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RELATIONSHIP BETWEEN MUSCLE STRENGTH AND FRONT CRAWL SWIMMING VELOCITY

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ABSTRACT
Purpose. Competitive performance in swimming depends on a number of factors including, among others, the development of relevant muscle groups. The aim of the study was to clarify the relationship between muscle strength and swimming velocity and the role of individual muscle groups in front crawl swimming. **Methods.** Sixteen physical education university students participated in the study. The strength values, defined as torque produced during isometric contractions, of eight upper and lower extremity muscle groups were measured. Data were compared with participants' front crawl swim times in the 25m and 50m distances. **Results.** Correlation analysis demonstrated a relationship between muscle strength and swimming velocity. Statistically significant relationships were observed between swimming velocity and the torque values of the elbow flexor and shoulder extensor muscles as well as the sum of upper extremity muscle torque values ($p < 0.05$). **Conclusions.** The results indicate the need for a focus on training those muscle groups identified as having a statistically significant relationship with swimming velocity for a given distance, as the sample showed deficiencies in the strength of those muscle groups responsible for generating propulsive force in the front crawl. Additionally, the collected data can serve as a diagnostic tool in evaluating the development of muscle groups critical for swimming performance.

Key words: muscle torque, swimming velocity

Introduction

Numerous advances in sports have brought with them the need to systematically observe and evaluate an ever-growing amount of parameters now critical for sporting success. This includes information pertaining to the technical, physical, and energy demands of a given discipline.

Overall, effective technique is considered to be one of the most essential components towards achieving competitive success especially in such sports as swimming. A swimmer who has proficient swimming technique may achieve far better results than one with less effective technique (at a corresponding fitness level). On the other hand, mastering optimal technique does not solely guarantee sporting success as other factors play a pivotal role, including fitness level, overall training experience, the development of relevant muscle groups, and other biomechanical characteristics.

The role of physical strength in swimming has been the subject of research for some time now. Several researchers have assumed that competitive swimming success is dependent on strength development [1], with research indicating a relationship between strength and swimming velocity. It should be noted that this relationship was statistically significantly stronger for shorter distances, with significance decreasing as the swimming distance increased. Bober and Pietraszewski [2] analyzed the degree of dependence between swimming velocity and strength capabilities. In dry land strength tests, swimming velocity was found to be larger with increased strength levels. However, velocity did not increase proportionally to an increase in strength. Besides achieving higher velocity, increased muscle strength is often associated with the ability to generate greater acceleration when swimming. Hence, besides specialized training performed in the water, some swimmers also perform dry land workouts so as to increase the overall efficiency of the musculoskeletal system. The most important element of dry land training is to develop muscle strength and increase the flexibility of those joints directly associated with the mechanics of a swimming stroke [3].

Strength training is nonetheless a controversial subject among many coaches and researchers. For example, some feel that in-water training and dry land strength development should be performed in parallel throughout the entire season regardless of a swimmer's specialization in any specific swimming distance. Others believe that primarily sprinters should focus on increasing strength and only during the preseason, whereas distance swimmers should avoid dry land training mainly due to its purported negative impact on endurance as well as a possible increase in drag due to muscle hypertrophy.

However, as supported by a number of studies [4–6], there is consensus that an increase in body strength has a direct effect on shorter swim times in sprinters. Some studies suggest specific training templates, such as Płatonow [7], who suggests that swimmers should use different dry land strength training loads depending on distance specialization (i.e. for the 100m and 200m dis-

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tances 54% of total training volume should be on land, for the 400–1500m distances approximately 39% of total training volume).

The movements performed by the extremities and trunk vary depending on swimming style and with it the amount of work performed by the muscles, all of which can cause changes in the strength of swimmers' various muscles groups. Since swimming is subject to numerous external forces which vary in relation to movement technique at different stroke phases and swimming velocities, the contribution of each muscle in these movements may also vary and thus affect their development and strength [8].

Many theoreticians believe that training adaptations are induced mainly in the muscle [9], hence the reason why strength training should be targeted at those muscle groups responsible for propulsive movement in the water. Depending on the chosen specialization and physical predispositions of the swimmer, coaches should take into account only those strength training activities that can lead to desired changes and training effects.

