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Correlations of jump height and lower limb power during jump tests with biomechanical parameters of dolphin kick in swimming

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Purpose: The aim of this study was to investigate the correlations of lower limb power and jump height in the SJ, CMJ, ACMJ and CJ30s tests with time, speed, force, power, and work done during dolphin kick. *Methods*: Seventeen female swimmers and seventeen male swimmers of an elite swimming sports school in Poland participated in the study. The parameters being recorded and used in the analysis were the jump height and lower limb power in jump tests. In the test of 25 meters of dolphin kick in swimming at maximum pace, the results used in the analysis were the mean values of time, velocity, power, force and work. Results were expressed as means ± standard deviations. Descriptive statistics of the groups were then compiled to finally perform Pearson correlation calculations. *Results*: The highest correlations occurred between lower limb power during jumps and swimming speed, especially for men in the ACMJ ($r = 0.5468$, $p = 0.023$) and SJ ($r = 0.5411$, $r = 0.025$) tests. Jump height was not as often and strongly correlated with swimming time and speed as lower limb power. An important observation is that no statistically significant correlations were found for power, force and work during dolphin kick with lower limb power and jump height. *Conclusions*: The present study showed strong correlations between the performance variables of swimmers on dry land and in water. The most important finding is that the power during all the jumps (ACMJ, SJ, CJ30s and CMJ) was strongly correlated with the time and speed of swimming using dolphin kick.

Key words: *correlation, swimming, dolphin kick, jump tests, power*

1. Introduction

Swimming, which belongs to the group of sports in which sports performance is constantly improved [26], requires a combination of many motor skills. The overall goal is to finish the race in the fastest time possible and, therefore, to have the best average swimming speed [18]. Sprinters differ from long-distance athletes not only by the distance covered but also by the goals and characteristics of exercise. For the former, the key role is played by force and power generated by the athlete [12], and for the latter – definitely by tactics and endurance [25]. They also differ in the age at which they reach peak performance [1]. Sports training is a long-term and complex process [2], [21]. As researchers emphasize, the four main components of sports training are tactical, technical, mental and motor components [11]. One of the elements that are common in the training process of swimmers regardless of the event is technique. As stressed by Riewald [24], this is the dominant component that coexists in achieving success. It is believed that the components of sports training in the form of tactics and technique are inadequate in today's sport [3]. Therefore, motor skills and special abilities specific to a given sport or event play an important role in achieving sports success [2], [21].

Many factors are important in achieving significant performance in sport, and these include physical and mental determinants and properly designed and performed training [19], [23], [27]. One of the com-

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ponents of athletic success is the high force and power generated by the athlete. They have been shown to have a positive effect on swimming performance during swimming races [15]. The lower limbs play a significant role in swimming. An example is a study by Morouço [18], who showed that the freestyle kick has a significant effect on total swimming speed, especially in sprint events, reaching 29.7% in men and 33.4% in women of the effect on the final result [18]. The significant effect of lower limb exercises in the form of jump squats on the development of explosive strength has also been demonstrated [28]. This, in turn, according to Keiner et al. [13], is important for improving the motor skills associated with the start dive. In the study, the authors analyzed the correlation between vertical jump test performance (rather than the start dive itself) and swimming a full 25 meters using the legs alone from pushing off the wall. So far, research has been done on the relationship between swimming and on-land tests based on such exercises as pull-ups [22], bench press [8], or seated cable lat pulldowns [17]. It is also known that the leg kick has a significant effect on the swimming speed [18].

The purpose of the present study was to identify the causal relationships of lower limb power and jump height determined by vertical jump tests performed on land, such as squat jump (SJ), countermovement jump (CMJ), akimbo counter movement jump (ACMJ), and continuous jump test (CJ30s) with the results of swimming tests performed using dolphin kick. The recorded parameters were speed, time, force, power and the amount of work done. This will answer the question of whether there is a relationship between these activities and whether they can be combined in training or used to test and predict sports performance. Significant correlations should confirm the fact that swimming performance can be developed not only by in-water training but also by proper on-land strength and power training [4], [13].

