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ENHANCING BREASTSTROKE PERFORMANCE: A FOCUS ON ARM MOVEMENT ANALYSIS

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Abstract. *Although constrained by World Aquatics regulations, advancements in analytical techniques are enhancing the execution of breaststroke swimming by evaluating the effectiveness of the swimmer's movements. This study proposes a new method to evaluate arms coordination and the improvement of strength in the breaststroke. Five national level swimmers were tested and recorded. They tested a new technology that measures forces of pressure on the water, applied by both hands on both palm surfaces. We observed that in the second test the average values are not statistically significant, but swimmers improved their results from initial to final testing, claim based on arithmetic average (Left impulse, Right impulse, Initial pressure on water, Final stroke - water pressure, when accelerating backwards, Water pressure traction, Right power), then the values obtained in the initial test. This analysis provides insights into refining swimming techniques so that specialists can enhance current speed capabilities. Additionally, the results offer guidance on the future development of swimmers within the studied group. Evaluating individual swimmers in this way establishes an important basis for designing interventions focused on strength and technique to enhance alignment and performance. Therefore, it represents a practical tool to be used by coaches and researchers to qualitatively evaluate the swimming technique and the way they apply forces on the water.*

Keywords: *asymmetry; propulsion efficiency; swimming technique.*

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Introduction

Swimming, one of the most beloved sports branches, has "plunged" into the digital age and, currently, there is no way back to the past. In recent years, the way in which coaches and all technicians in the various interdisciplinary teams in swimming approach new training methodologies, based on information and communication technologies (IT&C or ICT), decisively influences the results of athletes. The new trends are thus determined by the production and integration on an increasing scale of these modern computerized equipment, without which the educational process, at least at the level of the elites, can no longer be conceived. Thus, the aim of this research is to understand the impact of new digital technologies in the performance improvement of senior breaststroke swimmers. Integrating new digital technologies (IT&C), both in the water and on land, into sports training programs, based on this inventory of motor qualities, can positively influence the performance of breaststrokers through the information provided, through feedback, which provides reverse connections.

Many coaches believe that intense and intensive training is necessary in the process of achieving superior performance (Jayanthi et al., 2013). But one of the field's leading experts contradicts them, saying: "The key to success is not intense training, but deliberate and carefully targeted training according to the specifics of the process being swum" (Olbrecht, 2000).

The force required to move one's own body through the water must be worked throughout the annual cycle, as it ensures speed, but also the possibility of continuously increasing the overall training volume for these swimmers, who are unable to match the training volume of other athletes (freestyle, backstroke, butterfly swimmers) (Vasile, 2023). They must overcome the water resistance, or "resistive force" developed in the forward stroke by engaging in fast and powerful movements in this dense environment, about 1000 times thicker than air, so they need strength. This "elastic force (F-S) manifests itself differently at the level of body segments and must be constantly monitored" (Hollmann & Hettinger, cited by Vasile, 2023).

According to Maglischo (2016), the father of modern swimming theory, the breaststroker must possess great strength in the lower and upper segments. Many other specialists come in support of his ideas. "Breaststroke swimming is strictly governed by World Aquatics rules, in particular, the swimmer's arms and legs must have a coordinated action, and the head must appear above the water surface at least once in every stroke cycle. During the propulsion phases of the arms and legs very high forces must be generated" (Leblanc et al., 2007).

As far as the strength of the legs (lower extremity) of breaststrokers is concerned, it is stated that these propulsive motor structures are responsible for a considerable forward movement (Strzala et al., 2012). As such, improving the strength of these segments is important in this procedure. Regarding the arm (upper extremity) force, "after the propulsive movement of the legs, the swimmer decelerates before the propulsive force of the arms exceeds that of the legs. Therefore, underwater recovery of the upper extremity creates high forward resistance" (Kolmogorov et al., 1997). For this reason, the breaststroker must also develop arms strength, not only legs strength. ”Strength is the force of muscle contraction achieved in one maximum effort” (Ikhwani, 2021). For short events (50 or 100 m) they must develop even arms explosive power; ”this is a person's ability to perform maximum power” (Ambarwati et al., 2017).

Anyhow, breastroke is a significant and universally recognized swimming technique, garnering attention from athletes, researchers, coaches and enthusiasts across the globe. In swimming is important to conduct an objective of research and have an international critical review of the literature, taking into account multiple perspectives and available evidence. As we know, for the last ten years we can see the data base of the last update of best high-performance competitors and world records holders in 50 m and 100 m signed by Adam Peaty, a British swimmer known for his outstanding high performances in the breaststroke. One of Adam Peaty's greatest achievements is winning the gold medal at the 2016 Rio de Janeiro Summer Olympics and 2020 + one at Tokyo Summer Olympics, in the 100 m breaststroke; he's the first British male Olympic swimming champion since 1988. Peaty is the holder of the world record in 50 m and 100 m breaststroke events, and is unbeaten in either event in a long-course global championships since 2014, a streak of eight consecutive global titles across both events, a streak of titles only broken by injury-caused in 2022. He has broken world records 14 times, becoming the first man to swim under 26 seconds for the 50 m breaststroke and the first to swim the 100 m breaststroke under 57 seconds. He is the first swimmer ever to win both sprint breaststroke events at the same World championships, and the most successful British swimmer in a single World Championships. Adam Peaty is considered one of the world's best 100 m breaststroke swimmers and has made a significant contribution to the development and popularization of this style of swimming. He is an example of perseverance, dedication and talent in the world of swimming and it's a huge difference between the World and Olympic champion Adam Peaty and the rest of elite breastrokers of the world.