Therefore, it could be argued that competitive swimming success depends on both effective technique and the strength of those muscles most responsible for propulsion in a given swimming technique. This highlights the need to continually observe the development of muscular strength among swimmers. However, measurements of strength are difficult to perform in an aquatic environment due to difficulties in applying available research equipment and methodology. For this reason, research on swimmers' strength parameters necessitates the use of dry land measurements that can adequately represent their functioning and characteristics in an aquatic environment.

The aim of this study was to analyze the relationship between the strength (torque) of particular upper and lower extremity muscle groups and front crawl (freestyle) swimming velocity. Additionally, the study also attempted to establish which muscle group at each of the studied body joints determined front crawl swimming velocity to the greatest extent.

Material and methods

Sixteen university students from the University of Radom, Poland participated in the study. All were swimmers competing in the intra-national Students' Sport Association. Age, body mass, and body height was 23 ± 1.2 years, 78.3 ± 4 kg, and 180.8 ± 3.5 cm, respectively. Mean competitive swimming career with the Students' Sport Association was 2 years, and all had been attending training sessions at least three times a week. The training loads of the swimmers (training frequency, intensity, and volume) were similar.

The force generated by the muscles is one of the most important features of the human motor system. The vast majority of muscles produce movement by rotating at different joints, allowing muscle strength to be measured as a value of torque. Torque (N · m) is a physical quantity defined as the cross product of the force vector (*F*) and the lever arm distance vector (*r*), with respect to its axis of rotation at a joint.

All measures of muscle force were performed in static conditions due to the high accuracy afforded by this method and the ability to eliminate the influence of movement technique. A starting angle of 0° was adopted for the shoulder joint, whereas for all other joints it was 90°. Suitable stabilization methods (using belts and pads) were used during testing to allowed for the isolated and correct measurement of the selected muscle groups. Force was measured by a dynamometer connected to an electronic display with an accuracy to the nearest 0.5 N. Measurement error did not exceed 3%.

The shaft of the dynamometer was configured to be perpendicular to the lever arm of the applied force. Readings from the dynamometer were taken at the time of maximum muscle contraction. The lever arm of the applied force, as the distance of the axis of rotation at the joint to the force vector, was measured with a ruler to the nearest 0.5 cm. Participants performed two 3-second isometric contractions. A simple competition was introduced during testing in order to motivate the participants to perform as best as they could.

In diagnostic tests of this kind, a recognized indicator of physical fitness is maximum strength, or the algebraic sum of the torque values of ten muscle groups' extensors and flexors (torso, shoulder, elbow, hip, and knee joints). Such analysis allows for not only measuring torque values of individual muscle groups but also the ratio of strength of each group. In the present study eight muscle groups of four major upper and lower extremity joints were analyzed, composed of the flexors (F) and extensors (E) of the shoulder (s), elbow (e), knee (k), and hip joints (h). Figure 1 presents an example of how the elbow extensor and flexor muscles were measured for torque.

Measurements of swimming velocity were performed in an indoor 25 m swimming pool at a constant water

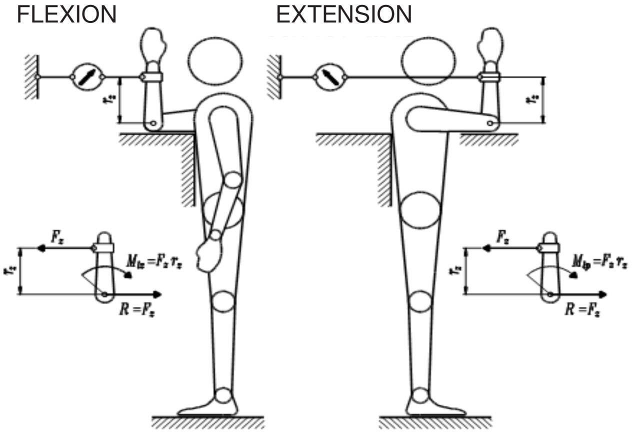


Figure 1. Example illustrating body position and method for measuring elbow flexion and extension

