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# Underwater and surface tethered swimming, lower limb strength, and somatic traits as the basic indices of young swimmers' sprint performance

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## Abstract

***Purpose***: The ability to swim fast underwater is believed to be connected to lower limb strength and some somatic traits. The main purpose of the study was to evaluate strength and speed parameters based on the relationship between the strength of underwater dolphin kicks and the counter movement jump test (*CMJ*) among adolescent swimmers. ***Methods***: 48 adolescent male swimmers (13.47 ± 0.84 years) were examined for muscle mass of arms ($m_{\text{m arms}}$), trunk ($m_{\text{m trunk}}$), and legs ($m_{\text{m legs}}$), body height (*BH*), and biological age (*BA*). An underwater tethered dolphin kicking test was conducted in a pool; average force ($5F_{\text{ave}}$) and impulse per single cycle ($5I_{\text{ave}}$) in the 5-s period were measured. Force indices ($20F_{\text{ave}}$ – average force from 20 seconds and $20I_{\text{ave}}$ – average impulse per single cycle from 20 seconds) were also measured in 20-s tethered front crawl swimming. During *CMJ* testing, general lower body muscle motor capabilities were evaluated by extracting the work (*CMJw* [J]) and height (*CMJh* [m]) of the jump. ***Results***: The strongest correlations were observed between: (a) $5F_{\text{ave}}$ and *BH*, $m_{\text{m arms}}$ and *CMJw*; (b) *CMJw*, $m_{\text{m arms}}$, and $20F_{\text{ave}}$; (c) indices of swimming speed and $5I_{\text{ave}}$ (*BA* control); (d) total swimming velocity and average tethered swimming force (*BA* control). Moderate partial correlations (*BA* control) were noted between speed indices of swimming race and *CMJ*. ***Conclusion***: The underwater tethered dolphin kick test is a useful predictor test of 50-m front crawl performance in young male swimmers, with better specificity for swimmers than *CMJ* results themselves.

***Key words:*** *submerged dolphin kick, tethered swimming, sprint front crawl, adolescent*

## INTRODUCTION

Several studies aimed to identify the most important determinants of successful age-group swimming, such as anthropometric [10], physiological [17], and biomechanical [6] factors. Sprint swimming of young swimmers also seems to be dependent on somatic traits (e.g. upper extremity length) [10], in-water strength abilities [23], and swimming technique (e.g. stroke index or intra-cyclic velocity variation) [33].

Substantial strength abilities are necessary to be successful in high-level swimming [40]. It was proven that dryland strength training (also power) could lead to swimming performance in adolescents [27]. However, as arms are considered the main propellers [9], most studies focused on the potential influence of in-water measurement of upper body strength on swimming performance [5]. Although assessments of the ability to generate power by the upper limbs have been also performed on land [11], along with the aerobic capacity [37], over time, the testing of the upper limb fitness has focused on measuring the ability to generate swimming propulsive force in more specific water conditions [24, 30, 36]. Nevertheless, sprint performance of young swimmers depends also on lower limb action [7], strength [38] efficient flutter kicking [35], and underwater swimming [41]. In a 50-m race, in a 25-m pool, around 50% of the distance is covered underwater [16]. It is also known that in sprint distances like 50 m, the time needed to cover the first 15-m underwater, as well other underwater sections, is crucial to the final time. As such, proper lower limb strength is necessary to be successful [15, 18]. Leg strength also influences block start [39] and turn zone performance [8]. Thus, specific strength training procedures (e.g. plyometric training) focused on lower limbs have been proven to affect the swimming start and turn performance [28].

Determining in-water strength abilities resorting to tethered or semi-tethered tests is a reliable method of swimming performance evaluation, especially at sprint distances [3]. However, most of the tethered swimming tests refer to the full stroke; few of them evaluate the lower limb participation in swimmers' body propulsion [24, 35].

CMJ testing is widely used to evaluate swimming performance. CMJ results (height/ or work) are correlated to swimming speed of adolescent swimmers [12, 37]. Almeida- Neto et al. [21] noted that 50-m performance of adolescent swimmers (crawl, breastroke, butterfly) is associated with the levels of upper limb power, lower limb power, and upper and lower limb lean mass. Marques et al. [20] results revealed that relative changes in CMJ performance are directly connected to relative changes swimming performance among young male swimmers (r = 0.83).

Swimming performance of young athletes is highly connected to their body size, e.g. total body length [17]. Coaches must be aware of the rapid changes in adolescent swimmers' developmental level, inducing growth, higher aerobic and anaerobic abilities, better movement coordination [43]. Wadrzyk et al. [41] claimed that the anthropometrics of young swimmers had little influence on kinematic indices of underwater undulatory swimming (UUS), but they found an association between body height and dimensions of the feet. West et al. [42], in systematic review, identified that UUS velocity was strongly connected to kick frequency, kick amplitude, vertical toe velocity, knee angular velocity. The number of studies that examined actual kicking thrust force is scarce.

The aim of this study was to verify if a newly introduced tethered underwater dolphin kicking test could be a better predictor of young swimmers' 50-m front crawl performance than surface tethered front crawl swimming or a counter movement jump (*CMJ*) test. A possible more accurate performance explanation by underwater dolphin kicking test could be due to general/ unspecific character of *CMJ* testing (dry land). A potential influence of anthropometrics, body composition, and lower limb strength on sprint swimming results of the tests were also evaluated.

