Auras Journal of Sports Sciences
Volume: 04/ Number:03 / Month July/ Year: 2026/ P.p.: 229-250

مجلــة الأوراس لعلوم الرياضة
المجلد:04/ العدد: 03/ الشهر : جويلية/ السنة:2026 /ص ص: 229-250

https://asjp.cerist.dz/en/PresentationRevue/935

Contribution of Kinematic Variables to 100 m Breaststroke Performance: An Analytical Study of Iraqi Youth National Team Swimmers

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Received:12-06-2026 Accepted:18-06-2026 Published:05-07-2026 https://doi.org/10.5281/zenodo.21182164

Abstract:

This study aimed to analyze the contribution of selected kinematic variables to 100 m breaststroke performance among swimmers of the Iraqi Youth National Team. A descriptive survey design was employed, and the study sample consisted of eight purposively selected breaststroke swimmers. Performance and kinematic data were collected and statistically analyzed using SPSS. The results revealed statistically significant relationships between several kinematic variables and 100 m breaststroke performance. Performance in the first 50 m was positively associated with horizontal push-off distance, knee joint angle, ankle angular velocity, and glide time, while a negative relationship was found with horizontal toe acceleration. Similarly, performance in the second 50 m showed significant positive correlations with several variables related to limb motion and center-of-mass mechanics, whereas negative correlations were observed with selected acceleration and angular velocity variables. The study concluded that a number of kinematic variables constitute important determinants of breaststroke performance, highlighting the value of biomechanical analysis in evaluating technical performance and guiding training programs toward the development of the variables that contribute most effectively to athletic achievement.

Keywords: Biomechanics; Kinematics; Athletic Performance; Swimming; 100 m Breaststroke.

1. Introduction:

Kinesiology is one of the fundamental scientific disciplines concerned with the study and analysis of human movement, with the primary aim of enhancing sports performance. It is closely associated with biomechanics, a field that explains the mechanical principles and laws governing human movement in sports contexts (Blazevich, 2017). The integration of kinesiology and biomechanics provides a robust scientific framework that enables coaches, practitioners, and researchers to make evidence-based training decisions, thereby contributing to improved athletic performance and higher levels of competitive achievement (Knudson, 2021).

Swimming is widely recognized as one of the most important Olympic and international sports due to its numerous physical, physiological, and psychological benefits. As a core Olympic discipline, swimming is characterized by intense competition among athletes striving to achieve superior performances and break world records (Barbosa et al., 2020). This growing level of competitiveness has stimulated scientific interest in the application of biomechanical approaches to investigate performance-related issues and identify effective strategies for optimizing swimming performance (McCabe et al., 2019).

Biomechanical analysis has become a fundamental methodological tool in the study of swimming performance because it facilitates the identification and evaluation of kinematic and kinetic variables that influence swimming speed and movement efficiency (Morais et al., 2021). Technical proficiency remains one of the most critical determinants of success in competitive swimming, particularly in breaststroke, which is generally regarded as the slowest of the four competitive swimming strokes due to its unique movement pattern and relatively high hydrodynamic resistance (Seifert & Chollet, 2018).

The effectiveness of breaststroke performance largely depends on the precise coordination between arm pull and leg propulsion, as well as the optimal timing of these actions to maintain forward velocity and minimize energy loss throughout the stroke cycle (Sanders & Psycharakis, 2020). Furthermore, several kinematic factors, including trunk position, center of mass displacement, and joint movement characteristics, play a significant role in determining swimming efficiency and overall performance outcomes (Barbosa et al., 2021).

Recent studies have also highlighted the importance of physical and sports activities in promoting health and improving various dimensions of human development. In this regard, (Benderradji, and Mouhoubi, 2023) reported that participation in sports activities contributes significantly to the enhancement of students' psychological well-being. These findings further emphasize the scientific and practical value of investigating variables associated with motor and sports performance and their contribution to athletic achievement.

Accordingly, the present study seeks to analyze the kinematic variables associated with 100-meter breaststroke performance in a systematic manner. By identifying the most influential biomechanical indicators, the study aims to provide practical insights that can be utilized by coaches and practitioners in the design of evidence-based training programs intended to improve technical efficiency and enhance competitive performance. Therefore, the significance of this research lies in its objective attempt to identify the kinematic variables that contribute most effectively to performance achievement and to provide scientifically grounded information that can be applied in the practical field of sports training.

2. Research Problem

Examining breaststroke swimming particularly in the 100-meter event—we find that the swimmer swims the first 50 meters, performs a turn, and then executes the second 50 meters. Through the researcher's observations, in his capacity as a coach at the Kut Sports Club, he noticed the performance of swimmers across these two covered distances (1st 50m and 2nd 50m). It became apparent that there is a difference in technical performance between the outward and return legs, as well as a variation in the time of the 1st 50m compared to the 2nd 50m.

Justifying and interpreting this difference, and identifying its causes, requires scientific study and analysis, in order to explain the positives and negatives of this change in performance—a change that affects the fluidity of movement, which in turn affects the overall final time of the 100-meter breaststroke race. Therefore, through this study, the researcher attempts to analyze the technical performance of 100-meter breaststroke swimmers in order to identify the nature of the specific kinematic variables that contribute most to and differ most across both covered distances, and ultimately across the full 100-meter distance.

3. Research Objective

To identify the percentage contribution of some kinematic variables to the achievement of 100-meter breaststroke swimming among Iraqi youth national team swimmers.

4. Research Hypothesis

There are statistically significant differences among the kinematic variables contributing to the achievement of 100-meter breaststroke swimming among Iraqi youth national team swimmers.

