine the stroke mechanics of breaststroke or butterfly style. In addition, whether there is a difference according to training levels in different age groups may be the subject of future research. The limitations of this study include the fact that only male athletes were included in this study and only the 50m distance backstroke style was analyzed.

Funding: This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

Conflicts of Interest: The authors declare that they have no conflicts of interest.

Authorship Contribution Statement: Study Design-BKA; AÖ, Data Collection-BKA; AÖ, Statistical Analysis-BKA, Manuscript Preparation-BKA; AÖ. All authors read and approved the final manuscript.

Generative AI Disclosure: All stages of this study including the research idea, design, data analysis, and writing were entirely carried out by the authors. No generative AI tools were used to produce content. Generative AI was employed solely to assist with minor grammatical corrections and to enhance the fluency of the English translation, without altering the meaning, scientific integrity, or original expression of the author.

Ethics Approval
Ethics Committee: Halic University Non-Interventional Clinical Research Ethics Committee
Date/Protocol number: Date 27.02.2025 Protocol Number 279

REFERENCES

Aprilo, I., Arfanda, P. E., Mappaompo, M. A., Rizal, A., & Asyhari, H. (2025). Biomechanical analysis of tennis spin serve technique using Kinovea in beginner athletes in South Sulawesi. *Journal Physical Health Recreation*, *5*(2), 472-478. [CrossRef]

Barbosa, A. C., Barroso, R., Gonjo, T., Rossi, M. M., Paolucci, L. A., Olstad, B. H., & Andrade, A. G. (2021). 50 m freestyle in 21, 22 and 23 s: What differentiates the speed curve of world-class and elite male swimmers?. *International Journal of Performance Analysis in Sport, 21*(6), 1055-1065. [CrossRef]

Barbosa, T. M., Marinho, D. A., Costa, M. J., & Silva, A. J. (2011). Biomechanics of competitive swimming strokes. In V. Klika (Eds.), *Biomechanics in applications* (pp.367-380). InTech.

Bulgan-Ercin, Ç. (2023). *Adölesan yüzücülerin alt ekstremite kinetik ve kinematiklerinin incelenmesi*. Spor.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences (2. edition).* Lawrence Erlbaum Associates.

Craig, A. B., & Pendergast, D. R. (1979). Relationships of stroke rate, distance per stroke, and velocity in competitive swimming. *Medicine and Science in Sports, 11*(3), 278-283.

Daly, D. J., Djobova, S. K., Malone, L. A., Vanlandewijck, Y., & Steadward, R. D. (2003). Swimming speed patterns and stroking variables in the paralympic 100-m freestyle. *Adapted Physical Activity Quarterly, 20*(3), 260-278. [CrossRef]

Delgado-Gonzalo, R., Lemkaddem, A., Renevey, P., Calvo, E. M., Lemay, M., Cox, K., Ashby, D., Willardson, J., & Bertschi, M. (2016). Real-time monitoring of swimming performance. In *2016 38th annual international conference of the IEEE engineering in medicine and biology society* (pp. 4743-4746). IEEE.

Feitosa, W. G., Correia, R. D. A., Barbosa, T. M., & Castro, F. A. D. S. (2022). Performance of disabled swimmers in protocols or tests and competitions: A systematic review and meta analysis. *Sports Biomechanics, 21*(3), 255-277. [CrossRef]

Figueiredo, P., Silva, A., Sampaio, A., Vilas-Boas, J. P., & Fernandes, R. J. (2016). Front crawl sprint performance: A cluster analysis of biomechanics, energetics, coordinative, and anthropometric determinants in young swimmers. *Motor Control*, *20*(3), 209-221. [CrossRef]

Garland-Fritzdorf, S., Hibbs, A., & Kleshnev, V. (2009). Analysis of speed, stroke rate, and stroke distance for world-class breaststroke swimming. *Journal of Sports Sciences, 27*(4), 373-378. [CrossRef]

Gonjo, T., & Olstad, B. H. (2021). Race analysis in competitive swimming: A narrative review. *International Journal of Environmental Research and Public Health, 18*(1), Article 69. [CrossRef]

Hair, J. F., Black, W. C., Babin, B. J., Anderson, R. E., & Tatham, R. L. (2013). *Multivariate data analysis*. Pearson Education Limited.

Kaya, B. (2012). 9-11 yaş grubu serbest yüzücülerde kulaç uzunluğu ve sıklığının performansa etkisi [Effect of stroke length and stroke frequency on performance for crawl swımmers in 9-11 age groups]. *Sport Sciences, 7*(2), 27-36.

