

Relationship between physical characteristics and 200-metre swimming performance in young amateur swimmers

ZIED ABBES¹, ABDEL-SALAM GOMAA², SENAID AL-MARRI¹, MONOEM HADDAD¹

¹Physical Education Department, College of Education, Qatar University, Doha, Qatar

²Student Experience Department, Student Affairs, Qatar University, Doha, Qatar

Purpose: In swimming, elbow extension and flexion are among the most important movements involved in the front crawl upper body propulsive phase. Therefore, this study aimed to investigate the characteristics of young swimmers in relation to 200-m performance. **Methods:** 16 male swimmers (Age: 13.13 ± 2.06 y; Body Mass: 60.88 ± 18.58 kg; Height: 164.75 ± 13.77 cm) underwent three laboratory tests followed by a 200m swim-test. **Results:** There was a significant relationship between the isometric elbow strength and 200-m speed ($P < .05$). Results also showed a significant relationship between the isokinetic contractions at angular velocities of $60^\circ/\text{sec}$ and $180^\circ/\text{sec}$ of elbow flexors and swimming performance ($P < .05$). However, the relationship between the isokinetic contractions at the angular velocities of $60^\circ/\text{sec}$ and $180^\circ/\text{sec}$ of elbow extensors and swimming performance was not significant ($P > .05$). There was no significant relationship between the values of the anaerobic and peak power and 200-m speed ($P > .05$) following the Wingate test. The variable "Isokinetic - Acceleration Time (msec) - Flexion $180^\circ/\text{sec}$ " had a significant and negative effect on speeds ($B = -.001$, P -value = $.029$; $R^2 = .298$, Adj $R^2 = .248$), while the variable "Isokinetic - Acceleration Time (msec) - Extension $60^\circ/\text{sec}$ " also had a significant and negative effect on speeds ($B = -.006$, p -value = $.013$; $R^2 = .368$, Adj $R^2 = .323$). **Conclusions:** Assessment of physical characteristics may help coaches understand the potential of their swimmers in a specific swimming event. Therefore, talented swimmers may be identified at an early age.

Keywords: performance; isometric; contraction; isokinetic; elbow; Wingate.

Introduction

Competitive swimming performance is influenced by muscular strength¹. In swimming, except the breaststroke, the muscles in the upper body contribute to about 90% of the swimmer velocity due to movement of the hands, while the lower body is mainly restricted to body position in water and poses a small contribution to general movement^{2,3,4}. Elbow extension and flexion are the main movements of the propulsive phase in swimming⁵. Particularly in front crawl swimming, elbow extension and flexion are among the most important movement involved in stroke⁵. Elbow extensors and flexors are very important in stabilization of the joint and transmission of hand and forearm strength for body displacement⁶. Due to their importance in performance control and muscle fatigue identification, the accuracy and reliability of neuromuscular assessment of these muscles have been controlled.

According to a study by Bassan, Natália and al.⁷, the isometric peak torque of the elbow flexor and extensor muscles showed moderate to excellent reproducibility. Thus, the elbow flexor and extensor muscle assessment through an isokinetic dynamometer is useful to provide information about strength, power, endurance, and balance ratio (conventional and functional ratios); thereby helping in the establishment of preventive and adequate muscular strengthening programs out of the water⁸. Alternatively, most swimming events, especially the 200-m race, are heavily dependent on the anaerobic energy system^{9,10}. Therefore, the assessment of these systems plays an important role in monitoring swimming performance and swimmers' progression through the season. Various anaerobic laboratory tests have been described in the literature as the Hand Grip or the Biokinetic swim bench test^{11,12,13}. However, the gold standard in the evaluation of anaerobic sports performance is the laboratory Wingate

