THE RELATIONSHIP BETWEEN SWIMMING PERFORMANCE AND ISOKINETIC SHOULDER STRENGTH OF ELITE SWIMMERS

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ABSTRACT

Purpose. The aims of the study were to determine the relationship between the shoulder muscles strength and the athletic performance of high-level swimmers and to detect the strength variables that had the biggest impact on high performance in sports swimming.

Methods. The study involved 39 high qualified swimmers (12 females and 27 males). To determine the strength variables, shoulder flexion and extension were carried out in isokinetic conditions. A Biodex S4 dynamometer was used. The following protocols were applied: (1) 3 repetitions, 60°/s; (2) 20 repetitions, 180°/s. The r-Pearson correlation analysis or the rho-Spearman correlation analysis were used. The family-wise error was checked.

Results. The level of strength had a greater influence on the swimming performance in males (25 of the 68 obtained variables) than in females (18 of the 68 variables). The strength variables that had the biggest impact on high performance in sports swimming were peak torque (r: 0.39–0.633), total work (r: 0.408–0.692), average power (r: 0.44–0.739), and average peak torque (r: 0.456–0.72).

Conclusions. Regardless of the respondents' gender or the analysed shoulder movement, the following variables were repeated: peak torque, total work, average power, and average peak torque. Unfortunately, the results were not statistically significant. Only acceleration time of the left shoulder in the arm flexion movement in males was significant. Despite this, once the muscular groups are similar for the listed strength variables, the swimmer's capability to produce force out of water seems to help them perform better in the water.

Key words: swimming, upper limb, athletic performance, strength, isokinetics, Biodex

Introduction

The main goal of sports swimming is to cover the set distance in the shortest possible time. Achieving this is conditioned by the level of technical, strength, coordination, and energy properties of the swimmer's body [1]. Strength, speed, and endurance are listed as motor skills that have the greatest impact on the result of sports swimming [2]. But sport swimming is a discipline in which the final result depends, to a large extent, on the level of strength abilities [3]. Different types of strength determine success over different distances. Maximum strength and explosive strength significantly affect speed, thrust, start jump, and turns – these are important factors influencing the result in swimming at distances of 50 m, 100 m, and 200 m. However, strength endurance ability has an impact on the results achieved at distances of 800 m and 1500 m [4].

Entering or keeping the body movement in water is conditioned by the driving force (thrust force), produced by upper limbs, lower limbs, and torso movements [5, 6]. These parameters are good predictors of results among young swimmers [7]. However, many researchers analyse mainly the strength of the upper limbs in swimmers because the cyclical movements of the upper limbs are the main source of propulsion while swimming. According to various authors, the upper limbs produce the basic driving force in crawl [6, 8, 9]; about 70–80% [10] or almost 90% [11] of the overall motive power; up to 80% of the driving power in crawler sprint competitions, and up to 100% in long-distance competitions [6].

Therefore, strength has been indicated as one of the main factors that can increase swimming speed, not only in sprint competitions [1], but also at medium distances [12, 13]. The thesis that force preparation is an essential component of the training cycle and has a significant impact on the sports performance during swimming races has been repeatedly confirmed [1, 14, 15]. An optimal level of strength and power is necessary for effective swimming because it is associated with a high ability to generate thrust forces [16, 17].

High-level international competition requires constant control of the athlete's health, as well as the use of the latest methods in the training process that would allow to achieve the best results [18]. To ensure adequate strength preparation, the latest biomechanical reports and muscle strengthening should be applied [19]. Morouço et al. [20] and Wiażewicz [21] highlight the role of quantitative measurement of strength and assessment of the muscle's ability to produce it. It is suggested to analyse new insights on strength abilities in training athletes practising sports swimming. The need for further rigorous research is underlined. According to Morouço et al. [20], the correlation of the strength abilities measured in land tests and swimming efficiency is not fully determined. Further considerations may lead to an explanation of this relationship.

The main aim of the study was to determine the relationship between the shoulder muscles strength and the athletic performance of high-level swimmers. The second aim was to detect the strength variables that had the biggest impact on high performance in sports swimming.

Two hypotheses were formulated: (1) There is a strong relationship between the shoulder muscles strength and the athletic performance in high-level swimmers. (2) Maximum strength, explosive strength, as well as strength endurance-related variables of the shoulder muscles have an influence on the athletic performance of females and males practising high-level sports swimming.