Kıstak-Altan, B., & Odabaş, H. İ. (2023). Yüzmede ısınma performansının kulaç mekaniğine etkileri: Tanımlayıcı araştırma [Effects of Warm-up Performance on Stroke Mechanics in Swimming: Descriptive Research]. *Turkiye Klinikleri Journal of Sports Sciences*, *15*(1), 25-33. [CrossRef]

Kyriakidou, G., Tsalis, G., & Evaggelinou, C. (2024). Impact of a three-month training break on swimming performance in athletes with intellectual disability. *Sports, 12*(12), Article 330. [CrossRef]

López-Plaza, D., Quero-Calero, C. D., Alacid, F., & Abellán-Aynés, O. (2024). Stroke steadiness as a determinant factor of performance in 100 m freestyle in young swimmers. *Sports*, *12*(4), Article 107. [CrossRef]

Madou, T., Vanluyten, K., Martens, J., & Iserbyt, P. (2023). Assessment and prediction of swimming performance using the SWOLF index. *International Journal of Kinesiology in Higher Education*, *7*(1), 76-85. [CrossRef]

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

Marinho, D. A., Barbosa, T. M., Rouboa, A. I., & Silva, A. J. (2011). The hydrodynamic study of the swimming gliding: A two-dimensional computational fluid dynamics (CFD) analysis. *Journal of Human Kinetics*, *29*, 49-57. [CrossRef]

McCabe, C. B., Sanders, R. H., & Psycharakis, S. G. (2015). Upper limb kinematic differences between breathing and non-breathing conditions in front crawl sprint swimming. *Journal of Biomechanics, 48*(15), 3995-4001. [CrossRef]

Mooney, R., Corley, G., Godfrey, A., Quinlan, L. R., & ÓLaighin, G. (2015). Inertial sensor technology for elite swimming performance analysis: A systematic review. *Sensors*, *16*(1), Article 18. [CrossRef]

Morais, J. E., Barbosa, T. M., Bragada, J. A., Nevill, A. M., & Marinho, D. A. (2023). Race analysis and determination of stroke frequency–stroke length combinations during the 50-m freestyle event. *Journal of Sports Science & Medicine, 22*(1), 156-165. [CrossRef]

Morais, J. E., Jesus, S., Lopes, V., Garrido, N., Silva, A. J., Marinho, D. A., & Barbosa, T. M. (2010). Linking selected kinematic, anthropometric, and hydrodynamic variables to young swimmer performance. *Pediatric Exercise Science*, *22*(4), 649–664. [CrossRef]

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), Article 75. [CrossRef]

Olstad, B. H., Wathne, H., & Gonjo, T. (2020). Key factors related to short course 100 m breaststroke performance. *International Journal of Environmental Research and Public Health, 17*(17), Article 6257. [CrossRef]

Özüak, A. (2023). *Teknikleri ile hızlı yüzme*. İstanbul Tıp Kitabevi.

Pérez-Tejero, J., Veiga, S., Almena, A., Navandar, A., & Navarro, E. (2017). Effect of functional classification on the swimming race segments during the 2012 London Paralympic Games. *International Journal of Performance Analysis in Sport, 17*(4), 406-417. [CrossRef]

Ruiz-Navarro, J. J., Santos, C. C., Born, D. P., López-Belmonte, Ó., Cuenca-Fernández, F., Sanders, R. H., & Arellano, R. (2025). Factors relating to sprint swimming performance: A systematic review. *Sports Medicine, 55*, 899-922. [CrossRef]

Santos, C. C., Marinho, D. A., Neiva, H. P., & Costa, M. J. (2024). Propulsive forces in human competitive swimming: A systematic review on direct assessment methods: Propulsive forces in competitive swimming. *Sports Biomechanics, 23*(10), 1263-1283. [CrossRef]

Seifert, L., & Carmigniani, R. (2023). Coordination and stroking parameters in the four swimming techniques: A narrative review. *Sports Biomechanics*, *22*(12), 1617-1633. [CrossRef]

Seifert, L., Chollet, D., & Bardy, B. G. (2007a). Effect of swimming velocity on arm coordination in the front crawl: a dynamic analysis. *Journal of Sports Sciences, 25*(14), 651-660. [CrossRef]

Seifert, L., Chollet, D., & Rouard, A. (2007b). Swimming constraints and arm coordination. *Human Movement Science, 26*(1), 68–86. [CrossRef]

Seifert, L., Komar, J., Barbosa, T., Toussaint, H., Millet, G., & Davids, K. (2014). Coordination pattern variability provides functional adaptations to constraints in swimming performance. *Sports Medicine, 44*, 1333-1345. [CrossRef]

Şenel, Ö., & Baykal, C. (2017). 11-12 yaş yüzücülerde kulaç oranı ve kulaç uzunluğunun bazı antropometrik özelliklerle ilişkisi [The relationship between stroke-rate, stroke-length and some anthropometric features in 11 - 12 year old swimmers]. *International Journal of Human Sciences*, *14*(4), 4077-4087.

Şimşek, H. B. (2024). *11-12 yaş erkek yüzücülerin 50 metre serbest yarışında kol sayısı ve sıklığının yüzme süresi ile ilişkisi*. [Unpublished master dissertation]. Marmara University.

Takagi, H., Nakashima, M., Sengoku, Y., Tsunokawa, T., Koga, D., Narita, K., Kudo, S., Sanders, R., & Gonjo, T. (2023). How do swimmers control their front crawl swimming velocity? Current knowledge and gaps from hydrodynamic perspectives. *Sports Biomechanics*, *22*(12), 1552-1571. [CrossRef]

Zamparo, P., Cortesi, M., & Gatta, G. (2020). The energy cost of swimming and its determinants. *European Journal of Applied Physiology, 120*(1), 41-66. [CrossRef]