5. Research Domains

Human Domain: Iraqi youth national team swimmers 100m breaststroke.

Temporal Domain: December 2, 2025 to February 2, 2026.

Spatial Domain: Al-Sha'ab Olympic Swimming Pool.

6. Research Methodology

The researcher adopted the descriptive survey methodology, as it is appropriate for the research problem and serves its stated objective.

7. Research Sample:

The research sample was selected purposively and comprised 8 breaststroke swimmers from the Iraqi youth national team.

8. Sample Homogeneity:

Table (1): Descriptive Statistical Summary of the Basic Variables for the Research Sample (N=8)

No	Basic Measurements	Unit	Mean	Median	Std. Dev	Skewness	Kurtosis
1	Age	Year	16.14	16.00	0.90	-0.35	-1.82
2	Height	cm	157.43	171.00	38.64	-2.62	6.90
3	Weight	kg	78.57	65.00	41.70	2.63	6.94
4	Time of 1st 50m	sec	34.50	34.50	1.19	-1.45	1.48
5	Time of 2nd 50m	sec	36.50	36.50	1.19	-1.45	1.48

** Statistical description of the kinematic variables for the research sample (Appendix 6)*

Table (1), which presents the descriptive statistical summary of the basic variables for the research sample, indicates that the data pertaining to the basic and anthropometric measurements are moderate, non-dispersed, and exhibit a normal distribution. The skewness coefficient values range between (-2.62 and 2.63), approximating zero, which confirms the normality of the data for the basic measurements of the research sample.

9. Data Collection Tools and Instruments

9.1 Tools and Instruments Used for Basic Measurements

- Calibrated medical scale for weight measurement
- Anthropometer for measuring total height and segment lengths
- Measuring tape (mazura) for circumference measurements
- Stopwatch (Stop Watch) for time measurement

9.2 Imaging and Biomechanical Analysis Equipment and Tools

- Five (5) HDR-AS100V High Speed Cameras (set to a frequency of 60 frames/second and an image quality of 1920×1080 pixels) (Appendix 7)
- Sony Live View Remote (RM-LVR1) for camera synchronization
- HP ProBook 4540s laptop computer
- ProDAD Defisher video processing software
- MP4-to-AVI video format conversion software
- Calibration Markers
- Skill Spector 2D Motion Analysis software
- Statistical analysis software: SPSS v.20 and Microsoft Excel 2010
- belitepro.com platform for biomechanical analysis and athletic performance enhancement services for professional athletes

10. Field Research Procedures

10.1 Identification of Research Variables

Research variables were identified through the researcher's personal expertise and personal interviews.

10.2 Pilot Study

The researcher conducted the pilot experiment with the assistance of the supporting team on December 10, 2025. The experiment was performed on two (2) swimmers using four (4) High Speed cameras (Sony AS100V model) to film the swimmers' performance. Camera (1) was positioned perpendicular to the swimmer's right side, 0.40 m below water, and fixed to the pool edge. Camera (2) was positioned perpendicular to the swimmer's left side, 0.40 m below water, and fixed to the outer edge of Lane 5, directly facing Camera (1), such that the swimmer performed in the middle of the distance between the two cameras during the first 50 meters. The same filming procedures were applied for the second 50 meters.

The breaststroke performance of two swimmers in the middle of Lane 3 was filmed using two different video settings:

- Swimmer 1 was filmed at a frequency of 60 frames/second with an image quality of 1920×1080 pixels.
- Swimmer 2 was filmed at a frequency of 120 frames/second with an image quality of 1080×720 pixels.

(This was done to determine the appropriate frame rate and image quality for filming the movement.) The objectives of the pilot study were:

- Selection and preparation of assistants to help the researcher in preparing tools and equipment, conducting measurements, and recording tests
- Verification of the availability, suitability, and operational efficiency of all measurement tools and equipment for test administration
- Verification of the suitability of the venue for test administration
- Determination of an appropriate filming zone for swimmer performance
- Determination of the appropriate frame rate for filming swimmer performance
- Determination of the appropriate image quality for conducting biomechanical analysis of swimmer performance

10.3 Main Experiment

The main study was conducted on eight (8) breaststroke swimmers. The aim of the main study was to record the 1st and 2nd 50-meter breaststroke times for the swimmers in the study sample, and to record the biomechanical variables under investigation.

A. Preparation Phase — Athletes and Equipment:

- Cameras were calibrated at 60 frames/second (1920×1080 pixels) and positioned in the appropriate filming zones as determined by the pilot study
- Swimmers were prepared by placing calibration markers on the body joints (Appendix 8)
- Cameras were fixed at the start of the 1st 25m and at the 75m mark to record the biomechanical variables during the swimmer's maximum organized speed; a 2D drawing scale was taken for each camera individually

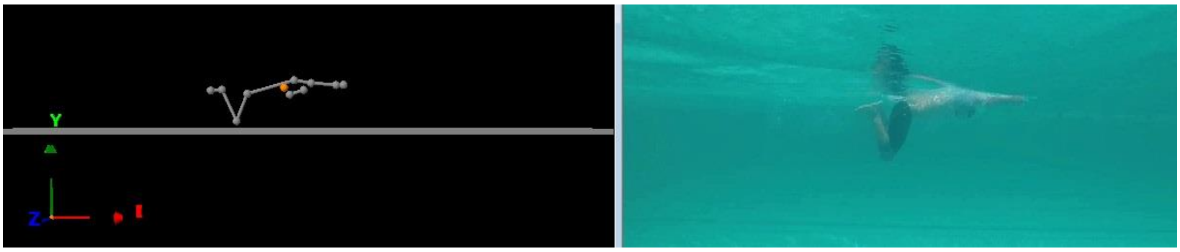
B. Measurement Phase:

Filming was conducted using five (5) high-speed cameras at Full HD 1080-pixel image quality, set to 60 frames/second. Camera (1) was fixed above the pool in the stands to record the total race distance time for each swimmer. Cameras (2) and (3) were positioned as follows: Camera (2) was placed 25 cm below water and Camera (3) was placed directly above the water surface above Camera (2), to record the breaststroke cycle (one stroke) during the first maximum speed zone at the 25meter mark. Cameras (4) and (5, referred to in the original as cameras 3 and 4 for the return) were positioned such that one was 25 cm below the water surface and the other directly above the water surface above it, to record the breaststroke stroke of the study sample during the return leg at the 75-meter mark of the 100-meter race. A posture drawing scale of 1.75m was taken at the midpoint of the filming lane.

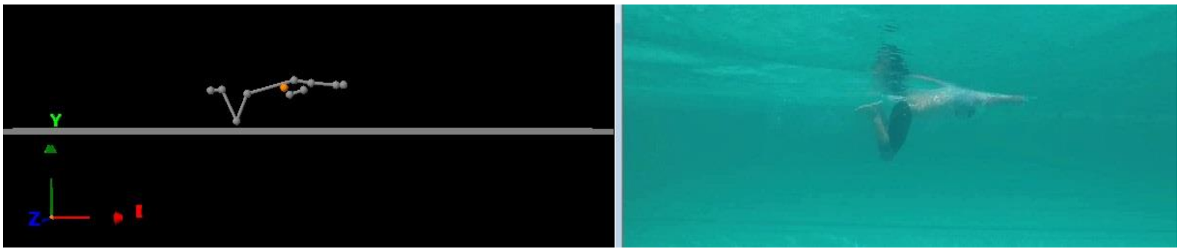
- The performance of all eight swimmers was filmed sequentially
- The 1st 50m and 2nd 50m times were measured
- The stroke count was recorded via Camera (1)

- Moment of arm pull initiation

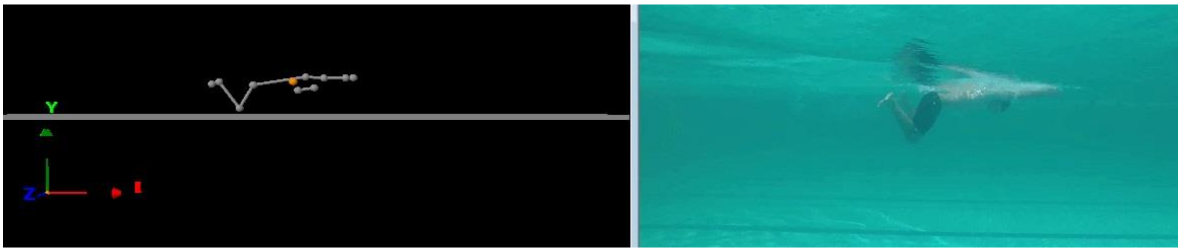
- Moment of arm pull completion



- Moment of maximum knee flexion



- Moment of leg thrust initiation



• Moment of leg thrust completion

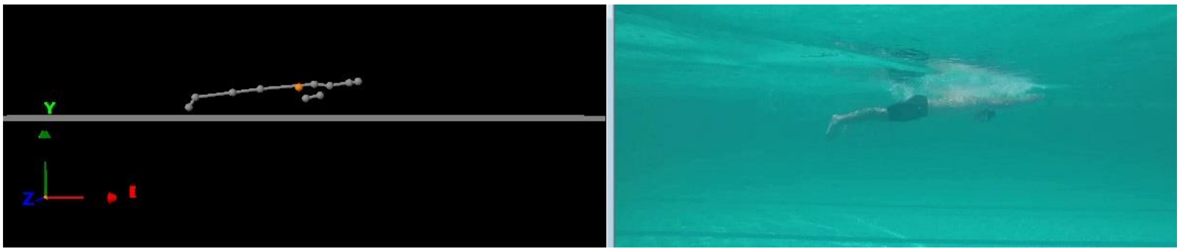


Figure (1) illustrates the performance moments during 50m breaststroke swimming:

C. Data Analysis and Processing:

After completing the measurement phase, data were transferred to a computer and the following processing steps were performed:

- Video processing using ProDAD Defisher software
- Stroke segmentation using VideoPad software
- Video format conversion using MP4-to-AVI conversion software
- Synchronization of video footage for each stroke individually

Biomechanical analysis was performed using Skill Spector 2D software for the following moments:

- Moment of arm pull initiation
- Moment of arm pull completion
- Moment of maximum knee flexion
- Moment of leg thrust initiation
- Moment of leg thrust completion

D. Key Extracted Biomechanical Variables:

Results of the following biomechanical variables were extracted during the performance moments. Biomechanical analysis was performed on 16 trials using Skill Spector 2D, with 8 trials analyzed for the forward leg and 8 for the return leg, extracting the following biomechanical variables:

Table 2. General Kinematic Variables of the Arm and Leg Cycle Phases in Breaststroke Swimming During the First and Second 50-Meter Splits