Material and methods

Overall, 39 high-level swimmers (12 females and 27 males) voluntarily participated in the current study. Their main physical and competitive characteristics were, respectively: 16.58 ± 1.93 vs. 17.8 ± 2.51 years of age, 61.25 ± 4.86 vs. 73.41 ± 8.46 kg of body mass, 171.25 ± 2.56 vs. 183.48 ± 5.56 cm of height, 9.67 ± 3.08 vs. 10.34 ± 2.8 years of training experience, and 650.08 ± 63.95 vs. 651.52 ± 105.51 FINA points

of best competitive performance. Their nutrition and lifestyle were controlled (diet catering, two trainings per day) and comparable. Before the research start, the athletes, trainers, and legal guardians were acquainted with the research procedure. The participants had the opportunity to report any pain or discomfort that might occur during the test. The respondents could also interrupt the tasks at any time and to withdraw from the project.

All measurements were made at the beginning of the transition period for the competitors, just after the competitive phase.

To determine the swimming performance (SP) of athletes, document analysis was performed. The time results obtained in the preferred swimming event, the Polish Championships in the short swimming pool (25 m) in Ostrowiec Świętokrzyski, were converted into FINA points. If a swimmer did not compete in the Polish Championships, the results from other swimming competitions were used from the similar time period (October-December), just before the measurements. The data were obtained from the online database of the European Swimming League (LEN) [22].

In order to obtain the anthropometric data, the length and circumference measurement technique was chosen. Upper limb length was measured on the acromion-dactylion section (a-daIII). Arm circumference was assessed at the place where the arm muscles are most strongly developed. At the time of measurement, the limb was lowered, without muscle tone. The anthropometric tape was positioned perpendicular to the long axis of the arm.

To determine the strength variables, shoulder flexion and extension were carried out in isokinetic conditions. For the isokinetic measurement, an appropriate tool was used: a Biodex System 4 dynamometer (Biodex Corp., Shirley, USA). In literature, the reliability of shoulder, i.e. rotator isokinetic strength imbalance measured with a Biodex dynamometer was found at high intraclass correlation coefficient (ICC) values (0.87–0.97) for peak torque. But also low to moderate relative reliability (ICC: 0.25–0.81) was observed for unilateral and bilateral strength imbalance ratios [23]. Other researchers imply good to excellent reliability in similar group studies (ICC: 0.69–0.92) [24]. For the post-fatigue strength measures, the test-retest reliability was excellent (ICC > 0.84) [25]. Peak torque, rate of torque development, and average torque of isometric elbow contractions also show excellent test-retest reliability (ICC: 0.98–0.92). The coefficient of variation varied from 5.97 ± 4.52% to 18.46 ± 14.78% [26].

For the shoulder joint examination, the standard shoulder/elbow adapter with a shoulder attachment was used. Foot support was not applied. The operations followed the equipment instructions. Before and after the tests, the calibration of the dynamometer was verified. The calibration was valid. It was carried out in accordance with the instructions provided by the apparatus manufacturer [27].

The test was performed in the morning (7:30–9:30 a.m.). The swimmers were instructed to come to the measurement room at the appointed time, in a sports outfit that did not interfere with the movements during the test. Before the measurement, the subjects started a 15-minute warm-up: 10 minutes of general warm-up on an elliptical machine and 5 minutes of warm-up focused on work in the upper limb area. Detailed information about the task to be carried out was provided. The subject was in a sitting position, the arm straightened down. As the axis of rotation, acromion was used in the sagittal plane. The athlete was fastened with straps to the chair around the trunk and pelvis in order to stabilize the body and eliminate compensatory movements. They grasped the dynamometer grip with the tested arm. The initial position was full extension of the arm, down, backwards, maximal in the range of motion. The arm which was not examined at the moment was free in neutral position or grasping the handle under the seat [27].