2. Materials and methods

Subjects

Seventeen female swimmers (15.87 ± 0.60 years, body mass: 60.88 ± 5.74 kg, body height: 168.53 ± 5.55 cm) and seventeen male swimmers (15.79 ± 0.59 years, 67.41 ± 8.22 kg, 179.88 ± 5.15 cm) of an elite swimming sports school in Poland participated in the study. To ensure a homogeneous level of performance, the inclusion criteria for the study were being a competitive athlete from two secondary school grades and competing at the national level in their junior category. At the time of the survey, the swimmers were less than a month after their peak performance developed to participate in the annual national championships. All procedures used in the study were approved by the University Bioethics Committee for Scientific Research of the Jerzy Kukuczka Academy of Physical Education in Katowice (No. 8/2018), including the requirement of informed consent of the participants, which, in this case, was their parents as they were under 18 years of age.

Procedures

Jump tests (SJ, ACMJ, CMJ and CJ30s) were evaluated with the OptoJump Next device (Microgate, Bolzano, Italy), which is used for biomechanical assessment of athletes and performance analysis, including time measurement in the flight phase and the foot contact phase while performing a series of jumps with an accuracy of a thousandth of a second [9]. The single meter module was used in the research. The tests were performed in a sports hall with a Linodur surface. All participants had sports shoes intended for training on dry-land. The SJ test consisted of performing a maximum vertical jump from a half squat with a 90° knee flexion and hands placed on hips [14]. The goal of the CMJ test was to jump up from a standing position, preceded by a quick flexion of the legs (up to 90°) and an arm swing. The ACMJ test is performed in a similar manner but without a swing, with the hands placed on hips [10]. The CJ30s test consisted of maximum continuous vertical jumps for 30 seconds in an upright position with hands placed on hips and the 90° knee flexion with each jump [5]. The parameters that were recorded and used in the analysis were the height covered by the center of gravity, calculated from the flight time. Then, lower limb power during jumping was calculated for SJ, CMJ and AMCJ using Sayers' formula (PAPw [Watts] = 60.7 – jump height [cm] + 45.3 – body mass [kg] – 2055). In the CJ30s test, the jump power result was recorded and presented in W/kg by the OptoJump software. Participants were informed about the purpose of the study and asked to perform each jump at their maximum. In the SJ, ACMJ and CMJ tests, participants performed two trials with a rest of approximately 5 minutes between each other. The better score of the two trials was analyzed. There was one trial in the CJ30s due to the nature of this test, which is very strenuous for competitors. Prior to the study, participants performed a 20-minute dynamic warm-up and then were thoroughly familiarized with the correct technique for each jump, after which they started the tests.

After a one-hour rest, study participants moved to an Olympic-sized (50-meter) swimming pool, where they performed a conventional warm-up in the water similar to that before a competition, by swimming 1000 ± 85.28 meters, to get ready for the participation in the tests. The athletes knew their order and the time of the test. They started the warm-up as scheduled so that they finished it about 20–30 min before the measurement. Next, they left the swimming pool and dried off by covering themselves with towels so that they would stay warm and ready to participate in the test. The test of 25 meters of dolphin kick at maximum pace was performed using a Sprint 1080 Motion system (Lidingo, Sweden), which is an advanced diagnostic device used in sports where speed of movement in one direction is important [20]. It has a 90-meter line made of carbon fiber that allows for conducting speed tests. Advanced software collects detailed results, displayed on a tablet connected to the system and simultaneously saves the data to the cloud. The results used in the analysis were the mean values of time [s], velocity [m/s], power [W], force [N], and work [J]. The device was located in lane 2, directly next to the water, at the edge of the wall, so that the line, whose pulley was 50 centimeters above the water surface, was in the middle of lane 2 (3.75 m from the wall of the swimming pool). Swimmers were connected to a waist belt by the device's line that extended 30 centimeters beyond the edge of the pool so that the participant could stand freely on the platform and hold onto the edge of the wall before performing the test. The participants held a kickboard in front of them, on outstretched and straightened arms. This swimming board was designed for advanced leg training, not requiring the intervention of the upper limbs. Then, the athlete waited for the measurement start signal given by the investigator. The Sprint 1080 Motion was programmed to measure selected physical quantities from the pull of the line to the crossing of the 25-meter distance, after which recording was turned off automatically. The minimum resistance level of the pulley was set to 1 kilogram. Each participant had their athlete profile created, with necessary information including body height and weight.

