Estimated Effect of Monofin Stiffness on Sports Performance in Marathon Swimmers

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Abstract: The study conducted has confirmed that the techniques and methods for training marathon swimmers in fins, tailoring the monofin stiffness to the individual capabilities of the athletes, play a major role in increasing the efficiency of training for competitions. The athletes can reliably achieve better results in the training process and in competitions. Training sessions with monofin stiffness taken into account have been found to have a higher efficiency. Our studies established that the kinematic characteristics undergo certain changes, some of them rather considerable. Using the monofin with the stiffness corresponding to individual capabilities of marathon swimmers allowed increasing the intracyclic speed of the strongest athletes from 2.53 m/s to 3.01 m/s (at the end of the experiment), i.e., the speed increase amounted to 19%. This is also confirmed by the increased average speed of distance swimming: 3.02 m/s and 3.48 m/s respectively, which is an increase of 17%. The study showed that successfully training athletes for competitions largely depends on accounting for the individual characteristics of muscular activity in marathon swimmers and the stiffness of the monofin. We have discovered that higher elasticity of an athlete's muscles should correspond to smaller monofin stiffness. The article presents the results of assessing the effect of monofin stiffness on the performance of marathon swimmers.

1 INTRODUCTION

Significance. Open-water marathon swimming with fins is a strenuous activity demanding high levels of physical fitness. For best results, the stiffness of the monofin should closely match the athlete's muscle structure. Monofin swimming provides an increase in speed due to:

- increased surface area of the monofin, generating large thrust in the water;
- large group of muscles of the athlete's legs, back and abdomen working simultaneously;
- wave-like bending and oscillatory movements made by the athlete's body and the monofin, which are more efficient from a hydromechanical standpoint.

Therefore, tailoring the stiffness of the monofin as well as matching it to the athlete's specific muscle structure and fitness levels is a major goal for coaches and marathon swimmers.

Analysis of the literature showed that the majority of studies on training of marathon swimmers in fins do not provide sufficient data on selecting monofin stiffness in accordance with individual capabilities of an athlete. This greatly limits the sports performance. Furthermore, methods for improving specific and general endurance in marathon swimmers in fins accounting for monofin stiffness have been developed insufficiently this far. The existing system for training marathon swimmers in fins for competitions does not offer satisfactory options accounting for monofin stiffness and adapting it to the individual characteristics of the athletes' muscular activity during practice The system's main drawback is in the general approach to training of marathon swimmers in fins, failing to consider the athletes' individual skills. This does not allow to effectively increase the general endurance and speed endurance in marathon swimmers in fins, which are imperative for improving the overall sports performance (Alpatov et al., 2020, Bakayev, 2015, Clemente-Suárez et al., 2017, Hue et al., 2006, Rejman and Borowska, 2008, Rejman, 2013, Pendergast et al., 2003).

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Thus, assessing the influence of monofin stiffness on sports performance in marathon swimmers is of great practical importance for improving the quality of the training process.

Goal: to evaluate the degree of influence that monofin stiffness has on the performance of marathon swimmers in order to improve the quality of the training process.

2 MATERIAL AND METHODS

The present study considers modern methods for assessing the degree of influence of monofin stiffness on the performance of marathon swimmers. The main method is predictive simulation in accordance with modern methods for assessing the properties of materials from which the monofin is made and the muscular structure of swimmers competing in open water. Analysis of modern methods for assessing the degree of influence of monofin stiffness on the performance of marathon swimmers has been carried out.

3 RESULTS AND DISCUSSION

The monofin has come a long way to achieve its overwhelming popularity in numerous studies of marathon swimmers. First, the monofin has driven out the elongated bi-fins in middle and long distances. Currently, all the leading marathon swimmers in the world compete in monofins (Takeda et al., 2020, Ng et al., 2019, Ganapolsky et al., 2019, Bolotin and Bakayev, 2017, Oshita et al., 2013, Vercruyssen et al., 2012, Bolotin and Bakayev, 2020).

Based on the goals of the study and the specifics of open-water marathon swimming, the athletes' physiology and the operating principles of the monofin, we formulated the following objectives:

1. Determine the design parameters of monofins.
2. Understand the relationships of these parameters with the performance of marathon swimmers and anthropometric characteristics of athletes.
3. Find ways to improve the monofin stiffness based on the requirements of hydro-bionics and individual capabilities of marathon swimmers.
4. Develop a technique for calculating the monofin stiffness based on the requirements of hydro-bionics and individual capabilities of marathon swimmers.