On the basis of the analysed literature [28–30], the following speeds and numbers of repetitions were selected for measurements of both arms. In protocol 1, the competitor performed 3 repetitions of flexion and extension, with an angular speed of 60°/s (additional continuous control and verbal stimulation in order to motivate to perform the maximal effort). Protocol 2 consisted of 20 repetitions, with an angular speed of 180°/s (continuous control and verbal stimulation every 5 repetitions). There were 2 repetitions allowed, not counted for measurement, before each test so that the subject got used to the position, speed, and task. A 2-minute break was applied between protocols. During the change of the testing site and adjustment of the apparatus, the rest lasted 4 minutes. Correction of gravity was adjusted because the weight of the upper limb could have affected the test result. The correct position of the body was also monitored, which is important in the interpretation of results [31].

Data from protocol 1 allowed to obtain the value of peak torque (PT), along with the deficit between the sides; peak torque to body weight (PT/BW); time to peak torque (PT TIME); angle of peak torque (PT ANGLE); maximal repetition work (MRW), along with the deficit between the sides; maximal work repetition (MW REP). From protocol 2, the variables used for the study were as follows: coefficient of variation (COV); work to body weight (W/BW); total work (TW), along with the deficit between the sides; work fatigue (WF); average power (AP), along with the deficit between the sides; acceleration time (AT); deceleration time (DT); range of motion (ROM); average peak torque (APT); agonists to antagonists ratio (AG:AN).

As for statistical methods, correlation analysis techniques were used to analyse the results. The Statistica 13.1 software was applied. The Shapiro-Wilk test served to examine the distribution of variables. Analysis of SP correlation with strength variables was performed, as well as distribution analysis of the variables. In the case when the Shapiro-Wilk test results indicated that the distributions of both correlated variables did not differ significantly from the normal distribution ($W > W_{\text{critical value for 12 cases}} = 0.859$ for females and $W > W_{\text{critical value for 27 cases}} = 0.923$ for males), r-Pearson correlation analysis was used (r_1). In the case when the result of the distribution analysis of at least 1 correlated variable indicated that the distribution deviated significantly from the normal distribution ($W < W_{\text{critical value for 12 cases}} = 0.859$ for females and $W < W_{\text{critical value for 27 cases}} = 0.923$ for males), analysis of the rho-Spearman correlation was used (r_2).

Distribution of the SP variable for females and males did not differ significantly from the normal distribution ($W_{\text{SP females}} = 0.949$ and $W_{\text{SP males}} = 0.947$, $p > 0.05$). The choice of the statistical test was dictated by the distribution of the strength variable. Statistically significant results were selected and ranked in accordance with the increase in the correlation value, separately for females and males in each movement.

Additionally, as several variables, therefore several hypotheses, were tested on a single population, the family-wise error was checked. The Holm-Bonferroni sequential correction was added to the calculations.

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Ethical Committee of the Regional Medical Chamber in Szczecin (resolution No. 5/KB/V/2013 of 10/12/2013).

Informed consent

Informed consent has been obtained from all individuals included in this study or their legal guardians.

Results

In AG:AN and ROM, there was no distinction of results in flexion or extension movements. In the examined females, the AG:AN of the left arm correlated highly and negatively (r_1 = –0.6391; p = 0.0253) with SP. This result was statistically significant. None of males' results in these variables reached the level of significance.

A detailed analysis of the variables correlated with SP showed that in the female group, 18 out of 68 variables (over 1/4) obtained by isokinetic measurement had a significant impact on their final SP. It is worth to note that a positive significant correlation with SP was detected for 13 variables. A negative significant correlation was demonstrated in 5 cases.

Among all the tested strength variables of the arm flexion correlated with SP in the examined females,

a significant correlation was found in 4 cases. The correlation coefficient for these variables was 0.6196–0.7386. The strength of these correlations was determined as high and positive. These were: AP of the right (r_1 = 0.6196; p = 0.0317) and left (r_1 = 0.7386; p = 0.0061) shoulder, APT of the left shoulder (r_1 = 0.6331; p = 0.0271), and W/BW of the left shoulder (r_1 = 0.6799; p = 0.0150) (Figure 1).