Methodology

Scope

The aim of this research is to understand the impact of new digital technologies in the performance improvement of senior breaststroke swimmers. Thus, we will focus on the IT&C (information and communication technologies - ICT) use in improving strength, through the computerized assistance it facilitates, through the information collected and digitally processed by these IT&C and transmitted to the athletes, sometimes even during the actual swim, information using the Bone Conductor headsets. In this context, we will refer to the strength of the athletes' arms. We believe that, due to remarkable performances at world elite level, breaststroke performance is not only based on lower segments strength, but also on upper segments strength.

Based on these considerations, however, we note that "the estimation of propulsive forces is still an open problem for determining swimmer performance. However, it is very important and computerized solutions for its evaluation are constantly being sought" (Wang et al., 2020).

Participants

The research subjects were the 5 breaststroke athletes (all men, aged between 22-33 years old); for brevity, we will present the graphic results just for two of the athletes.

Measures and Procedure

We designed an intervention plan in which we integrated many new strength drills for these breaststrokers, but also the following IT&C (information and communication technologies):

- Smart paddles EO SwimBetter;
- GoPro 7 technologies for video recordings.

Considering the motor profile of the breaststroke swimmers, in aquatic training for strength improvement and assessment we aimed to process this motor quality of the arms using *Smart paddles* data. This digitized equipment, *EO SwimBetter* handset, recorded the propulsive force of the swimmers' arms.

This research was carried out as part of the PhD studies of the first author and the testing took place at the UNEFS Research Centre, but also at the Premium Wellness sports pool, where the USH club and athletes train daily. The research period is represented by the time interval October 2023 - April 2024. During the period training, strength and breaststroke technique parameters were monitored using *Smart paddles EO SwimBetter* and *GoPro 7* technologies; video recordings were made with the underwater camera of the *GoPro* device. The technique was corrected by *Bone Conductor technology* - audio swimming headphones

The test consisted of the analysis of arm movements with the *EO SwimBetter*, which provide technical assistance for swimmers (Douglass et al. 2024). Video recording of the swimmers by *GoPro 7*, over the standardized distance of 25 m breaststroke. Athletes swam with smart paddles, which recorded certain arm strength values. Athletes practiced using only their upper limbs, with their arms, without leg movements, 3 x 25 m strokes. Only the 25 m distance that framed the most correct breaststroke arms movements, performed at maximum technically correct force and speed (intensity), was engaged in computer analysis. Movements in which the pace of the exercises slowed or were uncoordinated, were not counted or evaluated using the smart paddles.

In our research we analyzed the initial and final values for 9 variables, described below:
T effective - represents drag effective time; we expect that this indicator decreases after training; *Left Impulse* - propulsive action with left arm; we expect that this indicator increases after training; *Right Impulse* - propulsive action with right arm; we expect that this indicator increases after training; *Upward* - initial upward arm action; we expect that this indicator increases after training; *Downward* - final downward arm action; we expect that this indicator increases after training; *Hand Drag* - action through hand pressure; we expect that this indicator increases after training; *Left* - entire action with left arm; we expect that this indicator increases after training; *Right* - entire action with right arm; we expect that this indicator increases after training; *Propulsive* - propulsive faze; we expect that this indicator increases after training.

Results

The average values for all swimmers for the initial test and final test are presented in Table 1. One may observe that Tefectiv (effective time) didn’t decrease and Upward, Left and Propulsive didn’t increase. The other 5 variables met our expectation; thus, we may affirm that overall, the athletes improved their sportive performance.

Details might be observed in the figures presented in *Annex 1.*

Table 1. *Descriptive statistics – investigated parameters*

	N	Mean	SD	SE
T efectiv1	5	1301.8	169.1529	75.6475
T efectiv2	5	1383.2	163.3392	73.0475
Left Impulse1	5	1.146	0.15758	0.07047
Left Impulse2	5	1.588	0.63117	0.28227
Right Impulse1	5	1.174	0.15241	0.06816
Right Impulse2	5	1.614	0.8359	0.37383
Upward1	5	0.00332	0.00232	0.00104
Upward2	5	6.60E-04	5.77E-04	2.58E-04
Downward1	5	0.39578	0.02609	0.01167
Downward2	5	0.41424	0.06451	0.02885
Hand Drag1	5	0.00352	0.00263	0.00118
Hand Drag2	5	0.02996	0.02978	0.01332
Left1	5	0.1579	0.01727	0.00772
Left2	5	0.123	0.03322	0.01485
Right1	5	0.12602	0.0127	0.00568
Right2	5	0.14962	0.05948	0.0266
Propulsive1	5	0.31346	0.03007	0.01345
Propulsive2	5	0.2825	0.1125	0.05031

Swimmer 1. 25 m breaststroke (01/02/2024) - ANALYSIS: *EO SwimBetter*

Figure 1. Average force versus frequency of movements for the first swimmer

According to Figure 1, the first swimmer has on average an approximately equal force on the 2 arms (approx. 1.1 N), which is predictively expressed by the *EO SwimBetter* software for one minute, even though the athlete only swims 25 m arms with smart paddles, therefore in a much shorter time. This indicates a balance of force on both arms.

