BIOMECHANICAL QUALITATIVE ANALYSIS OF KAYAK ROWING TECHNIQUE IN INITIAL TRAINING OF STUDENTS

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Abstract: The educational policy of the Bulgarian education enables the teachers in secondary education to be carried out by choice in at least one obligatory educational field of educational content and one elective educational field of educational content. Our attention was drawn to the elective educational area "Rowing", introduced after 2019 in grades 8-12, 15-18 years old. For the convenience of teachers, we made a biomechanical qualitative analysis of the technique in the initial training in kayak style. By applying the analytical method for determining the center of gravity (CG), we determined the CG of the rowing-boat kinematic system, as a result of which, we determined the beomechanical expediency of the technique in the initial training in rowing style "kayak". Analysis of the spatial and spatial-temporal structures of rowing movements. Determining the main phases of work of the upper limbs, oars and torso. We used a cinematographic method in which a series of frames were made arranged in a cyclogram. The procedure for filming a kayak and a rower was organized in the sports hall "Dr. Stefan Mitov" of SWU "Neofit Rilski", Blagoevgrad. A 26 mp HUAWEI MATE 10 camera was used to capture the images. The graphics processing was done with PAINT 3D, Windows 10. The kayak is an "Ocean duo" model from RTM. The determination of CG by the analytical method is performed according to the following algorithm: 1) determination of partial centers of gravity (PCG) of the individual units of the kinematic chain of a certain sports posture (we worked on a photo); 2) according to external anatomical landmarks we plot the projections of the joint centers; 3) Connect the centers with straight lines - longitudinal axes; 4) measure the length of the longitudinal axis in mm for each segment separately and multiply it by the corresponding coefficient of the unit - (K) - shown in the figure as numerical values inscribed near the longitudinal axis. The resulting distance in mm is plotted from the proximal to the distal end along the longitudinal axis (from the inner to the body joint center to the outer) and we obtain the position of the Partial center of gravity; 5) after finding the PCG values in mm (X, Y) are measured on their coordinates. The data are recorded in a table, a value for X and Y is determined for each segment and plotted against a weighting factor of 0.07 head, 0.43 torso, etc. Multiply the values and get Δ X and Δ Y. Then add up all the values for X and Y. The values obtained are plotted on the graphic and the CG is localized. The CG data show that it is located below the base of the central sternum of the thorax, and in no rowing position does it extend beyond the body. For the initial study of rowing in such a kayak, in which the width of the board is greater and gives greater stability, it is important that the projection of the CG on the support area does not have large fluctuations in the anterior-posterior direction (sagittal plane) and lateral direction (frontal plane).The phase defining positions are catch, immersion, extraction, and release. After analyzing the kinematic chain rower-paddle-water mass, we found the following differences between the basic sports-competitive technique and the technique for initial training in students, basically they are due to size on the kayak (we used a tourist kayak). Angle of enter in the water (^{o}) 36.5 compared to 48-50 with us; lateral angle of the paddle in the water phase (^{o}) 43.3 versus 50; water phase length (m) 1.09 versus 0.83; Distance of the blade path when extracting (m) 0.33 versus 0.40. (López & Ribas, 2011). To perform the correct technique of transferring the paddle, it is necessary to limit the movement of the center of the paddle in a virtual cube with a side of 40 cm, which is located at chest height and at a distance to the elbow joint of a raking hand. The basic rowing technique must be built after refining the kinematic parameters of the movement and building a basic motor control of the student.
Keywords: biomechanical, qualitative analysis, kayak, initial training