In the examined female athletes, a significant correlation with SP in the shoulder extension movement was detected in 13 variables. Four of them showed a negative correlation, from –0.7280 to –0.5772. In 2 cases, the strength of correlation relationships was high negative. These were: the deficits of TW (r_1 = –0.6501; p = 0.0221) and AP (r_1 = –0.7280; p = 0.0073). Also 2 variables correlated moderately and negatively. These were: PT TIME for the left shoulder (r_1 = –0.5830; p = 0.0466) and AT for both arms, however, significant
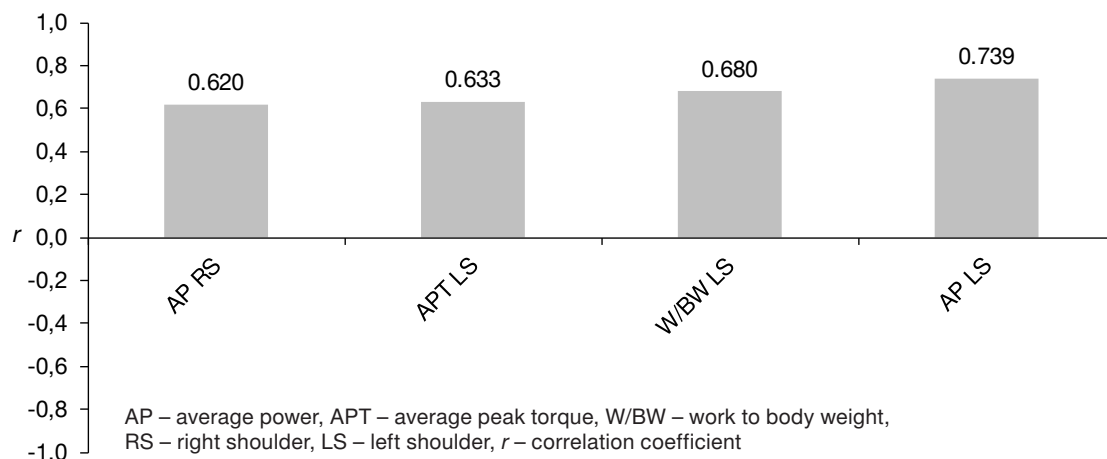

AP – average power, APT – average peak torque, W/BW – work to body weight, RS – right shoulder, LS – left shoulder, r – correlation coefficient

Figure 1. Significant correlation of strength variables in flexion movement with the swimming performance among female swimmers

AP – average power, TW – total work, PT TIME – time to peak torque, AT – acceleration time, MRW – maximal repetition work, PT – peak torque, W/BW – work to body weight, PT/BW – peak torque to body weight, MW REP – maximal work repetition, APT – average peak torque, DEF – deficit between body sides, LS – left shoulder, RS – right shoulder, r – correlation coefficient
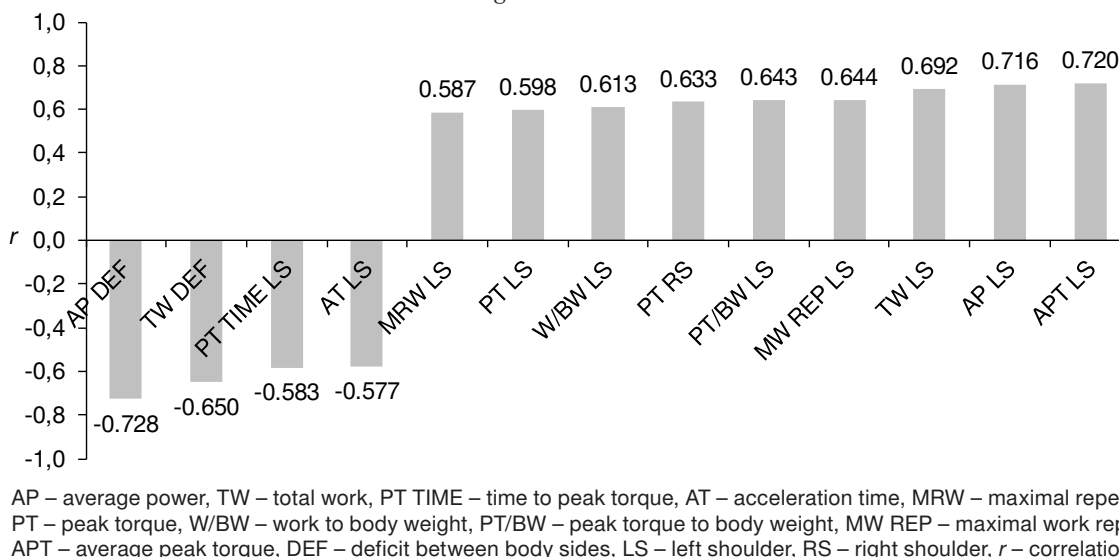
Figure 2. Significant correlation of strength variables in extension movement with the swimming performance among female swimmers