## MATERIALS AND METHODS

### Participants

Forty-eight young male swimmers (13.47 ± 0.84 years of calendar age; 14.56 ± 1.67 years of biological age [*BA*]) took part in the research. They were recruited as swimmers with the highest performance level in their age category from the Krakow region, Poland. The participants presented a swimming level which resulted in a mean value of 343.55 ± 72.1 World Aquatics Swimming Points for a 50-m front crawl short course race. All of them were healthy and had licences from the Polish Swimming Federation. All swimmers had a 4–5-year experience in systematic swimming, performed at least 10 training sessions weekly, and took part in national level competitions and national swimming championships for their age group. They were at the 5th and 4th threshold (below 650 points) of performance level according to the Ruiz-Navarro et al. [29] classification. Swimmers with less than 250 or more than 650 World Aquatics points for 50-m freestyle performance were not included in the study. Despite the swimming style specialization, all the individuals regularly participated in freestyle events. Their body height (*BH*: 168.56 ± 7.77 cm) and body mass (*BM*: 57.88 ± 10.06 kg) were measured with an anthropometer (Sieber Hegner Maschinen AG, Zurich, Switzerland) and digital scales (BC-418, Tanita, Tokyo, Japan), respectively. Body mass index was calculated in accordance with the following formula: body weight (kg)/body height squared ($m^2$) (20.27 ± 2.47). The research was approved by the Bioethics Committee at the Regional Medical Chamber (approval No.: 94/KBL/OIL/2020). All subjects and their parents provided informed consent for their participation in intensive physical effort during this study (parents of all participants had become acquainted with the study program and a short description of the tests).

### Body composition and biological age

A body composition analyser (BC-418, Tanita, Tokyo, Japan) was used to assess segmental body composition. In addition to *BM* (kg) measurement, the device performs bioelectrical impedance analysis, a method of analysing tissue composition based on varying electrical responses to the weak electrical current introduced into the body. Bioelectrical impedance analysis is a reliable method of assessing the tissue composition of the body; its reliability and validity have been recognized in many independent studies [1]. The participants, dressed in underwear, stood on the electrodes barefoot and gripped the handheld electrodes. This procedure provided data on the predicted muscle mass of body segments: arms – $m_{\mathrm{m\ arms}}$ [kg], trunk – $m_{\mathrm{m\ trunk}}$ [kg], and legs – $m_{\mathrm{m\ legs}}$ [kg]. *BA* examinations (14.74 ± 1.82 [years]) were conducted by an experienced anthropologist, who used the following calculation: $BA = (BH_{\mathrm{age}} + BM_{\mathrm{age}}) / 2$, where $BH_{\mathrm{age}}$ was the age obtained from percentile charts (growth charts by the Children's Memorial Health Institute; 50th percentile was used to align *BH* with age) on the basis of the participant's *BH*, and $BM_{\mathrm{age}}$ was the age obtained from percentile charts (growth charts by the Children's Memorial Health Institute, standardized and validated for the Polish population; 50th percentile was used to align *BM* with age) on the basis of the participant's *BM*.

## Testing procedure

All the anthropometric measurements and *CMJ* tests were performed at first. Then, the participants took part in three maximum swimming bouts: the first two involved tethered swimming and the last one was a 50-m front crawl race. Before each test, the swimmers completed a 1000-m in-water warm-up with low-to-moderate intensity [25], as suggested in the literature. After the tethered swimming test, the athletes performed an at least 15 min cool-down and had an additional 60 min of passive recovery before the 50-m race.

## Counter movement jump

Each participant performed three jumps on a force plate (BP400600, AMTI, Watertown, MA, USA) mounted on the laboratory floor (measuring frequency - 280 Hz). To achieve maximum intensity, 30 s of rest between the jumps were provided. Before the jump, the athlete stood upright on the force plate with their weight evenly distributed between both feet. Hands were placed on the hips throughout all the three jumps. *CMJw* (J) was defined as the work generated in a single jump and calculated from the best jump, and was deemed as an absolute indicator of the alactic anaerobic muscle system capabilities. The average elevation of the centre of mass – h (cm) – was considered as an indicator of motor abilities relative to body mass – *CMJh* (cm). The test was performed after a 5-min dynamic warm-up, which included dynamic stretching, progressive intensity shuttle runs, and body-weight squats [22].

## 5 s maximum underwater tethered dolphin kick test

During this newly designed test, the participants wore a waist belt and were connected to the flume wall by a 4.6-m steel cable (with two fixing points: 0.6-m below the surface, to avoid on surface wave occurrence, on the set of triangle, with the apex being a point of swimmers' location); a dynamometer attached at one of the fixing points recorded force data at a frequency of 100 Hz (Figure 1). Before the test, the participants received at least 5 attempts to familiarize with the new conditions and try to perform some movements at low intensity. The following indices were collected:

- average value of force ($5F_{\text{ave}}$, N);
- average impulse per single cycle ($5I_{\text{ave}}$, N·s$^{-1}$), defined as the integral of force over a period of time ($Fdt$) containing all full cycles divided by the number of completed cycles ($n$):

$$I_{\text{ave}} = \frac{\int_{t_0}^{t_1} Fdt}{n},$$

where: $t_0$ is the beginning of the first full cycle and $t_1$ is the end of the last full cycle in the 5 s period. Beginning and the end of the cycle was the moment when 5th toe starts to move downwards from the highest possible placement.

The athletes were asked to swim above a marked point below them, located in the symmetry axis of the system. The measuring system (Figure 1) consisted of a cable attaching the swimmer to the edge of the pool. The cable formed two equal arms. A force transducer (FT) was installed on one of the arms. The geometry of the system was the same for all swimmers. The propulsion force $F$ generated by the participants was calculated according to the following formula:

$$F = 2F_m cos\left[arcsin\left(\frac{b}{a}\right)\right],$$

where $F_m$ is the force measured with a force transducer, $a$ is the length of one arm of the cable, and $b$ is half of the distance between the attachments of the cable to the edge of the pool.

