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The elements of modelling leg and monofin movements using a neural network

MAREK REJMAN

Department of Swimming, University School of Physical Education, Wroclaw, Poland

The aim of the study was to verify the diagnostic value of modelling the monofin swimming technique by means of artificial neural networks in order to optimize the technique of legs and monofin movements. The practical aspect of the modelling of the monofin swimming technique is apparent, since the interpretation of the propulsion as such is much less complicated than it is in the case of traditional swimming. Assuming that the technical level of the swimmers participating in the study is high (elimination of the redundant degree of freedom in the chain of swimmer's body–monofin) the analysis was limited to the calf, foot and monofin movements. The model of the neural network allowed identifying the differences in the structure of the movements phases, pointing to extra margin that can be used to generate propulsion while making an upward movement and, simultaneously, paving the way to optimize the monofin swimming technique.

Key words: swimming, monofin, modelling, neural networks

1. Introduction

Rational management of training requires streamlining information flow between athlete and coach. The information must be fully objective and of precisely determined quality. Such criteria may be assessed by applying biomechanical methods, including modelling, to movement technique. The aim of this study was to verify the diagnostic value of the monofin swimming technique modelling by means of artificial neural networks. The research of legs and fin movements was carried out to achieve optimization which was measured by maximizing the swimming speed. The research on the monofin swimming technique involves the analysis of kinematics of propulsion in order to create the criteria for technique assessment, or in order to interpret the mechanisms that would explain the nature of swimming [1]–[4]. The dynamic structure of monofin movements has been studied less frequently

[5]–[7] and the knowledge on technique modelling is mainly based on the research conducted by Wu [8], [9]. The usefulness of the neural network in defining the relationships between variables that are either explaining or explained makes it a useful tool of modelling in sport. So far there have been no attempts to model the fin swimming by applying the neural network method, though there are works that have applied this method in traditional swimming [10]–[13]. The practical aspect of the monofin swimming modelling is clear as the interpretation of the propulsion is far less complicated than it is in the case of traditional swimming. The fin's size and the movement structure resulting in the fin movements are the only source of propulsion [5]. The clear interpretation of the one-dimensional movement structure allows collecting full biomechanical information in order to create the swimming technique model. We assumed that elimination of redundant degree of freedom in the chain of swimmer's body–fin is a measure of the technical level in swimming – it is analogous to Tuna's propulsion mechanism [2]. Therefore we limited the analysis of the movement to the calf, foot and monofin's movements. We hypothesized that the model based on the neural network is reliable to the extent that it can be the basis for identifying differences in the structure of the legs and monofin movements phases. Consequently, it is assumed that this can be used for the assessment of swimming technique.

2. Methods

11 swimmers were tested, all of whom are Polish Junior Monofin Team members. They displayed very high levels of swimming proficiency and had similar constitution (average body mass – 66 kg; SD = 4.4, average body height – 1.73 m; SD = 5.2). They swam a distance of 25 m underwater at a subjectively defined maximum speed while holding their breath. All trials were conducted under the same conditions.

One monofin of standard dimensions and flexibility was used for the research. The data describing the bending dynamics of the monofin surface in reaction to water resistance were collected using strain gauges (HBM, 120 Ohm, $k = 2.01$). Pairs of gauges were attached to the tail and in the middle of the fin, on its both sides, in the symmetry axis of the fin. The raw data were amplified (Microtechma 1503) and converted into a binary signal at the frequency of 50 Hz. They were in the form of voltage change time series, identified as the changes in the forces bending the monofin in reaction to water resistance [5], [6].

The scaling of the monofin involved exposing its surface to different weights, whose mass had been predetermined at 1 kG, and recording the degree of bending in a selected frame of reference. Five measuring points were determined on the symmetry axis (the first one near the strain gauge, the last one on the edge, with distances between them equal). Then weights of equal mass, bending the monofin, were hung in each of the measuring points. Changes in the voltage of the strain gauges were then recorded. These were the result of the application of weight to subsequent points. On the basis of the recorded changes the average value of voltage was calculated, with the same value of the force applied. Finally the scalability coefficient was determined.