temperature of 27° C. Two participants swam at the same time in separate lanes in the freestyle (front crawl). This was done in order to provide a degree of rivalry and motivate the swimmers. The two competing participants were partnered in terms of comparable fitness levels and similar competitive swimming results. Participants were assessed by swimming the 25m distance and then the 50m as fast as possible. Swim times were recorded by a Polish Swimming Association judge using an electronic timer with a measurement accuracy of up to 0.01 s. The swim tests were performed in accordance to the current racing regulations of the International Swimming Federation (FINA) except for the start, which was a water start where participants began the test by pushing off from the pool wall. A period of rest was provided between trials (25m and 50m) in order to counteract the effects of fatigue.

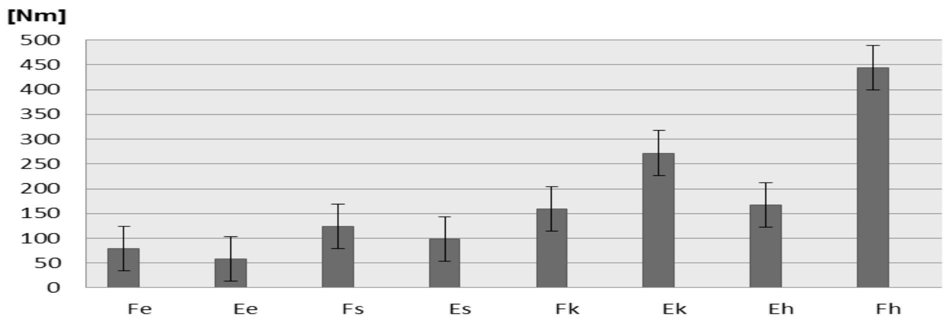
All collected data were then subjected to basic statistical analysis using Statistica 6 (Statsoft, USA). The relationships between the analyzed parameters were determined using correlation analysis at a significance level of $p < 0.05$.

Results

Figure 2 contains the mean torque values (N · m) of the analyzed muscle groups in the sample. Analysis of the mean torque values of the upper extremity muscle groups found the flexors to be at an advantage over extensor muscles in all participants. In this case, elbow joint flexors produced greater force than extensors by 20 N · m, whereas for the shoulder joint this difference was 26 N · m. The opposite was observed for the lower extremities. For the knee joint, the participants were characterized by larger torque values for the extensor muscles, with values a mean 113 N · m larger than for the flexors. For the hip joint, this difference was 277 N · m in favor of the extensor muscles.

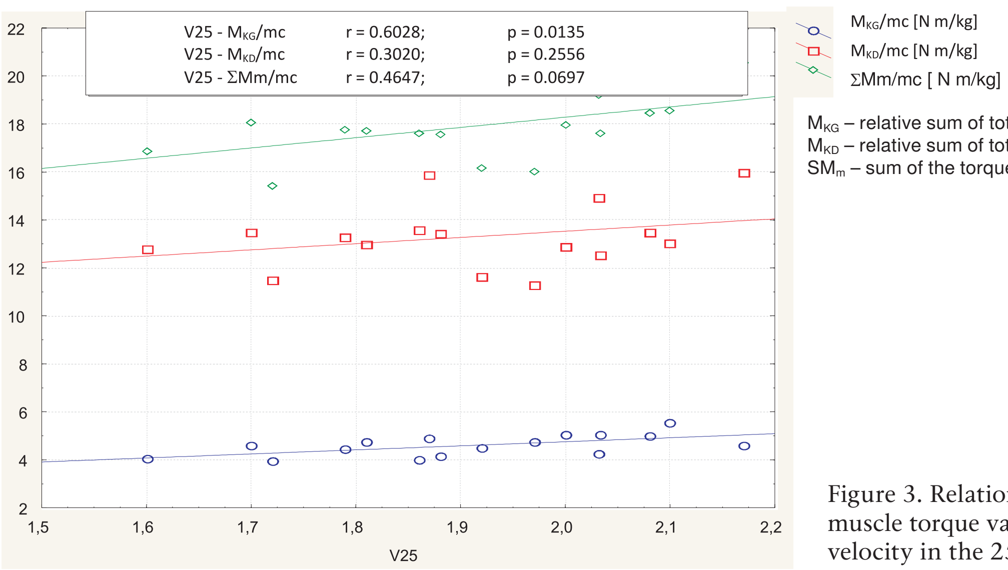
In terms of swimming velocity, the participants were found to average 2.17 m/s in the 25m and 1.91 m/s in the 50m, where a mean faster swimming velocity was achieved in the 25m by 0.24 m/s. The difference between the best and worst time for the 25m was 0.6 m/s, whereas for the 50m this difference was slightly smaller and amounted to 0.5 m/s. Of interest was that not all the swimmers who obtained a fast swim time in the 25m performed equally well in the 50m.

