Monitoring and Control of Power Preparedness of Athletes in Flatwater Rowing and Canoeing Using Strain Gauges

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Abstract: Control over the preparedness of flatwater rowers and canoeists is realized in the process of solving a variety of particular problems related to the organization of training activities, planning and dosing of loads, selection of training tools and methods for assessing various aspects of readiness and competent interpretation of the results obtained for carrying out corrective measures. Solving these problems is facilitated by strain gauges, which make it possible to record dynamic and some kinetic parameters in natural rowing conditions (on water recording) as part of training and monitoring activities. The article presents the developed strain gauge sensors, describes the features of their calibration and mounting on an athlete's paddle, and also proposes software for automated processing of recorded data. The article is based on a practice-oriented study on experimental testing of the developed sensors as part of the training and monitoring process.

1 INTRODUCTION

Monitoring technical and power preparedness in flatwater rowing and canoeing is an integral part of the training process, the results of which are purposefully used in the selection of training tools, planning and rationing of external loads, as well as in assessing the effectiveness of training sessions. The main criteria that determine the possibility of including certain indicators in the control program are their information content and reliability (Kolumbet, 2017).

Flatwater rowing and canoeing are sports with a predominant manifestation of power abilities of athletes that place high demands on the anaerobic mechanisms of energy supply for athletes (Rosdahl, 2019). Accordingly, the external manifestation of an athlete's strength and speed preparedness is the power of movements realized by explosive muscle efforts in a minimum period of time (Kvashuk, 2021). The performance of each stroke and the advancement of the boat directly depends on the power of the movements (Wainwright, 2014; Wainwright, 2015). The efficiency of the rower's movements can be assessed by various methods, starting with a simple measurement of the time it takes to cover the distance. Variables such as boat speed over the course and pace are indicators of an athlete's performance and can be used as a fairly simple method for comparing an athlete's performance with competitors, as well as with one's own previously demonstrated results (Gomes, 2022; Redwood-Brown, 2021).

However, these variables do not allow us to assess the level of speed-strength readiness, establish cause-and-effect relationships in achieving high performance of movements and understand how the rower achieves his results (Oronova, 2018; Brown, 2010). This gave impetus to the emergence of studies aimed at complex biomechanical control of the flatwater rower's motor actions, which would take into account objective data that comprehensively reflect the performance and efficiency of movements in terms of kinematic, dynamic, energetic and physiological parameters. In particular, one of the most relevant areas of research work today is the develop-

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ment, optimization and implementation of fully autonomous devices for measuring the dynamic parameters of rowing in natural conditions into the structure of the training process of professional rowers and amateur athletes (Galipeau, 2018).

2 STUDY METHODS

It is known that strength and force impulse reflect the realization of an athlete's speed-strength potential, however, to correctly assess the efficiency of a stroke, it is necessary to have data characterizing the movement of the boat for each stroke (Baker, 2012). To do this, in addition to the already indicated force and its impulse of force, in order to assess the effectiveness of interaction with the aquatic environment, it is necessary to have data reflecting the frequency of strokes (tempo), the length of the drive in the support part (amplitude), the area of the conditionally fixed support, the power of the stroke (characterizes the performance of movements athlete) and the length of the boat rental for each stroke (Gomes, 2022). To solve this problem, many researchers resort to the method of simulating racing conditions in non-competitive or training conditions, which makes it possible to analyze the relationship of various parameters (Bertozzi, 2022; Bonaiuto et al., 2020b). However, at present, this problem has not been fully solved, since it requires the use of several measuring systems simultaneously, which significantly complicates the process of data recording and has a negative impact on the biomechanical structure of the athlete's movements. Therefore, this direction can be considered promising with the need to overcome all kinds of technological limitations of existing and already used measuring systems.

Currently, there are no commercially available devices with the functionality to record and analyze the parameters of the force and impulse of the stroke force in natural conditions. However, the high relevance of research in this direction, including in solving the problem of developing methods and algorithms for monitoring and assessing speed-strength readiness in kayaking and canoeing in natural conditions, are confirmed by analysis of a significant number of publications (Bonaiuto et al., 2020a; Bonaiuto et al., 2022).