The following was established based on the objectives posed:

- monofin should be shaped as a semi-ellipse, avoiding sharp angles and bends of the side edges;
- area S_{mf} of monofin surface on one side was chosen from the ratio of the area S_b of the athlete's body to S_{mf}: $S_{mf} = 0.21\ S_t$;
- relative elongation of the monofin equals $Z=w/S_{mf}$, where w is the width of the monofin, in the range of $1.5 < Z < 1.7$;
- smoother profile creates a uniform distribution of stiffness along the entire length and area as a whole, increasing the speed of the athletes.

Monofin stiffness was further enhanced by air cavities specially created inside the foot pockets. Air or water (preferably salt water) was pumped into these pockets through nipple valves. The stiffness of the foot pockets and angle selected for the pressed wedge should ideally eliminate or at least minimize the angle between the longitudinal axes of the shins and the blade in a streamlined position of the athlete's stretched body with the monofin on the water surface.

Practically excluding the foot, which is in this case, a rather ineffective link of the lower limb, from swimming motion, makes the lower leg a powerful lever, providing a more efficient transfer of the energy generated by bending and oscillating movements to the monofin to achieve greater swimming speed.

Immobilizing the feet and symmetric (relative to shins) oscillations of the monofin blade in the vertical plane bring the kinematics of the underwater swimmer's movements even closer to swimming of aquatic animals (cetaceans, in particular), whose vertical oscillations of the tail fin are symmetric relative to the body axis. This produces a self-oscillatory swimming mode, which is the most resource-efficient.

The second feature of the monofin is the increased volume of the blade profile, with the stiffness varying based on the individual capabilities of marathon swimmers (Figure 1).

Our studies established that the kinematic characteristics undergo certain changes, some of them rather considerable. This refers, first of all, to intracyclic (per cycle) speed V_c as an integral indicator of the relationships between all other main parameters: time T_c of the movement cycle, 'step' L_c, and swimming pace N.

Using the monofin with the stiffness corresponding to individual capabilities of marathon swimmers allowed increasing the intracyclic speed