anaerobic test (WAnT) in both upper and lower body modifications^{14,15}. The Wingate test is widely used in swimming¹⁶⁻¹⁸. Several authors studied the relationship between the WAnT and swimming time. In an attempt to evaluate the efficacy of intermittent hypoxic training (IHT) on anaerobic and aerobic capacity and swimming performance in well-trained swimmers, Czuba, Wilk, Karpiński, Chalimoniuk, Zajac and Langfort¹⁷, implemented a 30 second sprint on an arm-ergometer, alternating with two-minute-high intensity intervals on a lower limb cycle ergometer. The most important finding of this study includes a significant improvement in anaerobic capacity and swimming performance after high-intensity IHT. In another study involving competitive swimmers, Hawley and Williams¹⁸ determined a highly positive correlation between peak and mean power of WAnT and the 50-m swim time ($r = .82$; $r = .83$, respectively). In another study, Hawley, Williams, Vickovic and Handcock¹⁹ confirmed the existence of a highly correlative relationship between arm and leg Wingate tests and 50-m swim time ($r = .63$; $r = .76$, respectively). Thus, measuring anaerobic energy will help coaches determine the progression of their swimmers and consequently, adapt the plan through the season. In the end, the assessment of the physical characteristics of young amateur swimmers in relationship to the 200-m swimming event will help coaches identify the potential predictors of this event according to their physical abilities at an early age. Therefore, this study aimed to investigate the characteristics of young amateur swimmers in relation to their swimming performance. Our hypothesis was that there is a positive relationship between swimming performance and young swimmers' physical abilities.

Methods

Participants

A total of sixteen males' swimmers (13.13 ± 2.06 years old; 5 years minimum of training experience; weight 60.88 ± 18.58 kg; height 164.75 ± 13.77 cm) were randomly selected to participate in this study. The mean personal time represented 400 World Aquatics points. The swimmers were training four to five sessions per week (Average training load per session was 4km). Swimmers were injury-free at the time of the experiment and did not have any history of injury that would have influenced their movement pattern or prohibited them from performing tasks at their maximum performance. They were also required to abstain from consuming any stimulants, depressants, or any other substances, including caffeine, for at least 6 hours prior measurement and to refrain from playing sports or performing exercise training for one day prior to the measurement day. Prior to participation, all swimmers were informed about the potential risks and benefits associated with the study, and the legal sponsor of the participant signed a written informed consent form in agreement with the protocol and publication of data. The study was conducted according to the Declaration of Helsinki and the protocol was approved by the University Institutional Review Board (QU-IRB 896-A/18). All swimmers were fully accustomed to the tests used in this research and informed that they could withdraw from the study at any time.

Procedures

The experiments were performed in Qatar University Laboratory and Aquatic Centre in the 50-m competition pool. A session for familiarization to all laboratory tests and procedures was held at the Qatar University. Detailed information about the power endurance and strength measurements was registered.

A total of three laboratory tests were performed for all athletes:

- Isometric maximal voluntary contraction (MVC) at 60° of elbow flexion and extension,
- Isokinetic elbow extensor and flexor strength measurements in concentric modes at two selected angular velocities ($60^\circ/\text{sec}$ and $180^\circ/\text{sec}$), and
- Wingate test.

After familiarization, the main laboratory session was performed.

The warm-up before the laboratory test included an active warming up on a stationary cycle ergometer for 5 minutes at 70 rpm and 1 kilopond four submaximal contraction of elbow flexors and extensors at approximately 50%-75% of the MVC for 4 seconds each and a 10-second rest period in-between. Verbal encouragement and visual feedback to all participants by the investigator assisted them in concentrating on the quality of their movements.

Field Test (48 h after the laboratory tests)

After a standardized 10-min swimming warm-up²⁰, the participants competed in a 200-m front crawl. The time was recorded with a manual stopwatch (Casio Stopwatch HS-70W-1JH, Japan).

Laboratory Tests

Wingate anaerobic test (30 s all-out)

The 30-second WAnT was an all-out anaerobic test. The test was performed on a cycle ergometer (The Monark 894E

Ergonomic Peak Bike, Sweden) with resistance adjusted to the athlete's body weight (0.45 NM/kg). The lactate level was measured at rest. The Monark was available at the laboratory of the University. The Lactate Scout+ Field Kit (SensLab GmbH, Germany) was used to measure the lactate level.