1. INTRODUCTION

The educational policy of Bulgarian education enables teachers in primary and secondary education to model the curriculum by choosing proposed areas of curriculum. In addition to the compulsory educational areas (Athletics, Gymnastics, Sports Games), the following elective educational areas are - Water Sports (Swimming and Rowing), Tourism, Martial Arts, Fitness and Bodybuilding. Our attention was drawn to the elective educational field "Swimming, water sports", the topic of rowing - rowing technique, which was introduced after 2019 in grades 8-12, for 15-19 year old students. In the elective educational areas, the main directions in water sports are included. The most accessible of them is swimming, given the existence of numerous swimming pools, as well as natural ones. Water skiing is a sports and recreational discipline that is related to the availability of water-motor equipment and its use depends on financial resources and a second person. Sailing is a discipline that depends on the availability of some material support (boat, sail, etc.), but is dependent on the presence of air currents. Only rowing sports, academic and canoe-kayak, rely on their own propulsion resources (muscle strength) and the availability of material support, boat and paddle. Here we must mention that after acquiring competencies and skills in this sport, we will provide an opportunity for good practice for recreational sports through the practice of water tourism.

The preparation, scientific support and implementation of training in rowing, kayak style, will be fruitful and well received by students and teachers in the field of Physical Education and Sports. It will respond to the solution of basic tasks, educational and upbringing of physical education and sports, and last but not least will perform its entertaining and relaxing function.

Although significant differences in kinematic parameters have been found in the performance of the same competitors in water and ergometer testing (Klitgaard, Hauge, Oliveira, & Heinen, 2021), we believe that our methodology is relevant to other authors such as Pace (2017) for determine the kinematics of rowing, kayak style. The aim of our research is to make the initial training in kayaking easy and accessible by revealing the basic laws of biomechanics of sports techniques.

The difference between a sports kayak and a tourist kayak is in the expensive sports boat, the difficult to manage, balancing and the difficult sports racing technique. On the other hand, the tourist kayak is stable, accessible and not difficult to manage, convenient for long water trips. In this study we will introduce you to the basic technique, the phases and subphases of the rowing technique, as well as the spatial and spatio-temporal characteristics of the rowing movements performed by us and other research teams (McDonnell, Hume, & Nolte, 2013; Li, 2017; Pace, 2017; Gomes, Ramos, Conceição, Sanders, Vaz, & Vilas-Boas, 2020).

2. MATERIALS AND METHODS

The aim of the research is to determine the CG (center of gravity) of the rowing-boat kinematic system by applying the analytical method for determining the CG, on the basis of which to specify the methodology for initial training in kayak style, in terms of the laws of stability and balance of bodies in static and dynamic systems. With a better understanding of the biomechanical properties and design features of kayaking, coaches and athletes can work for successful training and sports performance (Michael, Smith, & Rooney, 2009). For proper qualitative biomechanical analysis, we must determine: the amplitude of movement of the upper limbs; cyclicity; trajectory of the paddle; angular positions at the beginning and end of phases and subphases (analyzed in the frontal and sagittal planes); force phases and relaxation phases; conditions for balance of the boat; location of the Center of gravity; type of kinematic chain.

Analytical method for determining the Center of gravity.

The determination of CG by the analytical method is performed by the following algorithm:

1. Determination of partial centers of gravity (PCG) of the individual units of the kinematic chain of a particular sport posture (photos).
2. According to external anatomical landmarks we plot the projections of the joint centers.
3. We connect the centers with straight lines - longitudinal axes of the body segments.
4. Measure the length of the longitudinal axis in mm for each segment separately and multiply it by the corresponding coefficient of the unit - (K) (Table 01). The resulting distance in mm is applied from the proximal to the distal end along the longitudinal axis, from the inner to the body joint center (proximal) to the outer (distal) and we get the position of the partial centers of gravity.
5. After finding the PCG, their coordinates are measured in mm (X, Y). The data are recorded in a table, for each segment a value is determined for X and Y and plotted against the weighting factor: 0.07 head, 0.43 torso, etc. (Table 02). The values for X and Y are multiplied by the weight coefficients of the body segments and values for ΔX and ΔY are obtained. Then add up all the values for ΔX and ΔY and get the average values (Σ). The obtained data are plotted on the cinematogram, on the abscissa and the ordinate, the CG is determined at the intersected place.

