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Investigation of the Relationship Between Arm-Leg Volume and Stroke Length with Swimming Performance in Young Male Swimmers

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Research Article

Keywords: Arm-Leg Volüme, Stroke Length, Swimming

Posted Date: June 10th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9790684/v1

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Additional Declarations: No competing interests reported.

Abstract

Background

The aim of this study was to investigate the relationship between arm and leg volume and stroke length and swimming performance in young male swimmers.

Methods

A minimum of 15 young male licensed swimmers voluntarily participated in this study. The swimmers were measured for height, weight, BMI, arm volume, leg volume, and stroke length, as well as swimming performance over 50, 100, and 200 meters in all swimming styles. The obtained data were analyzed using SPSS software. Descriptive statistics were used for the demographic information of the swimmers, while Pearson correlation analysis was used to determine the relationships between total arm-leg volumes, stroke length, and 50-, 100-, and 200-meter swimming performances in all styles. The significance level was accepted as “$p < 0.05$”.

Results

A significant relationship was found between arm volume and 50-meter and 100-meter performances in the backstroke style in young male swimmers. While there was no significant relationship between leg volume and 50-meter and 200-meter performances in freestyle, significant relationships were found with performances in all other styles. In addition, although there was no significant relationship between stroke length and 200-meter performances in freestyle and breaststroke styles, stroke length had significant effects on performances in the other styles and influenced overall swimming performance.

Conclusions

Arm and leg volume together with stroke length appear to be important anthropometric and biomechanical determinants of swimming performance in young male swimmers, with their effects varying according to swimming style and race distance. These findings suggest that optimizing limb development and stroke mechanics may contribute positively to overall swimming performance in young athletes.

Introduction

Swimming is a complex sport that encompasses endurance, strength, and technical skills, and involves numerous physiological and biomechanical factors affecting performance (Smith et. al., 2002). It is widely practiced among young age groups both as a competitive and recreational activity. Since young performance athletes are in a stage of physical and physiological development, training programs

implemented during this period must be carefully planned. The bodies of young athletes possess the flexibility and endurance capacity to adapt to training intensity and workloads. However, due to significant differences in physical development during this stage, a training model that takes individual variations into account should be adopted. Training programs focusing on muscle strength, endurance, and flexibility not only help young athletes move more efficiently in the water but also optimize hydrodynamic advantages (Liu et. al., 2025; Jin et. al., 2024). Young swimmers should learn to adapt their movement mechanics to progress through the water with minimal resistance. Training emphasizes fundamental biomechanical factors such as stroke length, stroke rate, body position, and breathing techniques can enhance swimming efficiency. Determinants of swimming performance include stroke rate, stroke length, body composition, muscle strength, and the volume of body segments (Kılıç, 1999).

Among these factors, arms and legs represent the primary components of movement in swimming; therefore, the influence of arm and leg volume on swimming performance has become an important subject of research. A larger arm and leg volume may provide an advantage by increasing swimming speed, while at the same time affecting hydrodynamic resistance. For this reason, it is necessary to examine in detail the impact of body segment volume on swimming performance (Alp, 2022).

A greater muscle mass and volume in the arms and legs may positively influence swimming performance by providing a higher force production capacity (Salo & Riewald, 2008). In particular, the strength and muscle volume of the upper extremities are directly related to stroke length and stroke rate. An increase in stroke length enables the swimmer to cover more distance per stroke, creating a more efficient movement mechanism and contributing to energy conservation. However, since muscle volume increases proportionally with body weight, it may also affect buoyancy. Therefore, swimmers must maintain an optimal muscle volume to ensure ideal density and balance in the water (Dekerle et. al., 2002; Şenel & Baykal, 2017).

The relationship between muscle mass and swimming performance may also vary depending on the swimming style. While upper extremity strength plays a more decisive role in freestyle, the volume and strength of the lower extremities are more influential in styles such as breaststroke. Moreover, the impact of body muscle ratio on swimming performance can differ according to factors such as sex, age, and training level (Klentrou & Montpetit, 1991; Siders et. al., 1993; Mazza et. al., 1993).