only for the left arm (r_1 = –0.5772; p = 0.0494). Among the calculated correlations, 9 with a positive direction of correlation were recorded (0.5870–0.7200). Of these, 7 were characterized as a high positive correlation relationship. These were: PT of the right shoulder (r_1 = 0.6330; p = 0.0272) and the left arm variables: MW REP (r_2 = 0.6435; p = 0.0240), TW (r_1 = 0.6921; p = 0.0126), AP (r_1 = 0.7155; p = 0.0089), APT (r_1 = 0.7200; p = 0.0083), PT/BW (r_1 = 0.6426; p = 0.0242), W/BW (r_1 = 0.6127; p = 0.0342). A moderate positive correlation occurred between SP and 2 variables: PT of the left shoulder (r_1 = 0.5981; p = 0.0399) and MRW also of the left shoulder (r_1 = 0.5870; p = 0.0448) (Figure 2).

Among the male group, the analysis of variables showed that a total of 25 of the 68 obtained variables (over 1/3) had a significant impact on the sports score. A positive significant correlation with the sports result was detected in 19 cases. The negative significant correlations, which were demonstrated for 6 variables, are also worth for note.

As for the tested force variables in the arm flexion movement correlated with SP in the examined males, a significant correlation was detected in 11 cases. Two of them showed a negative correlation. In 1 case, the strength of correlation relationship was high and negative: this was AT of the left shoulder (r_2 = –0.6358; p = 0.0004); in the other case, it was low and negative: this was MRW (r_2 = –0.3846; p = 0.0476). Among the calculated correlations, 9 with a positive direction were recorded. The correlation coefficient for these variables equalled 0.3897–0.5735. The strength of these correlation relationships in 8 cases can be defined as moderate positive. These were: PT of the left shoulder (r_1 = 0.4529; p = 0.0177), MRW of the left shoulder (r_1 = 0.4067; p = 0.0353), TW of both right (r_1 = 0.4703;

p = 0.0133) and left (r_1 = 0.4415; p = 0.0211) shoulder, AP for the right (r_1 = 0.5257; p = 0.0049) and left (r_1 = 0.4708; p = 0.0132) shoulder, and APT for the right (r_1 = 0.5735; p = 0.0018) and left (r_1 = 0.5273; p = 0.0047) shoulder. One was defined as low positive: PT for the right shoulder (r_1 = 0.3897; p = 0.0445) (Figure 3).

In the examined male swimmers, a significant correlation with SP in the shoulder extension movement was detected in 14 variables. Four of them showed a negative correlation, from –0.5642 to –0.4154. In all these cases, the strength of correlation relationships was moderately negative. These were: AT of the right (r_2 = –0.4821; p = 0.0109) and left (r_2 = –0.5642; p = 0.0022) shoulder, DT of the right arm (r_2 = –0.5443; p = 0.0033), and PT TIME of the right shoulder (r_1 = –0.4154; p = 0.0312). Ten among the calculated correlations were found in the positive direction (0.3888–0.5080). Nine results were characterized as moderate positive correlations. These were: MW REP (r_2 = 0.5080; p = 0.0068) only for the right arm, PT for the right (r_1 = 0.4595; p = 0.0159) and left (r_1 = 0.4349; p = 0.0234) shoulder, TW for the right (r_1 = 0.4148; p = 0.0314) and left (r_1 = 0.4080; p = 0.0347) shoulder joint, AP for both right (r_1 = 0.4598; p = 0.0158) and left (r_1 = 0.4398; p = 0.0217) arms, and APT for the right (r_1 = 0.4564; p = 0.0167) and left (r_1 = 0.4602; p = 0.0157) shoulder. One result showed a low correlation: MRW, statistically significant in the case of the left arm (r_1 = 0.3888; p = 0.0450) (Figure 4).

