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Exploring the Correlation between Physical Fitness and Kinematic Parameters in Butterfly Stroke among Physical Education Students

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Abstract The study aimed to investigate the potential relationship between physical conditioning and several kinematic variables associated with the butterfly stroke, specifically butterfly swimming arm stroke length, frequency, and average swimming speed over 25m. The study sample comprised twelve proficient butterfly swimmers who were students enrolled in swimming courses within a physical education faculty. Data were collected through a pre-designed physical condition description test. The test items used in this study were categorized based on the five dimensions of physical fitness, namely muscular strength, endurance, speed, flexibility, and agility, which were employed to assess the participants' physical states. The statistical analysis of the study was conducted by the researcher using various statistical variables, including averages, standard deviations, and the Pearson correlation coefficient. The following kinematic variables were analyzed based on this data: stroke length, stroke frequency, and swimming speed. The results of the study revealed a positive correlation between the muscle strength state and the average stroke length of the arms during butterfly swimming. Additionally, a positive correlation was found between speed and the stroke frequency rate, as well as swimming speed. In light of these findings, the researcher recommends that swimming courses should prioritize the enhancement of muscle strength and speed elements to improve the kinematic variables associated with butterfly swimming among students of the Faculty of Physical Education.

Keywords Physical Conditioning, Stroke Length, Stroke Frequency, Physical Fitness, Kinematic Parameters, Butterfly Stroke, Physical Education Students

1. Introduction

In various sports, specific physical characteristics, including anthropometrics and body profile, serve as indicators to determine a player's suitability for competing at the highest level in those particular sports [1]. Achieving success in various sports often hinges on the physical attributes of young athletes [2]. The significance of physical conditioning for athletes cannot be overstated, as its absence can lead to a rapid decline in physical fitness [3]. Coaches and athletes alike must, therefore, place importance on monitoring the physical condition of athletes, as it can have a direct impact on their performance and success during competition [4], [5].

While swimming performance is a complex interplay of factors [6], it is the specific physical traits of swimmers that ultimately determine their success [7]. Research indicates that anthropometric, biomechanical, and physical fitness characteristics are correlated with human exercise performance [8]. Additionally, body composition plays a pivotal role in determining the levels of swimming performance [9], [10]. The proficiency of young athletes is influenced by factors such as training, physical growth, and development [11]. Swimming performance exhibits a direct correlation with anthropometric parameters [12] and physiological parameters [13]. Certain anthropometric and physiological characteristics closely align with the performance of young swimmers [14]. Human and physiological factors stand as crucial determinants for competitive swimming success [15], [16], and a robust association exists between age and height in relation to swimming performance [17].

As previously mentioned, there exists a notable connection between the performance of young swimmers and anthropometric as well as physiological parameters [12]. However, only a limited number of studies have explored the correlation between these parameters and performance, yielding either conflicting results or no apparent relationship at all [14], [15], [18]. In 2017, one study established a robust link between anthropometric measurements, such as height, upper extremity length, and bilateral iliopsoas diameter, and performances in the 50m, 100m, and 400m events among young male swimmers [19]. Another study from the same year emphasized that fat mass serves as a crucial and distinctive whole-body characteristic influencing butterfly swimming speed performance [20]. Swimmers' recorded metrics revealed numerous significant negative relationships, encompassing arm length, forearm length, hand length, arm-inch length, foot length, palm width, forearm circumference, hand grip strength, body fat percentage, swimming history, forearm length-to-height ratio, and lean body mass to height [21]. Positive associations between hand and foot size and swimming performance were reported in study conducted in 2013 [14]. A separate study suggested an inverse relationship between swim race performance and anthropometric measurements in elite high-endurance swimmers [15]. In 2013, it was found that, with the exception of BMI in men, anthropometric characteristics did not correlate with race time [22]. Other studies indicated a lack of a significant relationship between anthropometric and physiological parameters and swimming performance in both sexes at an early age [23].