Stroke length is a determining factor in swimming velocity and, together with stroke rate, defines a swimmer’s optimal performance. Stroke length is closely related to the force applied to the water and body position during swimming. Longer strokes reduce the number of strokes needed to cover a given distance, allowing the swimmer to expend less energy while contributing to increased velocity. However, this is directly dependent on muscle strength, flexibility, and technical proficiency (Morais et. al., 2022).

One of the factors influencing stroke length is the ratio of body height to arm length. Swimmers with longer arms can cover a greater area of the water, enabling more effective forward propulsion. In addition, the proper timing of force application and synchronization of movements throughout the stroke cycle significantly affect performance (Morais et. al., 2020).

In addition to technical factors, the hydrodynamic resistance of water is one of the fundamental elements influencing stroke length. Swimmers must optimize body position and minimize resistance to maximize stroke length efficiency. In this context, it is crucial that training programs are designed with a balanced focus on both technical development and muscular strength enhancement (Naemi et. al., 2009).

In the light of this information, the aim of our study is to investigate the relationship between arm and leg volume, stroke length, and swimming performance in young male swimmers.

Method

Characteristics of Athletes Participating in the Study

The study was conducted with 15 licensed young male athletes from the Provincial Directorate of Youth and Sports Swimming Team. Prior to participation, each athlete and their parents were informed about the confidentiality of the collected data and personal information, and both the “Voluntary Participation Form” and the “Parental Consent and Information Form” were obtained.

The mean age of the athletes was 14.93 ± 0.799 years, the mean body weight was 61.53 ± 10.36 kg, the mean height was 171.40 ± 8.69 cm, and the mean BMI was 20.91 ± 3.09 kg/m².

Location and Time of Study

The measurements of the athletes were carried out between February 1, 2025, and March 1, 2025, at the Tahsin Bilginer Swimming Pool of the Isparta Provincial Directorate of Youth and Sports.

Criteria for Including and Excluding Swimmers in the Study

Fifteen male athletes, licensed in the youth category, participated in the study. The inclusion criteria for the study were as follows:

- Being between 14 and 17 years of age.
- Having no chronic injuries or history of injuries.
- Being licensed swimmers in the swimming discipline for at least 5 years.

The exclusion criteria for the study were as follows:

- Athletes younger than 14 years of age.
- Athletes with chronic injuries or a history of injuries.
- Athletes who have been licensed swimmers in the swimming discipline for less than 5 years.

Data Collection Tools

Height Measurement: The athletes' height was measured using a SECA stadiometer with a precision of 0.1 mm. Measurements were taken with the athletes in an anatomical standing position, arms hanging down, and head in a horizontal position, and were recorded in centimeters (cm).

Body Weight Measurement: The athletes' body weight was measured using a SECA electronic scale with a precision of 0.5 kg. Measurements were taken with the athletes barefoot and wearing only shorts and a T-shirt and were recorded in kilograms (kg).

BMI Calculation: The swimmers' BMI values were calculated and recorded in terms of body weight (kg) divided by height squared (m^2).

Determining the Gluteal Crease: For the measurement, the athlete wore a brief swimsuit, and the gluteal fold of the leg to be measured was identified. While standing upright, the athlete placed the contralateral leg on a bench or supporting device so that the knee was flexed at 90° and the thigh formed a 90° angle with the torso. The gluteal fold of the leg to be measured was then marked with a pen to clearly indicate the reference point. After marking, the athlete lowered the leg and stood with feet shoulder-width apart in an upright position. A 50 cm ruler was then aligned with the mark, kept straight, and the gluteal fold line was drawn. For bilateral measurements, the gluteal fold of the opposite leg was determined using the previously measured leg as a reference to minimize error.

Arm Volume Measurements

Arm Volume Measurement and Calculation: The athletes' arm volumes were measured with the arms positioned shoulder-width apart, and the distance between the acromion and olecranon was recorded at 10% intervals with a precision of ±1 mm.

After measuring arm volume at 10% intervals, the volume of each segment was calculated according to the frustum marking method. The total arm volume was then determined by summing the volumes of all segments measured between the acromion and olecranon (Lund et. al., 2002; Sukul et. al., 1993; Karges et. al., 2003).

