PhD Thesis Summary

KINETIC AND KINEMATIC EXAMINATION OF FIXED POSITION ARM COORDINATION IN FREESTYLE SWIMMING

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1. Introduction

The coordination of movement is a reply of the system that optimizes the dynamic operation of the biological organization. The coordination comes about through the activation of self-regulatory mechanisms. The quality of the reply depends on the organization's inner operational capacities, as well as on the conditions set by the environment and on the movement to be performed. The inner operational capacities are structural factors like the size of the body or functional abilities. The environmental factors affect biological organizations in accordance with their well described laws. By altering the aim and level of difficulty of the exercise, the effectiveness of inner functions can be studied.

The goal of the athlet is to do his best on a competition, therefore he gets prepared following a training plan. Information obtained during the preparatory training program can indicate its effectiveness. As far as swimming is concerned, the propulsive force is a decisive factor. However, data necessary for the assessment of the technique cannot be measured in a direct way.

In this study the freestyle swimming (a crossed cycled periodical movement) was examined and tested as the most effective form of swimming for humans, in which the propulsive force of the upper-limb is dominant. The aim of this thesis is to reveal the structure of swimming motion performed among special conditions. To this end kinetic, kinematic and somatometric parameters were used. The role of asymmetry and frequency of motion, which can give further information on the habilitating and debilitating factors, were also observed. The information gained about the functioning of the movement structure can be adapted to free swimming condition. Based on the findings the swimming technique can be assessed, the effectiveness of the trainings can be improved, and the incorrect, injury-prone techniques can be filtered out and eliminated.

2. Objectives

a, By increasing the frequency of motion, implementation will be more and more difficult. Therefore it is advised to examine the effect of growing freqency on the other parameters by using the **gradual frequency raising test**.

b, In earlier studies the rate of average force and average peak force was used for the analysis of the results of fixed position swimming tests. This method did not differentiate between the performance of the two upper-limbs. However, it is advisable to determine and separately observe the functioning of **the dominant and nondominant sides**.

c, In order **to describe the structure of the movement** it is advisable to set and determine further mechanical parameters, for example the maximal rate of force development (RFDmax), force production peak **per cycle** (Fmax) and the impulse of force (ImpF50%). These parameters should also be incorporated into the analysis.

d, Apart from kinetic data it is paralelly advisable to record kinematic data about the movement. It is important to determine the relation between the observed kinetic and relevant kinematic data, and also it is important to see if there is a discrepancy between the two sides concerning the observed parameters.

e, Our goal was to determine **the Effectiveness Factor of the swimming motion** by the application of a simplified "quasi steady" method.

f, **Multiple Regression Analysis** was employed to determine which parameters influence significantly the speed of sprint swimming, the Effectiveness Factor, and the structure of the motion on the dominant and nondominant sides.

3. Materials and Methods

3.1. Subjects

Eight internationally recognized swimmers of the Portuguese national team were involved in this study (age: 19.09 ± 09 years, height: 181.73 ± 5.59 cm, weight: 73.94 kg). All the participants have considerable experience in competing in short distance freestyle swimming.

3.2. Protocol

The observed swimmers following a warm-up session got 5 minutes practice time to familiarize with the test task. In order to measure the horizontal force component a TENZI TNF 006 (Tenzi Kft. Budapest) type swimming pool ergometer was used in thrust mode. The force was transmitted with the help of a special helmet. The observed individuals performed fixed positioned arm only swimming with signals given through a headphone. They started at 30 cycle/minute increased by 5 cycles/minute until they reached 55 cycles/minute. Between the stages the individuals rested for one minute. In a given frequency range a span of 20 seconds without inhaling was recorded. The trunk and the legs were fixed with the help of bouys. Four underwater cameras synchronized with the dynamometer recorded the arm movements of the swimmers.

Having performed the tests the time results of the fastest 50 meters were manually measured and the somatometric data were recorded.

The tests were authorized by the ethical committee of the National Assossiation of Portuguese Coaches.