Figure. 2. Force versus frequency of movements for the first swimmer

In the 10 strokes for first athlete, the arms show almost perfectly overlap, indicating a balance of force on the arms. The left arm acts with a higher force at the fourth stroke (1.4 N), at the ninth (1.1 N), and at the tenth stroke (1.1 N). This aspect of dynamics can be corrected by practicing the technique. The software registers fluctuations in the rate of the strokes for the arms, especially for strokes 2, 3, 4, 7-9, and for the left arm. These harmonize towards the end, with an upward trend, which indicates a technical recovery (Figure 2).

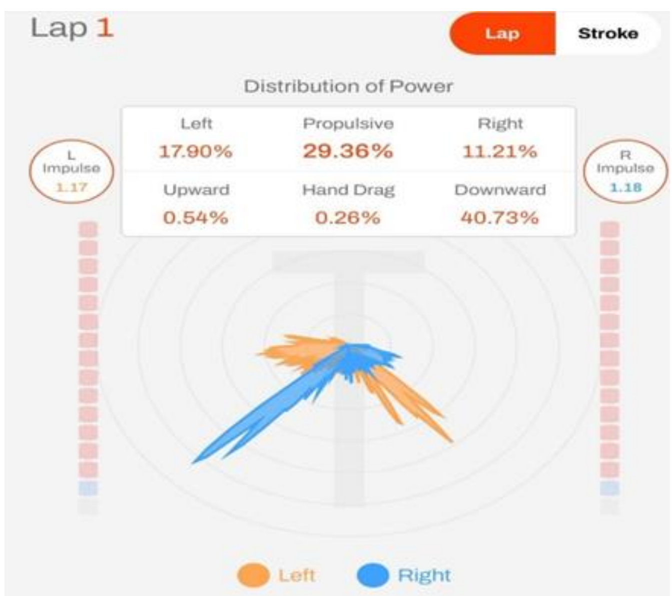


Figure 3. Power distribution of the two arms for first swimmer

For first swimmer, the power distribution is higher on the left arm (17.99%) than on the right arm (11.21%). This power is distributed on the specific movement as follows: initial pressure on the water 0.54%; traction with water pressing in 0.26% and final stroke (water pressure) when accelerating backwards 40.73%. The propulsive phases represent for this athlete 29.36% of the total complete movement cycle (arm entry path, water catch, traction, kick push, and arm recovery path in return stage) (Figure 3).

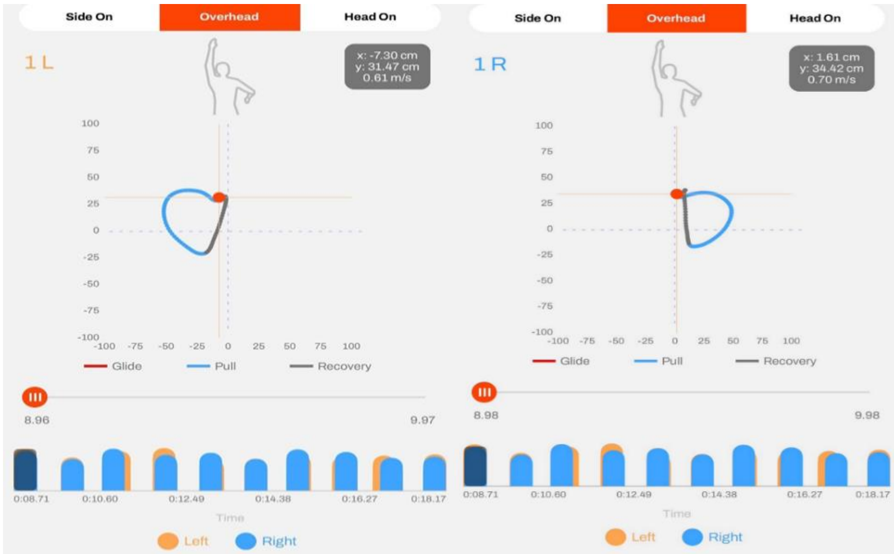


Figure 4. Action speed of the both arms for first swimmer

The left arm speed is 0.61 m/s, and the right arm speed is 0.70 m/s. In this athlete, both force and speed are higher on the right arm. The right arm does not come close to the center line in the recovery stage and the left arm crosses the midline of the body, a technical aspect that needs to be corrected as soon as possible (Figure 4).