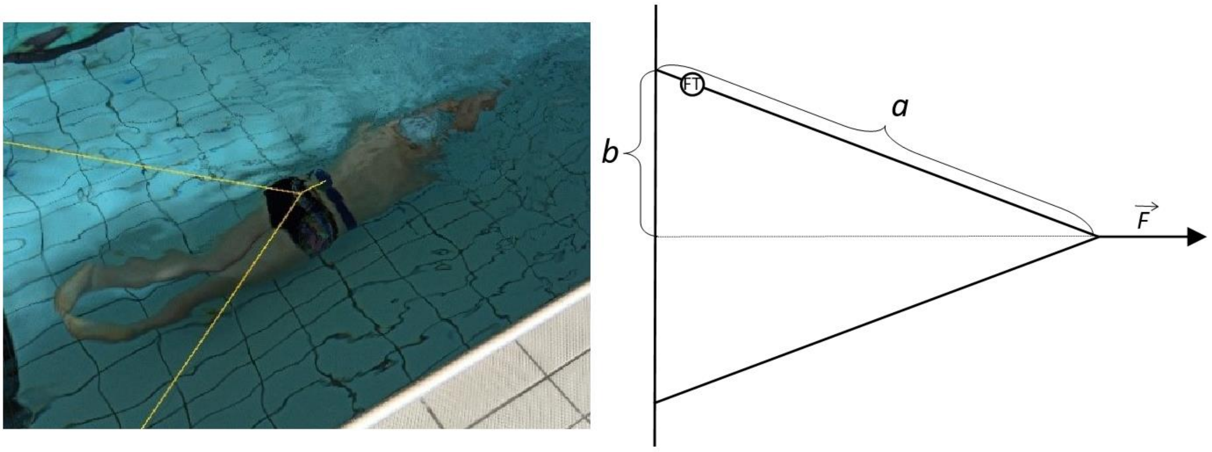

Figure 1. a) A swimmer during the 5 s maximum submerged dolphin kick test in the flume, b) Schematic of the measurement system. *F* - propulsion force, *a* - length of one arm of the cable, *b* - half of the distance between the attachments of the cable to the edge of the pool, FT - force transducer

## 20 s tethered swimming test

In the 20 s tethered swimming test, the participants wore a waist belt and were connected to a steel pole (fixing point: 0.49 m above the surface) by a 5.65-m steel cable; a dynamometer was attached with a recording frequency of 100 Hz [34]. Before the test, the athletes received at least 20 s to familiarize with the new conditions and try to perform some movements at low intensity. The following indices were collected:

- average value of force ($20F_{\mathrm{ave}}$, N);
- average impulse per single cycle ($20I_{\mathrm{ave}}$, N·s$^{-1}$), defined as the integral of force over a period of time containing all full cycles divided by the number of completed cycles:

$$I_{\mathrm{ave}} = \frac{\int_{t_0}^{t_1} F dt}{n},$$

where: $t_0$ is the beginning of the first full cycle and $t_1$ is the end of the last full cycle in the 20 s period.

## 50-m front crawl race

The 50-m race was carried out in a 25-m swimming pool that met the World Aquatics requirements. The ultimate results and split times of the race were measured with an automatic timing device (Omega OCP5, Switzerland) (accuracy of 0.01 s). Each race trial was performed by five to four swimmers, similarly to competition conditions. All trials were recorded with a camera (GC-PX100BE, JVC, Japan; 50 Hz). The camera was placed on a tripod at the stands, 6-m above the water surface, in the extension of the middle point of the pool. To separate the areas of surface swimming, the pool was divided into zones. Markers were placed at the side of the pool to locate the line of 7-m from each of the walls. For the first lap, the first marker was attached 10-m from the starting block, the second one at 15-m, and the third 7-m from the wall. The pool (excluding the first lap) was divided to three zones: I – turn zone (7 m), II – surface swimming zone (11-m), III – turn zone (7-m). Including the first 10-m start zone, this resulted in: (a) 31-m for the start, turn, finish velocity ($v_{\mathrm{STF}}$) calculation; (b) 19-m for surface swimming velocity ($v_{\mathrm{surface}}$) examination. $v_{\mathrm{total50}}$ is the swimming speed for all the distance, $v_{15}$ is the swimming speed for the first 15-m of the race. Times for separate sectors were measured when the swimmer's head crossed the imaginary line linking the markers at the sides of the pool; Kinovea software (v0.8.15) was used (Figure 2). Swimming speed were calculated by dividing distance by measured time. V Stroke kinematic indices of stroke rate (*SR*), stroke length (*SL*), and stroke index (*SI*) were calculated from surface swimming zones. The average *SR* (cycle·min$^{-1}$) was determined from 12 cycles (3 cycles form each of the 4 laps, measured in the surface swimming zone); *SL* was estimated as: $SL = \frac{V_{\text{surface}}}{SR}$ (m); and *SI* was calculated as: $SI = V_{\text{total}} \cdot SL$ (m$^2$·cycle$^{-1}$·s$^{-1}$).