Biokinematic Variables	Unit of Measurement
Speed of body center of gravity (CoG) at end of leg thrust	m/s
Average CoG speed resulting from the arm and leg cycle	m/s
Time of 1st 50m	sec
Time of 2nd 50m	sec
100m breaststroke time	sec
Horizontal distance of leg thrust	m
Vertical distance of leg thrust	m
Resultant distance of leg thrust	m
Horizontal distance of arm pull	m
Vertical distance of arm pull	m
Resultant distance of arm pull	m
Horizontal CoG displacement due to arm pull	m
Vertical CoG displacement due to arm pull	m
Resultant CoG displacement due to arm pull	m
Horizontal CoG displacement during leg thrust	m
Vertical CoG displacement during leg thrust	m
Resultant CoG displacement during leg thrust	m
Horizontal CoG displacement resulting from leg thrust (glide)	m
Vertical CoG displacement resulting from leg thrust (glide)	m
Resultant CoG displacement resulting from leg thrust (glide)	m
Resultant CoG displacement from the arm and leg cycle	m
Pull time	sec
Recovery and hand-glide time	sec
Thrust time	sec
Glide time	sec
Total cycle time	sec
Average CoG speed during the pull phase	m/s
Average CoG speed during the thrust phase	m/s
Average CoG speed during the glide phase	m/s

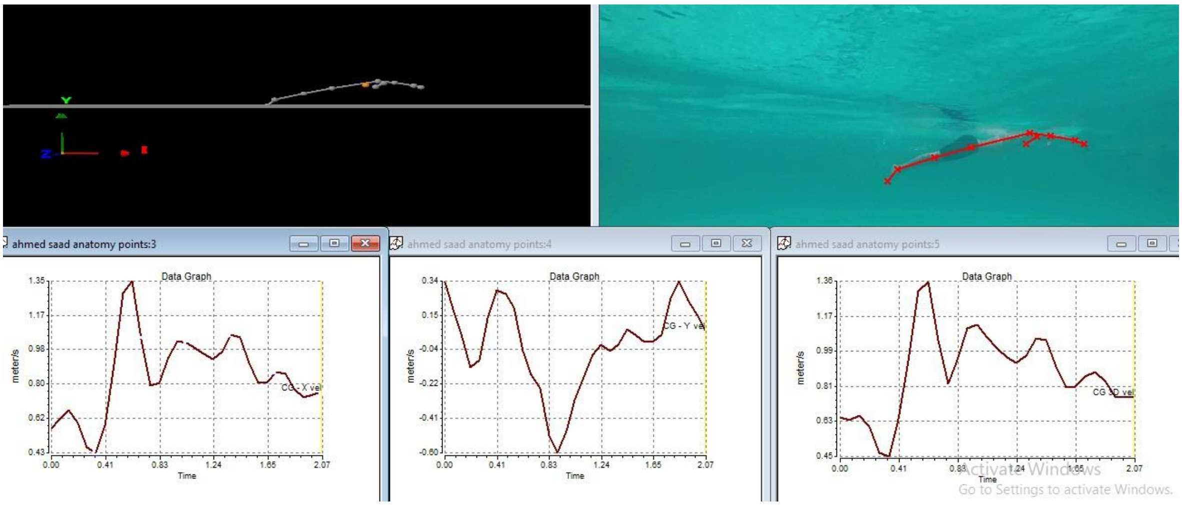


Figure (2): Horizontal, vertical, and resultant velocity curves during arm stroke analysis for the research sample.

11. Statistical Methods

Statistical processing was performed using Microsoft Excel 2010 and SPSS v.20 for the humanities and educational sciences, at a significance level (probability of error) of 0.05, corresponding to a confidence level of 0.95. The following statistical procedures were applied:

- Arithmetic mean (Average)
- Standard deviation
- Skewness coefficient
- Median
- Kurtosis coefficient
- Multiple linear regression and contribution ratios
- Pearson correlation coefficient

12. Presentation and Discussion of Results

12.1 Presentation of Results

12.1.1 Correlation Coefficients:

General Kinematic Variables vs. Performance Indicators (Outward 50m)

Table (4/1): Correlation between General Kinematic Variables (Phase-based) and: CoG Speed at the End of Leg Thrust, Average CoG Speed from the Arm-Leg Cycle, 1st 50m Time, 2nd 50m Time, and 100m Breaststroke Time (N=8)

Biokinematic Variables	Unit	CoG Speed at End of Thrust	Avg. CoG Speed (Cycle)	1st 50m Time	2nd 50m Time	100m Time
CoG speed at end of leg thrust	m/s	1.000	-0.610	-0.378	-0.563	-0.544
Average CoG speed from arm-leg cycle	m/s	-0.610	1.000	0.210	0.608	0.472
1st 50m time	sec	-0.378	0.210	1.000	0.500	.866**
2nd 50m time	sec	-0.563	0.608	0.500	1.000	.866**
100m breaststroke time	sec	-0.544	0.472	.866**	.866**	1.000
Horizontal leg thrust distance	m	0.137	-0.554	0.073	-0.155	-0.048
Vertical leg thrust distance	m	.777*	-.948**	-0.227	-0.547	-0.447
Resultant leg thrust distance	m	.731*	-.955**	-0.179	-0.522	-0.405
Horizontal arm pull distance	m	0.046	-0.434	0.449	-0.033	0.240
Vertical arm pull distance	m	0.423	-0.378	-0.259	0.079	-0.104
Resultant arm pull distance	m	0.339	-0.454	-0.071	0.032	-0.022
Horiz. CoG displacement (arm pull)	m	0.279	0.294	-0.134	0.374	0.139
Vert. CoG displacement (arm pull)	m	0.164	-0.262	0.434	0.463	0.518
Result. CoG displacement (arm pull)	m	0.312	0.263	-0.118	0.394	0.160
Horiz. CoG displacement (leg thrust)	m	0.114	0.278	0.111	0.529	0.369
Vert. CoG displacement (leg thrust)	m	0.030	-0.559	-0.127	-0.072	-0.115
Result. CoG displacement (leg thrust)	m	0.124	0.242	0.101	0.522	0.359

*** Significant (positive/inverse) at 0.01 level   * Significant (positive/inverse) at 0.05 level*

Table (4/1) reveals the presence of a significant positive correlation at the 0.01 and 0.05 levels between the 1st 50-meter time and: the 100-meter breaststroke time, horizontal leg thrust distance, glide time, and total cycle time, with r values of (0.866**, 0.769*, 0.826*) respectively.