As mentioned, the relationships between the forces generated by the swimmers' muscles and swimming velocities were assessed by correlation analysis. As muscular strength may depend on body mass, correlation analysis was performed using relative muscle torque values (N · m/kg). Taking into account that statistically significant correlations were observed between the muscle



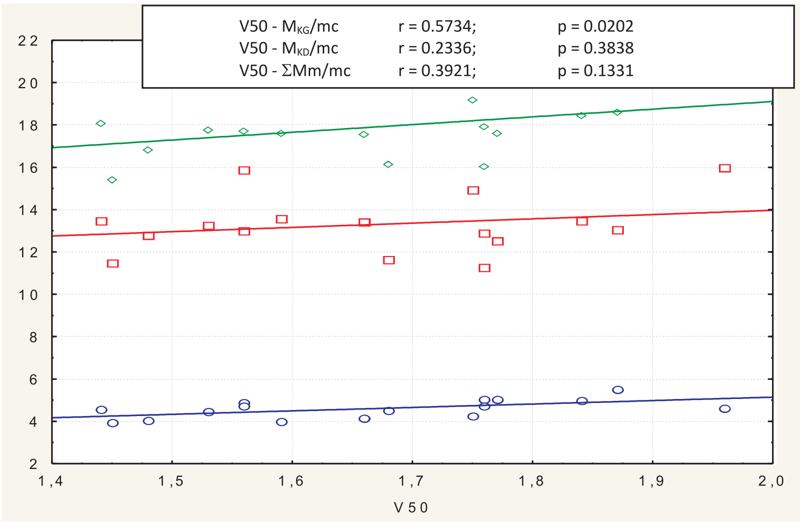
F – flexor, E – extensor; e – elbow, s – shoulder, k – knee, h – hip joints

Figure 2. Mean ± *SD* muscle torque values for the analyzed muscle groups



M_{KG} – relative sum of total torque for the upper extremity muscles
M_{KD} – relative sum of total torque for the lower extremity muscles
SM_m – sum of the torque values for all muscle groups

Figure 3. Relationship between relative and total muscle torque values (N · m/kg) and swimming velocity in the 25m distance (V25)



M_{KG}/mc [N m/kg]
M_{KD}/mc [N m/kg]
ΣMm/mc [N m/kg]

M_{KG} – relative sum of total torque for the upper extremity muscles
M_{KD} – relative sum of total torque for the lower extremity muscles
SM_m – sum of the torque values for all muscle groups

Figure 4. Relationship between relative and total muscle torque values (N·m/kg) and swimming velocity in the 50m distance (V50)

