Proceeding

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Kinematic analysis with motion sensors in kayakers: A study with boyacense athletes

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ABSTRACT

Objective: The results of the stroke cycle kinematic analysis of a group of kayakers from a city of Colombia are presented, using a motion capture platform based on inertial and magnetic sensors. Method: Quantitative approach of a cross-sectional descriptive type. A group participated with similar anthropometric characteristics such as size, mass, and body mass index. A technological platform was used that allowed the measurement of the kinematics of their movements from the first stroke cycle until the end at a 200-metre distance. Results: With the use of inertial and magnetic sensors, a comparative study of the kayakers of the sample was carried out, verifying that the distance reached by the boat in every stroke is greater on the right side with a distance of 3.651 metres and the minimum on the left side with a distance of 0.762 centimetres. The smaller amount of strokes that were made in the 200-meter test was 81 strokes/minute and the best displacement average was 2.387 meters, data that allow the measurement of the speed, displacement of the boat and number of strokes, are the most important factors to obtain better marks in this sport discipline. Conclusions: The lack of preparation of the kayakers was demonstrated since the stroke cycle in the aerial and aquatic phases is deficient, as the paddle blade does not enter the water in its maximum amplitude and the fluctuation in the control of the rate are factors that generate a smaller displacement of the boat.

Keywords: Motion sensors; Kayak; Kayakers; Stroke cycle; Kinematics.

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INTRODUCTION

Like any other, kayaking is a sport that requires as much preparation and training in its technique as in athletic performance, processes which are developed through the constant work and the correct manoeuvrability of their tools by means of actions that are possible due to the advancement in the knowledge of this sport and the implementation of technological instruments that make viable and optimize their results. Thus, in the exercise of kayaking, in its practice as entertainment or as a sport discipline, solid bases are required that structure and reinforce their competition and effectiveness not only in the action, but that theoretically support and impel their execution and advances. To this effect, the implementation of a motion capture system supported by inertial sensors is important to be able to record in real-time the movements that are generated in this discipline and their application in the field. The implementation of these technological instruments allows for obtaining measurements regarding displacement, speed, acceleration and time, contributing with relevant information in the systematization of the data since it allows for the analysis and conclusion of important aspects during the sport cycle, which are essential tools for the accomplishment of in-depth studies, whose results can be transferred to the exercise of this sport.

Undoubtedly, identifying characteristics such as movement, force, time, speed, effort, displacement and acceleration, is necessary to establish and obtain concrete kinematic and dynamic measurement results that strengthen the practice, technique and effectiveness of the sportsperson (Helmer, et al. 2011; Gomory et al., 2011). The above, to determine the improvement of athletic skills during the stroke cycle, that it is constant and efficient (Baker, 1998; Espinosa, 2011; Jones, 2010), as well as to determine the utility and effort of muscles implied in the activity, the energy used and the efficiency of the movement (Smith, 2010). The interaction of the athletes with the Motion Capture System Platform IMOCAP, the effects of the practice of this discipline are seen in the results measured during the tests conducted in this investigation by which, the interaction of the athletes with a motion capture platform and a measurement system, (Callejas-Cuervo et al, 2016; Callejas-Cuervo et al, 2017; Pineda, J. 2016, Callejas-Cuervo et al, 2020) used in the process, allowed the determination of the efficiency of the sporting gesture, using motion and magnetic sensors. The use of IMOCAP also permitted the analysis of the stroke frequency, displacement, speed, acceleration, and time employed by the athletes to identify errors in the execution of the stroke cycle in their aerial and aquatic phases.

In this sense, a computer science system and the interconnection with IMOCAP were implemented to determine the kinematic characteristics in the execution of the technique of the stroke cycle of the athletes of the *Liga de Canotaje of the Department of Boyacá* (Canoeing League of Boyacá), employing the placement of three motion sensors on the blade of the paddle, the shaft of the paddle (water sensors), on the arm, forearm and third vertebra of the participants (inertial and magnetic sensors), important to identify performance values and force applied during the test. Significant values were found that helped to determine the deficiencies of the athletes and, therefore, the results of this study.