Swimmer 2. 25m breaststroke (01/02/2024) - ANALYSIS: *EO SwimBetter*

Figure 5. Average force versus stroke frequency for the second swimmer

According to Figure 5, the second swimmer has on average a higher force of the right arm (about 1.2 N) compared to the left arm (about 1.3 N), which is predictively expressed by the *EO SwimBetter* software for one minute.

Figure 6. Force versus frequency of movements for the second swimmer

According to Figure 6, in the 13 strokes for the second swimmer, the arms do not show a perfect overlap, indicating a small force unbalance, which needs to be corrected over time. The left arm achieves maximum values in the fifth row (1.6 N). He also applies higher forces on the left arm at the ninth stroke (1.3 N). Aspects of dynamics can be corrected by practicing technique, strength and rhythm, with an emphasis on dominant movements at the end. Corrective drills are required, as well as specific strength motor structures, performed in the water - exercises with paddles for the arm process (Figure 6).

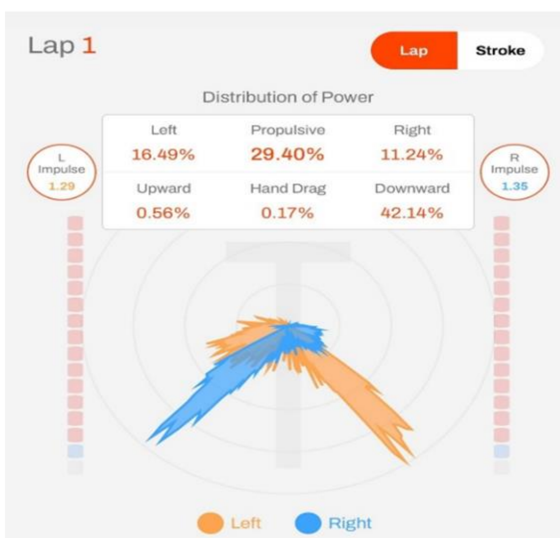


Figure 7. Power distribution of the both arms for second swimmer

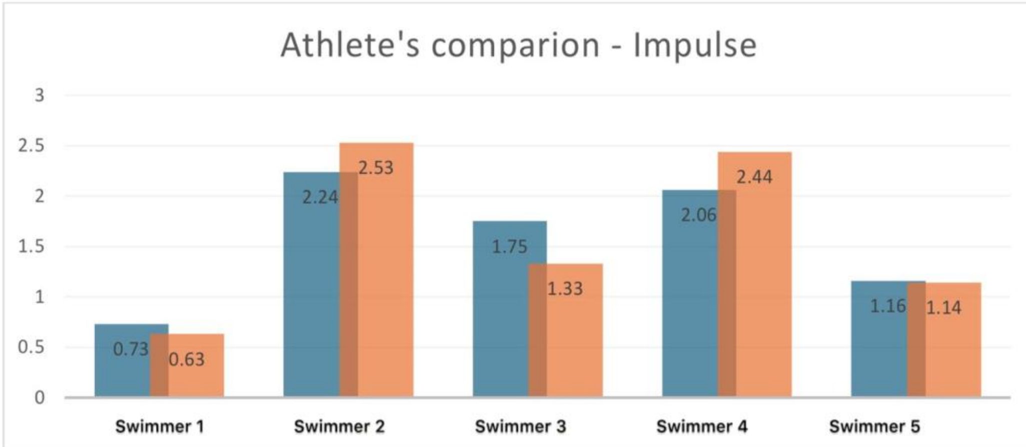
As far as the second swimmer is concerned, the power distribution is higher on the left arm (16.49%) than the right arm (11.24%). This power is distributed on the specific movement as follows: initial pressure on the water - 0.56%; traction with water pressure - 0.17%, and final pressure accelerated backwards - 42.14%. The propulsive stages represent for this athlete 29.40% of the total complete movement cycle (arm entry path, water grip, traction, push, and air path - with recovery stage) (Figure 7).

Figure 8. Action speed of the both arms for second swimmer

The speed of left arm is 0.76m/s and of right arm 1.117m/s. In this swimmer, both force and speed are higher for the right arm. The athlete performs a much longer movement (75) with the right arm and a shorter movement with the left arm (65).

In the recovery phase the left arm crosses the midline of the body, a technical aspect that needs to be corrected as soon as possible (Figure 8).