The most promising direction in harnessless rowing to solve this problem seems to be the use of portable wearable strain gauge sensors, circuitry implemented on the basis of MEMS technology. This makes it possible to create ergonomic designs (with small overall dimensions and weight), with functionality that allows for high-frequency data recording with high accuracy. Such sensors provide not only registration and conversion of the relative magnitudes of the mechanical impact on the sensitive element into an electrical signal, but also its primary processing and conversion into a discrete numerical and graphic signal in real time.

The purpose of the study is experimental testing of the developed strain gauge sensors in real conditions of the training and monitoring process for a long period of time.

2.1 Research Methods

In this study, we used strain gauge sensors developed by us, structurally implemented in the format of a two-section measuring device. Sensor section is connected to the data recording section via connecting PDC (Power and Data cable) plugged into the appropriate connectors (Figure 1).

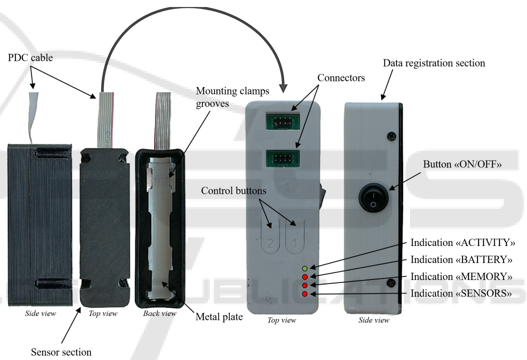

Figure 1: Strain gauge on the oar to record the dynamic characteristics of the stroke.

Sensor section is mounted on the paddle shaft using metal or plastic mounting clamps. The sensitive element, represented by a strain gauge, is glued to the elastic thin metal plate of the sensor section. The plate fits tightly directly to the paddle shaft. The profile of the metal plate provides improvised grooves for mounting clamps. Microcircuits, controls and indicators of operation and mode changes are placed in the data recording unit.

The data recording unit has the necessary hardware and software capabilities for simultaneous recording of signals from 4 sections with strain gauge sensors. The initial recorded data is the time and the resulting external load acting on the paddle during rowing and expressed in Newtons. To ensure correct use of the strain gauge sensors, calibration must first be carried out. The calibration functionality is preinstalled in the software part of the data recording section.

2.1.1 Strain Gauge Calibration

The calibration process consists of several required steps and can only be performed on one sensor at a time. First you need to correctly configure the system file. In particular, it is necessary to indicate the weight of the calibration weight in newtons. Next, it is necessary to secure the paddle in a horizontal position on two fixed supports, the location of which corresponds to the athlete's grip (Figure 2); A – diagram of the calibration of sensors installed on the paddle for canoeing; B – diagram of the calibration of sensors installed on the paddle for kayaking).

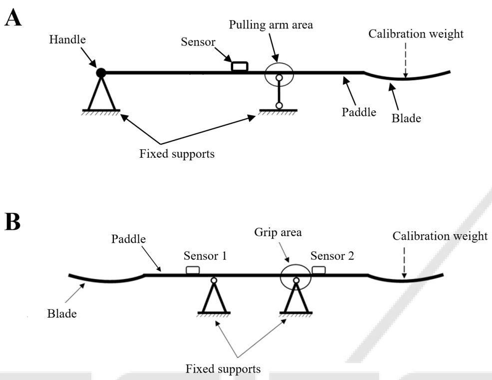

Figure 2: Schemes for calibrating strain gauge sensors on different paddles.

The support points must have a cylindrical cross-section, the radius of which should not exceed the radius of the paddle shaft. This is really necessary to create the point interaction under conditions of the two-point deformation. Then you need to change the operating mode of the device by pressing a certain combination of buttons. The transition to calibration mode will be accompanied by a corresponding indication.