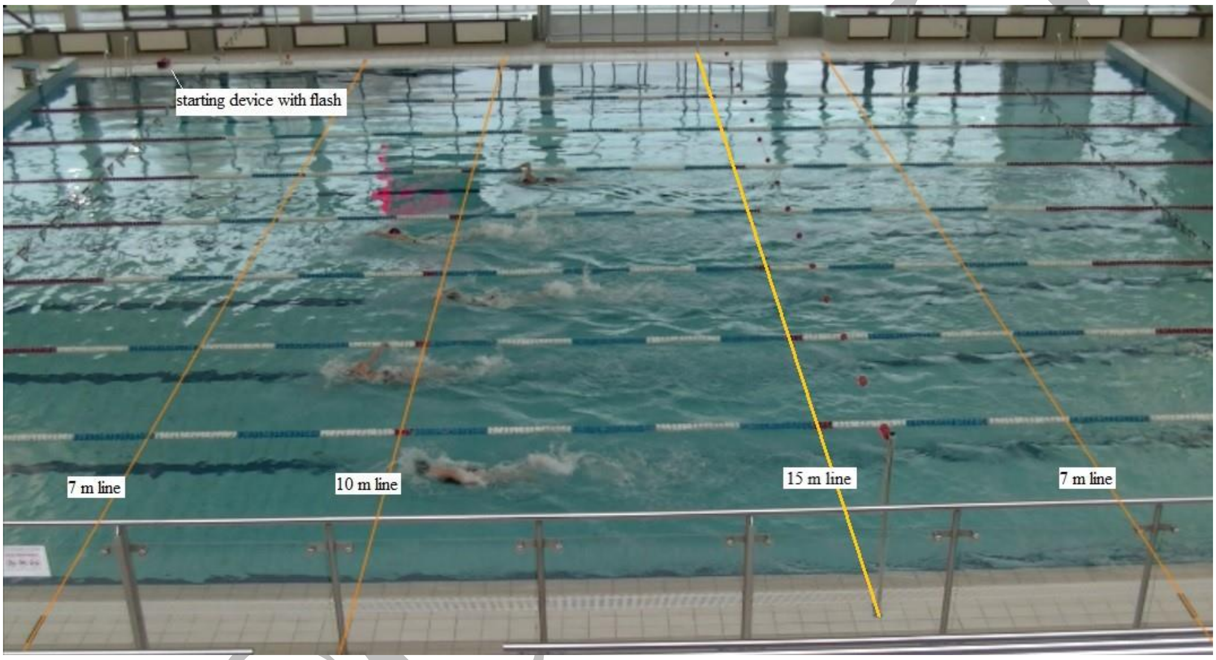

Figure 2. Demonstration of recording analysis (Kinovea software - v0.8.15) with lines dividing swimming pool into zones.

## Statistical analysis

Individual, mean, and standard deviation (*SD*) computations for descriptive analysis were obtained for all studied variables. For checking the normality of the data assumptions, Shapiro-Wilk tests were conducted. Pearson's correlations were computed between the indices of: (a) anthropometrics, body composition, and lower body strength (*BH*, *BM*, $m_{\text{m arms}}$, $m_{\text{m legs}}$, $m_{\text{m trunk}}$, *CMJh*, *CMJw*); and (b) tethered front crawl and underwater dolphin kick swimming ($20F_{\text{ave}}$, $20I_{\text{ave}}$, $5F_{\text{ave}}$, $5I_{\text{ave}}$). The magnitude of the correlations were deemed as: trivial ($r \leq 0.1$), low ($0.1 < r \leq 0.3$), moderate ($0.3 < r \leq 0.5$), high ($0.5 < r \leq 0.7$), very high ($0.7 < r \leq 0.9$), nearly perfect ($r > 0.9$), and perfect ($r = 1$) [13]. To avoid spurious correlation caused by an extraneous variable – *BA*, the partial correlations were conducted between: (a) kinematic indices of swimming speed ($v_{15}$, $v_{total50}$, $v_{surface}$, $v_{STF}$), technique (*SR*, *SL*, *SI*); and (b) tethered front crawl, underwater dolphin kick swimming indices, *CMJh*, and *CMJw*.

Variations of indices: $20F_{ave}$, $20I_{ave}$, $5F_{ave,}$ $5I_{ave}$, *CMJh, CMJw* categorized by *BA* values (from 12 to 18 years) were analysed using One-way ANOVA. Due to variance differences Post-hoc T3 Dunnett test was used for identify possible differences between the values of mentioned indices measured in each of the *BA* categories. Post–hoc test was not calculated for *CMJh* because of ANOVA test insignificance. ANOVA for repeated measures and Post-hoc Tukey HSD test were calculated for values of swimming speed: $v_{15}$, $v_{total50}$, $v_{surface}$, $v_{STF}$.

The statistical significance was set at $p \leq 0.05$. All statistical analyses were conducted by using the Statistica 13.3 software (TIBCO Software Inc., Palo Alto, CA, USA).

## RESULTS

There were significant correlations between all measured anthropometric, *CMJ* indices, and results of the 5 s maximum underwater dolphin kick test. The strongest correlations were observed between the $5F_{ave}$ and *BH*, $m_{m\ arms}$ and *CMJw* (Table 1).

Table 1. Correlations between anthropometric, body composition, and *CMJ* indices and average force, average impulse of force from 5 s maximum underwater dolphin kick test.

| ***Linear correlations*** | | *BH* (cm) | *BM* (kg) | $m_{m\ arms}$ (kg) | $m_{m\ legs}$ (kg) | $m_{m\ trunk}$ (kg) | *CMJw* (J) | *CMJh* (cm) |
|---|---|---|---|---|---|---|---|---|
| | | 168.6 ± 7.77 | 57.9 ± 10.06 | 4.61 ± 0.86 | 16.17 ± 2.77 | 25.66 ± 3.62 | 177.0 ± 46.30 | 32.3 ± 5.19 |
| $5F_{ave}$ (N) | 86.93 ± 16.98 | 0.72** | 0.60** | 0.72** | 0.66** | 0.68** | 0.69** | 0.40* |
| $5I_{ave}$ (N · s) | 54.22 ± 12.89 | 0.63** | 0.45** | 0.59** | 0.54** | 0.54** | 0.55** | 0.36* |

* $p \leq 0.01$; ** $p \leq 0.001$

All the anthropometric, *CMJ* indices were moderately to very highly correlated with average tethered swimming force ($20F_{ave}$) and average impulse of force per cycle ($20I_{ave}$). The correlations between *CMJw*, $m_{m\ arms}$, and $20F_{ave}$ were the strongest (Table 2).