All swimmer's comparison with *EO SwimBetter*

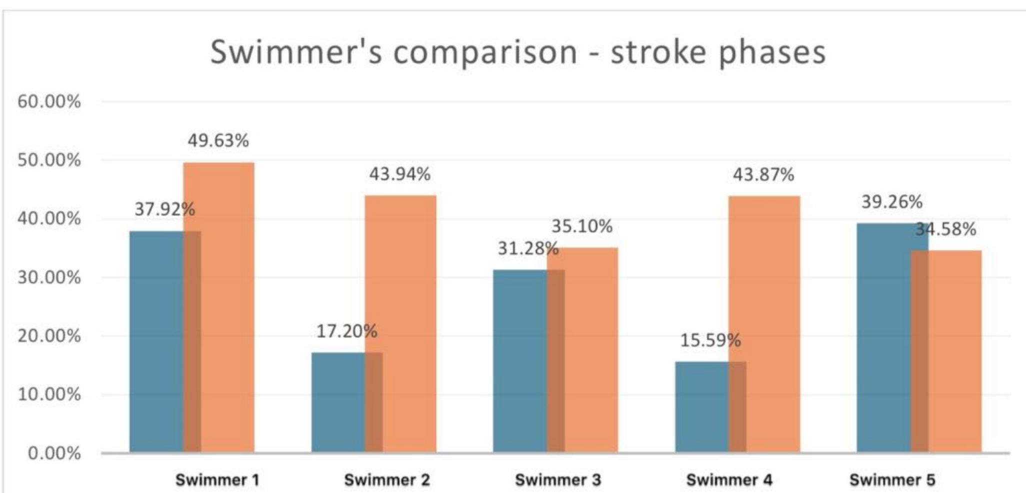


Note: Blue color: Left impulse; Red color: Right impulse

Figure 9. Comparison between the 5 swimmers on the right versus left arm impulse

Figure 9 shows that there is an imbalance between the left and right arm in terms of impulse in all our swimmers. The second and fourth swimmers have the highest impulse strength on both arms, while on the right arm the impulse is slightly higher. In contrast to them, third, first and fifth swimmers obtained much lower values overall, they have a higher force impulse on the left arm.

Additional drills to improve segmental strength and summarization of movements should be worked on for these athletes.



Note: Blue color: Propulsion; Red color: Final pressure accelerated backwards

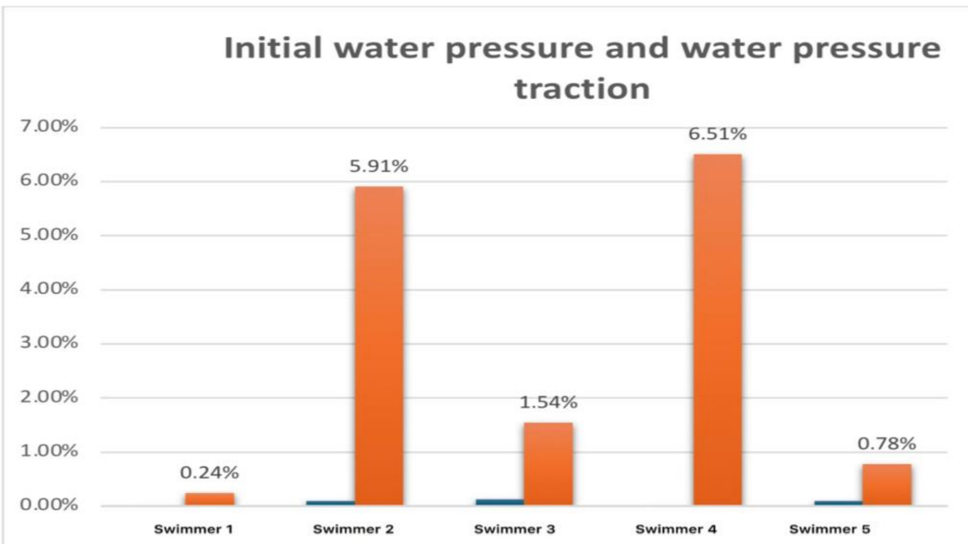
Figure 10. Comparison between the 5 swimmers on propulsion and backward accelerated final pressure

Figure 10 indicates that in general the backward accelerated final pressure is higher for all Swimmers except the fifth athlete. Swimmers like fourth and second, who had a very strong impulse also obtain high values for the final stroke while accelerating backwards, but have the lowest values for propulsion.

They are overtaken by the first swimmer, who obtains the highest value in backward accelerated final pressure and a high value in propulsion, offsetting the very weak impulse in initial water pressure and traction pressure, similarly very weak water pressure.

Fifth and third swimmers also offset lower values of impulse and initial pressure on water and traction with water pressure with medium values of final pressure accelerated backwards and propulsion.

The highest value of backward propulsion is obtained by first swimmer.