Table (4/5) which concerns the correlation between kinematic variables at the moment of leg thrust initiation and: CoG speed at the end of leg thrust, average CoG speed from the arm-leg cycle, 1st 50m time, 2nd 50m time, and 100m breaststroke time reveals a significant positive correlation at the 0.05 level between the angular velocity of the ankle joint and the 1st 50-meter time, with r = (0.769*).

12.1.2 Presentation of Statistical Coefficients for Biomechanical Variables Return 50m Leg

Correlation coefficients between the general kinematic variables (phase-based) and: CoG speed at the end of leg thrust, average CoG speed from the arm-leg cycle, 1st 50m time, 2nd 50m time, and 100m breaststroke time.

Table (4/7): Correlation between General Kinematic Variables (Phase-based) and: CoG Speed at the End of Leg Thrust, Average CoG Speed from the Arm-Leg Cycle, 1st 50m Time, 2nd 50m Time, and 100m Breaststroke Time (N=8)

Biokinematic Variables	Unit	CoG Speed at End of Thrust	Avg. CoG Speed (Cycle)	1st 50m Time	2nd 50m Time	100m Time
CoG speed at end of leg thrust	m/s	1.000	-0.562	0.560	0.124	0.394
Average CoG speed from arm-leg cycle	m/s	-0.562	1.000	-0.439	-0.398	-0.484
1st 50m time	sec	0.560	-0.439	1.000	0.500	.866**
2nd 50m time	sec	0.124	-0.398	0.500	1.000	.866**
100m breaststroke time	sec	0.394	-0.484	.866**	.866**	1.000
Horizontal leg thrust distance	m	-0.014	-0.208	-0.428	-0.376	-0.464
Vertical leg thrust distance	m	0.586	-0.586	-0.051	-0.325	-0.217
Resultant leg thrust distance	m	0.414	-0.517	-0.186	-0.369	-0.320
Horizontal arm pull distance	m	-0.214	-0.511	0.223	0.666	0.513
Vertical arm pull distance	m	0.669	-0.210	0.587	0.565	0.665
Resultant arm pull distance	m	0.493	-0.337	0.608	.724*	.769*
Horiz. CoG displacement (arm pull)	m	.733*	-0.481	.845**	0.552	.807*
Vert. CoG displacement (arm pull)	m	-0.029	-0.495	-0.224	0.305	0.047

Biokinematic Variables	Unit	CoG Speed at End of Thrust	Avg. CoG Speed (Cycle)	1st 50m Time	2nd 50m Time	100m Time
Result. CoG displacement (arm pull)	m	.728*	-0.521	.847**	0.577	.822*
Horiz. CoG displacement (leg thrust)	m	.735*	-0.357	0.690	0.225	0.529
Vert. CoG displacement (leg thrust)	m	0.186	-0.281	0.042	0.091	0.077
Result. CoG displacement (leg thrust)	m	.734*	-0.363	0.688	0.224	0.526
Horiz. CoG displacement due to leg thrust (glide)	m	-0.032	-0.256	0.023	-0.038	-0.009
Vert. CoG displacement due to leg thrust (glide)	m	-0.200	0.165	-0.441	-.715*	-0.667
Result. CoG displacement due to leg thrust (glide)	m	-0.032	-0.256	0.024	-0.039	-0.008
Result. CoG displacement from arm-leg cycle	m	0.226	-0.398	0.288	0.091	0.219

*** Significant at 0.01 level   * Significant at 0.05 level*

12.2. Multiple Regression Analysis General Biomechanical haracteristics (1st and 2nd 50m Legs)

Table (4/31): Multiple Regression Analysis of General Biomechanical Characteristics for the 1st and 2nd 50m Legs Contributing to 100m Breaststroke Race Time

Step	Constant	Biomechanical Characteristic(s)	Regression Coefficient	Contribution %
1	82.009	Recovery and hand-glide time during 2nd 50m	-21.587	84.2%
2	74.347	Recovery and hand-glide time during 2nd 50m Recovery and hand-glide time during 1st 50m	-21.182 14.619	98.7%

Table (4/31) reveals that two variables contributed sequentially to the 100m breaststroke time: (1) recovery and hand-glide time during the 2nd 50m, and (2) recovery and hand-glide time during the 1st 50m, with contribution ratios of 84.2% and 4.5% respectively.

Indicator 1:

The recovery and hand-glide time during the 2nd 50m is the general biomechanical indicator contributing most to the 100m breaststroke time, with a contribution rate of 84.2%.

Based on the above, the predictive regression equation is:

$Y = a + b_1x_1$

$= (82.009) + (-21.587)(0.510)$

Where: a = constant; b_1 = regression coefficient for recovery and hand-glide time during the 2nd 50m; x_1 = value of recovery and hand-glide time during the 2nd 50m.

Indicator 2:

The recovery and hand-glide time during the 1st 50m is the second most contributing general biomechanical indicator, with a contribution rate of 4.5%.