Table 2. Correlations between anthropometric, body composition, and *CMJ* indices and average force, average impulse of force from 20 s maximum tethered swimming test.

| ***Linear correlations*** | | *BH* (cm) | *BM* (kg) | $m_{m\ arms}$ (kg) | $m_{m\ legs}$ (kg) | $m_{m\ trunk}$ (kg) | *CMJw* (J) | *CMJh* (cm) |
|---|---|---|---|---|---|---|---|---|
| $20F_{ave}$ (N) | 86.93 ± 16.98 | 0.78** | 0.71** | 0.80** | 0.74** | 0.79** | 0.80** | 0.40* |
| $20I_{ave}$ (N · s) | 54.22 ± 12.89 | 0.76** | 0.66** | 0.78** | 0.73** | 0.75** | 0.76** | 0.42* |

* $p \leq 0.01$; ** $p \leq 0.001$

From all the indices of swimming speed and stroke kinematics from the 50-m front crawl, only *SR* did not partially correlate with the 5 s maximum underwater dolphin kick test (while controlling for *BA*). The highest correlations were observed between the indices of swimming speed and average impulse of force from the 5 s underwater dolphin kicking (Table 3).

Table 3. Partial correlations controlled for *BA* between indices of 5 s maximum underwater dolphin kick test and swimming speed, stroke kinematics indices from 50-m front crawl race.

| ***Partial correlations (BA control)*** | $v_{15}$ ($\mathrm{m \cdot s^{-1}}$) | $v_{total50}$ ($\mathrm{m \cdot s^{-1}}$) | $v_{surface}$ ($\mathrm{m \cdot s^{-1}}$) | $v_{STF}$ ($\mathrm{m \cdot s^{-1}}$) | *SR* ($\mathrm{cycle \cdot min^{-1}}$) | *SL* (m) | *SI* ($\frac{\mathrm{m^2}}{\mathrm{s}}$) |
|---|---|---|---|---|---|---|---|
| | 1.94 ± 0.14 | 1.71 ± 0.11 | 1.61 ± 0.10 | 1.79 ± 0.13 | 55.4 ± 4.77 | 1.75 ± 0.16 | 2.85 ± 0.36 |
| $5F_{ave}$ (N) | 0.69** | 0.70** | 0.69** | 0.67** | 0.17 | 0.29* | 0.53** |
| $5I_{ave}$ (N · s) | 0.56** | 0.54** | 0.58** | 0.48** | 0.13 | 0.27 | 0.47** |

* $p \leq 0.05$; ** $p \leq 0.001$

Moderate to high correlations were noted between the indices of swimming speed and tethered swimming. *SR* was not significantly related to the indices of tethered swimming force. The highest correlations were reported between total swimming velocity and average tethered swimming force. *SL* and *SI* were moderately to highly correlated with tethered swimming force (Table 4).

Table 4. Partial correlations controlled for *BA* between swimming speed, stroke kinematics indices from 50 m front crawl race, and tethered swimming indices.

| ***Partial correlations (BA control)*** | $v_{15}$ ($\mathrm{m \cdot s^{-1}}$) | $v_{total50}$ ($\mathrm{m \cdot s^{-1}}$) | $v_{surface}$ ($\mathrm{m \cdot s^{-1}}$) | $v_{STF}$ ($\mathrm{m \cdot s^{-1}}$) | *SR* ($\mathrm{cycle \cdot min^{-1}}$) | *SL* (m) | *SI* ($\frac{\mathrm{m^2}}{\mathrm{s}}$) |
|---|---|---|---|---|---|---|---|
| $20F_{ave}$ (N) | 0.66** | 0.75** | 0.72** | 0.74** | 0.21 | 0.26 | 0.51** |
| $20I_{ave}$ (N · s) | 0.65** | 0.71** | 0.62** | 0.73** | –0.15 | 0.58** | 0.71** |

** $p \leq 0.001$

Moderate partial correlations were noted between: $v_{15}$, $v_{total50}$, $v_{STF}$, and the *CMJ* test indices. There were no correlations between *CMJ* indices and $V_{surface}$, *SR*, *SL*, *SI* (Table 5).

Table 5. Partial correlations controlled for *BA* between swimming speed, stroke kinematics indices from 50-m front crawl race and *CMJ* test.

| ***Partial correlations (BA control)*** | $v_{15}$ ($\mathrm{m \cdot s^{-1}}$) | $v_{\mathrm{total50}}$ ($\mathrm{m \cdot s^{-1}}$) | $v_{\mathrm{surface}}$ ($\mathrm{m \cdot s^{-1}}$) | $v_{\mathrm{STF}}$ ($\mathrm{m \cdot s^{-1}}$) | *SR* ($\mathrm{cycle \cdot min^{-1}}$) | *SL* (m) | *SI* ($\frac{\mathrm{m^2}}{\mathrm{s}}$) |
|---|---|---|---|---|---|---|---|
| *CMJw* (J) | 0.34* | 0.35* | 0.27 | 0.38* | 0.15 | 0.01 | 0.10 |
| *CMJh* (m) | 0.36* | 0.33* | 0.27 | 0.35* | –0.04 | 0.22 | 0.28 |

* $p \leq 0.05$

Significant differences between the mean values of $v_{15}$, $v_{\mathrm{total50}}$, $v_{\mathrm{surface}}$, $v_{\mathrm{STF}}$ were observed (Figure 3). There was a significant difference between measured average speed values of: $v_{15}$, $v_{\mathrm{total50}}$, $v_{\mathrm{surface}}$, $v_{\mathrm{STF}}$ (F = 431,43; $p \leq 0.001$). Post-hoc Tukey's (HSD) test confirmed significant differences among all of the measured averages ($p \leq 0.001$).