Forearm Volume Measurement and Calculation: The athletes' forearm volumes were measured with the legs positioned shoulder-width apart, and the distance between the olecranon and ulnar styloid processes was recorded at 10% intervals with a precision of ±1 mm. After measuring forearm volume at 10% intervals, the volume of each segment was calculated according to the frustum marking method. The total forearm volume was then determined by summing the volumes of all segments between the olecranon and ulnar styloid processes (Lund et. al., 2002; Sukul et. al., 1993; Karges et. al., 2003).

Leg Volume Measurements: When calculating leg volume, the volume between the gluteal fold and the foot bone was determined, and the total thigh and calf volumes were then summed to obtain the overall leg volume.

Thigh Volume Measurement and Calculation: The swimmers' leg volumes were measured from the inguinal fold to the tibial point to determine thigh volume. These distances were recorded at 10% intervals and measured according to the frustum marking method (Lund et. al., 2002; Sukul et. al., 1993; Karges et. al., 2003).

Thigh volume was measured along the distance between the tibial point and the inguinal fold at 10% intervals. The volume of each segment was then calculated according to the frustum marking method, and the total thigh volume was obtained by summing all segments between the tibial point and the inguinal fold (Lund et. al., 2002; Sukul et. al., 1993; Karges et. al., 2003).

Calf Volume Measurement and Calculation: The swimmers' calf volumes were measured from the tibial point to the medial malleolus. These distances were recorded at 10% intervals and measured according to the frustum marking method (Lund et. al., 2002; Sukul et. al., 1993; Karges et. al., 2003).

Calf volume was measured along the distance between the tibial point and the medial malleolus at 10% intervals. The volume of each segment was then calculated according to the frustum marking method, and the total calf volume was obtained by summing all segments between the tibial point and the medial malleolus (Lund et. al., 2002; Sukul et. al., 1993; Karges et. al., 2003).

Stroke Length Measurements: The swimmers' stroke lengths were measured with the legs positioned shoulder-width apart and the arms extended laterally, parallel to the ground, by measuring the distance between the dactylion points of the right and left hands using a tape measure. Prior to the measurements, all swimmers were provided with the necessary information regarding the tests. All tests were conducted at the same time of day as the athletes' regular training sessions to ensure consistency. All measurements were carried out at the Tahsin Bilginer Swimming Pool of the Isparta Provincial Directorate of Youth and Sports by qualified personnel.

Swimming Performance Measurements: Prior to the assessment of swimming performance, the swimmers performed warm-up exercises, after which the tests were conducted. The 50 m, 100 m, and 200 m performance times were recorded using a Casio stopwatch (USA) with a precision of 1/1000 seconds.

Statistical Analyses

A statistical software package was used to evaluate the statistical analyses of the study. For all variables, the Shapiro-Wilk test, which is preferred for small datasets, was applied to assess the assumption of normal distribution. The test results indicated that all variables were normally distributed. Descriptive statistics were used to present the demographic information of the swimmers, while Pearson correlation analysis was applied to examine the relationships between total arm and leg volumes, stroke lengths, and swimming performance in 50 m, 100 m, and 200 m across all styles. All analysis results are presented in tables along with their explanations. Data were evaluated at a significance level of $p < 0.05$.

Results

Table 1 Descriptive Statistics for Swimmers' Age, Height, Weight, and BMI

	N	Min.	Max.	Mean±SD
Age	15	14	16	14.93±0.799
Height	15	156	187	171.40±8.69
Weight	15	43	78	61.53±10.36
BMI	15	17.10	27.30	20.91±3.09

As shown in Table 1, the swimmers had a mean age of 14.93 ± 0.799 years, a mean body weight of 61.53 ± 10.36 kg, a mean height of 171.40 ± 8.69 cm, and a mean BMI of 20.91 ± 3.09 kg/m².