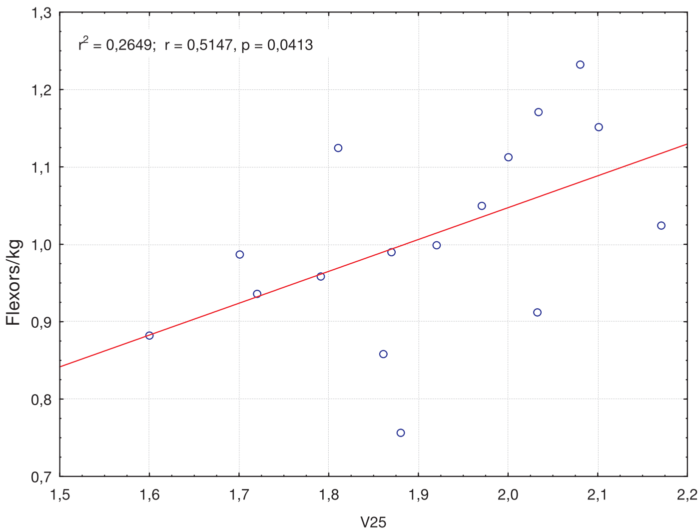


Figure 5. Relationship between the relative sum of elbow flexor muscle torque values (N · m/kg) with swimming velocity in the 25m distance (V25)

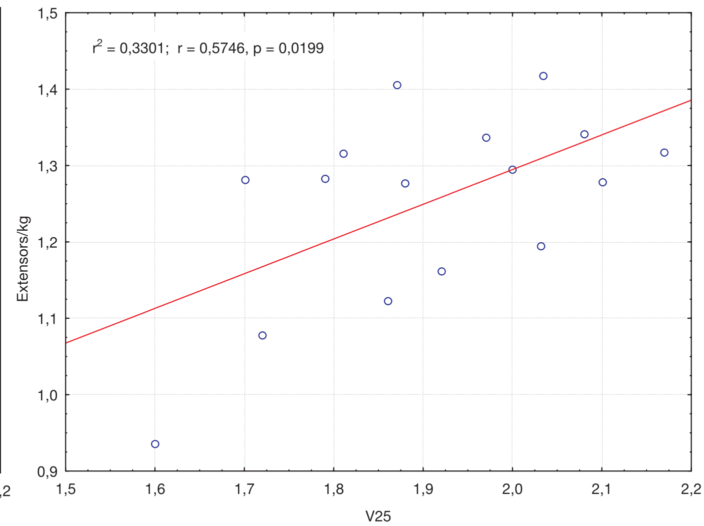


Figure 6. Relationship between the relative sum of shoulder extensor muscle torque values (N·m/kg) with swimming velocity in the 25m distance (V25)

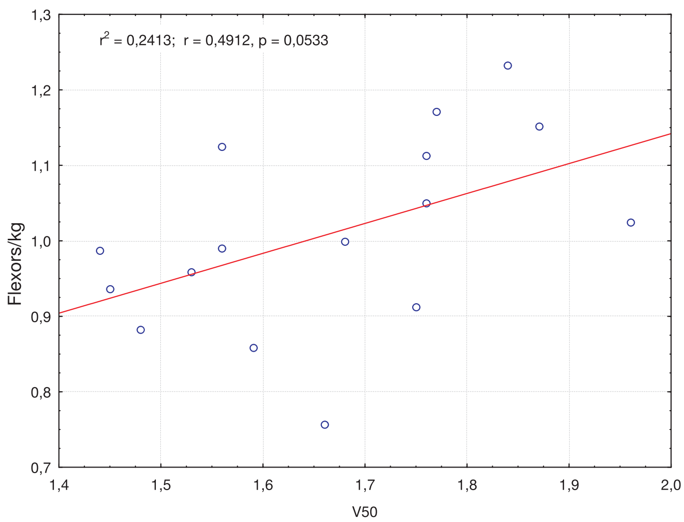


Figure 7. Relationship between the relative sum of elbow flexor muscle torque values (N·m/kg) with swimming velocity in the 50m distance (V50)

torque values (M_m, expressed in N·m) and body mass (mc, expressed in kg) during correlation analysis between the torque values and the obtained swimming velocities, it was decided to also include the relative sum of total torque for the upper extremity muscles (M_{KG}), the total torque for the lower extremity muscles (M_{KD}), and the sum of the torque values for all muscle groups (SM_m). The results of this analysis are provided below (Fig. 3–7).

A statistically significant relationship was found between the relative sum of the upper extremity muscle torque values and swimming velocity in both distances, denoted as V25 (25 m) and V50 (50 m) (Fig. 3, 4).

Evaluating each muscle group individually provided statistically significant correlations between the flexor muscles of the elbow joint with swimming velocity in both distances (Fig. 5, 6) as well as the extensors of the shoulder joint and swimming velocity in the 25m (Fig. 7).