METHODOLOGY

Participants

An analytical empirical study was carried out on a group of 3 male canoers, on the kayak modality, the elite category of the *Liga de Canotaje de Boyacá,* deliberately selected and starting from their competitive performances and results at a national and international level. A descriptive analysis of exploratory type was developed on certain characteristics of the group studied, where the variables of mass, size, body mass index, and age, were analysed. These variables were interpreted through statistical SPSS software.

The canoers that integrate the prioritised group of the *Liga de Canotaje de Boyacá* are aged between 21 and 28 years old, with an average age of 23,333 years, with a size ranging from 1.81 meters and 1.79 meters, an average weight of 77 kilograms and a body mass index of 23.93 kilograms (See Table 1).

Table 1. Size, mass, body mass index

	N	Minimum	Maximum	Median	Tip. Dev.
Size	3	1.78	1.81	1.7933	0.01528
Body mass index	3	22.72	24.97	23.9333	1.13536
Mass	3	72.00	80.00	77.0000	4.35890
Valid N (according to list)	3				

Instrument

For the acquisition and data processing a motion capture system (IMOCAP Platform) with motion sensors was implemented. It allowed the measurement of kinematic movements of the stroke cycle, from the moment at which the kayaker begins its first stroke cycle until finalizing at a distance of 200 meters. The motion sensors, of reference *Motion Process Unit* - MPU-9150 (Invensense, New York, United States) were placed: first, in the centre of the paddle blade (water sensor, Figure 1); the second is located in the centre of the paddle shaft (Figure 2); the third, was located in the forearm and arm of the kayaker (Figure 3) and the last, the magnetic inertial sensor, goes on the back, on the third vertebra (Figure 4). The motion capture process was supported by the recording through two video cameras (Action Git2 Double bed Pro). The first was located on the prow of the boat and another one on the dinghy that accompanied the kayaker during the route of the test, and the respective chronometric measurement (Digisport Chronometer - stopwatch with 60 memories, and another Interval TM 2000 NK).

Figure 1. Left. Water sensor. Right. Motion sensor of the paddle

Figure 2. Left. Sensors on the arm. Right. Back sensor.

Motion measurement platform for kayakers

General overview

The motion measurement platform for kayakers provides relevant information regarding the movement of the upper limb of the human body, back and paddle, as well as the basic characterization of the sportsman's technique. This set of characteristics is provided by several electronic and software elements, which make the detection of the aerial and aquatic phases of the movement possible, also providing information to detail to the kinematic chain.

This measurement platform is composed of two main elements that allow their operation:

The first element, and the most important one, is the motion capture system IMOCAP, which is destined for the detection of the movements of the sportsman and its interaction with the real world. This system integrates a set of sensors, processor and communication modules that are located on the back, arm and paddle of the sportsman to be analysed. The second element, that complements the motion capture system, is a computer science application that processes and integrates the information provided by the capture system, makes mathematical calculations, saves diverse parameters as record and graphic files, and presents the information in an orderly, clear and precise manner, where the characteristics of the execution of the sportsman's movement are evidenced.