3.3. Data Collection and Analysis

The exact frequency of movements, the standard deviation of force development (FRSD), and the average force development were determined by the readings of force and time on the ergometer. Subsequently, the movements for further analysis were chosen. The orienting points were determined (Fmax and RFDmax) for 3-3 subsequent strokes for each side. Furthermore, the value of ImpF50% was calculated for each cycle. This value was calculated by integrating a section of the force – time curve, which represents the 50% value of points Fmax in the declining and inclining sections of a given cycle. On other sections of the force – time curve the arms jointly create a propulsive force. Certain kinematic data defined by APAS 3D analyzing programme were assigned to the orienting points on both sides; the upper arm's saggital plane position (αFmax and αRFDmax), the upper arm's frontal plane position (βFmax and βRFDmax), and the elbow joint's 3D position angle rate (γ Fmax and γRFDmax).

To determine the Effectiveness Factor of the swimming motion we used the BIOMATA1 programme developed by us, which give the quotient of force values estimated with "quasi steady" method and the actual readings of force.

3.4 Applied Statistical Methods

The results were processed with the help of SPSS for Windows v1.3 statistical analysis program. The difference of mean rates were compared either with Student's t-test or if the data did not comply with normal distribution with Mann-Whitney test. With several groups a sinlge-factor analysis of variance was employed, where the Bonferoni Post Hoc test was used to determine the difference between the groups. To establish the degree of the relation between the data Pearson and Spearman correlation computing methods were applied. The difference or the relation shall be considered significant if the value is $p<0,05$. Multiple Regression Analysis (MRA) was employed to determine the charachteristic model of movement structure. Criterion variables were considered to be determined by predictor variables if - in the ANOVA regression model at the value of $p<0,05$; and if in the MRA model determining the coefficients - to every β there is a corresponding $p<0,05$ value.

4. Results and Discussion

4.1. The effect of increased frequency

By increasing the frequency of movement cycle the average force increased. However, the relation is non-linear since increase only occured up to 'critical' frequency, which was reached in the third stage of the test. By further increasing the frequency the average force started to decrease and FRSD greatly increased. Elevated frequency of strokes seems to be a plausible way of increasing average force, which results in greater propulsion. However, elevating frequency is effective only up to a 'critical' degree. Our results are in accordance with the results of those researchers who examine the relation between speed and frequency of strokes in the free swimming condition. According to related literature, deliberately exploiting hydrodynamic potentials is key to increasing speed effectively. This ability reflects that the swimmer is quite skilled in controlling and exploiting flow. During our study we observed that by increasing the frequency of strokes over the 'critical' degree this ability to exploit flow and coordinate movement will be jeopardized.

The observed similarities in results give grounds to the conclusion that kinetic and kinematic data gained during fixed position swimming tests will help to infer tendencies occuring during free swimming.

4.2. Differences between the two sides, the relation of kinetic and kinematic variables

A significant difference was shown between the dominant and non-dominant sides as fars as Fmax and RFDmax and αFmax are concerned. However, the difference between the rates of ImpF50% was as little as 4.49%. Among kinematic readings αFmax showed significant difference.

Fmax and RFDmax measured during the phase of 'critical' frequency strokes represent the level of neuromuscular adaptation resulting from training sessions. They also represent the functionality of the regulatory system. It can be claimed that the system reflects the signs of asymmetry in the rates of Fmax and RFDmax. Also, the system regulates ImpF50% in accordance with the laws of mechanics. When a greater effort is required in order to make greater propulsion and thus greater speed, then the dominant side reaches it by giving the impulse in a shorter time with increased Fmax and RFDmax rates. Exercises that involve only one limb are widely known and used in trainings. However, these exercises – almost without exception – are assigned by coaches with the requirement of lower frequency and of lower effort. With symmetric swimming styles (butterfly and breast stroke) visual feedback can help the swimmer to create an equally strong force on both sides or else they would get off course.

Striving for symmetry; transferring skills, that had been learnt through such unilateral exercises, to increased frequency and stronger strokes – with crossed cycle swimming styles only the most gifted competitors are able to fully live up to these conditions. Only the best can achieve better results by following these guidelines.