Based on the above, the predictive regression equation is:

$Y = a + b_1x_1 + b_2x_2$

$= (74.347) + (-21.182)(0.510) + (14.619)(0.510)$

Where: a = constant; b_1 = regression coefficient for recovery and hand-glide time during the 2nd 50m; x_1 = its value; b_2 = regression coefficient for recovery and hand-glide time during the 1st 50m; x_2 = its value.

12.3 Multiple Regression — Arm Pull Initiation Moment (1st and 2nd 50m)

Table (4/32): Multiple Regression Analysis of Biomechanical Characteristics at the Moment of Arm Pull Initiation for the 1st and 2nd 50m Legs Contributing to 100m Breaststroke Race Time

Step	Constant	Biomechanical Characteristic(s)	Regression Coefficient	Contribution %
1	75.241	Vertical CoG displacement at the moment of arm pull initiation during 2nd 50m	-335.904	54.9%

Table (4/32) reveals that vertical CoG displacement during the 2nd 50m contributed a rate of (54.9%) to the 100m breaststroke time.

Based on the above, the predictive regression equation is:

$Y = a + b_1x_1$

$= (75.241) + (-335.904)(0.012)$

Where: a = constant; b_1 = regression coefficient for vertical CoG displacement during the 2nd 50m; x_1 = value of vertical CoG displacement during the 2nd 50m.

12.4. Multiple Regression Maximum Knee Flexion Moment (1st and 2nd 50m)

Table (4/33): Multiple Regression Analysis of Biomechanical Characteristics at the Moment of Maximum Knee Flexion for the 1st and 2nd 50m Legs Contributing to 100m Breaststroke Race Time

Step	Constant	Biomechanical Characteristic(s)	Regression Coefficient	Contribution %
1	65.927	Resultant acceleration of knee joint during 2nd 50m (return)	0.334	80.6%
2	69.613	Resultant acceleration of knee joint during 2nd 50m (return) Horizontal CoG speed during 1st 50m (forward)	0.315 -3.984	98.6%
3	69.430	Resultant acceleration of knee joint during 2nd 50m (return) Horizontal CoG speed during 1st 50m (forward) Resultant speed of knee joint during 2nd 50m (return)	0.297 -3.972 0.702	99.8%
4	69.410	Resultant acceleration of knee joint during 2nd 50m (return) Horizontal CoG speed during 1st 50m (forward) Resultant speed of knee joint during 2nd 50m (return) Resultant CoG speed during 1st 50m (forward)	0.295 -7.611 0.438 3.606	100%

Table (4/33) reveals that four variables contributed in the following order: (1) resultant acceleration of knee joint during 2nd 50m return (80.6%), (2) horizontal CoG speed during 1st 50m forward (18%), (3) resultant speed of knee joint during 2nd 50m return (1.2%), and (4) resultant CoG speed during 1st 50m forward (0.2%).

Indicator 1:

Resultant knee joint acceleration during the 2nd 50m (return) is the most contributing biokinematic indicator, with a rate of 80.6%.

$$Y = a + b_1x_1$$
$$= (65.927) + (0.334)(15.17)$$

Where: a = constant; b_1 = regression coefficient for resultant knee joint acceleration during the 2nd 50m (return); x_1 = its value.

Indicator 2:

Horizontal CoG speed during the 1st 50m (forward) is the second most contributing biomechanical indicator, with a rate of 18%.

$$Y = a + b_1x_1 + b_2x_2$$
$$= (69.613) + (0.315)(15.17) + (-3.984)(0.85)$$

Where: b_2= coefficient for horizontal CoG speed during 1st 50m; x_2= its value.

Indicator 3:

Resultant speed of knee joint during the 2nd 50m (return) is the third most contributing indicator, with a rate of 1.2%.

$$Y = a + b_1x_1 + b_2x_2 + b_3x_3$$
$$= (69.430) + (0.297)(15.17) + (-3.972)(0.85) + (0.702)(0.63)$$

Where: b_3 = coefficient for resultant speed of knee joint during 2nd 50m (return); x_3 = its value.

Indicator 4:

Resultant CoG speed during the 1st 50m (forward) is the fourth most contributing indicator, with a rate of 0.2%.

$$Y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4$$
$$= (69.410) + (0.295)(15.17) + (-7.611)(0.85) + (0.438)(0.63) + (3.606)(0.92)$$

Where: b_4= coefficient for resultant CoG speed during 1st 50m (forward); x_4= its value.

12.5 Multiple Regression Leg Thrust Initiation Moment (1st and 2nd 50m)

Table (4/34): Multiple Regression Analysis of Biomechanical Characteristics at the Moment of Leg Thrust Initiation for the 1st and 2nd 50m Legs Contributing to 100m Breaststroke Race Time

Step	Constant	Biomechanical Characteristic(s)	Regression Coefficient	Contribution %
1	57.743	Right knee joint angle during 1st 50m (forward)	0.266	63.8%
2	59.451	Right knee joint angle during 1st 50m (forward) Vertical acceleration of ankle joint during 1st 50m (forward)	0.277 0.161	90.2%
3	60.376	Right knee joint angle during 1st 50m (forward) Vertical acceleration of ankle joint during 1st 50m (forward) Vertical displacement of toe joint during 1st 50m cycle	0.225 0.206 8.517	98.9%
4	60.769	Right knee joint angle during 1st 50m (forward) Vertical acceleration of ankle joint during 1st 50m (forward) Vertical displacement of toe joint during 1st 50m cycle Resultant acceleration of hip joint during 2nd 50m cycle	0.210 0.209 6.573 0.207	99.9%

Table (4/34) reveals that four variables contributed in the following order: (1) right knee joint angle during 1st 50m forward (63.8%), (2) vertical acceleration of ankle joint during 1st 50m forward (6.2%), (3) vertical displacement of toe joint during 1st 50m cycle (2.7%), and (4) resultant acceleration of hip joint during 2nd 50m cycle (1%).