The calibration process itself consists of two mandatory procedures: fixing the "zero indicator" of the calibration - an unloaded state, when the paddle is not affected by any external load, and it is located in a horizontal position on two fixed supports; fixation of the "load indicator" of calibration - a state when a calibration weight is applied to the paddle blade, and the paddle is located in a horizontal position on two fixed supports. These two states are fixed by pressing one of the sensor control buttons.

To verify the accuracy and reliability of the values, which were recorded by the sensor, a study was previously conducted using a specially designed stand and a universal electronic testing machine MTS Criterion 43 (limits of permissible relative error of force measurements – no more than 1%) (Guseinov D.I., 2024).

2.1.2 Starting the Data Registration Process

To record biomechanical rowing data, an paddle with attached strain gauge sensors and a recording unit is transferred to the athlete into the boat. The wires are fixed on the forearms and shoulders with elastic bandages (Figure 3).

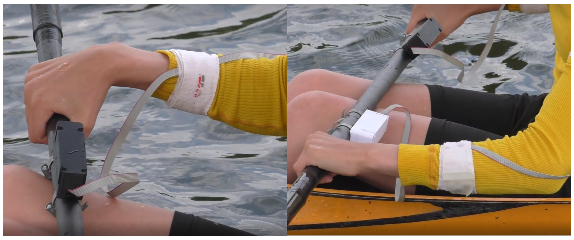

Figure 3: Strain gauges attached to the athlete's paddle.

It should be noted that the orientation of the sensor sections coincided with the orientation of the paddle blades. The sections themselves were connected to the data recording unit via PDC wires.

Next, the conditions for performing test tasks are announced and explained to the athlete, data recording is activated and the recording unit is placed in the boat (Figure 4).

Figure 4: Activate data recording and place the recording unit in the boat.

2.1.3 Testing

One athlete aged 17 years, with experience of performing at regional competitions, took part in the study. He is included in the roster of the national team (trainee variable team composition). The athlete was asked to perform 3 accelerations with maximum intensity over a 100 m distance. The study was carried out in the equipped rowing channel. Specialized floats (buoys) installed along the distance every 10 meters acted as reference points for athlete when passing control segments. Between accelerations, the athlete rested all the time during the next 100 m. He covered the recovery 100 m with low intensity.

2.1.4 Data Processing

The processing of the obtained data was carried out using specially developed software, which allows you to automate the basic manipulative procedures usually performed with such data (Figure 5).

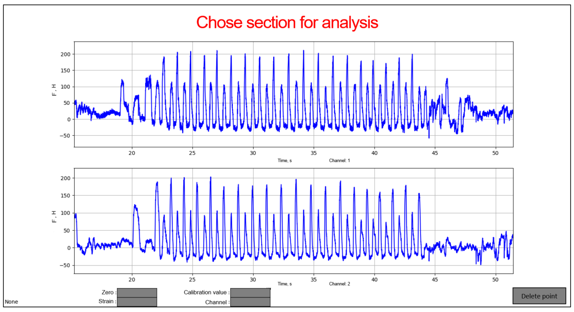

Figure 5: Software screenshot for automated processing of sensor data.

The software allows us to interactively designate the boundaries of the recording segment of interest, filter using a digital filter with a moving average (the size of the filter window is also customizable and selected by the user), and automatically designate the boundaries of the beginning and end of the supporting part of each stroke included within the previously designated limits recording segment, and also calculate all the necessary rowing parameters. Current software can process up to 4 signals simultaneously, and the computing functionality allows it to be used to process recordings of kayaking and canoeing. In particular, for canoeing it is necessary to calculate parameters for each stroke, and for kayaking it is necessary to calculate only for target strokes (Figure 6).

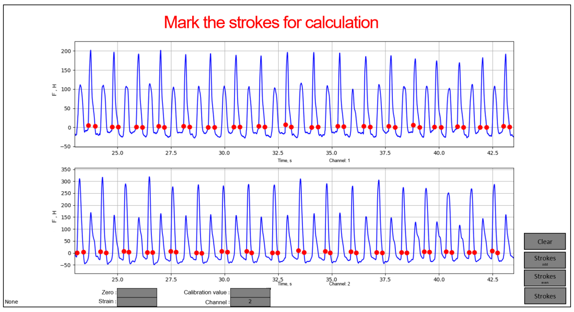

Figure 6: Interactive designation of the boundaries of the supporting part of the strokes.