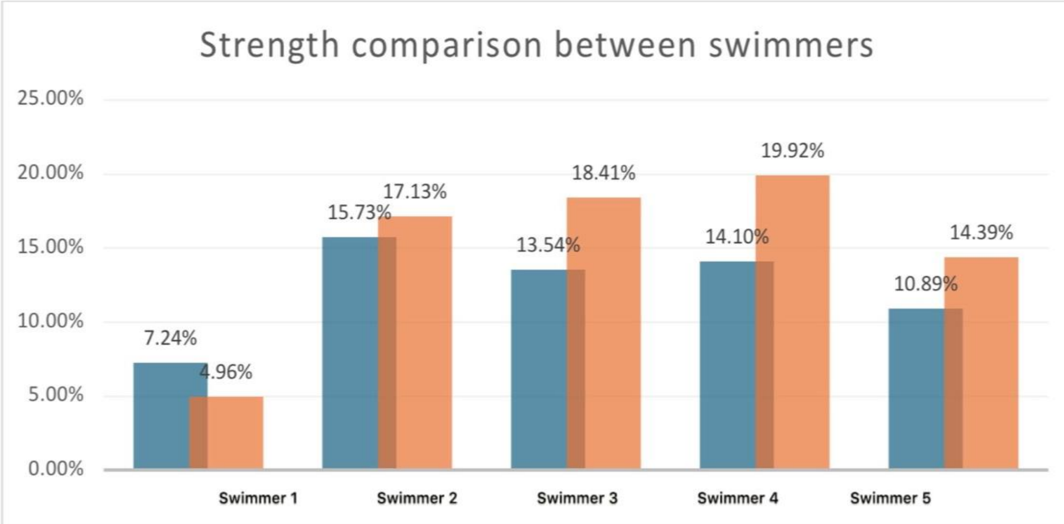


Note: Blue color: Initial water pressure; Red color: water pressure traction

Figure 11. Comparison between the 5 swimmers on initial water pressure and water pressure traction

From Figure 11 we observe that the initial pressure on the water is very low in all athletes and almost non-existent in first and fourth swimmers. If we analyze the traction with water pressure it reaches the maximum value in fourth swimmer (6.51%), closely followed by second swimmer (5.91%).

Third swimmer (1.54%) and fifth swimmer (0.78%) reach quite low, unsatisfying values, and first swimmer (0.24%) has the lowest value.



Note: Blue color: Left Power; Red color: Right Power

Figure 12. Comparison between the 5 swimmers on left versus right arm strength

Figure 12 leads to the conclusion that athletes consume more energy with their right arm than with their left arm to perform the movement, except for the first swimmer.

If we analyze the data in Table 2, we notice that the alpha threshold is higher than 0.05 and, thus, it is found that the differences between the initial average values and the final average values are not statistically significant. However, swimmers improved their sports results from initial to final testing (claim based on arithmetic average) for the Left Impulse, Right Impulse, Downward, Hand Drag, and Right values improved. The indicator targeting the effective propulsion phase has improved, which means a greater pressure force on the water, which increases from the first to the second test. However, we believe that a longer training period with the new information technologies (IT&C) is necessary, so that the differences between the tests also gain statistical significance.

Table 2. Paired Sample T-test

		Student's t	df	p	Mean difference	SE difference
T effectiv1	T efectiv2	-2.066	4	0.11	-81.4	39.40888
Left Impulse1	Left Impulse2	-1.708	4	0.16	-0.442	0.25874
Right Impulse1	Right Impulse2	-1.303	4	0.26	-0.44	0.33756
Upward1	Upward2	2.431	4	0.07	0.00266	0.00109
Downward1	Downward2	-0.767	4	0.49	-0.01846	0.02408
Hand Drag1	Hand Drag2	-2.012	4	0.11	-0.02644	0.01314
Left1	Left2	1.905	4	0.13	0.0349	0.01832
Right1	Right2	-0.986	4	0.38	-0.0236	0.02392
Propulsive1	Propulsive2	0.646	4	0.55	**0.**03096	0.04795

Note: 1 - first test; 2 – second test

In the end, as we see that each individual athlete has a weakness, which they compensate with a strength, so that overall, they achieve the best times in the competition. However, the coach has to design personalized programs for each athlete, considering the advantages and invaluable help provided by new technologies.

This data gives the coach a great deal of guidance in what he will propose to his athletes in order to correct their entire training (improving strength, training pace and technique, for whom work is always in progress) and make the most of the benefits brought by these IT&C.

Discussion and Conclusions

The processing of data through various information systems radically transforms sport. This new trend promises to change the way swimmers train and even revolutionize our overall understanding of the sport itself. Traditionally, the training, monitoring and evaluation of swimmers was based on an amalgam of feedbacks, resulting from the coach's observation and explanations or from the athlete's own sensations and perceptions. The coach corrects a certain motor behavior based on what he saw, and the swimmer adapted according to these data or based on what he perceived directly (interoceptive – proprioceptive), saw, heard or felt himself (exteroceptive – visual, auditory, tactile-thermal, etc.). Although this feedback produced champions, they had certain limits given primarily by the filter of one's judgment. How accurate these data, mostly subjective, were, we can only imagine. Today, information coming from any sensory-perceptual modality is associated with computer processing. Digital devices or educational software facilitate interpretations and organize abundant data. Moreover, it diversifies the indicators that can be received, analyzed and interpreted, sometimes in real time. Information and communication technologies, such as those developed for swimmers - *Smart paddles, Phlex, Smart Goggles, Whoop bracelet* etc., currently offer significant spatio-temporal and dynamic indicators for a performance athlete, but also some functional data, related to the parameters of effort. The data are "superimposed" on the request, and the understanding of movement is internalized, by moving from the register of sensitivity to that of cognitive-motor processing. Now, aspects such as the force applied on the water, swimming speed, the efficiency of turns and even the duration of underwater phases, for example, are processed and sometimes transmitted and operated parametrically during swimming, through these information technologies.