Among the various forms of swimming strokes, the butterfly stroke is particularly demanding, requiring high levels of physical strength and endurance, especially during the retrograde motion where the arms, shoulders, head, and torso are lifted above water for breathing purposes [24]. Successful execution of the butterfly stroke requires the learner to possess the necessary physical abilities and perform them accurately and smoothly [25]. The butterfly stroke is similar to the movements of dolphins and demands high muscle strength and joint flexibility, ranking second in speed after the crawl stroke [26]. To improve swimming performance, athletes must have a strong grasp of motor performance and the mechanical factors influencing it [27].

Given the importance of mechanical variables in skilled performance, they are often used as a determinant of success or failure in various activities [26]. In the case of swimming, the kinematic variables associated with the butterfly stroke are particularly important to consider. There are challenges involved in mastering the skills necessary for the butterfly stroke, along with the high physical and psychological requirements needed to enhance the level of kinematic variables.

This study aims to investigate the relationship between physical conditioning and various kinematic variables associated with the butterfly stroke among swimming students in the Faculty of Physical Education at the University of Jordan. The significance of this research lies in assessing physical conditioning and its potential correlation with kinematic variables in the butterfly stroke. The educational process necessitates teachers to develop fitness elements associated with the skill to improve students' performance. It is hypothesized that the values of physical conditioning and kinematic variables associated with the butterfly stroke among students at the Faculty of Physical Education are high, and there exists a statistically significant relationship between them.

2. Materials and Methods

The study utilized various tools for data collection, including Sony digital video cameras capturing 25 images per second, a tape measure (meter), and a standard 1-meter plastic cube as a photographic reference. Kinovea, a kinematic analysis program known for its credibility, consistency, and objectivity, was employed for data analysis. To assess the physical condition of the study participants, the researchers used the Physical Condition Description Test designed by Mohammed Allawi [28]. This test, a multidimensional measure of self-concept for physical qualities, encompasses the essential elements of physical fitness, evaluating dimensions such as muscular strength, endurance, speed, flexibility, and agility. The test items were categorized based on the five dimensions of physical fitness. For each dimension, three items were positively phrased (aligned with the dimension), and three were negatively phrased (opposite to the dimension). The phrase numbers for each dimension were as follows:

1. Muscular strength: 6, 16, and 26 for positively phrased items; 1, 11, and 21 for negatively phrased items.
2. Endurance: 2, 12, and 22 for positively phrased items; 7, 17, and 27 for negatively phrased items.
3. Speed: 8, 18, and 28 for positively phrased items; 3, 13, and 23 for negatively phrased items.
4. Flexibility: 4, 14, and 24 for positively phrased items; 9, 19, and 29 for negatively phrased items.
5. Agility: 10, 20, and 30 for positively phrased items; 5, 15, and 25 for negatively phrased items.

The Likert pentagonal ladder was used as a response scale to measure participants' physical fitness levels. The scale included five degrees: "applies to a very large degree (5)," "applies to a large degree (4)," "applies to an average degree (3)," "applies to a small degree (2)," and "applies to a very small degree (1)." Each dimension was evaluated separately, and scores ranged from 6 to 30 degrees. Total scores, indicating an individual's overall physical fitness level, ranged from 30 to 150 degrees. During scoring, phrases aligned with the dimension received the determined score, while those in the opposite direction were reversed, along with their scores. The study was conducted in the faculty's swimming pool under the supervision of the swimming course teacher for students. Participants were provided instructions on the butterfly stroke, and after correction, scores for phrases in the direction of the dimension were recorded, with scores for phrases in the opposite direction being reversed.

2.1. Scientific Coefficients of Tests

2.1.1. Credibility of the Test

To establish the content validity of the physical condition description test, the assessment form was presented to a panel of three experts in the field of teaching swimming and teaching methods. Their opinions were sought regarding the suitability and feasibility of applying the assessment form to the study sample to achieve the research objectives.

2.1.2. Test Stability

The study utilized the Pearson correlation coefficient to evaluate the stability of the measurement of study variables through the Test-Retest method. The test was administered twice to the rationing sample of the survey study, comprising 10 students under the same conditions, with a time interval of five days between the two administrations. The stability coefficient for the tests employed is presented in Table 1, indicating the strength of the correlation between the scores obtained from the two test administrations. It is noteworthy that the results of ten students were excluded from the study.