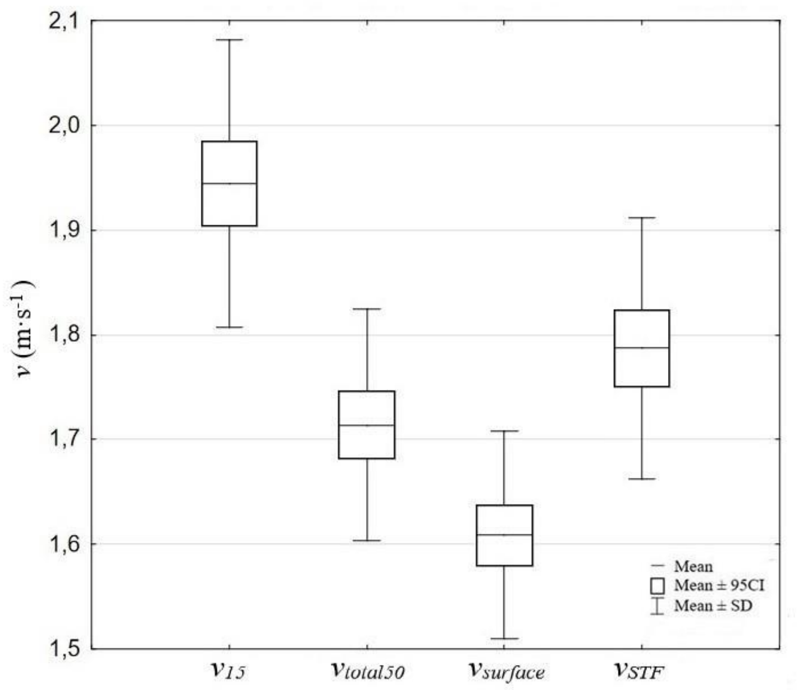

Figure 3. Average values of kinematic indices calculated from 50-m front crawl race.

Significant One-way ANOVA test were calculated for: $20F_{\mathrm{ave}}$, $20I_{\mathrm{ave}}$, $5F_{\mathrm{ave}}$, $5I_{\mathrm{ave}}$ and *CMJw*. For *CMJh* result was insignificant (Table 6).

Table 6. Results of ANOVA test for values of the underwater tethered dolphin kicking, tethered front crawl swimming, and *CMJ* categorized by *BA*.

| | *F* (6, 40) | *p* |
|---|---|---|
| $20F_{\mathrm{ave}}$ | 11.35 | <.001 |
| $20I_{\mathrm{ave}}$ | 12.34 | <.001 |
| $5F_{\mathrm{ave}}$ | 8.83 | <.001 |
| $5I_{\mathrm{ave}}$ | 4.37 | .002 |

| | | |
|---|---|---|
| *CMJh* | .86 | .534 |
| *CMJw* | 15.82 | <.001 |

Figure 4 presents the mean and *SD* values of the underwater tethered dolphin kicking, tethered front crawl swimming, and *CMJ* categorized by *BA*.