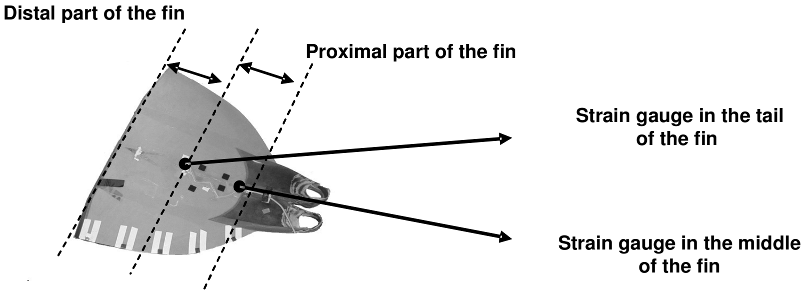
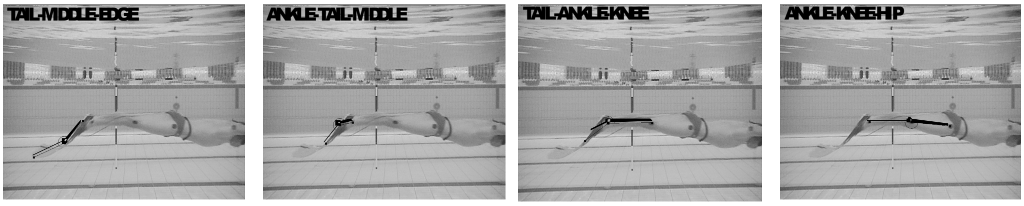


Fig. 1. Placement of the strain gauges and markers on the monofin

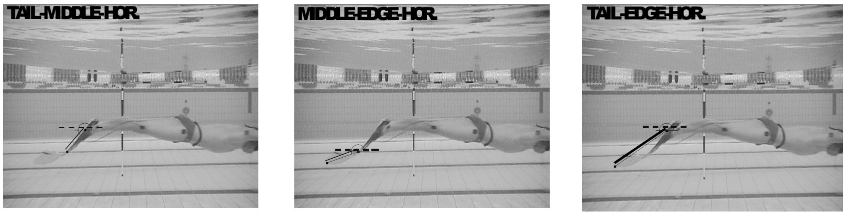


Angle of middle sag
(**T-M-E**)
(T-M-EW angular velocity
(T-M-EE angular acceleration

Angle of tail sag
(**A-T-M**)
(A-T-MW angular velocity
(A-T-ME angular acceleration

Angle of ankle flexion
(**K-A-T**)
(K-A-T-W angular velocity
(K-A-T-E angular acceleration

Angle of knee flexion
(**A-K-H**)
(A-K-HW angular velocity
(A-K-HE angular acceleration



Angle of attack of proximal part
(**T-M-Hor**)
(T-M-HorW angular velocity
(T-M-HorE angular acceleration

Angle of attack of distal part
(**M-E-Hor**)
(M-EHorW angular velocity
(M.-EHorE angular acceleration

Angle of attack of whole surface
(**T-E-Hor**)
(T-E-HorW angular velocity
(T-E-HorE angular acceleration

Fig. 2. Procedure establishing and the basis for interpretation of kinematic parameters of the legs and monofin movements

In order to record the kinematics data of the legs as well as monofin movement, all the swimmers were filmed underwater. A digital camera (DCR-TRV8E) was placed on a rigid tripod in the middle of the swimming pool, assuming that the swimmers and the monofin move only in a lateral plane, without insweep, upsweep or rotation movements [6]. Special care was taken into the position of the lens axis as perpendicular as possible to the object filmed. Points were marked on the swimmers' bodies and on the side of the monofin (figure 1). Kinematic analysis of the legs and monofin movements was carried out using the SIMI Movement Analysis System. The results took the form of time-dependent series representing the angles of flexion of the leg's and fin's segments and the angles of attack of proximal part, distal part and the entire monofin surface (figure 2). A series of approx. 44 samples were subjected to analysis. Force sampling synchronization and recording of the filmed image were done with SIMI® (ISO 9001:2001) for a single randomly selected cycle of each swimmer (a cycle being an upward and downward movements of the monofin's edge).

Horizontal infra-cycle velocity in the swimmer's Center of Body Mass (CMB) was assumed as the output variable of the network. While 23 input variables were used to define model correlations against the output variable:

Forces of the reaction of the monofin to water resistance (forces bending the tail (**F. Tail**); forces bending the middle (**F. Middle**).

Angles of bending, monofin's tail (**A**nkle–**T**ail–**M**iddle); middle (**T**ail–**M**iddle–**E**dge); knee joints (**A**nkle–**K**nee–**H**ip), ankle joints (**K**nee–**A**nkle–**T**ail) and also angular velocities (**W**) of flexion and angular accelerations of flexion (**E**); in the points mentioned.