Table 1. Values of the stability coefficient for the study variables

The number	Variants	Coefficient of stability
1	The state of muscular strength	*0.72
2	Endurance status	*0.76
3	Speed status	*0.87
4	State of elasticity	*0.76
5	Fitness status	*0.87
6	Overall physical condition	*0.8

*D at the level of $\alpha \geq 0.05$

Table 1 indicates that the study variables possess high stability coefficients, which are deemed acceptable for implementing the physical condition description test evaluation form in the research and fulfilling its intended aims.

Potential confounding variables are factors that might influence both the physical condition and kinematic variables, thus posing a threat to the internal validity of this study. Some possible confounding variables include:

1. Previous Physical Training: Participants may have varying levels of previous physical training or experience in swimming, which could impact both their physical condition and kinematic performance.
2. Swimming Technique Proficiency: Individual differences in swimming technique proficiency may influence both physical fitness levels and kinematic variables during the butterfly stroke. Participants with more advanced swimming skills might exhibit different kinematic patterns compared to those with less proficiency.
3. Health Conditions: Participants with different health conditions may have distinct physical fitness levels and kinematic responses. Health conditions such as musculoskeletal issues or respiratory conditions could affect both physical condition test scores and kinematic measurements.
4. Motivation and Effort: Variability in participants' motivation and effort levels during the physical condition test and kinematic analysis sessions could introduce bias. Individuals who are more motivated might perform better in both assessments.
5. Nutritional Factors: Differences in participants' nutritional habits may affect physical condition and performance. While it might be challenging to control dietary factors completely, collecting information on general dietary habits can help account for potential confounding.

2.2. Participants

The study population consisted of students from the Faculty of Physical Education at the University of Jordan who volunteered to participate. The study sample, comprising 12 students who excelled in the butterfly stroke, was selected using purposive sampling from those enrolled in swimming courses at the same faculty.

Table 2 presents the descriptive statistics for the study sample. The mean weight was 71 kg (SD = 4.6 kg), the mean height was 175 cm (SD = 4.5 cm), and the mean age was 21 years (SD = 1 year).

A survey study involving 10 students was conducted before the main study. Three of these students had successfully completed the previous semester. The tests were repeated after five days, and none of these participants were included in the study sample. The aim of the survey study was to validate the research tools and derive scientific conclusions for the tools used in this study.

Table 2. The descriptive statistics of the study sample, including the arithmetic mean, standard deviation, highest and lowest values for mass, height, and age

The Variant	The Arithmetic mean	The Standard deviation
Mass (kg)	71	4.6
Length (CM)	175	4.5
Age (year)	21	1

3. Statistical Analysis

The statistical analysis of the study was conducted by the researcher using various statistical variables, including averages, standard deviations, and the Pearson correlation coefficient. The level of statistical significance was set at p = 0.05 or higher. Data analysis was performed using SPSS software, a widely recognized and commonly used tool for statistical analysis in research studies.

4. Results

The descriptive statistics for the physical condition and kinematic variables of the study sample are presented in Table 3. Participants demonstrated a high level of endurance, with an average of 23.2 degrees and a standard deviation of 4.6 degrees. The relatively higher standard deviation suggests some variability in endurance levels among individuals. Similarly, elasticity exhibited an average of 23.2 degrees with a standard deviation of 4.6 degrees, indicating a notable level of elasticity among participants. Muscular strength followed in third place with an arithmetic mean of 21.5 degrees out of 30 degrees, while the speed element had an arithmetic mean of 21 degrees out of 30 degrees. The total physical condition score was 109.9 degrees out of 150 degrees, indicating a high level of physical condition among the study sample. In terms of kinematic variables, the average arm stroke length was 1.4 meters, calculated by dividing the distance by the number of arm strokes. The arm stroke frequency rate was 0.59 strokes per second, calculated by dividing the number of strokes by the distance. The average swimming speed for the 25m butterfly stroke was 1.01 meters per second, obtained by dividing the distance by the time.