Statistical analysis

Results were expressed as means ± standard deviations. Normality of distribution was confirmed using the Shapiro–Wilk test. Descriptive statistics of the groups were then compiled to finally perform Pearson correlation calculations of mean time, speed, power, force, and work with the height and power of SJ, ACMJ, CMJ and CJ30s jumps. The scale on which Pearson's correlation coefficient (r) was evaluated was as follows: correlations 0–0.10 were considered trivial, 0.11–0.30 were small, 0.31–0.50 were moderate, 0.51 –0.70 were large, 0.71–0.90 were very large, and 0.91–1 were excellent. A p-value of less than 0.05 was set as statistically significant. Testing and analysis of the material collected during the study were conducted using Statistica 13.1 software.

3. Results

In Table 1, the mean results of time, speed, power, force and work for dolphin kick performed over a distance of 25 meters are shown. Female athletes achieved a time of 27.42 ± 3.84 s, speed of 0.93 ± 0.13 m/s, power of 16.01 ± 2.39 W, force of 15.57 ± 0.56 N and work of 430.73 ± 13.17 J. Male athletes had time shorter by 2.15 s (25.27 ± 3.49 s), whereas the other results were higher: speed – by 0.08 m/s (1.01 ± 0.13 m/s), power – by 2 W (18.01 ± 2.46 W), force – by 0.22 N (15.79 ± 0.57 N) and work – by 17.06 J (447.79 ± 27.54 J).

In Table 2, the mean height and power scores for the SJ, ACMJ, CMJ and CJ30s jump tests are shown. In female athletes, the mean highest jump height (and power) at CMJ was the highest, with 29.05 ± 3.38 cm (2466.48 ± 289.14 W) and the lowest at SJ: 24.10 ± 3.42 cm (2165.84 ± 283.87 W). In the CJ30s test, the mean height was 17.44 ± 2.98 cm and the mean power was 14.25 ± 1.74 W/kg. In the male group, the same trend as in females was observed in jump tests, i.e., the mean highest jump height (and power) in CMJ (42.16 ± 8.47 cm (3557.79 ± 762.49 W)) and the lowest – in SJ (32.71 ± 7.74 cm (2984 ± 687.63 W)). In

Table 1. Means and standard deviations of the results of men's and women's 25-meter swimming using the dolphin kick

Sex	Swimming				
	Time [s]	Velocity [m/s]	Power [W]	Force [N]	Work [J]
Women	27.42 ± 3.84	0.93 ± 0.13	16.01 ± 2.39	15.57 ± 0.56	430.73 ± 13.17
Men	25.27 ± 3.49	1.01 ± 0.13	18.01 ± 2.46	15.79 ± 0.57	447.79 ± 27.54

Table 2. Means and standard deviations of results of the SJ, ACMJ, CMJ, and CJ30s tests in women and men

Sex	SJ		ACMJ		CMJ		CJ30s	
	Height [cm]	Power [W]	Height [cm]	Power [W]	Height [cm]	Power [W]	Height [cm]	Power [W/kg]
Women	24.10 ± 3.42	2165.84 ± 283.87	24.65 ± 3.83	2199.4 ± 293.01	29.05 ± 3.38	2466.48 ± 289.14	17.44 ± 2.98	14.25 ± 1.74
Men	32.71 ± 7.74	2984 ± 687.63	34.56 ± 7.52	3096.83 ± 679.69	42.16 ± 8.47	3557.79 ± 762.49	24.81 ± 5.37	18.25 ± 3.25