Among both female and male groups, small differences were found in mean values of right and left upper limbs length: 0.21 cm in females and 0.03 cm in males. Also, slight differences were observed between mean values of right and left arm circumferences:
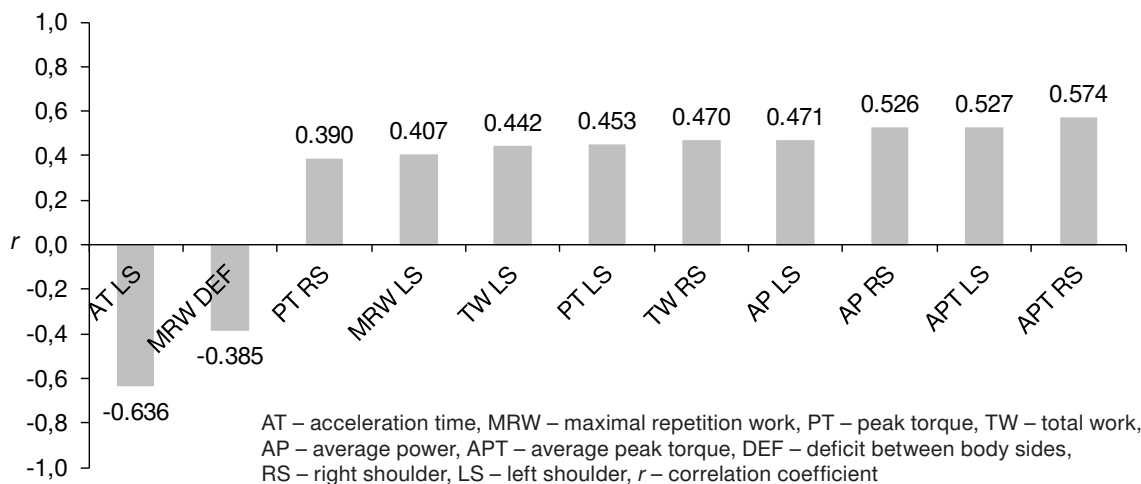

Figure 3. Significant correlation of strength variables in flexion movement with the swimming performance among male swimmers

AT – acceleration time, DT – deceleration time, PT TIME – time to peak torque, MRW – maximal repetition work, TW – total work, PT – peak torque, AP – average power, APT – average peak torque, MW REP – maximal work repetition, RS – right shoulder, LS – left shoulder, r – correlation coefficient
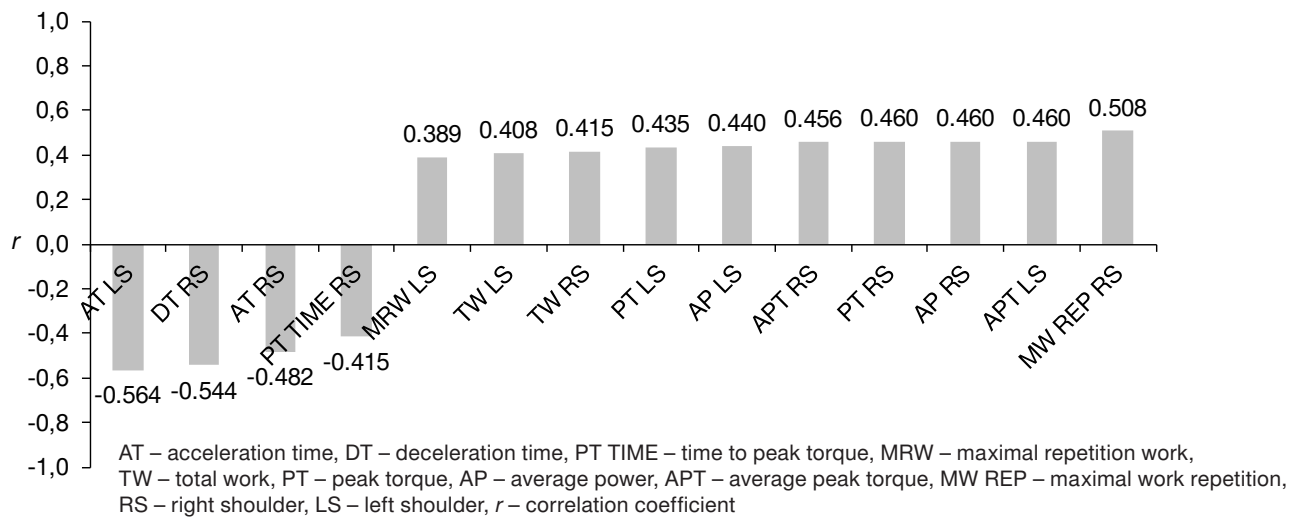
Figure 4. Significant correlation of strength variables in extension movement with the swimming performance among male swimmers