Table 4 presents the correlation coefficients between the physical condition and kinematic variables of the butterfly stroke in the study sample from the Faculty of Physical Education. The results reveal a statistically significant positive correlation (α ≤ 0.05) between the element of muscular strength and the average arm stroke length. Additionally, a statistically significant positive correlation (α ≤ 0.05) was observed between the velocity component and the average swimming speed over the 25m butterfly. These findings suggest that muscular strength and swimming speed are important factors positively associated with the physical condition during the butterfly stroke in the study sample.

Table 3. The measurements of physical condition and selected kinematic variables in the butterfly stroke among students enrolled in the faculty of physical education

The number	The variables (unit of measurement)	The Arithmetic mean	Standard deviation
1	Muscle strength status (degree)	21.5	1.3
2	State of endurance (degree)	23.2	4.6
3	Speed status (degree)	21	2
4	State of elasticity (degree)	23.2	4.6
5	Fitness status (degree)	20.8	4.4
6	Overall physical condition (degree)	109.9	12.8
7	Average arm stroke length in butterfly swimming (meters)	1.4	0.02
8	Butterfly swimming arm stroke frequency (stroke/second)	0.59	0.02
9	Average swimming speed of 25 M Butterfly (M/s)	1.01	0.03

Table 4. Correlation Coefficients between Physical Condition and Kinematic Variables in Butterfly Swimming among Students of a Physical Education Faculty: Study Sample Results

The Variants	Average arm stroke length in butterfly stroke	Butterfly stroke arm stroke frequency	Average swimming speed 25m butterfly
The state of muscular strength	*0.86	0.08	0.42
Endurance status	0.05	0.39	0.41
Speed status	0.21-	*0.97	*0.87
State of elasticity	0.05	0.39	0.41
Fitness status	0.5	0.07	0.27
Overall physical condition	0.26	0.47	0.56

*D at the level of 0.05≥ α

5. Discussion

In this study, we initially hypothesized that the values of physical condition and kinematic variables in the butterfly stroke among the students of the Faculty of Physical Education would be high, and there would be a statistically significant relationship between these values. However, our analysis results indicated variations in the dimensions of physical condition and kinematic variables among the participants, with the highest values observed in the endurance and flexibility dimensions.

This finding may be attributed to the crucial role of endurance in successful swimming, as emphasized in educational and training programs for swimming courses at the university. Additionally, flexibility is essential for swimming, particularly in the shoulder joint for performing movements such as flexion, extension, distancing, approximation, and rotation. Muscular strength was ranked third among the physical elements, followed by the speed element. The overall physical condition of the participants was observed to be at a high level.

In comparison to previous studies on swimmers, the kinematic variables in this study were found to be lower among the students of the sports education college. This can be attributed to the fundamental requirement of muscular strength in swimming, as applied in Newton's second law, which states that the greater the force applied, the greater the acceleration gained by the body. Newton's third law also plays a role, stating that for every action, there is an equal and opposite reaction resulting in acceleration of the body. The speed component is also a crucial requirement in swimming, depending on the internal compatibility within the motor unit and the coordination between different body parts. A higher motor speed of the limbs leads to a greater transitional speed of the body as a whole.

Nevertheless, the relationship between propulsive force and swimming speed remains uncertain in the existing literature, particularly concerning the butterfly stroke. There is limited research on the connection between momentum and swimming speed in this stroke, with only one experimental study indicating that the average force production during arm retraction significantly foretells swimming speed in the butterfly stroke [29]. Conversely, Schleihauf et al. [30] proposed that elevated propulsive forces correlate with increased swimming speed, highlighting the lifting motion as the phase where the highest propulsive force is attained. Furthermore, elite swimmers refine their propulsive techniques by optimizing the coordination between their upper and lower extremities, ultimately augmenting swimming speed [31].