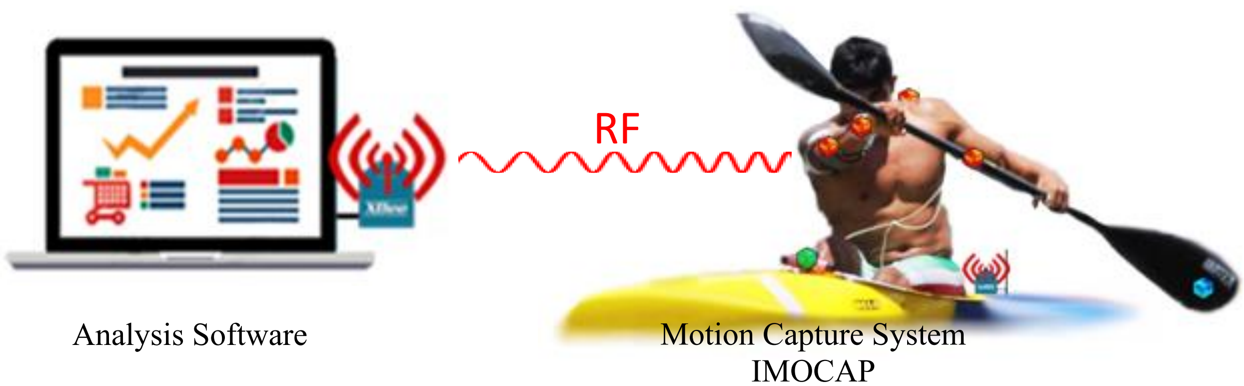

Figure 3. Motion measurement platform for kayakers.

Figure 4. Main elements of the IMOCAP platform.

Description of the motion capture system IMOCAP

This system is the main electronic component that is part of the measurement platform of the kayakers. The motion capture system IMOCAP is a set of sensors, processors of information and data transmitters, which collect information of the sportsman's movement and the variables of other sensors, such as water detection. As the system is modular it is distributed throughout the paddle, the sportsman and his boat. Next, a general scheme of the system is presented.

The system is composed of the following elements:

- Two motion processing units were located on the upper limb, one for the segment of the arm and another one for the forearm. The motion processors collect the following parameters:
    - Flexion-extension angle $\propto_a$ (articular amplitude) between the segments of the arm and the forearm.
    - Three-dimensional Euler angles per segment ($\propto_x, \propto_y, \propto_z$), which record the upper limb movement in the space.
    - Accelerations experienced per segment (a_x, a_y, a_z), provide relevant information about the technique of the movement.
    - Relative position with gyroscope and magnetometer measurements per segment, which complement the data obtained, useful in the processing of the signals by the analysis software.
- Processing motion unit located on the sportsman's back. It collects the following parameters:
    - Flexion-extension angle$\propto_i$ which registers the inclination of the back onwards and backwards.
    - Rotation angle $\propto_r$ which registers the rotation of the sportsman's torso towards the right and the left.
- Processing motion unit located on the sportsman's back. This sensor allows the recognition of the inclination of the oar in any direction, allowing for correlations of information for a better understanding of the technique of the sportsman.
- Water detection sensor located inside the left blade of the sportsman's paddle. This allows for the precise measurement of the amount of water present on the paddle's blade on the aquatic phase. This information is useful if it is correlated with the inclination angle of the paddle, revealing the exact moment when the aquatic phase began, what angle the paddle had at that moment, and when the paddle finishes its work in the water and goes to the aerial phase.
- GPS Module. It consists of a Garmin Forerunner 620 watch, which traces the trajectory covered, it registers the time of arrival and emits an audible signal to indicate the 200-metre limit. It is used to verify the IMOCAP measurement system through the correlation of registered times and distance covered.
- Central processing module. It manages the functioning of the motion processing units, receives data about them, conducts mathematical processes, and, finally, gives precise values related to the nature of the movement. This element is located on the boat behind the sportsman's chair, and it also stores the information in a memory card and sends information to the processing software in real-time.
- Information transmitter module. As far as the wireless technology used, this is a system based on low-power radio frequency called XBEE S2. This wireless transmission based on radio frequency grants flexibility and comfort in the delivery of data since the sportsman is not limited in his movements at the time of making the proposed exercise of evaluation.
- Feeding system. The electric energy that requires the system to work is covered by a battery of lithium ions which provides the necessary power to make the described electronic set work.