No other statistically significant correlations were determined in the remaining muscle groups.

Discussion

The role of strength training in swimming should be to develop those strength capabilities beneficial for swimming training and competition. This would undoubtedly require a balance between developing strength and improving the movement technique used in a given swimming style.

There are numerous types and methods of strength training, with isometric training, among others, singled out to help swimmers swim faster. One of the cited advantages of isometric training is the ability to concentrate on individual muscle groups. During local muscle contractions performed in such static conditions, swimmers may ‘feel’ the activity of each muscle more precisely and translate this knowledge by specifying what strength development is needed in different swimming stroke phases. The isometric method has been used relatively infrequently in swimming. However, some swimmers from the USA (Furniss, Spitz, Montgomery, and Murphy) have successfully used short 5–10 second static contractions to increase maximum strength levels and longer 15–40 second contractions to develop strength endurance. Nonetheless, the present study did not address the impact of strength training on swimming velocity but instead attempted to find a link between swimming velocity and the strength of swimmers measured in isometric conditions.

Based on the results, no statistically significant correlations were obtained between the muscle strength and swimming velocity. However, those participants who achieved some of the fastest swimming velocities in both distances featured greater upper extremity muscle torque values for elbow flexors and shoulder flexors and extensors. For these muscle groups the correlations were statistically significant. Additionally, these correlations were found mainly in the 25m distance, which confirms the results of other authors who claim that the role of muscular strength is larger in sprinting distances and decreases as the swimming distance increases.

One interesting aspect was the high correlation between swimming velocity at both distances and the torque values for the elbow flexor muscle. The relationship between the swim results and this muscle group has also been observed by researchers who evaluated differences in the torque values of different muscle groups depending on stroke specialization during a training macrocycle [10]. This group found that swimmers specializing in the freestyle (front crawl) demonstrated the largest gains in force for the elbow flexor muscles over the training period.

When considering the movement phases of the upper extremities when swimming (assuming that correct front crawl technique is performed), the correlation between the strength of the elbow muscles with swimming velocity is further bolstered. It has been found that the order of upper extremity movements during the front crawl begin at the shoulder joint and continue to the elbow, superior radioulnar, and then hand [11]. The downsweep phase, when water is caught and pulled down by the hand, requires appropriate flexion at the elbow joint in order to effectively propel the body forward. In addition, the correlation observed with the shoulder extensors also corresponds with the main propulsive movement during the upsweep phase.

Research has found that 70% of the propulsive force in the front crawl comes from the upper extremities [11], albeit swimming velocity and the ability to maintain a constant velocity may also depend on the strength of the lower extremities. It was found that the lower extremities are responsible for about 25% of the propulsive force in this swimming stroke, with those muscles acting on the hip and knee joints generating the majority of propulsive force [12].

In the present study, no statistically significant correlations were found with the muscle torque values of the lower extremities and swimming velocity. It may be posited that these muscles groups among the examined swimmers are poorly developed in terms of strength. However, such a hypothesis requires additional and more detailed research.

A number of studies have concluded that static strength measurements do not correlate with sporting results. However, this study shows that they can serve as a diagnostic tool when determining the role of leading muscle groups in various competitive swimming styles. In order to enhance the value of such data, future research should be performed on swimmers specializing in the front crawl and include the influence of various front crawl techniques on swimming velocity using kinematic analysis [13] as well as include a greater number of muscle groups with measurements performed in different dimensional planes.

Conclusions

Analysis of the data obtained allowed for a partial confirmation of the importance of the strength and role of individual muscles groups in front crawl swimming.

The results of the present study:

– indicate the need for strength training those muscle groups identified as having a statistically significant relationship with swimming velocity for a given distance,

– show deficiencies in the strength of other muscle groups responsible for generating propulsive force in the front crawl.

The results indicate the usefulness and objectivity of this method for measuring muscle torque and their relationship with swim times. Additionally, the collected data can serve as a diagnostic tool in evaluating the development of muscle groups critical in swimming performance.

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