Angles of attack, of the monofin: (the entire surface (**T**ail–**E**dge–**Hor**); proximal part (**T**ail–**M**iddle–**H**or), the distal part (**M**iddle–**E**dge–**H**or) also angular velocities (**W**) of attack and angular accelerations of attack (**E**); in the parts mentioned.

In developing an ANN model, a genetic algorithm verifying stepwise backwards and forwards and other neural nets were used, i.e., probabilistic and regression networks (GRNN, RBF, PNN). Also selection, mutation and cross-over operators were applied. The model's development was based on multi-layer perception (MLP) [14], which uses the PSP linear activation function with a non-linear activation function and a logistic (sigmoid) function. The network's learning process was based on a back propagation algorithm [15]–[17].

For the purposes of research and the preliminary interpretation of the network model, sensitivity analysis and regression statistics were used. Sensitivity was described on the basis of the values of weight, error and quotient. All outcomes have been depicted as numbers in regression statistics tables and set out independently for the training, validation or testing sets. Response graphs were used only to display graphically the role which is proven by upward and downward movements in the process of achieving the maximal swimming speed.

3. Results

Ranking of parameters as a basement of the network model (created on the basis of error values and response grafs) (figure 3) shows that the swimming speed in a cycle is the effect of the movements of all the elements of the leg–fin chain. In the upward movement, swimming speed is determined by parameters related to monofin's angles of attack (T–M–HorE, M–E–HorE and T–E–Hor). In the downward movement, swimming speed is determined by parameters describing angles of leg (calf) extension and fin's tail bending (A–K–HW, A–T–MW, A–T–M and K–A–T). Other parameters of attack of the fin in the downward movement and K–A–TW have a less significant effect on the swimming speed. There is also the relationship between the swimming speed and T–E–HorW and M–E–HorW in both phases of the cycle.

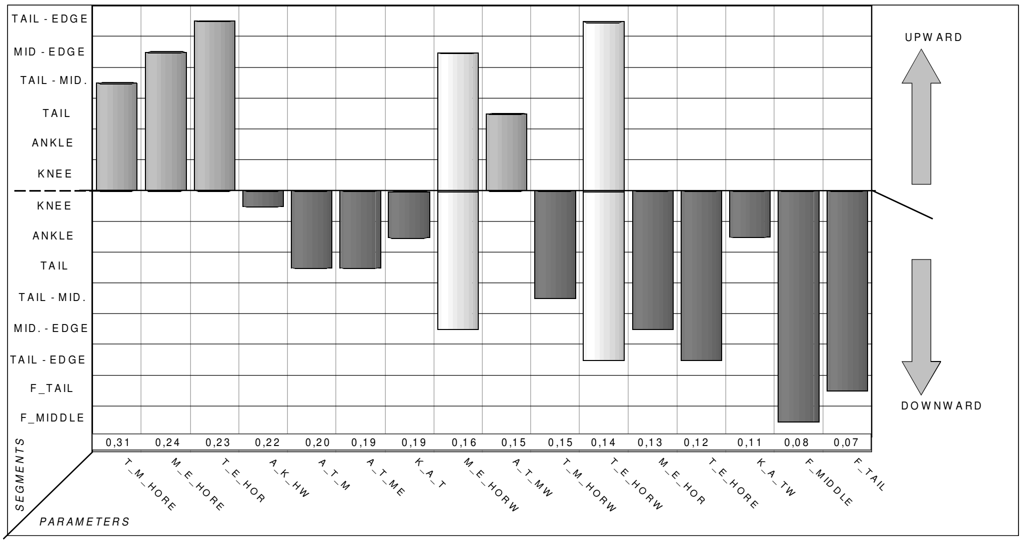


Fig. 3. Ranking of the parameters described in the neural network model according to their significance (error values (presented in bracket)) for swimming speed achieved in the cycle of monofin swimming, taking into account movements of particular segments of the biokinematic chain (legs–monofin) in the upward and downward phases of the movement

4. Discussion

Error values in the test (figure 3) show that if the most significant parameters are not accounted for (T–M–HorE, M–E–HorE, T–E–Hor, H–K–AW, A–T–M, A–T–ME, K–A–T) the diagnostic value of the model would decrease by 19–31% (figure 1).

The regression statistics table is the measure tool of the diagnostic value of the standard deviation quotient is the main indicator of the quality of the model. Additionally the similarity between the values of quotients and errors in the teaching and validation tests were also apparent. This testifies to relevance of the model to real swimming conditions.