The software is implemented using the Python programming language based on the public libraries Pandas, Numpy and Matplotlib.

This study calculated the numerical values of the average force (F_{mean}) and peak force (F_{max}) within each stroke, as well as the ratio of average force to peak (F_{mean}/F_{max}), which can quantitatively characterize the density of the stroke. The numerical value of this parameter ranges from 0 to 1. The higher the value, the denser and better quality the stroke is in terms of propulsive efficiency. In addition, some other biomechanical parameters of rowing have been calculated. In particular, the time of the supporting part of the stroke (t_{sup}), cycle time (t_c), as well as the tempo of rowing (T). Also, for a better understanding of the speed-force nature of rowing, the values of the impulse (I) are calculated.

3 RESEARCH RESULTS

The results of each test task are presented in Table 1. For each parameter, the standard deviation (SD) was also calculated, which quantitatively characterizes the stability of the rowing process.

According to the recorded data, the athlete has a pronounced force asymmetry. In particular, the forces developed by the left hand are greater than those developed by the right. This is a certain kind of motor dysfunction, since it provokes the boat to turn to the left, which the athlete is forced to compensate for by steering through the steering mechanism of the boat. This circumstance reduces the propulsive efficiency of rowing. In addition, one can notice that the degree of asymmetry of movements decreases with each subsequent attempt, which indicates a slight increase in the propulsive efficiency of rowing against the background of fatigue. Analyzing the numerical indicators of the standard deviation, there is reason to assert that the athlete is distinguished by high rowing stability, since the standard deviation values do not exceed 5% of the target indicator.

To assess the trustworthiness of the recorded and calculated data, their statistical processing was carried out by means of two-factor analysis of variance with repetitions (ANOVA). Such an analysis makes it possible to determine whether the differences in the analyzed values are random. The numerical values of the analysis are presented in Table 2.

The results of the analysis indicate statistically significant differences in 4 of the 6 registered and calculated parameters ($p < 0.05$). The p-values for t_{sup} and I parameters are statistically insignificant (the probability of accidental differences is 56% and 23%, respectively). Such a phenomenon, it seems to us, is caused by the imperfection of the algorithm for automated marking of the boundaries of the beginning and end of the supporting part of each stroke. The improvement of this algorithm is a priority task in the framework of future research activities.

Table 1: Results of test tasks.

Trial	Sensor	F_{mean}, N SD	F_{max}, N SD	F_{mean}/F_{max} SD	t_{sup}, s SD	t_c, SD	T, min^{-1} SD	I, Ns SD
1	Left	87.09 4.62	188.45 9.32	0.46 0.02	0.43 0.04	0.95 0.04	55.01 0.32	37.78 3.99
	Right	114.37 7.30	211.56 12.92	0.54 0.04	0.43 0.06	0.94 0.05	52.81 0.40	47.35 6.78
2	Left	91.28 4.11	195.94 9.08	0.47 0.02	0.42 0.03	0.91 0.05	59.05 0.27	38.44 3.28
	Right	112.73 6.94	204.11 11.70	0.55 0.04	0.44 0.04	0.93 0.04	56.84 0.36	47.76 5.50
3	Left	89.41 3.93	173.96 8.72	0.51 0.02	0.43 0.03	0.95 0.02	55.29 0.62	39.14 3.81
	Right	107.62 4.24	199.15 9.13	0.54 0.03	0.44 0.04	0.94 0.04	54.84 0.73	45.43 4.27

Table 2: Results of test tasks.