Table 3. Correlations of the mean values of time, speed, power, force, and work for swimming 25 meters using dolphin kick with the height and power results in the SJ, ACMJ, CMJ, and CJ30s jump tests in men and women

		SJ		ACMJ		CMJ		CJ30s	
		Height [cm]	Power [W]	Height [cm]	Power [W]	Height [cm]	Power [W]	Height [cm]	Power [W]
Women									
Swimming 25-m legs butterfly	Time [s]	–0.1363 p = 0.602	–0.3264 p = 0.201	–0.1208 p = 0.644	–0.3154 p = 0.218	–0.1951 p = 0.453	–0.3610 p = 0.155	–0.1314 p = 0.615	–0.2144 p = 0.409
	Velocity [m/s]	0.1362 p = 0.602	0.3306 p = 0.195	0.1069 p = 0.683	0.3084 p = 0.228	0.1834 p = 0.481	0.3568 p = 0.160	0.1353 p = 0.605	0.2140 p = 0.410
	Power [W]	0.0937 p = 0.721	0.2741 p = 0.287	0.0720 p = 0.784	0.2562 p = 0.321	0.1296 p = 0.620	0.2938 p = 0.252	0.1173 p = 0.654	0.1642 p = 0.529
	Force [N]	–0.2103 p = 0.418	–0.0829 p = 0.752	–0.2477 p = 0.338	–0.1277 p = 0.625	–0.2317 p = 0.371	–0.0947 p = 0.718	–0.1126 p = 0.667	–0.0012 p = 0.996
	Work [J]	–0.2249 p = 0.385	–0.2348 p = 0.364	–0.1907 p = 0.463	–0.2193 p = 0.398	–0.2510 p = 0.331	–0.2470 p = 0.339	–0.0907 p = 0.729	–0.2182 p = 0.400
Men									
Swimming 25-m legs butterfly	Time [s]	–0.4603 p = 0.063	–0.5256 p = 0.030	–0.4924 p = 0.045	–0.5442 p = 0.024	–0.4649 p = 0.060	–0.5039 p = 0.039	–0.4892 p = 0.046	–0.5254 p = 0.030
	Velocity [m/s]	0.4737 p = 0.055	0.5411 p = 0.025	0.4870 p = 0.047	0.5468 p = 0.023	0.4547 p = 0.067	0.5027 p = 0.040	0.4893 p = 0.046	0.5243 p = 0.031
	Power [W]	0.3355 p = 0.188	0.4115 p = 0.101	0.3050 p = 0.234	0.3891 p = 0.123	0.3493 p = 0.169	0.4000 p = 0.112	0.3649 p = 0.150	0.4139 p = 0.099
	Force [N]	–0.1263 p = 0.629	0.0539 p = 0.837	–0.2058 p = 0.428	0.0036 p = 0.989	–0.0660 p = 0.801	0.0819 p = 0.755	–0.1678 p = 0.520	–0.1660 p = 0.524
	Work [J]	–0.2883 p = 0.262	–0.2574 p = 0.319	–0.3917 p = 0.120	–0.3241 p = 0.204	–0.2267 p = 0.382	–0.2074 p = 0.425	–0.2664 p = 0.301	–0.2357 p = 0.362

the CJ30s test, the mean height was by 7.37 cm (24.81 ± 5.37 cm) higher than in female athletes, similar to mean power, by 1.51 W/kg (18.25 ± 3.25 W/kg).