*Table 01. Location of **Partial centers of gravity** on the mechanical axes of the body segments (K).*

	Body segment	PCG (%)
1.	Thigt	0,44
2.	Torso	0,44
3.	Arm	0,47
4.	Lower leg	0,42
5.	Foream	0,42
6.	Foot	0,44

3. RESULTS

The data for location of CG showed that it was located below the radius of the thorax, did not extend beyond the body in any of the rowing positions (Figure 1). There is some fluctuation in the different dynamic phases of the rowing technique, but this does not significantly affect the stability of the rowing position.

Figure 01 graphically shows us, the location of the Center of gravity and the partial centers of gravity in the first sub-phase of the Water Phase. PCG are applied along the mechanical axis of the body segments, and only the head and arms are determined octometrically. For a head Inion (the projecting part of the occipital bone at the base of the skull) and Glabella (part of the forehead above and between the eyebrows for head), between the second and third fingers of the palm for hand.

We determined the Center of buoyancy (CB) of the boat, the center of gravity (CG) and the axis of rotation of the boat (AR).

Figure 01. Graphical representation of the location of the common Center of gravity, in the first aqueous phase-engagement. Coordinates for ΔX = 12.19 cm and for ΔY = 4.84 cm

Table 02. Values of data for the location of partial centers of gravity by coordinates X and Y

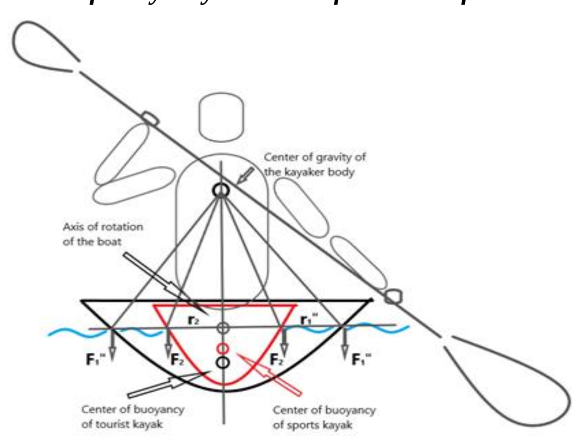
	Body segment	Relative weight (%)	X	Y	ΔX	ΔY
1.	Head	0,07	11	10,5	0,77	0,74
2.	Torso	0,43	12,7	5,2	5,5	2,23
3.	R. hand	0,01	4,5	5,5	0,045	0,055
4.	L. hand	0,01	9	12,3	0,09	0,123
5.	R. forearm	0,02	6,8	5,4	1,36	0,108
6.	L. forearm	0,02	11,3	12	0,226	0,240
7.	R. arm	0,03	9,2	6,2	0,28	0,19
8.	L. arm	0,03	12,8	10	0,384	0,31
9.	R. foot	0,02	3,1	2,2	0,062	0,044
10.	L. foot	0,02	1,5	1,2	0,030	0,024
11.	R. lower leg	0,05	6,4	2,7	0,32	0,135
12.	L. lower leg	0,05	6,5	2	0,325	0,10
13.	R. thigh	0,12	11,3	2,6	1,36	0,31
14.	D. thigh	0,12	12	2	1,44	0,24
				Σ=	**12,19**	**4,84**

We have identified a lever system that works to maintain the balance of the rowing system, a first-class lever known as the two-arm balance lever $F_1'' \times r_1'' = F_2 \times r_2$.

We determined the main phases of rowing in the basic macro-technique of implementation for initial training. **Water phase with three sub-phases:**

* **entry** (**catch**) - the paddle blade entry into the water at 48-50^o at an angle between the mechanical axes of the paddle boat. The kayaker closes the kinematic chain made up of the right lower limb, torso, upper arm, forearm, palm and paddle.