Isokinetic & Isometric Variables of the Elbow

Isokinetic and isometric strength was determined using the Biodex Pro 4 (Biodex Medical Systems, NY, <http://www.biodex.com> and the computer software program version 3.29 and 3.30). This equipment was available in the laboratory of the University. The tests were performed for the dominant hand. The two tests were separated by 3 minutes.

Isometric Peak Torque (IPT)

Two maximal voluntary contractions (maintain 3 seconds and 2 minutes rest in-between) were performed for each muscle (elbow flexor and elbow extensor muscles). As explained by Girold, Maurin, Dugué, Chatard and Millet²¹, athletes were seated with the elbow resting on a cushion with forearm flexion of 90° (in supine position) for the elbow flexor muscle. For the elbow extensor muscles, the position was the same; however, the initial forearm positioning was in pronation. Swimmers started the contraction as strong and fast as possible and maintained the effort until the end of 3 seconds. The highest peak torque was used in the statistical analysis.

Velocity Specific Isokinetic Torques:

Five maximal concentric isokinetic trials were performed. The procedure was performed at speeds of $60^\circ/\text{sec}$ and $180^\circ/\text{sec}$. These different angular velocities were chosen because they seemed to be the most representative of a swimmer's movement speed²². The evaluation procedure was the same as described above for each muscle. However, for isokinetic contractions of elbow extensor muscles, the initial position was regarded as the point at which the elbow flexed at 90° and finally at 180° (total extension) with a motion range of 90° . For elbow flexor muscles, only the forearm position was changed to the supine position. In this case, the initial position adopted was the point in which the arm was in full extension, and the final position with elbow flexed at 110° . The highest value attained in contraction at each of the speeds was considered.

Statistical analysis

Means \pm standard deviations (SD) were used to describe variables. Before using parametric tests, the assumption of normality was verified using the Kolmogorov-Smirnov test. The relationships between isokinetic and isometric variables, Borg rating of perceived exertion, and swimming speed as well as the anaerobic and peak power from the WAnT were determined using the Pearson correlation analysis. Variables significantly associated with 200-m swimming speed were entered into the regression model as independent variables. Statistical analyses were performed using the SPSS software statistical package (SPSS Inc., Chicago, IL, version 23.0), and statistical significance was set at P -value $< .05$.

Results

General physical characteristics of the 16 participants (mean \pm SD: age 13.13 ± 2.06 years; weight 60.88 ± 18.58 kg; height

164.75 ± 13.77 cm) and Pearson correlation coefficient analysis of these values with the swimming speed are presented in Table 1. There was a statistically significant linear relationship between height, body mass, and swimming speed in the 200-m event (P -value $< .05$).

Table 1. General physical characteristics and 200-m swimming speed of participants

Variables	Mean \pm SD	200-m swimming speed (r)
Age (years)	13.13 ± 2.06	.455
Height (cm)	164.75 ± 13.77	.490
Body mass (kg)	60.88 ± 18.58	.465
200-m swimming speed (m/sec)	$1.27 \pm .14$	1

* $P < .05$; r = Pearson correlation coefficient; SD = standard deviation

The isometric strength values of elbow extensors (EE) and flexors (EF) (peak torque expressed in N·m) and correlation analysis of these values with best swimming speed are presented in Table 2. The results demonstrated that there was a significant relationship between isometric elbow strength and 200-m swimming speed ($P < .05$).

There was a significant relationship between the isokinetic

contractions at the angular velocities of $60^\circ/\text{sec}$ and $180^\circ/\text{sec}$ of EF and swimming performance ($P < .05$). However, the relationship between the isokinetic contractions at the angular velocities of $60^\circ/\text{sec}$ and $180^\circ/\text{sec}$ of EE and swimming performance was not significant ($P > .05$).

There was no significant relationship between these values and 200-m swimming speed ($P > .05$).