Based on the results presented in Table 3, no significant correlations were found between the parameters during swimming and on-land jump tests in women. A moderate correlation was observed for swimming time and speed with jumping power (excluding CJ30s) with an average of $r = 0.334$ and $r = 0.332$, respectively, but the results were not statistically significant ($p > 0.05$), making it impossible to draw conclusions. In male swimmers, there was a statistically significant high/strong correlation of swimming time and speed with power in all jump tests, averaging $r = 0.525$ and $r = 0.529$, respectively. It was most noticeable for swimming speed [m/s] vs. power [W] in ACMJ – $r = 0.547$ ($p = 0.023$) and swimming time [s] vs. power [W] in ACMJ – $r = 0.544$ ($p = 0.024$), and least pronounced in swimming speed [m/s] vs. power [W] in CMJ – $r = 0.503$ ($p = 0.040$) and swimming time [s] vs. power [W] in CMJ – $r = 0.504$ ($p = 0.39$). All results were statistically significant ($p < 0.05$) and correlations were over $r = 0.5$. The correlation results between swimming time and speed and jump height in two tests, i.e., ACMJ, with ($r = 0.492$ ($p = 0.045$) and $r = 0.487$ ($p = 0.047$), respectively, and CJ30s, with $r = 0.489$ ($p = 0.046$) and $r = 0.489$ ($p = 0.046$), respectively, were also statistically significant. The other two jump height results, i.e., SJ and CMJ, also showed correlations with time and speed at a similar level. However, they were not statistically significant ($p = 0.55$ and 0.67, respectively).