Figure 02. Graphical representation of the location of the common Center of gravity of kayaker body, Center of Buoyancy and axis of rotacion of the boat



* **pull,** (water work) after the perpendicular - active inclusion of the forward and down right shoulder and twisting of the body, after reaching 90^o (perpendicular to the water surface), followed by extension in the knee joint and pushing, reacts to the support in the kayak step.

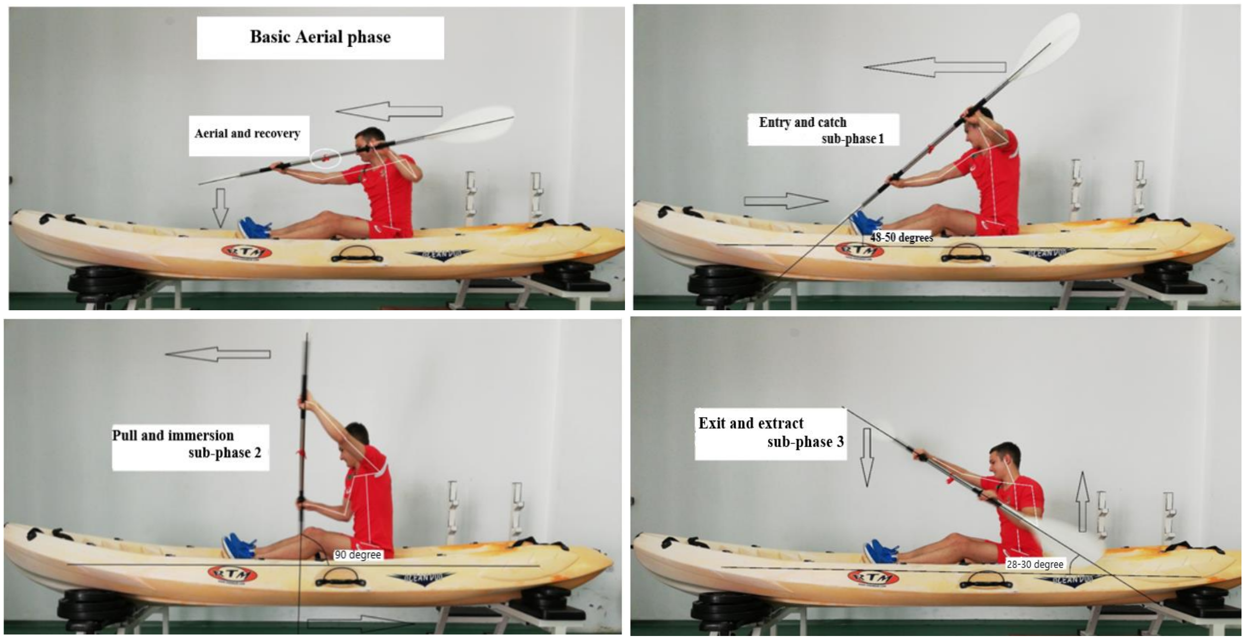
* **exit** (extraction) of the blade from the water - the extraction at 28-30^o at an angle between the mechanical axes of the paddle and boat **(*Figure 03).***

Basic Aerial phase - The marker placed by us in the middle of the paddle shows that the center of the mechanical axis of the paddle moves in a three-dimensional plane (OX, OY, OZ and the starting point O) of no more than 35-40 cm. (*Figure 3, 4)*

4. DISCUSION

A group of scientists McDonnell et al (2013) conducted an in-depth study of databases and recommended, as in our study, to describe two main phases: water and air. For a more detailed analysis, a four-phase model consisting of sub-phases of entry, pull, output and air phases should also be used. (López & Serna, 2011). Other researchers (Liu, Wang, Qiu, Zhang, & Y.-C. ve Hao, 2021) have identified four sub-phases of the Water phase from the moment of

Figure 03. Basic Aerial phase and Basic Water phase with three sub-phases



entry, pull, output, extraction of the paddle and release from the water. In the initial study of rowing technique it is essential to maintain dynamic stability in the stereotype of basic movements.