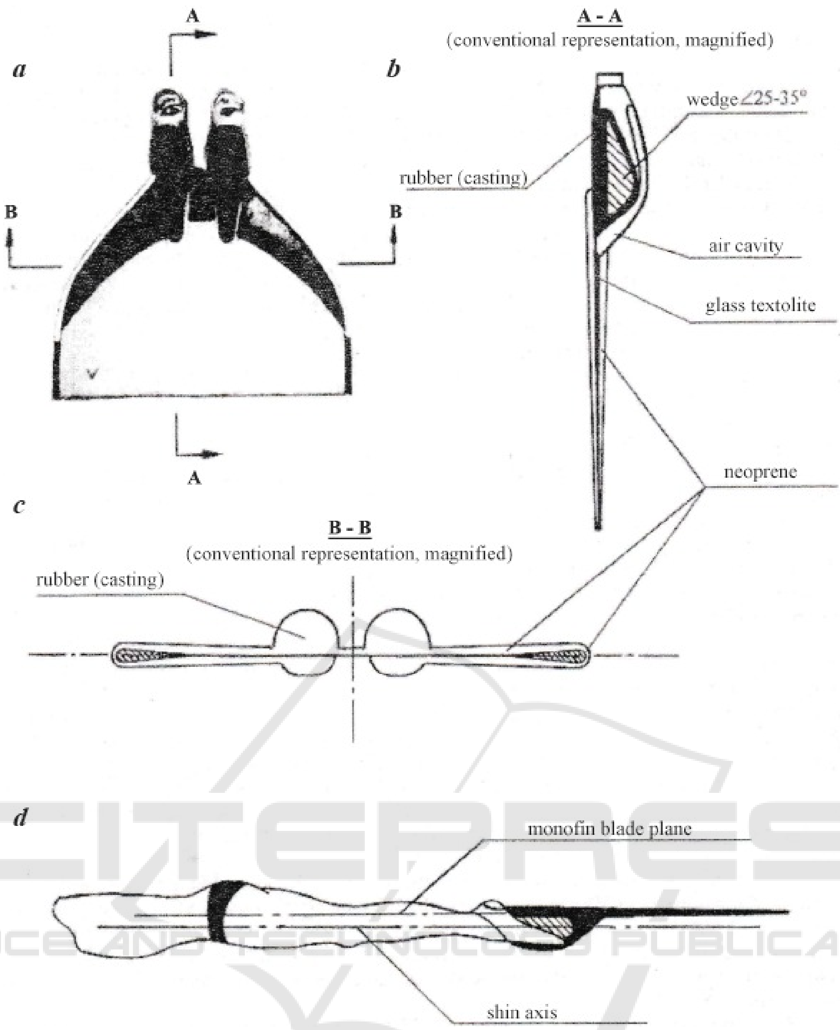

Figure 1: Schematic view of monofin: photo (*a*); sections (*b*, *c*); position of feet in the pockets, shown conventionally (*d*).

Table 1: Comparative assessment of parameters in swimming with monofins of different stiffnesses for strongest marathon swimmers.

Leading athletes of the Russian Federation	X ± σ	Kinematic characteristics									
		T_c (m)	L_c (m)	V_c (m/s)	N (1/s)	Amplitude (span), m					
						A_h	A_{cm}	A_{hj}	A_{kn}	A_{an}	A_{mf}
Athletes using a ‘rigid’ monofin (n=7)	X	0.49	1.21	2.51	2.3	0.11	0.12	-	0.23	0.28	0.47
	σ	0.04	0.05	0.17	0.19	0.03	0.03	-	0.03	0.02	0.03
Athletes using a ‘soft’ monofin (n=7)	X	0.41	1.29	3.02	2.5	0.12	0.15	-	0.32	0.37	0.53
	σ	0.04	0.06	0.23	0.24	0.03	0.03	-	0.05	0.04	0.03

Note: T_c - movement cycle time, L_c - movement step, movement step, V_c - intracycle velocity, N - pace of movement, A_h - amplitude of the hands, A_{kn} - knee vibration amplitude, A_{an} - ankle vibration amplitude, A_{mf} - amplitude of oscillation of the trailing edge of the monofin.

of the strongest athletes from 2.53 m/s to 3.01 m/s (at the end of the experiment), i.e., the speed increase amounted to 19%. This is also confirmed by the increased average speed of distance swimming:

3.02 m/s and 3.48 m/s respectively, which is an increase of 17%. This increase in speed is very substantial for the longest distance (6 km).

Since the limits (quantitative and qualitative) for functional training of athletes (amount and intensity of training) have long been reached, this increase in the long-distance swimming speed of marathon swimmers depends on the monofin stiffness selected based on the individual capabilities of marathon swimmers.

Analyzing the oscillation amplitudes at the points of the ‘athlete–monofin’ system (Table 1), we can observe an increase in all oscillation amplitudes in marathon swimmers, starting from the hands (A_h) to the trailing edge of the monofin (A_{mf}).

Large amplitudes characteristic for the modern swimming techniques, especially the oscillation amplitudes of knee (A_{kn}) and ankle (A_{an}) joints, as well as the trailing edge of the monofin (A_{mf}) are explained, in our opinion, by only one factor, which was already discussed above: a new, longer lever connected to the monofin, i.e., the athlete's shin.

This is explained by:

1. Increase in the level of functional training, so that modern marathon swimmers can ‘rotate’ the heavier monofin with a higher frequency (rate) of oscillations.
2. Self-oscillatory mode, where the muscular effort corresponds to the stiffness of the monofin. This is reported by the athletes themselves based on their sensations and experience in overcoming the distance. Marathon swimmers use the inertia of the monofin oscillations to switch to self-oscillatory mode with a quick pace.
3. Optimization and coordination of trajectories of points in the body and the monofin during bending and oscillatory movements of marathon swimmers.

4 CONCLUSIONS

1. The monofin has evolved into a better and more efficient accessory, corresponding to the individual capabilities of marathon swimmers, providing an increase in the athletes' swimming speed.
2. The monofin with optimal stiffness provides a ‘new link’ in the athletes' lower limbs, that is, the feet with the monofin, which act as a single unit, optimal in terms of the muscular structure of marathon swimmers.
3. The ‘new link’ in the lower limbs helped adjust the swimming kinematics, optimizing the technique for bending and oscillatory movements of marathon swimmers, with a self-oscillatory mode emerging, consequently yielding an increase in speed.

Research on developing new types of monofins with stiffnesses matching the individual capabilities of marathon swimmers should involve specialists in the field of sports physiology, programming and sports metrology.

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