Table 2 Descriptive Statistics of Arm and Leg Volumes, Stroke Lengths, and Swimming Performance

	Distances (m)	N	Mean±SD
Total Arm		15	5820.77±1777.09
Total Leg		15	25852.93±4969.41
Stroke Length		15	176.80±11.90
Freestyle Swimming	50	15	31.60±2.29
	100	15	76.00±9.76
	200	15	157.73±14.08
Backstroke Swimming	50	15	39.20±4.31
	100	15	83.27±6.11
	200	15	188.47±9.76
Breaststroke Swimming	50	15	42.20±3.14
	100	15	94.20±4.16
	200	15	220.07±7.38
Butterfly Stroke Swimming	50	15	37.07±5.12
	100	15	85.47±8.16
	200	15	203.67±12.44

As shown in Table 2, the swimmers mean total arm volume was 5820.77 ± 1777.09, mean total leg volume was 25852.93 ± 4969.41, and mean stroke length was 176.80 ± 11.90. The mean freestyle performance times were 31.60 ± 2.29 s for 50 m, 76.00 ± 9.76 s for 100 m, and 157.73 ± 14.08 s for 200

m. Backstroke times were 39.20 ± 4.31 s for 50 m, 83.27 ± 6.11 s for 100 m, and 188.47 ± 9.76 s for 200 m. Breaststroke times were 42.20 ± 3.14 s for 50 m, 94.20 ± 4.16 s for 100 m, and 220.07 ± 7.38 s for 200 m. Butterfly times were 37.07 ± 5.12 s for 50 m, 85.47 ± 8.16 s for 100 m, and 203.67 ± 12.44 s for 200 m.

Table 3 Pearson Correlation Test Results Between Total Arm Volume and 50-, 100-, and 200-m Swimming Performances

Swimming Strokes	Distances (m)	Mean	SD	r	Sig.
Freestyle Swimming	50	31.60	2.29	-0.284	0.306
	100	76.00	9.76	-0.432	0.108
	200	157.73	14.08	0.234	0.402
Backstroke Swimming	50	39.20	4.31	-0.516	**0.049**
	100	83.27	6.11	-0.535	**0.040**
	200	188.47	9.76	-0.245	0.378
Breaststroke Swimming	50	42.20	3.14	-0.262	0.345
	100	94.20	4.16	-0.237	0.395
	200	220.07	7.38	-0.214	0.443
Butterfly Stroke Swimming	50	37.07	5.12	-0.394	0.146
	100	85.47	8.16	-0.554	**0.032**
	200	203.67	12.44	-0.406	0.133

As shown in Table 3, a significant relationship was found between arm volume and backstroke performance at 50 m and 100 m ($p < 0.05$). However, no significant relationships were observed between arm volume and backstroke 200 m performance or the 50 m, 100 m, and 200 m performances in all other swimming strokes ($p > 0.05$).

Table 4 Pearson Correlation Test Results Between Total Leg Volume and 50-, 100-, and 200-m Swimming Performances

Swimming Strokes	Distances (m)	Mean	SD	r	Sig.
Freestyle Swimming	50	31.60	2.29	-0.487	0.066
	100	76.00	9.76	-0.623	**0.013**
	200	157.73	14.08	0.228	0.413
Backstroke Swimming	50	39.20	4.31	-0.787	**0.000**
	100	83.27	6.11	-0.833	**0.000**
	200	188.47	9.76	-0.673	**0.006**
Breaststroke Swimming	50	42.20	3.14	-0.592	**0.020**
	100	94.20	4.16	-0.537	**0.039**
	200	220.07	7.38	-0.568	**0.027**
Butterfly Stroke Swimming	50	37.07	5.12	-0.677	**0.006**
	100	85.47	8.16	-0.706	**0.003**
	200	203.67	12.44	-0.705	**0.003**

As shown in Table 4, no significant relationship was found between leg volume and freestyle performance at 50 m and 200 m ($p > 0.05$). However, significant relationships were observed between leg volume and freestyle performance at 100 m, as well as the 50 m, 100 m, and 200 m performances in all other swimming strokes ($p < 0.05$).