The emphasis on traditional methods and means in training, monitoring, and evaluating athletes no longer leads to exceptional results. Now, in the field of performance sport, "invaded" by new information and communication technologies, which can process and organize multiple parameters of training and evaluation, sometimes with a great role in providing feedback, great performances can only be achieved by engaging IT&C equipment.

Moreover, improving swimmers' performance requires the control of several variables (biomechanical, bioenergetic and psychological), which positively or negatively influence the four phases of an event: the start, the actual swim (the displacement), the turns and the finish. In these phases, "the measurement of performance-related parameters can provide a motor profile for each individual swimmer, which can be used to improve his or her sporting performance" (Toussaint, 2007).

Based on the specialists' clear statements, but also on the results recorded in the paper, we consider that the integration of new IT&C in the training and testing of senior breaststroke swimmers, according to the motor profile from the literature, digital equipment and educational software, ensures important improvement of their results in segmental strength tests - arms (*EO SwimBetter*).

Information technology equipment provides consistent feedback where reverse connections ensure that the data state can be modified and reorganized in accordance with the new information recorded, which is made possible by this feedback. Reverse connections or feedback are sensorial feedback information. These reverse afferents represent immediate information on the quality of the feedback response. Regardless of the receptive modality that provided them, they improve the individual's behavior (Vasile, 2023).

We recommend these IT&C solutions because digitalization facilitates practice and adapts it to training and competitive requirements, based on accurate and objective data, eliminating from the equation a large part of the unknowns of the concrete situation under recurrent monitoring and evaluation. IT&C's new equipment will advise athletes to respect the technique of the training and stabilize it in an efficient conduct, especially when associating strength improvement structures.

We can consider that, while detecting and analyzing the strengths of the arms disjunctively, the coach is able to issue proper assessment, but, above all, ensures a good knowledge of the "weak" strength (pressure) or strong moments. He will thus know how to model the motor structures to improve the strength of each individual breaststroker. The specialist will also be able to determine how strong the traction is over the entire propulsive stroke, understand what causes the reduction of pressure forces on the water, and at what point the athlete stops using the same high values of force and even accentuated intensity (power). The coach will be able to take corrective action very quickly and address the situation efficiently. He can assist „a better streamlined body position and/or timing between the completion of the kick and start of the propulsive phase of the arm pull" (D'Acquisto & Costill, 1998), when the swimmer uses *EOswimBetter*.

By reading the IT data, the coach will also be able to check whether there are any muscle imbalances between the right and left sides that may negatively affect the swimmer's position in the water. He will correct the imbalances and technically stabilize each individual athlete.

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Institutional Review Board Statement: The research was conducted according to the principles stated in the Declaration of Helsinki and approved by the Research Ethics Committee of UNEFS Bucharest (number assigned 54/1402).

Informed Consent Statement: Written informed consent was obtained from all participants involved in this study.

Data Availability Statement: Data can be made available upon request to the contact author.

Conflicts of Interest: The authors declare no conflict of interest.

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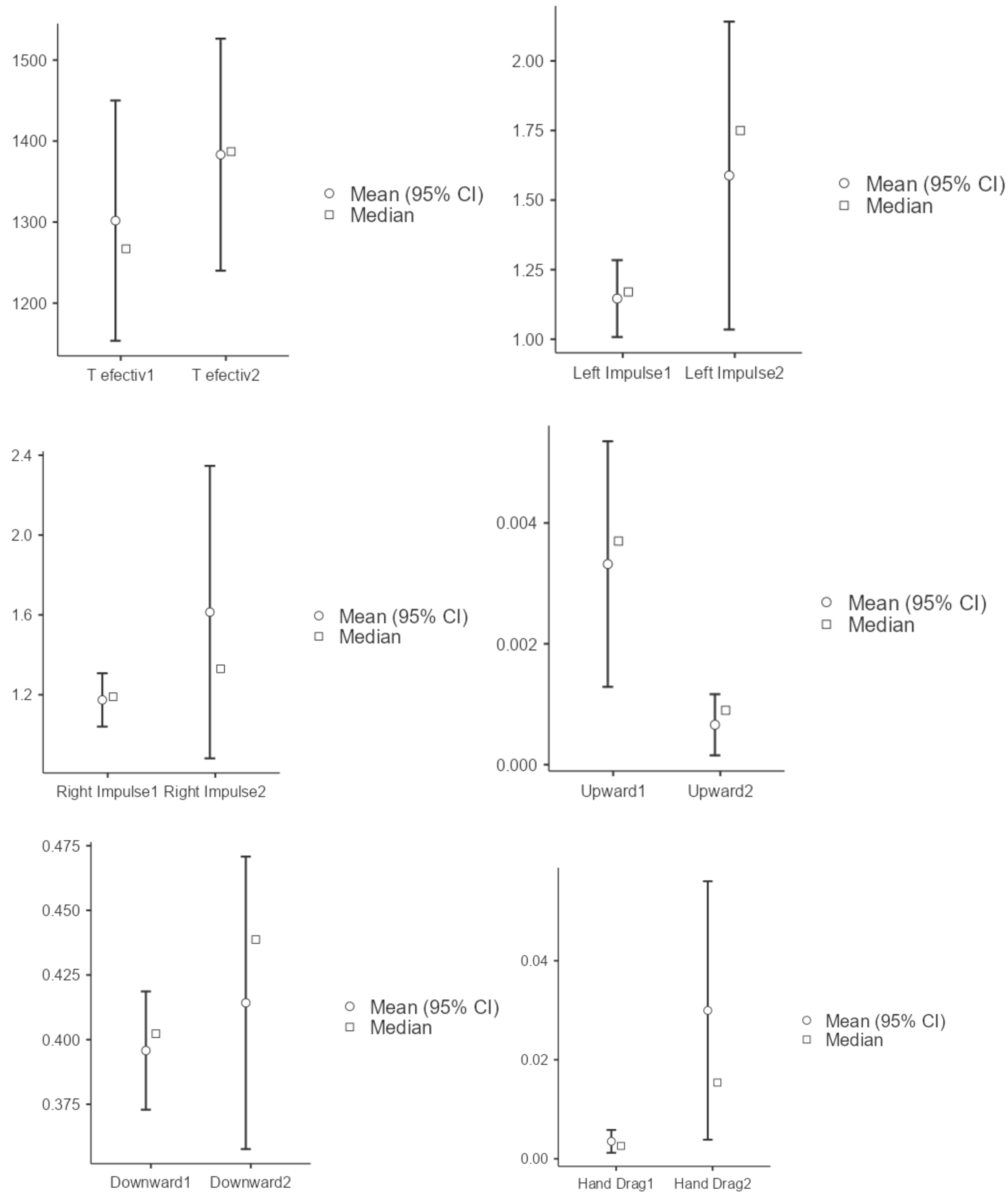
Annex 1