At this stage of training, this is possible due to the low sailing speed of the boat, which allows for the practice of individual elements of rowing, with relative stability of the dynamic system. Such an approach in training was used by Pace (2017), which identifies two important moments in the degeneration of the rowing technique Meta-technics and Micro-technics. Meta-technics is related to building knowledge and skills about the hydrodynamic characteristics of the rowing process. That's why we determined Center of Buoyancy, who is the center of gravity for the volume of water which a hull displaces. For example, the lower Center of Buoyancy leads to greater buoyancy, $F = V \rho g$, where F = buoyant force (N), V = body volume (m^3), ρ = density of fluid (kg/m^3), g = acceleration of gravity (= 9.81 m/s^2). But this leads to a slower linear speed of the boat.

As we know, the tourist (training) kayak is wider than the sports kayak. Therefore, with the constant weight of the rower (identical position of the CG), it is easier to steer the tourist kayak. The created equilibrium system, known as the first-order lever (two-arm balance lever, is a two-arm lever with the axis of rotation located between the two points of application of the forces. In this case, the lever arms **(r_1)** in the training kayak are longer than the lever arms in the sport kayak **(r_2)**. To equalize the equation $F_1'' \times r_1'' > F_2 \times r_2$, the value of the applied force will have to be increased F_2 *(Figure 02)*. The applied greater force (F_2) will lead to a greater moment of inertia of rotation around the axis of the boat, which in initial training will lead to instability and risk of overturning. On the other side, micro-technics - refers to the specifics of the application of muscular strength in order to achieve the desired goals, following the biomechanical rationality of the basic technique.

Analysis and more specific recommendations for the application of methodological guidelines

The **starting position** of the rower is a seat. This posture should be free and natural. The legs are slightly flexed at the knee joints, with the feet resting on the step of the boat. The torso is slightly flexed, from a vertical plane, forward at about 7-10^o in the sagittal plane. The rowing arm is stretched forward, the wrist is at the height of the chin between the keel and the work board, the right shoulder is slightly forward and slightly lower in the lateral plane.

Water phase with three sub-phases:

*** entry (catch) на лопатката във водата**

- the paddle blade entry into the water at 48-50^o at an angle between the mechanical axis of the paddle and boat. It is necessary to apply pressure with hip, with the foot, on the step surface of the kayak to use the force of the closed kinematic chain (Brown, Lauder & Dyson, 2011). A group of scientists used a Force decks of the step and determined the generated pressure force with legs 600 N, compared to 200 N when paddling in the water (Tornberg, Håkansson, Svensson, & Wollmer, 2019).

The results of a study by Nilsson and Rosdahl (2016) reported that a decrease in both compressive and leg pulling forces resulted in a 21% reduction in mean rowing force and 16% in average kayak speed. Thus, the internal forces (muscle tension) interacting with reaction of the support with the water fluid and with the footrest like the external forces.

In this way, the resulting force generates the movement of the boat. Along with the removal of the right arm, it activates and turns on the right shoulder and begins to twist the body back from left to right.

At the same time, the left hand pushes the paddle up and forward, changing the movements of the blade from vertical and horizontal directions.

*** pull, (water work) after the perpendicular**

When the paddle reaches a position perpendicular to the keel of the boat, the effort is most effective. Active inclusion of the forward and downward right shoulder and torsion of the body, after reaching 90° (perpendicular to

Table 03. Data for length and angular position of the rowing cycle (López, & Serna, 2011)

Optimal profile of the trajectory of the paddle in angular positions and phase length	Data from other studies	Data from our study
Angle of entry of blade paddle in water (°)	36,4	48-50
lateral angle of rowing of blade paddle at water phase (°)	43,3	50
Length of water phase of rowing (m)	1,09	75
Traveled path of the blade during extraction (m)	0,33	40

the water surface). The direction of the force vector is in the proximal direction of the hip joint, giving rotational movement along the longitudinal axis (rotational plane of the longitudinal axis of the spine 20-25 degrees). This results in rotation of the pelvis at about 5-10° in the transverse plane.