Indicator 1:

Right knee joint angle during the 1st 50m (forward) is the most contributing biokinematic indicator, with a rate of 63.8%.

$$Y = a + b_1x_1$$
$$= (57.743) + (0.266)(49.8)$$

Where: b_1 = coefficient for right knee joint angle during 1st 50m; x_1 = its value.

Indicator 2:

Vertical acceleration of ankle joint during the 1st 50m (forward) is the second most contributing indicator, with a rate of 6.2%.

$$Y = a + b_1x_1 + b_2x_2$$
$$= (59.451) + (0.277)(49.8) + (0.161)(-14)$$

Where: b_2 = coefficient for vertical ankle acceleration during 1st 50m; x_2 = its value.

Indicator 3:

Vertical displacement of toe joint during the 1st 50m cycle is the third most contributing indicator, with a rate of 2.7%.

$$Y = a + b_1x_1 + b_2x_2 + b_3x_3$$
$$= (60.376) + (0.225)(49.8) + (0.206)(-14) + (8.517)(0.56)$$

Where: b_3 = coefficient for vertical toe joint displacement; x_3 = its value.

Indicator 4:

Resultant acceleration of hip joint during the 2nd 50m cycle is the fourth most contributing indicator, with a rate of 1%.

$$Y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4$$
$$= (60.769) + (0.210)(49.8) + (0.209)(-14) + (6.573)(0.56) + (0.207)(4.45)$$

Where: b_4 = coefficient for resultant hip joint acceleration during 2nd 50m; x_4 = its value.

12.6. Multiple Regression Leg Thrust Completion Moment (1st and 2nd 50m)

Table (4/35): Multiple Regression Analysis of Biomechanical Characteristics at the Moment of Leg Thrust Completion for the 1st and 2nd 50m Legs Contributing to 100m Breaststroke Race Time

Step	Constant	Biomechanical Characteristic(s)	Regression Coefficient	Contribution %
1	75.486	Vertical acceleration of knee joint during 2nd 50m cycle	0.429	64.9%
2	75.375	Vertical acceleration of knee joint during 2nd 50m cycle Horizontal acceleration of toe joint during 2nd 50m cycle	0.344 -0.167	98.1%
3	75.325	Vertical acceleration of knee joint during 2nd 50m cycle Horizontal acceleration of toe joint during 2nd 50m cycle Vertical speed of knee joint during 1st 50m cycle	0.436 -0.187 1.696	99.4%

Step	Constant	Biomechanical Characteristic(s)	Regression Coefficient	Contribution %
4	75.316	Vertical acceleration of knee joint during 2nd 50m cycle Horizontal acceleration of toe joint during 2nd 50m cycle Vertical speed of knee joint during 1st 50m cycle Vertical displacement of ankle joint during 2nd 50m cycle	0.470 -0.206 2.588 1.967	99.9%

Table (4/35) reveals that four variables contributed in the following order: (1) vertical acceleration of knee joint during 2nd 50m (64.9%), (2) horizontal acceleration of toe joint during 2nd 50m (3.2%), (3) vertical speed of knee joint during 1st 50m (1.3%), and (4) vertical displacement of *ankle joint during 2nd 50m (1%).*

Indicator 1:

Vertical knee joint acceleration during the 2nd 50m cycle is the most contributing biokinematic indicator, with a rate of 64.9%.

$$Y = a + b_1x_1$$
$$= (75.486) + (0.429)(-9.33)$$

Indicator 2:

Horizontal toe joint acceleration during the 2nd 50m cycle is the second most contributing indicator, with a rate of 3.2%.

$$Y = a + b_1x_1 + b_2x_2$$
$$= (75.375) + (0.344)(-9.33) + (-0.167)(4.93)$$

Indicator 3:

Vertical speed of knee joint during the 1st 50m cycle is the third most contributing indicator, with a rate of 1.3%.

$$Y = a + b_1x_1 + b_2x_2 + b_3x_3$$
$$= (75.325) + (0.436)(-9.33) + (-0.187)(4.93) + (1.696)(0.65)$$

Indicator 4:

Vertical displacement of ankle joint during the 2nd 50m cycle is the fourth most contributing indicator, with a rate of 1%.

$$Y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4$$
$$= (75.325) + (0.436)(-9.33) + (-0.187)(4.93) + (1.696)(0.65) + (1.967)(0.65)$$

Where: b_4 = coefficient for vertical ankle joint displacement during 2nd 50m; x_4 = its value.