Table 1. The results of anthropometric measurements

Gender	Parameters	Right shoulder $\bar{x}$ (SD)	Left shoulder $\bar{x}$ (SD)	p
Females	Length (cm)	76.94 (1.19)	76.73 (1.26)	0.7499
	Circumference (cm)	29.09 (1.09)	29.13 (1.25)	0.9466
Males	Length (cm)	82.06 (2.95)	82.09 (2.91)	0.9666
	Circumference (cm)	31.27 (1.78)	31.49 (1.93)	0.7167

0.04 cm in females and 0.22 cm in males. These differences were not statistically significant (Table 1). Thus, the possible impact of morphological asymmetry on the results of tests has been eliminated.

After adding the Holm-Bonferroni sequential correction to the calculations, the results showed that in males, only 1 of the 68 variables was significant: AT of the left shoulder (r_2 = –0.6358; p = 0.0004) in the arm flexion movement. In females, none of the variables was significant after the correction.

Discussion

Only selected strength variables (PT, TW, AP, APT) of the shoulder muscles obtained in the isokinetic measurement had a moderate or strong correlation with the athletic performance of both females and males practising high-level sport swimming. Łubkowska et al. [1] reported that the high level of strength was indispensable in sports swimming. However, Morouço et al. [32] noted that the relationship between maximal strength and swimming speed might be non-linear. In contrast, a linear relationship occurs with the 'maximal force impulse'. However, the assumptions of Mo-

rais et al. [3] imply that the strength level is largely responsible for the final result in sports swimming.

The strength variables that have the biggest impact on high performance in sports swimming were detected. There were variables related to the maximal force. Klarowicz et al. [33] conducted different studies on the possibility of kinaesthetic differentiation of motion in water depending on the maximal force generated. They revealed that the maximal force was highly correlated with SP. This was confirmed by the results of females from the presented study.

Sharp et al. [34] evaluated 22 athletes and found that the power variables of the shoulder muscles measured on a biokinetic station were strongly related to the swimming speed of the crawl (r = 0.90). The upper limb strength analysis carried out by Hawley and Williams [12] in 30 swimmers (16 females and 14 males) showed moderate and high correlations of peak power, average power, and coefficient of fatigue with swimming speed at 50 m (r = 0.82, r = 0.83, r = 0.41, respectively). Again, the correlation was much higher than in the presented study; however, these variables were directly related to the swimming speed, not to SP (as in the above analyses). Nevertheless, the trend

has been confirmed. Improvement of variables related to strength endurance can increase swimming efficiency [35].

Morouço et al. [36] concluded that absolute force values were more related to SP than relative values (normalized to body weight). However, this concerned the tethered swimming test. In contrast, Morais et al. [3] reported that the magnitude of the propulsive force produced by a swimmer depends, among other things, on the weight of the subject. This partially confirmed the dependence of achieving a high result in sports swimming from a high level of shoulder muscle strength (measured in similar movement to swimming) among females. This was in line with the results by Alonso-Cortés Fradejas et al. [28], who confirmed that female athletes had higher values of shoulder strength variables in the extension movement than in flexion.

A positive significant relationship with SP was also found for reverse (flexion) movements rather than standards in sport swimming. This testified the necessity of balanced muscle strengthening, not only directed at 'stereotype' movements [21].

It can be concluded that increasing the disproportion between antagonistic muscle groups was associated with the improvement of SP. However, this situation can be analysed in the opposite way. Probably, for female athletes representing higher sports levels, the value of AG:AN was increasing. This could cause instability in the joint, increase the risk of injury [37], and negatively affect the results in sports swimming. The value of the above coefficient has been recognized as an important information in pathological conditions. On the other hand, restoration to normal value should be the main goal of rehabilitation [38]. The presented argument confirmed the necessity of using compensatory training in unilateral approach and achieving a balance of strength between standard and non-standard movements [21, 28, 30].

There is a possibility of improving SP by reducing the differences between the body sides (deficits). According to Alonso-Cortés Fradejas et al. [28], in the swimming sport contestants should strive for the harmonious development of both sides of the body. Similarly, Havriluk [35] described the differences in strength between right and left shoulder as one of the factors limiting the efficiency of movement in water, also occurring among high-class swimmers. Wiażewicz [21] and Batalha et al. [30] proposed that trainers should consider implementing a compensatory strength program for sports training.