Table 5 Pearson Correlation Test Results Between Stroke Lengths and 50-, 100-, and 200-m Swimming Performances

Swimming Strokes	Distances (m)	Mean	SD	r	Sig.
Freestyle Swimming	50	31.60	2.29	-0.532	**0.041**
	100	76.00	9.76	-0.570	**0.027**
	200	157.73	14.08	0.329	0.231
Backstroke Swimming	50	39.20	4.31	-0.846	**0.000**
	100	83.27	6.11	-0.730	**0.002**
	200	188.47	9.76	-0.616	**0.014**
Breaststroke Swimming	50	42.20	3.14	-0.554	**0.032**
	100	94.20	4.16	-0.641	**0.010**
	200	220.07	7.38	-0.467	0.079
Butterfly Stroke Swimming	50	37.07	5.12	-0.621	**0.014**
	100	85.47	8.16	-0.883	**0.000**
	200	203.67	12.44	-0.737	**0.002**

As shown in Table 5, no significant relationship was found between stroke length and freestyle 200 m and breaststroke 200 m performance ($p > 0.05$). However, significant relationships were observed between stroke length and the 50 m, 100 m, and 200 m performances in all other swimming strokes ($p < 0.05$).

Discussion

Swimming is regarded as one of the fundamental sports contributing multidimensionally to individuals' physical development. In addition to improving endurance, speed, agility, coordination, flexibility, and motor skills, swimming possesses a highly complex performance structure from both biomechanical and physiological perspectives. In recent years, the role of anthropometric characteristics in determining performance, particularly among young athletes, has become an important area of research interest. José M. González-Ravé and colleagues (2025) reported that swimming performance is closely associated not only with technical capacity, but also with anthropometric, biomechanical, and physiological variables. Similarly, Tiago M. Barbosa et al. (2013), in their deterministic model developed to explain swimming performance, stated that performance emerges from the interaction between energy system capacity, biomechanical structure, hydrodynamic characteristics, and anthropometric variables. The authors emphasized that the balance between propulsive force production and water resistance is one of the major determinants of swimming performance. In addition, Ludovic Seifert et al. (2011) suggested that swimming performance should not be evaluated solely through physical characteristics, but also in conjunction with technical coordination, neuromuscular adaptations, and movement synchronization. In this context, the present study provides important findings regarding the

relationship between arm volume, leg volume, and stroke length with performance across different swimming strokes in young male swimmers.

In the present study, the athletes' mean height was 171.40 ± 8.69 cm, mean body weight was 61.53 ± 10.36 kg, mean BMI was 20.91 ± 3.09 kg/m², mean total arm volume was 5820.77 ± 1777.09 ml, mean total leg volume was 25852.93 ± 4969.41 ml, and mean stroke length was 176.80 ± 11.90 cm. Examination of swimming performance revealed that 50 m, 100 m, and 200 m times in freestyle, backstroke, breaststroke, and butterfly were associated with different anthropometric parameters. In particular, the significant negative relationships observed between arm volume and 50 m and 100 m backstroke performance suggest that upper extremity volume may be an important determinant of short- and middle-distance backstroke performance. Vincenzo Perciavalle et al. (2014) similarly reported that anthropometric characteristics such as height, arm length, forearm length, shoulder width, and arm span significantly influence swimming performance. The researchers emphasized that longer extremities may contribute to swimming speed by generating a larger propulsive surface area. These findings support the results of the present study.

The fact that propulsive force generation in backstroke swimming largely depends on the effective use of the shoulder girdle and upper extremity musculature may explain the current findings. It is thought that increases in upper extremity volume may enhance muscular force production capacity, thereby improving the propulsive force generated per stroke. Huub M. Toussaint and Peter J. Beek (1992), in their investigation of the biomechanics of competitive front crawl swimming, reported that swimming velocity is largely dependent on stroke length, stroke frequency, and propulsive force production in water. They particularly emphasized that the force applied to the water by the upper extremities directly affects swimming economy. Nevertheless, the absence of significant relationships between arm volume and other swimming strokes indicates that swimming performance cannot be explained solely by segmental volume measurements. In freestyle and butterfly swimming, factors such as technical coordination, stroke frequency, energy economy, and hydrodynamic structure also play major roles in performance. Jorge E. Morais et al. (2022) reported that the relationship between stroke length and stroke frequency in freestyle swimming is directly associated with propulsive force production, and that anthropometric advantages can only translate into improved performance when accompanied by sufficient muscular strength. This may explain the absence of significant relationships in some strokes in the present study.