The neural networks method is only one of the mathematical variants describing the situation. Knowledge gained from the process is then the basis for optimization of the variant. The network accounts for the dynamics of the process and therefore the relationships between input parameters influencing the result based on the distribution of the parameters to the output variable indicate no basis for conducting a model simulation in isolation from the complexity of the whole process. Apart from statistical verification, the model can be considered a useful tool for assessment of monofin swimming technique.

The prerequisite to swimming with the maximum speed uses available sources of the thrust, and – at the same time – minimizing adverse phenomena related to water resistance. The amount of reaction forces (thrust, lift and acceleration reaction), which determine propulsion, depends on the shape and trajectory of the monofin movements. This trajectory is the result of change in the angle of attack to the direction of swimming. The shape of the fin is the result of angles of bending of its surface to the direction of the water flow. In both cases, changes in the configuration of angles are strictly related to forces recorded in the tail and in the middle of the fin [7]. The propulsion effect depends on the volume of water pushed backward (directly by the fin and, additionally, in the form of the water mass) [2]. Limiting the adverse resistance is related to minimizing the inertia forces while making the movements identical to the direction of swimming (knee flexion during the upward phase) [19] and to maintaining a constant, high infra-cycle velocity [5]. The dependencies between swimming speed and the distribution of the fin's angles of attack in the upward movement and the angles of bending of the tail in the downward movement explain the difference in the propulsion hydrodynamics in the above mentioned phases. Optimization of the monofin's shape and the trajectory in the downward movement is subjected to the structure of the knee extension and the arch of the foot (forced by the "wedge" shape of the monofin shoe). When the legs are in a straight position (the length of the arm of the force bending the fin is maximum), the propulsion effect depends on the downward movement speed because the water resistance slows down the acceleration generated by the fin surface. The need for knee flexion in the upward phase, directly associated with functional abilities of the flexors and the necessity to stretch the extensors prior to the initiations of the downward phase, induces an alternative mechanism of propulsion. The efficiency of this alternative mechanism is determined by several factors such as: evading the horizontal translocation of the fin tail, more dynamic movements in knee joint and a limited feet dorsal flexion. These actions are meant to limit the horizontal trajectory of the fin tail and, at the same time, to increase the fin bending [6], [20]. Bending of the tail shifts to the middle and the distal part of the fin and increases the vertical dimension of the movement trajectory for the whole surface. Angular acceleration of attack increases the vertical movement trajectory and thus activates reaction forces on the fin's surfaces. It also creates circumstances where the additional water mass can be used [2]. Minimizing time, the parallel positioning of the monofin's parts to the direction of swimming eliminates "circumventing" water resistance. This proves the crucial part played by the monofin's distal part in propulsion generating [7].

Reserves in the upbeat structure may also be used for the reduction of the degrees of freedom of legs and fin movements. This postulate does not apply to the limitation of the movements in knee joints and shin–ankle joints as the monofin's flexibility, being its specific feature, fulfils a certain function in the process of generating propulsion. This thesis is proved by the analogy between monofin swimming and the mechanism of Tuna fish swimming [2].

From a physiological perspective the limited functional possibilities of knee joint flexors in comparison with the possibilities of antagonistic muscles prove the necessity to flex the legs in upbeat. Additionally, the extension of muscles (which potentially determine the propulsive effect) before their contraction increases the downbeat phase efficiency. Having accepted the laws of physiology, attention should be given to the results of the research on the structure of the movements of dolphin tails and human monofin swimming. These show slight differences in the values of forces generated, giving more prominence to the downbeat [3]. Similarly, almost equal values were recorded while comparing the kinematics of dolphin leg movements on the chest and on the back [21] and while analyzing movements performed with the use of the model fin [22]. As a result of symmetrical movements of the fin in both directions the angle of attack changes in constant ranges. Therefore the scope and the width of the vortex determined by the amplitude and frequency of movements remains constant [23]. Hence, from a biomechanical perspective, there are no obstacles to creating effective propulsion in both phases of monofin movement. Moreover, similar kinematic and dynamic characteristics of monofin movement in both phases of the cycle (stability) act as a criterion for assessing monofin swimming technique [5].

5. Conclusions

Verification of the model's diagnostic value on the basis of the empirical research and knowledge creates the foundation for future research. At the present stage the model's description, focusing on reserves in the technique of upward movements, paves the way to understand the nature of the monofin swimming technique.

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