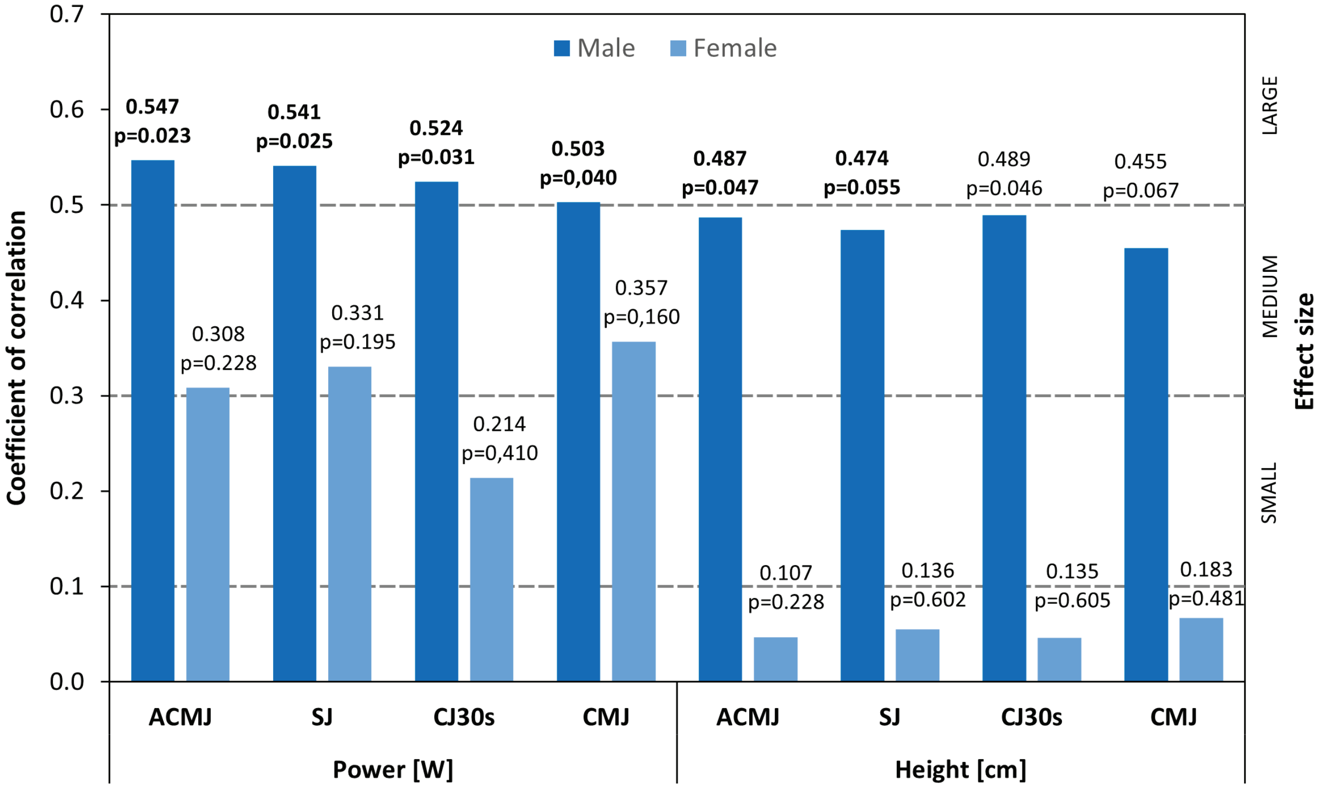

Fig. 1. Pearson's correlations (*r*) of mean values of swimming speed [m/s] with lower limb power and jump height in individual tests (ACMJ, SJ, CJ30s and CMJ) in male and female groups

4. Discussion

Based on the presented results, it can be concluded that the most significant finding of the research project was strong correlations observed for in-water tests compared to on-land tests. Correlations of the highest strength were found for the ACMJ test. Therefore, it seems that it is the best test for diagnosing swimmers in terms of dolphin kicking performance, and it can be hypothesized that it is likely to positively support the swimming training process. The lowest correlation strength was observed in CMJ, which is one of the most popular tests used by researchers [15]–[17], [22]. The CMJ jump is very similar to ACMJ, but the main difference is the use of the upper limbs [6], which makes the former less related to swimming speed than when placing hands on the hips.

The greatest correlations occurred between jumping power and swimming speed. An interesting observation is that jump height is not as frequently and strongly correlated with swimming time and speed. Similar conclusions were reached by Perez-Olea et al. [22]. Morouco [17] also demonstrated that jump height does not correlate well with swimming [17]. This is important information for individuals diagnosing the potential of future swimming champions/athletes as the jump height is not as strong (reliable) a determinant or predictor as lower limb power expressed in watts. It can be concluded that on-land training to improve lower limb power may provide greater benefits than strenuously targeting only jump height. It should be noted that strength training improves CMJ height performance [16], which affects in-water speed parameters, but it is also important to consider increasing lower limb power first and foremost.

Previous results of studies of correlations between parameters recorded during the jump into the water/start dive and vertical jump tests showed significant correlations [7]. The lower limbs play a significant role in technical elements, especially over short distances and in the 25-meter pools [29]. Our study provides new insights and confirms correlations between the power generated by athletes during all four on-land jump tests and the speed and time of the dolphin kick. The study also showed no correlations of power, force, and work in water with the height and power during jump tests.

The strong correlations we observed between the results of lower limb power tests and the parameters of speed generated in water by swimmers confirm the validity of the thesis proposed by researchers [15], [16] of the importance and purposefulness of on-land strength training in order to improve swimming performance in water. To the best of our knowledge, no study has evaluated such a large number of parameters during a single in-water test by correlating them with each other and the results of four different on-land jump tests. It is worthwhile to perform similar research using the same equipment to extend the knowledge with the correlations observed for using the hands alone and the full stroke. This can provide a more complete picture of how jump tests affect the parameters used by competitive swimmers in the water and how they can be used in training and diagnosis.

5. Conclusions

In conclusion, the present study showed large and strong correlations between the performance variables of swimmers on dry land and in water. The most important finding is that the power during all the jumps (ACMJ, SJ, CJ30s, and CMJ) was strongly correlated with the time and speed of swimming using dolphin kick. The second finding is that a better estimator of velocity generation in water is power rather than height, with the largest relationship in male swimmers observed in the ACMJ test and the smallest – in the CMJ test. An important observation is that no statistically significant correlations were found for power, force and lower limb work during dolphin kicking with lower limb power and jump height.

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