The significant relationships observed between leg volume and performance times in backstroke, breaststroke, and butterfly indicate the critical role of lower extremity volume in swimming performance. Considering the dominant contribution of the legs to propulsive force generation in breaststroke, the contribution of lower extremity volume to performance becomes even more evident. Alp (2022) reported significant relationships between total leg volume and performance across all swimming strokes in swimmers. The findings of the present study are largely consistent with these results. Furthermore, Fajar M. Ihsan and colleagues (2022) stated that leg length and leg muscle strength significantly contribute to 100 m freestyle performance, with the relative contribution of leg muscle strength reaching

approximately 30%. These findings support the notion that lower extremity force production plays an important role in maintaining swimming velocity.

On the other hand, Işıldak et al. (2020) identified a significant negative relationship between leg volume and 50 m freestyle performance, suggesting that increased leg volume may not always provide a performance advantage. The authors proposed that greater volume may be associated more with adipose tissue accumulation than muscle tissue, thereby increasing hydrodynamic resistance. Similarly, Barbosa et al. (2015) reported that the hydrodynamic profile of young swimmers changes throughout the competitive season and that the positioning of body segments in water directly influences swimming economy. In particular, reducing water resistance was reported to play a major role in performance enhancement. In the present study, the lack of significant relationships between leg volume and some performance parameters further suggests that the quality of volume increase is an important consideration. Therefore, in addition to segmental volume measurements, parameters such as lean body mass, muscle quality, and muscle fiber distribution should also be evaluated.

When the relationships between stroke length and performance were examined, significant associations were found for all strokes except 200 m freestyle and 200 m breaststroke. Particularly in short- and middle-distance events, the reduction in swimming times with increased stroke length demonstrates the determining role of stroke length in swimming economy. Ömer Şenel and Baykal (2017) reported a significant negative relationship between performance time and stroke length in male swimmers. Similarly, Kılıç (1999) stated that stroke length and stroke frequency are among the primary determinants of swimming velocity in elite swimmers. Burak Yavaş and Karadenizli (2024) also reported that increases in height are accompanied by increases in stroke length, which may positively contribute to swimming performance. These findings are consistent with the results of the present study. Moreover, Toussaint and Beek (1992) indicated that longer stroke distances may increase the distance traveled per stroke while reducing energy expenditure, thereby improving swimming economy.

The absence of significant relationships between stroke length and 200 m freestyle and breaststroke performance may be explained by the increasing predominance of physiological factors in long-distance events. In particular, aerobic capacity, energy economy, lactate tolerance, and pacing strategies become major determinants of long-distance swimming performance. David B. Pyne and Sharp (2014), in their evaluation of the energy demands of swimming competitions, reported that anaerobic capacity predominates in sprint and middle-distance events, whereas aerobic energy systems become more dominant in longer-distance races. This may explain the reduced influence of anthropometric variables on some 200 m performances observed in the present study. Morais et al. (2013) further reported that, in addition to anthropometric variables, energy systems and kinematic characteristics significantly affect performance in young swimmers. They also noted that high-performing athletes tended to have greater anthropometric characteristics and longer training histories. Similarly, Cüneyt Ölmez et al. (2017) reported that increasing training age improves swimming performance, particularly in backstroke, breaststroke, and butterfly events. These findings indicate that swimming performance is influenced not only by morphological characteristics but also by long-term training adaptations.

Although the relationship between BMI and performance was not directly examined in the present study, Süleyman Yüksek et al. (2017) reported a significant negative relationship between BMI and 50 m backstroke performance in male swimmers. This finding highlights the importance of optimal body composition for swimming performance. Excessive body fat may increase drag forces in water and negatively affect swimming economy. However, excessively low body fat percentages may also adversely affect energy metabolism and recovery processes in young athletes.

The literature also includes studies examining the relationship between extremity volumes and performance in different sports branches. Serkan Dağlı and Alp (2025) investigated the relationship between leg volume and vertical jump performance in female basketball and volleyball players and reported a positive relationship between leg volume and jump performance measured in watts, particularly in basketball players. Similarly, Ahmet Özkan et al. (2023) stated that leg volume and mass play important roles in determining anaerobic performance. In contrast, Özkan et al. (2015) reported no clear relationship between leg volume and anaerobic performance in football players. These differences indicate that performance characteristics vary according to the biomechanical demands specific to each sport. In swimming, due to hydrodynamic structure, water resistance, and propulsive force production, the effects of extremity volume on performance may differ substantially from land-based sports.