*** exit (extraction) of the blade from the water**

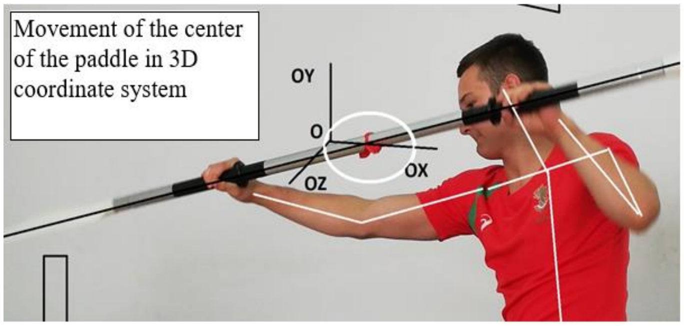
Extraction of the blade - at the end of the water work the blade abruptly leaves the water, ending the extraction. Extraction phase at 28-30° at an angle between the mechanical axes of the rowing boat. The wrist together with the forearm is flexed to 90° relative to the arm, followed by extension to 45°, followed by abduction 115-125° in the shoulder joint.

Basic Aerial phase

After completing the entire aqueous phase with extraction, preparation for the next rowing cycle follows, which, as the rhythm and distance traveled by the paddle blades, must be identical to the previous one. The marker placed by us in the middle of the paddle shows that the center of the mechanical axis of the paddle moves in a three-dimensional plane of no more than 35-40 cm.

For comparison, in kayak sport rowing, using microsensors placed on the body segments of the rower and paddle (Liu, Wang, Qiu, Zhang, & Y.-C. ve Hao, 2021) shows that the center of the paddle goes out of area. We suggest to limit the movement of the center of the paddle in this three-dimensional coordinate system, because we aim to build a basic basic rowing technique in teaching students in the context of school physical education (Figure 04). Learning the basic parameters of the technique, achieving stability in the boat, will be the basis on which to upgrade and improve training in rowing kayak style. The angular positions of the paddle blades relative to the transverse plane and the length of the water phase established by us are presented in Table 03.

Figure 04. Representation of the movement of the center of the mechanical axis of the paddle in a three-dimensional coordinate system made of the axes OX, OY, OZ and the starting point O



General methodological requirements:

- Initially, the movement is performed only by hands.
- Study the rotation of the body left and right araund the longitudinal axis of the torso.

- Combining the movement of the arms with twisting in the body.
- Training of all elements by more repetitions.
- Pay attention to the position and role of the legs.
- Combining body and arm movements.
- Rowing with delayed removal of the paddle and faster and bolder rowing, as well as getting into the habit of rhythm of movement.
- Balance exercises with sliding the paddle on the water.

5. CONCLUSIONS

As main conclusions we can offer the methodical instructions for initial training in tourist style "kayak":

- The CG of the rower is located below the radius of the thorax, and in no rowing position does it protrude beyond the body. Slight inclination of the longitudinal axis of the torso in the sagittal plane of 7-10^{o}.
- The whole motor action is divided into separate methodological units, air phase and water phase, with the three sub-phases: entry, pull and exit. Each one is worked out separately, observing the requirements for posture of body and amplitude and angular positions of the body parts and the paddle.
- The angular positions of the mechanical axes of a rowing boat are determined: entry 48-50^{o}; extraction -exit 30^{o}; lateral angle of rowing 50^{o}, which must be observed during the initial training in the kayak.
- To perform the correct technique of the air phase of the paddle, it is necessary to limit the movement of the center of the paddle in a virtual cube with a side of 40 cm, which is at eye level and away from the elbow joint of the paddle arm.
- The length of the water phase is 75 cm, and is performed smoothly with rapid extraction of the blade of paddle.