The fact that speed-strength variables play a significant role in sports swimming was partially confirmed. Shortening the time of the time-related variables may trigger the desired effect of improving the swimming result [14, 15, 20].

The dependence of SP on the shoulder power variables in males almost completely confirmed the strength and power relationship described in the literature [1, 14, 15]. However, correlation coefficients were not as high as in the studies by Sharp et al. [34] ($r = 0.90$) or Hawley and Williams [12] ($r = 0.82$, $r = 0.83$), who proved that also among men, the strength of the shoulder muscles was strongly related to the crawl speed over short distances. But the high level of shoulder muscle strength variables related to both the maximal strength [33] and strength endurance [35] (measured in both standard and non-standard movements) positively influenced SP in high-class swimmers. The need to use muscle balance training was reaffirmed [21, 30].

Reducing the difference in maximal force variables between the right and the left side of the body could improve SP. Wiażewicz [21], Alonso-Cortés Fradejas et al. [28], and Havriluk [35] repeatedly confirmed the need for symmetrical development of body parts by sports swimming athletes. It is suggested that the above-mentioned effect should be obtained by compensatory training [30]. It could be applied especially in non-standard movements for sports swimming.

Also, the fact that speed-strength variables in males play a significant role in sports swimming has been partially confirmed, as mentioned in other studies [14, 15, 20].

It was detected that the level of strength had a greater influence on SP in males than in females. This is supported by studies conducted among master swimmers [39], where better values were observed in men compared with women, probably because of the greater muscle mass in males.

In the investigated females and males, no significant morphological asymmetry was found. This is in line with the proposals by Jaszczanin et al. [40] that trainers should pay special attention to the equal, symmetrical use of loads on the 2 sides of the body. This should strive to eliminate disparities in somatic development because they can affect strength abilities.

Limitations of the study

The authors are aware that for different distances, like 50 m and 1500 m, the same performance level (FINA points) does not represent the same swimmers' physiological and biomechanical responses. Strength preparation plays a special role during short-distance

competitions compared with technical preparation [36]. However, strength has also been indicated as one of the main factors that can increase swimming speed, not only in sprint competitions [1, 8], but also at medium distances [12, 13]. Clearly, different types of strength determine success over different distances. Maximum strength and breaking strength significantly affect speed, thrust, and start jump characteristics, as well as relapse – these are important factors influencing the result in swimming at distances of 50 m, 100 m, and 200 m. However, strength endurance has the greatest impact on the results achieved at distances of 800 m and 1500 m [4]. The division of the study group in terms of preferred style or distance would have disturbed statistical comparisons owing to the small group to be analysed.

It is worth remembering that there is a possibility of getting a statistically significant result when performing multiple tests. To manage this family-wise error for multiple hypotheses tests, the Holm-Bonferroni sequential correction was added to the calculations [41].

After adding this correction, the results showed that only AT in the arm flexion movement in males was significant. The AT represents the time value that is needed by a subject to reach the given angular velocity. As a result, the neuromuscular ability of the subject to cause movement was assessed [37]. The lower the value of this parameter, the higher the neuromuscular capacity of the subject. A negative AT correlation for one shoulder partly confirms that in sports swimming, speed-strength parameters play a significant role. Shortening the times of the above-mentioned variable can bring the desired effect of improving the swimming result [4, 14, 15, 20].

Conclusions

The authors showed that there was a relationship between the shoulder muscles strength and the athletic performance in high-level swimmers. However, it was found that not all, but only selected strength variables of the shoulder muscles obtained in the isokinetic measurement exhibited a moderate or strong correlation with the athletic performance of females and males practising high-level sports swimming. Also, all of these strength variables presented a high diagnostic value. Unfortunately, the results were not statistically significant. Regardless of the respondents' gender or the analysed shoulder movement, the following variables were repeated: PT, TW, AP, and APT (also not significant). Only AT of the left shoulder in the arm flexion movement in males was significant. Despite this, once the muscular groups are similar for the listed strength variables, the capability of a swimmer to produce force out of water seems to help them perform better in the water.

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Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

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