The backwash of making efforts only on one side is that a revolving force is being created during crossed cycle movements. The swimmer is starting to rotate around his center of gravity. This force has to be compensated by the following stroke. However, this following stroke will cause further unwanted impact on the movement. The compensational movement is to keep the course of the swimmer and to decrease the resistant factors and it remarkably appears around point Fmax. Segments of the arm show the most remarkable difference in their regulation on each side around point Fmax. A greater Fmax value on the dominant side of the swimmer is exerted near to the longitudinal axis of the body. Whereas on the non-dominant side the necessary compensatory turning-moment will be exerted at a lower Fmax value a bit further away from the centre of gravity of the swimmer. By adjusting the saggital or frontal position of the upper-arm the swimmer can shorten or lenghten the lever arm in accordance with the values of Fmax on the dominant and non-dominant side. If the 3D elbow joints' angular position is similar at Fmax points, it may refer to maximal exploitation of the hydrodynamical potential. Based on the readings we can establish that by adjusting the elbow joint the swimmer can better exploit the hydrodynamical potential and by positioning the non-dominant upper-arm the swimmer can better compensate the manouver.

At the non-dominant RFDmax and Fmax points the values of saggital and frontal planes representing the angular position of the upper-arm show a very positive relation and the trend lines rise very similarly. The moderated RFDmax and Fmax values suggest that on the non-dominant side by creating an elongated impulse there is enough time to synchronize the mechanically significant RFDmax value with Fmax value. The detected mechanism is responsible for harmonizing impulses.

4.3. Multiple Regression Analysis (MRA)

4.3.1. Effectiveness Factor, somatometric and kinematic parameters

The logically related variants - that jointly influence the variant of criterion - can significantly verify the hypothesised model structure based on MRA. The variant of criterion in this model is the factor of efficiency characteristic to the frequency of sprint swimming. Based on MRA the variant of criterion is determined by three kinematic and two somatometric parameters (αFmax – dominant side, γFmax – dominant side, γFmax – non-dominant side, the width of palm and weight).

Earlier, on comparing the two sides, we observed that the adjustment of elbow joints has to comply with the rules of hydrodynamics and thus it should determine the values of importatnt mechanical characteristics. On computing the model, this result was verified again since among the components of the model the formentioned variants take the biggest β value (0.945 and 0.620). The criterion variable in the model is also greatly influenced by the saggital plane position of the dominant upper-arm in point Fmax. This determines the impulse of the dominant side. The formentioned upper-arm position is indicated with a negative sign, which implies that positions prior to vertical position is the best as far as the increase of Effectiveness Factor is concerned. Among somatometric parameters the width of the palm proved to be the most significant one, which result pulled the attention of several researchers. The size and shape of the hand is significant from a mechanical point of view in order to create an effective propulsive force. Body weight is also important in the model, which contributes to the modellstructure with negative sign. Swimmers with relatively bigger weight usually opt for simpler, less effective movement patterns. The explanation to this is that the opportunity to exert greater force has a negative effect on consistent impulse generation.

4.3.2. Speed of swimming and the impulse

Based on MRA, the results of 50 m freestyle swimming are greatly influenced by the impulses created on the dominant and non-dominant sides. In this model the value of ImpF50% on the non-dominant side is more significant than the same value for the dominant side. In our study we confirmed that there is a relation between free swimming and the mechanical performance of swimmers – the parameter for this is ImpF50% on each side.

4.3.3. Impulse, kinetic and kinematic variables

By employing MRA enter method we observed the parameters that create ImpF50%. It turned out that ImpF50% as the criterion variable is significantly determined by the parameters that we entered. The model is determined by variables Fmax, αFmax, Fmax, γFmax, RFDmax on the dominant side. As for the dominant side the variables in the model are formulated around creating the maximal force. The adjustment of the elbow joint as well as the adjustment of the frontal plane of the upper-arm in point Fmax are important factors. on the non-dominant side the position of the elbow joint in point RFDmax and the positions of the upper-arm in point Fmax together with the rate of RFDmax are significant parameters in creating impulse.