Table 2. Regression Models (With intercept)

Variables	B	SE	P-value	R ²	Adj R ²
(Constant)	.943	.108	<.001		
Isometric Ave PEAK TORQUE/BODY WEIGHT (%) - Flexion 90°	.006	.002	.007	.413	.371
(Constant)	1.397	.06	<.001		
Isokinetic - ACCELERATION TIME (msec) - Flexion $180^\circ/\text{sec}$	.001	.00	.029	.298	.248
(Constant)	1.568	.108	<.001		
Isokinetic - ACCELERATION TIME (msec) - Extension $60^\circ/\text{sec}$	-.006	.002	.013	.368	.323

Table 3. Regression Models (No intercept)

Variables	B	SE	P-value	R ²	Adj R ²
Isometric -Ave PEAK TORQUE/BODY WEIGHT (%) - Extension 90°	.008	.001	<.001	.982	.979
Isometric - AGON/ANTAGON RATIO (%) - Extension 90°	.009	.002	<.001		
Isokinetic - ACCELERATION TIME (msec) - Extension $60^\circ/\text{sec}$	.013	.002	<.001	.97	.966
Isokinetic - Avg PEAK TORQUE - Flexion $60^\circ/\text{sec}$	.023	.004	<.001		
Isokinetic - ACCELERATION TIME (msec) - Extension $180^\circ/\text{sec}$	.006	.001	<.001	.986	.984
Isokinetic - Avg PEAK TORQUE - Extension $180^\circ/\text{sec}$	.019	.002	<.001		

Regression Models (No intercept)

The variable "Isometric Ave PEAK TORQUE/BODY WEIGHT (%) Flexion 90° " has a significant and positive effect on speeds ($B = .008$, P -value $< .001$). Moreover, the variable "Isometric - AGON/ANTAGON RATIO (%) - Extension 90° " has a significant and positive effect on speeds ($B = .009$, P -value $< .001$). The values of R^2 and Adj R^2 for this model were

.982 and .979, respectively.

The variable "Isokinetic - ACCELERATION TIME (msec) - Extension $60^\circ/\text{sec}$ " has a significant and positive effect on speeds ($B = .013$, P -value $< .001$). Moreover, the variable "Isokinetic - Avg PEAK TORQUE - Flexion $60^\circ/\text{sec}$ " has a significant and positive effect on speeds ($B = .023$, P -value $< .001$). The values of R^2 and Adj R^2 for this model were .97 and

.966, respectively.

The variable “Isokinetic - ACCELERATION TIME (msec) - Extension 180°/sec” has a significant and positive effect on speeds ($B = .006$, P -value $< .001$). Moreover, the variable “Isokinetic - Avg PEAK TORQUE - Extension 180°/sec” has a significant and positive effect on speeds ($B = .019$, P -value $< .001$). The values of R^2 and Adj R^2 for this model were .986 and .984, respectively.

Discussion

In this study, the results of analyzing the influence of selected body properties on 200-m swimming speed showed that height and body mass play an important role as a basis for propulsion, which supports other studies where participants were at similar or younger ages²³⁻²⁵. Additionally, multiple studies have reported strong associations between anthropometric variables and swimming performance²⁶⁻²⁸. Thus, those measures play an important role in talent identification and development in talented young swimmers. Nevertheless, upon reaching adulthood, the contributions of anthropometrical traits for swimming performance are not so obvious²⁹.

Data of the present study demonstrated also that there was a significant relationship between isometric elbow strength and 200-m swimming speed among young swimmers ($P < .05$). In front crawl swimming, the key part in the underwater “catch and pull” phase is played by flexor muscles of the elbow joint – biceps brachii and brachialis³⁰. Different muscle actions (isometric and isokinetic, respectively) have been used for performance control and muscle fatigue identification^{7,31}. EF and EE are also among the major muscle groups used in the stroke due to their importance in stabilizing the joint and transmission of hand and forearm strength for the body displacement⁶. In a recent study, Bassan, Natália and al.⁷, found that the isometric elbow flexor muscles was significantly decreased (~16%) after exhaustive swimming exercise (~220 sec). The findings of this study and the aforementioned results suggest that an increase in elbow strength training may improve propulsive force and swimming performance in young male swimmers.