Evidence has shown that significant disparities in daily value are linked to subpar performance among butterfly swimmers [32]. This adverse impact of DV could be ascribed to the swimmer's hydrodynamic profile during the butterfly arm pull [33]. The butterfly stroke is distinguished by a notable anisotropy in frontal surface area, which could detrimentally affect swimmers' hydrodynamics and, consequently, their swimming speed [34]. International swimmers have been observed to demonstrate diminished wave characteristics and reduced movement variability compared to their regional counterparts, emphasizing the critical importance of technique in the butterfly stroke [35]. Consequently, swimmers and coaches should be vigilant about the potential drawbacks of excessive undulating movements, which could significantly increase the frontal surface area and compromise hydrodynamics.

Moreover, body dimension-related variables play a crucial role in determining swimming speed during growth periods [36]. Noteworthy is the observation that anthropometry has a positive and noteworthy impact on the swimmer's propulsive force in the front crawl arm drag, ultimately influencing swimming speed [37].

In terms of overall physical condition, the students at the sports education college in this study were evaluated to be at a high level, possessing the physical fitness required for sports games. This finding aligns with previous studies that emphasized the need for fitness levels to apply skills in various games and sports [38].

The importance of muscular strength was highlighted in this study, particularly concerning the arm stroke's length, which requires this element. Greater strength in the arms and legs results in a longer blow distance, comprising two arm cycles (one arm stroke and two leg strokes). Additionally, an increase in the force in the arm stroke leads to a greater distance of the body forward, consistent with previous findings [26].

It's essential to note that this study was conducted among students of the sports education college, who undergo educational and training programs that focus on endurance training. This emphasis on endurance training may explain the high values observed in the endurance and flexibility dimensions. These findings underscore the necessity for tailored training programs designed for different groups of swimmers based on their levels and specific requirements. The study revealed a significant positive correlation between the speed element and the average stroke frequency in the arms during the butterfly stroke. This implies that as the stroke frequency in the arms increases, the speed also increases. Additionally, a positive correlation was found between the speed element and the average swimming speed of a 25m butterfly. This relationship can be attributed to the correlation between the stroke frequency in the arms and speed. The adjusted speed of the butterfly can be calculated using the equation: adjusted speed of butterfly = frequency of arm's stroke in butterfly * stroke length rate in arms during the butterfly style. In conclusion, the study suggests that stroke frequency in the arms and stroke length rate are crucial factors in determining the speed of the butterfly stroke, and the speed element plays a significant role in enhancing the performance of this stroke style.

6. Conclusions

To conclude, this study highlights the direct correlation between muscular strength and the average length of the arm stroke, as well as the association between speed and both arm stroke frequency and swimming speed in the butterfly stroke among students within a specific faculty. It underscores the importance of considering the physical condition of students enrolled in swimming courses, emphasizing the need to prioritize the development of muscular strength and speed to enhance kinematic variables in the butterfly stroke. However, it is crucial to acknowledge certain limitations that warrant consideration in future research. The generalizability of our findings is confined to the specific population of students from the examined faculty, necessitating caution when extending the results to broader demographics. The reliance on self-reported data introduces potential bias, emphasizing the need for future studies to incorporate more objective measures to enhance the accuracy of physical condition assessments. Moreover, the exclusive focus on muscular strength and speed as determinants of butterfly stroke performance leaves other potentially influential factors, such as flexibility, technique, and psychological aspects, relatively unexplored. Future investigations could expand their scope to encompass these variables for a more comprehensive understanding of performance determinants. The cross-sectional design of this study poses limitations in establishing causation. Longitudinal studies tracking participants over time would provide a more nuanced understanding of the observed relationships. Additionally, the study did not extensively examine external factors like variations in training methods or coaching styles, which could impact performance. Future research might delve into these contextual factors to refine training practices and interventions. In essence, while our study sheds light on crucial aspects of butterfly stroke performance, recognizing and addressing these limitations in subsequent research will fortify the robustness and applicability of our findings. This approach will contribute to a more nuanced comprehension of the multifaceted dynamics influencing butterfly stroke performance across diverse populations.

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