5. Summary of new findings

1. This is the first time that fixed positioned force production has been measured paralelly with synchronized 3D video recorded analysis of movement. To implement this measuring a special measuring tool had to be designed and constructed. Furthermore, for the evaluation of findings novel methods had to be developed. Our findings verified the applicability of our novel methods.

2. Similarly to free swimming tests, there is a **frequency threshold** in fixed position swimming tests as well. On exceeding this threshold the structure of the movement will change for the worse. Above the threshold the rate of force drops and the ability to keep up the level of frequency is also jeopardized.

3. The Effectiveness Factor (EF) have been developed to describe that **by increasing the frequency of the movement cycle** the propulsivity changes. On increasing frequency, the value of **EF grows** along with the average and maximal force production. However, to keep EF growing, the swimmer needs to continuously adjust the position of the upper limbs' segments. The antropometric features also have an important role in determining EF.

4. **The dominant and non-dominant sides function in a remarkably different way** at the frequency yielding the greatest propulsive force. The dominant and non-dominant sides show different values for Fmax and RFDmax. Furthermore, the xy plane of the upper-arm in point Fmax greatly differs on the dominant and non-dominant sides. The difference between the rates of ImpF50% is 4.49%. With highly qualified swimmers the readings may orientate further examinations.

5. Because the two sides have differing force production and turning-moment, **the upper-arms can and should systematically compensate the movement.** With hydrodynamics in mind the adjustment of the elbow joints should be similar on both sides at given points of force production. Supposedly, the regulatory mechanism observed during tests will be used among free swimming conditions as well.

6. By employing MRA the predictor variables that greatly affect the speed, the rates of EF and ImpF50% (criterion variables) were defined. **Based on our measurements we found that the methods we employed are suitable for analysing and describing the structure of movement.** Further investigations are necessary to find out about the relation between fixed position and uncontrolled swimming with the help of our findings.

6. Use of findings, further plans

- With the help of this combined measurement procedure the mechanical performance of the swimmers can be evaluated. The discrepancies of the two sides and the position of the arm segments in characteristic points of effort production can be described and thus the findings inform coaches and swimmers about their current technique. The information provide feedback on the effectiveness of trainings and help planning.

- By using longitudinal examinations, the development of swimming technique can be tracked down over a period of time. Some backwash effects can easily be traced. Techniques that might harm the elbow or mechanically weaken the performance can be excluded.

- An opportunity presents itself to map the relationship between fixed position and free swimming condition by using the elaborated procedure. (A collaborative study is being prepared at the University of La Coruna, Spain).

- There are further research opportunities to study movement structure based on our methodology. New findings can be researched by complemeting the methodology with EMG and MAD systems. (Some pilot measurements have been done at the Institute of Sport and Physical Education, University of Pécs and also at the Faculty of Human Movement Kinetic, Technical University of Lisbon as part of a cooperation between the research teams).

- With the help of these findings a rehabilitational swimming therapy can be developed for physically challenged people (a collaborative project is running at the Faculty of Physical Education and Sport Sciences, SOTE, Budapest). The findings can be applied in parasports in many ways.

- The methodology presented in the survey can give impetus to further methodological develoments. The currently used video recording system can later be replaced by a higher resolution automated device. With the development and introduction of this automated movement analyzing system the procedure might become widely known and used.

7. List of Publications

7.1 Publications related to the thesis

Karsai, I., Garrido, N., Louro, H., Leitão, L., Magyar, F., Alves, F., Silva, A. (2010) Force production and spatial arm coordination profile in arm crawl swimming in a fixed position. Acta Physiologica Hungarica, 98: 376–383 **IF.: 0.750**

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7.2 Further publications

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Karsai, I., Ángyán L., Magyar, F. (2008) Biomechanical aspects of the human swimming. „Physical activity and quality of life" International conference on sport sciences, Pécs, Hungary, Book of abstracts, p. 38

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