Based on the observations of Hopkins, Schabert and Hawley³², angular velocities 60°/s-1 and 180°/s-1 were adopted due to their resemblance to the speed of swimmer’s movements. Thus, in our study, there was a significant relationship between the isokinetic contractions of EF at angular velocities of 60 and 180°/sec and swimming performance ($P < .05$). However, the relationship between the isokinetic contractions of EE at the angular velocities of 60°/sec and 180°/sec and swimming performance was not significant ($P > .05$). These results are in part similar to a study by Girold, Calmels, Maurin, Milhau and Chatard³³, where they suggested that 100-m swim performance was related to the strength of the EF and EE at 60°/sec ($r = .67$; $.66$) and 180°/sec ($r = .64$; $.66$), which was contradictory to our findings about the EE. The latter might be related to the difference in swim distance between both studies.

The present investigation also showed no significant relationship between the values of the anaerobic and peak power (W) and 200-m swimming speed ($P > .05$). This result can be explained by the total propulsive force generated by the arm stroke (90%) in front crawl compared to that by the legs, which are restricted to maintain body balance^{2,4}. Additionally,

propulsive forces of the arm are highly related to swimming performance as 85-90% of the propulsive power comes from the arms³⁴. Generally, peak, and mean power values generated during the WAnT demonstrate decreasing correlations, as swimming distance increases and speed decreases¹³.

According to our study, the variable “Isokinetic - ACCELERATION TIME (msec) - Flexion 180°/sec” has a significant and negative effect on speeds ($B = -.001$, P -value = $.029$; $R^2 = .298$, Adj $R^2 = .248$). Moreover, our study suggested that the variable “Isokinetic - ACCELERATION TIME (msec) - Extension 60°/sec” has a significant and negative effect on speeds ($B = -0.006$, P -value = $.013$; $R^2 = .368$, Adj $R^2 = .323$). These data contradict the results of the study by Guzik-Kopyto, Nowakowska-Lipiec, Nocoń, Gzik and Michnik³⁵, which suggested that statistically significant differences were observed for EF among female swimmers ($P = .014$) at an angular velocity of 60°/sec. Consequently, it appears that the isokinetic elbow muscle acceleration time is inversely related to the 200-m swimming speed among female swimmers. Nevertheless, further research needs to be conducted on this topic to understand the difference in impact on both sexes and its effect on swimming performance. Especially, that these variables are related to muscle reaction time which is considered an essential element in the protection against episodes of joint injuries^{36,37}.

A potential limitation of this study is the sole focus on the male sex. Nevertheless, the incorporation of sex-based analysis may contribute to the understanding of physical characteristics and 200-m swimming performance in young amateur swimmers. Future studies should analyze the sex-related differences and the impact of physical characteristics in other swimming events such as sprints (50 m) or long distance (800 m).

Conclusion

The assessment of the physical characteristics of young amateur swimmers in relationship to the 200-m swimming will help coaches in the process of talent identification and development of young swimmers who want to achieve success in the 200 m front crawl. It can also be used to monitor, diagnosis the progression and the different trainings plans (dryland and in the water) of the young swimmers through the season.

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Conflict of Interest

The authors declare that the present work was not carried out in the presence of any personal, professional or financial relationships that could potentially be construed as a conflict of interest.

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Author Contributions

Conceptualization, M.H. and Z.A.; methodology, M.H. and Z.A.; formal analysis, A.S.G.; investigation, Z.A. and M.H.; writing—review and editing, Z.A. A.S.G. S.M. and M.H.; supervision, M.H.; funding acquisition, M.H.; All authors have read and agreed to the published version of the manuscript.

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Corresponding information:

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Correspondence to: Haddad, Monoem, PhD

University: Physical Education Department, College

of Education, Qatar University, Doha, Qatar

E-mail: mhaddad@qu.edu.qa