Metrics	F_{mean}, N	F_{max}, N	F_{mean}/F_{max}	t_{sip}, s	t_c, s	I, Ns
p-value	0.0002	0.00007	0.000003	0.56	0.006	0.23

4 THE DISCUSSION OF THE RESULTS

The development and implementation of various wearable and mounted sensors and measuring systems as means of diagnosing and monitoring the preparedness of athletes is a relevant and popular area of research and inventive activity, as evidenced by a large number of thematic publications (Warmenhoven, 2018; Vėžys et al., 2020; Löppönen et al., 2022; Annino et al., 2023; Cristian Romagnoli and Gatta, 2022). However, the process of introducing such sensors into sports, in which training and competitive activities are carried out at the junction of air and water environments, is accompanied by certain difficulties.

In particular, there are problems of adapting the design of sensors to the amplitude deformations of equipment, as well as ensuring hardware resistance to conditions of high humidity and immersion in water (Cruz et al., 2023). However, it is noted that the use of strain gauge elements in the base of the sensor is the most preferable option for circuit implementation, since the electrical behavior of the strain gauge remains stable both in dry conditions and in conditions of high humidity (Laaraibi et al., 2024). In addition, there is information that the numerical data obtained using strain gauges, provided that the measures for their installation and calibration are followed, are reliable and make it possible to record with a sufficient degree of accuracy the mechanical stresses arising during rowing, as well as to objectively determine the indicators characterizing power of movements of athletes when interacting with the surface of the water in the supporting part of the stroke (Vėžys et al., 2020).

It should be noted that the design of such sensors and measurement systems must also be accompanied by necessary and sufficient ergonomic measures, which will improve mechanical strength and electrical insulation, as well as eliminate various potential movement restrictions that can reduce the reliability of the recorded data (Laaraibi et al., 2024; Rana and Mittal, 2021). Based on the results of the analysis of thematic publications, it was established that in practice, within the framework of diagnostics and monitoring of the readiness of rowing athletes, both wired and wireless configurations of sensors are applicable and useful. However, it should be noted that for research work, as well as when working with two or more devices, the most preferable method is a wired data recording method, which allows for high-frequency data recording without loss. A wireless configuration, in turn, may be more preferable for providing prompt feedback, while this information will be useful to the coach, but not to the athlete himself, who is fully concentrated on performing the motor task.

As mentioned earlier, in order to achieve high efficiency in diagnostics and control of rowers' readiness at various stages of the training process, it is necessary to determine the most informative control parameters. Such parameters that would allow one to judge, to the necessary and sufficient extent, the technical and speed-strength readiness of athletes. It is known that such parameters are the forces developed by the athlete when interacting with the surface of the water, as well as their derivatives, including the power of movements, force impulse, force gradient and others (Bonaiuto et al., 2020b; Bonaiuto et al., 2020a). The use of sensors based on strain-resistive circuit elements makes it possible to register and calculate the numerical values of these and many other parameters that quantitatively characterize the temporal features of rowing.

Strictly speaking, to ensure regular monitoring, it is very important to have the ability to digitally represent each stroke when an athlete performs target training and training-diagnostic tasks. This will allow us to form an objective idea of the athlete's level of preparedness, as well as track the dynamics of his/her results.

5 CONCLUSION

The work demonstrates an experimental device developed for technical equipment of diagnostic procedures and monitoring of technical and speed-strength readiness of athletes specializing in kayaking and canoeing. An experimental testing of the device was carried out under the conditions of the training process. Empirical data recorded using the developed device and processed using specialized software are presented.

The results of the experimental testing of the developed strain gauge sensors and automated processing software can be considered positive, since the sensors themselves worked properly, the athlete did not feel discomfort during the test tasks, and the duration of the data collection process within the training and diagnostic process did not exceed the wishes of the coach. Obviously, an additional series of experiments is required to test devices and software on various data. However, there are already grounds to assert that such devices are necessary to ensure an effective training process, especially for professional athletes.

To summarize, it should be noted that the effectiveness of flatwater rowing and canoeing technique can be determined quite accurately and objectively by comparing individual movements with references values, establishing the relationship between individual indicators of technique and sports results, as well as regular monitoring of the dynamics of indicators. All of the listed tasks in the field of kayaking and canoeing can be solved through the use of similar technical devices and appropriate software.

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