Although it was found by Gomes et al (2020) that the duration of the water and air phases correlated negatively with the rowing speed ($r = -0.929$, $p < 0.001$; $R = -0.909$, $p < 0.001$), in the initial training, we offer longer and slow phases - about 60 per minute, during which sensory corrections of the spatio-temporal characteristics of the rowing technique are possible.

ACKNOWLEDGEMENTS

I would like to thank the students majoring in „Physical Education and Sports“ and „Sports“ at South-West University "Neofit Rilski", Blagoevgrad, for the support and patience of the shooting of the photographic material used in the present study.

REFERENCES

Bonaiuto, V., Gatta, G., Romagnoli, C., Boatto, P., Lanotte, N., & Annino, G. (2020). A Pilot Study on the e-Kayak System: A Wireless DAQ Suited for Performance Analysis in Flatwater Sprint Kayaks. Sensors (Basel, Switzerland), 20(2), 542. https://doi.org/10.3390/s20020542

Brown, B.M., Lauder, M.A., & Dyson, R.J. (2011). Notational analysis of sprint kayaking: Differentiating between ability levels. International Journal of Performance Analysis in Sport, 11, 171 - 183.

Gomes, B. B., Ramos, N. V., Conceição, F., Sanders, R., Vaz, M., & Vilas-Boas, J. P. (2020). Paddling time parameters and paddling efficiency with the increase in stroke rate in kayaking. Sports biomechanics, 1–9. Advance online publication.

Klitgaard, K. K., Hauge, C., Oliveira, A. S., & Heinen, F. (2021). A kinematic comparison of on-ergometer and on-water kayaking. European journal of sport science, 21(10), 1375–1384. https://doi.org/10.1080/17461391.2020.1831617

Li, M. (2017). The Progress of Biomechanical Researches in Kayaking. Yangtze Medicine, 1, 30-44. doi: 10.4236/ym.2017.11004.

Liu, L., Wang, H.-H., Qiu, S., Zhang, Y.-C. ve Hao, Z.-D. (2021). Paddle Stroke Analysis for Kayakers Using Wearable Technologies. Sensors, 21(3), 914. doi:10.3390/s21030914.

López, C.L. & Serna, J.R. (2011). Quantitative Analysis of Kayak Paddling Technique: Definition of an Optimal Stroke Profile. Revista Andaluza de Medicina del Deporte, 4, 91-95.

McDonnell, L. K., Hume, P. A., & Nolte, V. (2013). A deterministic model based on evidence for the associations between kinematic variables and sprint kayak performance. Sports biomechanics, 12(3), 205–220. https://doi.org/10.1080/14763141.2012.760106

Michael, J. S., Smith, R., & Rooney, K. B. (2009). Determinants of kayak paddling performance. Sports biomechanics, 8(2), 167–179. https://doi.org/10.1080/147631409027450191. Li, M. (2017) The Progress of Biomechanical Researches in Kayaking. Yangtze Medicine, 1, 30-44. doi: 10.4236/ym.2017.11004.

Nilsson, J. E., & Rosdahl, H. G. (2016). Contribution of Leg-Muscle Forces to Paddle Force and Kayak Speed During Maximal-Effort Flat-Water Paddling. International journal of sports physiology and performance, 11(1), 22–27. https://doi.org/10.1123/ijspp.2014-0030

Pace, A., (2017). Complements to the Base Technique in Sprint Kayak methods of evaluation; Methods of Evaluation. EBS Print-ISBN 9788893491389

Tornberg, Å. B., Håkansson, P., Svensson, I., & Wollmer, P. (2019). Forces applied at the footrest during ergometer kayaking among female athletes at different competing levels - a pilot study. BMC sports science, medicine & rehabilitation, 11, 1. https://doi.org/10.1186/s13102-018-0113-5