One of the major strengths of the present study is the simultaneous evaluation of three race distances across four different swimming strokes. Nevertheless, several limitations should be acknowledged. First, the relatively small sample size limits the generalizability of the findings. In addition, because only male athletes were included, the results cannot be directly generalized to female swimmers. The absence of assessments related to muscular strength, body fat percentage, stroke frequency, maximal oxygen consumption, and biomechanical analyses also constitutes an important limitation. Future studies employing longitudinal designs with larger sample sizes are recommended to further investigate the effects of anthropometric development on swimming performance.

Conclusion

The present study demonstrated that arm volume, leg volume, and stroke length are important anthropometric parameters associated with swimming performance in young male swimmers. However, the effects of these parameters varied according to swimming stroke and race distance. Significant relationships between arm volume and 50 m and 100 m backstroke performances suggest that upper extremity morphology may play a critical role in short- and middle-distance backstroke events. Similarly, the significant associations identified between leg volume and performance in backstroke, breaststroke, and butterfly indicate the importance of lower extremity contribution to propulsive force production and swimming velocity maintenance.

In addition, stroke length was found to be significantly associated with performance in most swimming events, particularly in short- and middle-distance races, highlighting the importance of stroke mechanics and swimming economy in competitive performance. Nevertheless, the absence of significant

relationships between stroke length and some 200 m performances suggests that physiological determinants such as aerobic capacity, energy efficiency, and pacing strategies may become more influential in longer-distance events.

Overall, the findings of the present study support the notion that swimming performance cannot be explained solely by technical proficiency, but rather emerges through the interaction of anthropometric, biomechanical, hydrodynamic, and physiological factors. In this context, extremity volume and stroke length may provide valuable indicators for athlete monitoring, talent identification, and individualized training program design in young swimmers.

Practical Implications and Recommendations

Based on the findings of the present study, it is recommended that coaches and sports scientists consider anthropometric characteristics such as arm volume, leg volume, and stroke length during athlete selection and long-term performance development processes. Since the influence of these variables differs according to swimming stroke and race distance, individualized training approaches should be adopted for each athlete.

Particularly in backstroke and breaststroke events, training strategies aimed at improving upper and lower extremity strength and propulsive force production may contribute positively to performance enhancement. Furthermore, technical training focused on optimizing stroke length and stroke efficiency may improve swimming economy, especially in short- and middle-distance races.

Future studies should include larger and more heterogeneous samples involving both male and female swimmers from different competitive levels. In addition, longitudinal research designs examining the interaction between anthropometric development and performance changes throughout maturation are recommended. The inclusion of biomechanical analyses, body composition measurements, stroke frequency assessments, muscular strength evaluations, and physiological parameters such as maximal oxygen uptake and lactate responses may provide a more comprehensive understanding of the determinants of swimming performance.

Finally, integrating anthropometric evaluations with biomechanical and physiological monitoring systems may contribute to the development of evidence-based training models and more effective talent identification programs in competitive swimming.

Declarations

Acknowledgements

The authors thank all athletes who participated in the study.

Authors’ contributions

SS and EY contributed to the concept and design of the study; SS collected the data; EY contributed to the analysis and interpretation of the data; SS and EY drafted the manuscript; SS and EY critically revised the manuscript for important intellectual content.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability

Raw data supporting the findings of this study will be provided by the corresponding author upon reasonable request.

Ethics approval and consent to participate

The entire study protocol was approved by the Ethics Committee of Süleyman Demirel University (Date/No.: 02/01/2025–E.917267; Approval Code: 2A501E1B). All procedures performed in this study involving human participants were conducted in accordance with the ethical standards of the institutional research committee and with the Declaration of Helsinki. Written informed consent was obtained from all participants or their legal representatives prior to participation in the study.

Consent to publish

Not applicable.

Competing interests

The authors declare no competing interests.

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