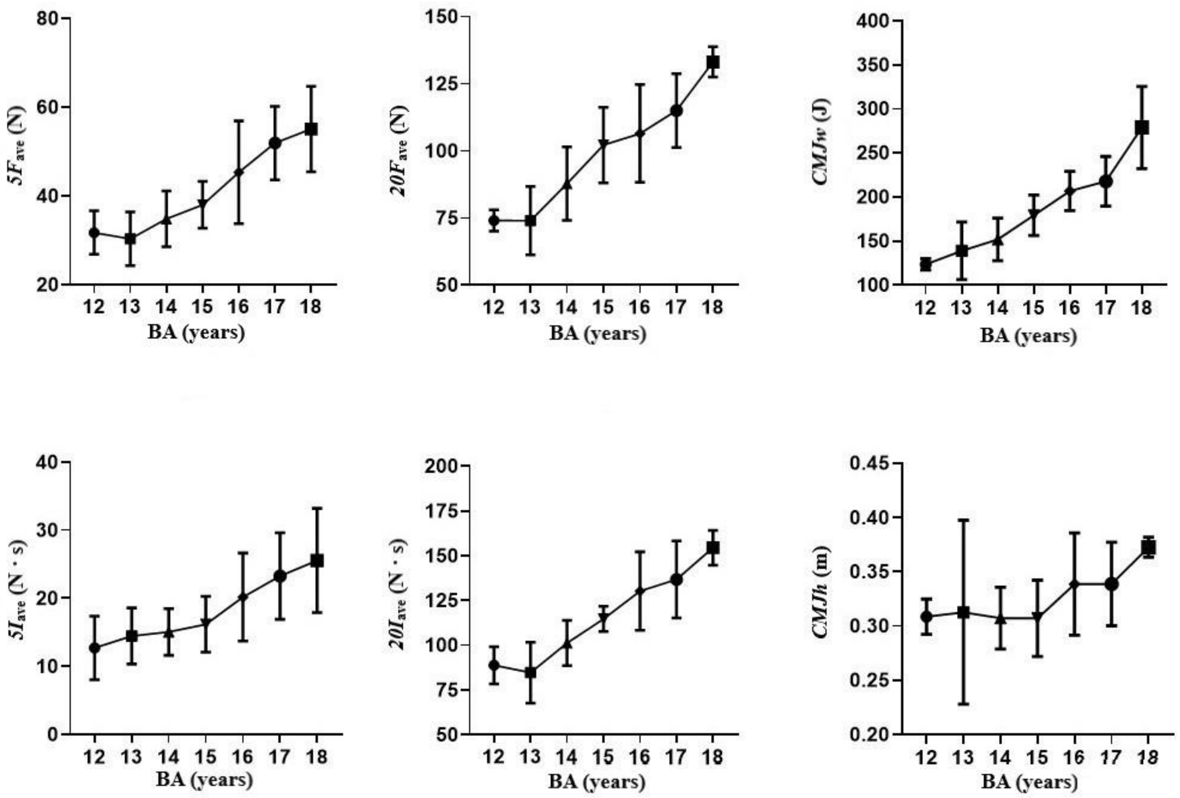

Figure 4. Mean and *SD* values of $5F_{ave}$, $5I_{ave}$, $20F_{ave}$, $20I_{ave}$, *CMJh, CMJw* in *BA* groups.

T3 Dunnett test results (Table 7) revealed differences between values of: $20F_{ave}$, $20I_{ave}$, $5F_{ave}$, $5I_{ave}$ and *CMJw* collected for each *BA* category. They were no significant differences only for the $5I_{ave}$ values. Test does not indicate differences between adjacent categories (e.g. 12 vs 13 years). The highest differences noted for the 2 years span (e.g. 14 vs 16 years) were: a) $20I_{ave}$ 13 vs 15 (.007), b) *CMJw* 14 vs 16 (.001).

Table 7. Results of T3 Dunnett Post-hoc test performed for values of: $20F_{ave}$, $20I_{ave}$, $5F_{ave}$, $5I_{ave}$ and *CMJw* in *BA* groups.

| | | 12 years | 13 years | 14 years | 15 years | 16 years | 17 years |
|---|---|---|---|---|---|---|---|
| $20F_{ave}$ | 13 years | 1.000 | | | | | |
| | 14 years | .299 | .337 | | | | |
| | 15 years | .180 | .165 | .762 | | | |
| | 16 years | .016 | .009 | .306 | 1.000 | | |
| | 17 years | .002 | <.001 | .012 | .885 | .994 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 18 years | .043 | .007 | .014 | .153 | .103 | .299 |
| | | 12 years | 13 years | 14 years | 15 years | 16 years | 17 years |
| $20I_{\text{ave}}$ | 13 years | 1.000 | | | | | |
| | 14 years | .842 | .270 | | | | |
| | 15 years | .430 | .007 | .318 | | | |
| | 16 years | .155 | .003 | .066 | .689 | | |
| | 17 years | .103 | .001 | .028 | .312 | 1.000 | |
| | 18 years | .110 | .051 | .131 | .220 | .479 | .774 |
| | | 12 years | 13 years | 14 years | 15 years | 16 years | 17 years |
| $5F_{\text{ave}}$ | 13 years | 1.000 | | | | | |
| | 14 years | .993 | .822 | | | | |
| | 15 years | .868 | .445 | .995 | | | |
| | 16 years | .399 | .071 | .373 | .878 | | |
| | 17 years | .157 | .001 | .006 | .088 | .957 | |
| | 18 years | .449 | .433 | .523 | .610 | .917 | 1.000 |
| | | 12 years | 13 years | 14 years | 15 years | 16 years | 17 years |
| $5I_{\text{ave}}$ | 13 years | 1.000 | | | | | |
| | 14 years | .996 | 1.000 | | | | |
| | 15 years | .986 | 1.000 | 1.000 | | | |
| | 16 years | .710 | .444 | .543 | .950 | | |
| | 17 years | .482 | .085 | .112 | .451 | .998 | |
| | 18 years | .677 | .708 | .732 | .804 | .975 | 1.000 |
| | | 12 years | 13 years | 14 years | 15 years | 16 years | 17 years |
| *CMJw* | 13 years | .931 | | | | | |
| | 14 years | .140 | .997 | | | | |
| | 15 years | .104 | .316 | .644 | | | |
| | 16 years | <.001 | .001 | .001 | .636 | | |
| | 17 years | <.001 | .001 | .002 | .372 | .999 | |
| | 18 years | .350 | .368 | .415 | .514 | .675 | .762 |

Validation of the 5 s maximum submerged dolphin kick test was conducted. The intraclass correlation for the average $5F_{\text{ave}}$ (N) was ICC = 0.93 (95% CI: 0.874–0.958) (reliability level: > 0.9: excellent; 0.9–0.75: good; 0.75–0.5: moderate; < 0.5: poor).

## DISCUSSION

The purpose of this study was to examine whether the underwater tethered dolphin kicking test was suitable for evaluating the sprint performance/power generating potential of young swimmers. We observed that the $5F_{\text{ave}}$, $5I_{\text{ave}}$, $20F_{\text{ave}}$, $20I_{\text{ave}}$ presented similar, high strength of correlations with swimming speed. *CMJw* (J) and *CMJh* (cm) were moderately correlated with 50-m front crawl performance. A strong relationship between both tethered test results and anthropometric indices was also detected. Therefore, the right solution to estimate the impact on real swimming performance was to separate/control biological age (partial correlations) as a controlling variable. We could state that a specific in-water test like the novel tethered underwater dolphin kick (similarly to tethered full front crawl swimming) is useful in evaluating anaerobic conditioning and provides a greater potential to explain the sprint performance of youth swimmers than the general *CMJ* test.