1500
1400
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1200
T efectiv1
T efectiv2
Mean (95% CI)
Median
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1.75
1.50
1.25
1.00
Left Impulse1
Left Impulse2
Mean (95% CI)
Median
2.4
2.0
1.6
1.2
Right Impulse1
Right Impulse2
Mean (95% CI)
Median
0.004
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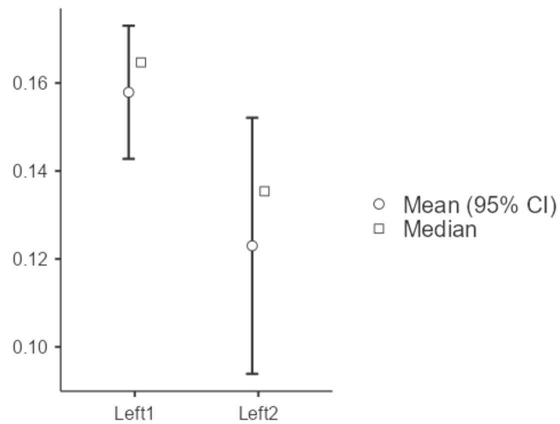
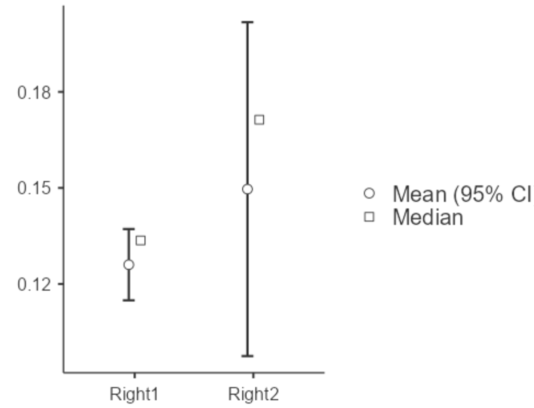
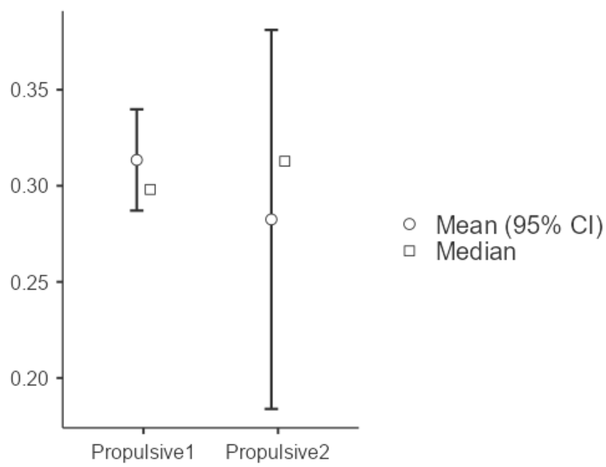
0.000
Upward1
Upward2
Mean (95% CI)
Median
0.475
0.450
0.425
0.400
0.375
Downward1
Downward2
Mean (95% CI)
Median
0.04
0.02
0.00
Hand Drag1
Hand Drag2
Mean (95% CI)
Median


0.16
0.14
0.12
0.10
Left1
Left2
Mean (95% CI)
Median


0.18
0.15
0.12
Right1
Right2
Mean (95% CI)
Median


0.35
0.30
0.25
0.20
Propulsive1
Propulsive2
Mean (95% CI)
Median