13. Discussion of Results:

The results of the correlation analysis (N= 8) revealed a detailed and interrelated pattern between kinematic variables and performance outcomes in both the 50 m and 100 m breaststroke events. Overall, the findings demonstrate that swimming performance is strongly influenced by propulsion efficiency, coordination between limbs, and the effectiveness of body center of mass (CM) control during different phases of the stroke cycle. These results are consistent with contemporary research in swimming biomechanics, which emphasizes the integrated nature of propulsion and hydrodynamics in performance optimization (Nicol et al., 2022; Olstad et al., 2022).A very strong positive correlation was observed between body CM velocity at the end of the leg-drive phase and the average CM velocity generated during the arm–leg cycle ($r = 0.866$). This relationship highlights the critical role of lower-limb propulsion in maintaining and enhancing whole-body velocity. The findings suggest that swimmers who generate higher instantaneous velocity during the kick phase are more capable of sustaining effective forward motion throughout the stroke cycle. This is consistent with recent biomechanical evidence indicating that the breaststroke kick contributes substantially to overall propulsion, particularly during sprint distances where time spent in propulsion phases is crucial (Gourgoulis & Nikodelis, 2022; Nicol et al., 2022).In relation to performance outcomes, the 100 m breaststroke time showed strong negative correlations with both horizontal and vertical leg-drive distances ($r= -0.955$ and $r = -0.948$, respectively). These results indicate that greater effective displacement during the leg-drive phase is associated with improved performance (lower race time). In biomechanical terms, this suggests that swimmers who are able to optimize the direction and amplitude of their kick produce more efficient forward propulsion while minimizing non-propulsive movements. Similar findings have been reported in recent studies, which highlight that inefficient kick mechanics increase drag and reduce propulsion effectiveness, negatively affecting overall performance (Olstad et al., 2022; Seifert et al., 2021).Furthermore, significant relationships were found between the first and second 50 m split times and several kinematic variables related to propulsion efficiency and body CM displacement. These results suggest that performance in both sprint segments is not solely dependent on raw swimming speed but is also strongly influenced by stroke coordination and mechanical efficiency. In particular, coordinated timing between arm recovery, pull phase, and leg propulsion appears to play a central role insustaining velocity across different race phases. This finding aligns with motor control theories in swimming, which emphasize the importance of inter-limb coordination in optimizing propulsion continuity and reducing intra-cycle velocity fluctuations (Seifert et al., 2021; Olstad et al., 2022).In addition, body CM displacement variables during both arm-pull and leg-drive phases demonstrated varying degrees of association with performance measures. Although some correlations were weak, the overall trend indicates that better-controlled CM movement contributes to improved hydrodynamic efficiency. Excessive vertical oscillation of the body is generally associated with increased drag forces, whereas a more streamlined and forward-directed motion enhances swimming efficiency. This interpretation is strongly supported by hydrodynamic principles in aquatic locomotion, which emphasize minimizing resistance while maximizing propulsion effectiveness (Nicol et al., 2022).It is also noteworthy that some kinematic variables showed weak or inconsistent relationships with performance outcomes. This may be attributed to the relatively small sample size (N = 8), individual differences in technique, and the highly complex and coordinated nature of breaststroke swimming, where performance outcomes are influenced by multiple interacting variables rather than isolated biomechanical factors. Such variability has also been reported in previous studies examining elite and sub-elite swimmers, where inter-individual differences significantly affect kinematic-performance relationships (Seifert et al., 2021).The strong negative correlations observed between 100 m performance and leg-drive distances further emphasize the importance of propulsion efficiency in longer sprint events. In particular, effective leg drive appears to play a decisive role not only in short-distance performance but also in maintaining speed endurance across the full 100 m distance. This reinforces the idea that lower-limb contribution is a key determinant of breaststroke performance, especially when combined with efficient arm–leg synchronization (Gourgoulis & Nikodelis, 2022).Overall, the findings of this study confirm that breaststroke performance is highly dependent on the efficiency of the leg-drive phase, the coordination between upper and lower limbs, and the effective management of body center of mass motion. Improvements in these factors lead to enhanced propulsion, reduced hydrodynamic resistance, and ultimately better performance times in both 50 m and 100 m events. These conclusions are strongly supported by recent literature in swimming biomechanics and sports science (Nicol et al., 2022; Olstad et al., 2022; Seifert et al., 2021).

14. Conclusions and Recommendations

14.1 Conclusions

- A significant positive correlation exists between (horizontal leg thrust distance, knee joint angle, angular velocity of the ankle joint, and glide time) and the 50-meter time.

- A significant inverse correlation exists between the horizontal acceleration of the toe muscle variable and the 1st 50-meter time.

- A significant positive correlation exists between the 2nd 50-meter time and: resultant ankle joint speed, knee joint angle, resultant hip joint speed, resultant arm pull distance, glide, pull time, recovery and hand-glide time, horizontal acceleration of the body center of gravity joint, hip joint angle, vertical speed of the toe joint, vertical speed of the ankle joint, resultant knee joint acceleration, and elbow joint angle.

- A significant inverse correlation exists between (horizontal toe joint acceleration, vertical ankle joint acceleration, and angular velocity of the knee joint) and the 2nd 50-meter time.

- The following variables contributed most to the 1st 50m: horizontal CoG speed, resultant CoG speed, knee joint angle, vertical ankle acceleration, vertical toe joint displacement, vertical knee acceleration, horizontal toe joint acceleration, and vertical knee joint speed.

- The following variables contributed most to the 2nd 50m: vertical CoG displacement, resultant knee joint acceleration, resultant knee joint speed, resultant hip joint acceleration, and vertical ankle joint displacement.

14.2. Recommendations

- Conduct similar studies employing kinematic variables across different age groups.

- Utilize the findings of this study and attempt to analyze other skills across various age levels.

- Ensure the availability of motion analysis equipment and underwater cameras capable of synchronization with motion analysis devices, to better investigate interrelated variables.

- Use the mean values of the kinematic variables under study for 100-meter breaststroke swimmers to guide performance modification and to develop specialized training programs accordingly.

- Give attention to the kinematic variables specific to 100-meter breaststroke swimming when designing event-specific training programs.

- Train on maintaining the movement path for the arm and leg phases throughout the pull and thrust stages of 100-meter breaststroke.

- Conduct periodic assessments based on the kinematic variables for 100-meter breaststroke swimmers and utilize these results in the evaluation of training curricula.

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