The swimming performance of young competitors has been proven to be associated with anthropometrics [6]. West et al. [42] mentioned that effective propulsion increments and drag minimization in UUS might be influenced by anthropometry, range of motion, and flexibility of the swimmer. Our study revealed moderate-to-strong relationship between *BH*, *BM*, muscle mass of body segments, and the indices of underwater tethered dolphin kick. Wadrzyk et al. [41] did not find significant correlations between the distance per kick cycle and the frequency of underwater dolphin kick and anthropometric variables. They claimed that younger swimmers' differences in performance could be explained by variance of technical level. Ruiz-Navarro et al. [30] stated that results in swimming were less dependent on the strength of the competitor, and more on their ability to effectively applying force in water, although biological age (*BA*) control was not included in their study.

There is a great variety of methods used among studies which include UUS measurements [42]. UUS testing methods consist of free swimming [4, 14], swimming with a towing mechanism [19], or flume swimming [32]. We did not find studies with a similar method including tethered dolphin kick, although its strength is perceived as decisive for performance in swimming after the starts and turns, especially in events in short course pools. Proper depth of underwater dolphin kick is also important for propulsion maximization; it was concluded by Lyttle and Blanksby [19] that a glide depth of 0.4-m or more provided a pronounced decrease in drag force acting on the swimmer's body. With this in consideration, in our study, the swimmers were set in place during the test on the proper depth (0.6-m); this prevented them from discernible force loss, which in free swimming is related to waves created on surface.

Strzała et al. [35] revealed that there was a moderate relationship (maximum force 0.49, $p < 0.05$; average force 0.54, $p < 0.01$) between 20 s maximum surface tethered flutter kick swimming and 50-m front crawl performance in male senior swimmers. It is interesting that the mentioned test results presented the highest correlation with performance as compared with other tests, such as arm cranking, *CMJ*, or tethered swimming with the arms only. This also corroborates the findings of an earlier study by Strzała et al. [36], where a significant relationship between 40 s tethered flutter kick swimming and 100-m front crawl performance was also revealed (0.40, $p < 0.05$).

Ruiz-Navarro et al. [30] reported that the force generated in tethered full-stroke swimming was strongly related to 50-m performance. Loturco et al. [18] noted correlations between the average force in tethered swimming and 50-m front crawl at the level of 0.85 ($p < 0.01$). In our study, the lower but still strong correlation was 0.75 ($p < 0.01$), which confirms the conclusion of Papoti et al. [26] that tethered performance is strongly related to the anaerobic potential of the swimmer.

Considering the swimmer's ability to produce propulsion by the dolphin kick, Atkinson et al. [4] stated that vertical toe velocity was the kinematic variable most correlated with UUS performance. It was also discovered by Sánchez and Arellano [31] that swimmers at a higher performance level extended the hip before a flexed knee during the up-kick. Ikeda et al. [14] identified that greater angular displacement of the lower trunk was associated with better dolphin kick performance. Our swimmers were able to apply quite comfortably the underwater dolphin kick and could perform the test with great (race-like) power. However, to assess the possible differences in the biomechanical structure of the movement between free and tethered dolphin kick is an issue worth exploring in future research. On the other hand, in a study by Swaine [38], in which swimmers performed an on-land kicking benchmark test, it was stated that testing on ergometers simulating swimming movement was (including possible limitations) more natural for the swimmer than performing arm cranking or cycling tests. Earlier [11] and contemporary [2, 35] studies were performed to identify the relationships between the upper, lower body strength and sprint performance using dryland testing. Our study results revealed strong relationship between dolphin kick strength and sprint swimming performance of young swimmers. Similarly, Strzała and Tyka [37] reported that 25 to 100-m performance of adolescents was correlated with upper and lower limb anaerobic power, and although less specific (in dryland), the power of lower limbs presented higher correlations. Marques et al. [20] concluded that the explosive strength of lower limbs was likely to indicate the execution of the race elements like start, turn, and therefore overall sprint swimming performance. On the basis of the results of our study, one might state that in-water specific tests (even considering potential limitations) presented similar or higher reliability and were more likely to be linked to the swimming performance than general tests like *CMJ*. It is worth noting, however, that this is not always the case: Keiner et al. [15] found a strong correlation between *CMJh* and 50-m freestyle time (–0.82, $p < 0.05$) in a group of male and female swimmers (aged 17.5 ± 0.2 years). As the swimmers in the present study (aged 13.5 ± 0.85 years) were younger than those from the study by Keiner et al. [15], it is possible that maximum speed/strength abilities were not fully developed in our group yet and, because of that, our correlation between *CMJh* and 50-m front crawl is lower (0.33, $p < 0.05$).

## CONCLUSIONS

The novel underwater tethered dolphin kick test could be considered appropriate in associating submerged swimming with anaerobic strength and trainable technique abilities, which influence free swimming sprints, both the immersion and surface parts. The underwater tethered dolphin kick test presents similar correlations with the 50-m front crawl performance as the full-stroke tethered front crawl swimming test and a stronger correlation than the *CMJ* results. Bearing in mind the influence of biological development in the observations and limiting this impact on the results controlled for *BA*, we can state that lower limb strength potential, measured in water, should feature in future research as a useful, specific in-water evaluation tool for swimmers.

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