A detailed description of the system

Next, a general scheme of the central processing unit, the wireless transmitter and the feeding is presented:

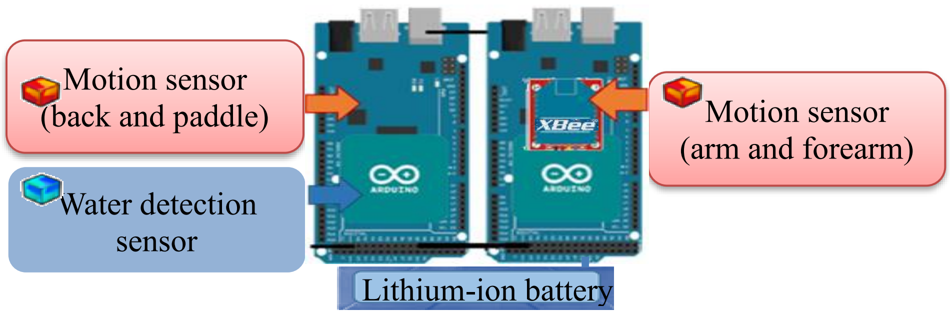

Figure 5. Central processing unit.

This element constitutes the main information processor to be able to process the information coming from the different sensors and elements located on the paddle and the sportsman.

The motion processing units (MPU) collect the movement of the arm, forearm, back and paddle. These motion processing units are a set of sensors that are able to detect movement in their simpler forms and achieve the fusion of the information to describe the movement in a more precise and efficient form.
Next, an image of the device is presented.

Figure 6. Motion processing units MPU.

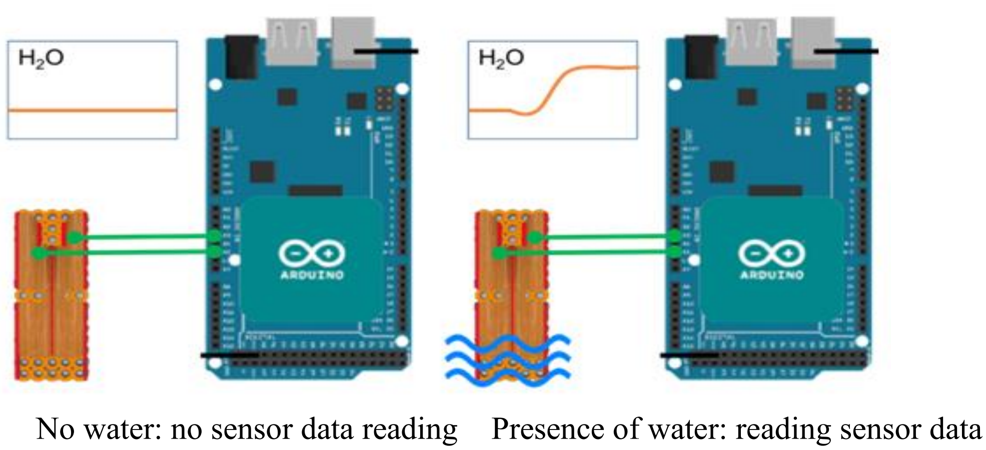

Figure 7. Water detection sensor.

Finally, the water detection sensor is a passive electronic element that detects the presence or absence of water inside the left blade of the paddle. At a general level, this sensor is composed of two metal layers which, when in contact with water, change their electrical properties.

The electrical change produced when the plates make contact with the water is detected by the central processing unit, which determines how much water there is in the sensor and registers the information.

In summary, within IMOCAP, the motion processing units and the water sensor provide information about the movement, acceleration and detection of water to the central processing unit, which then sends this information wirelessly to the analysis software, completing the information that the software needs in order to display the results regarding the execution of the technique by the kayaker.

Description of the data analysis software

The analysis software serves the function of collecting the information provided by the shot detection platform and IMOCAP in real-time and continuously, or else, based on registries previously stored by the system. It makes mathematical calculations with the input information, saves diverse parameters in the form of registry archives or graphs and presents the information in an ordered, clear and accurate way, where it mainly demonstrates the characteristics of the execution of the movement of the kayaker. This software was constructed with the tools provided by MATLAB.

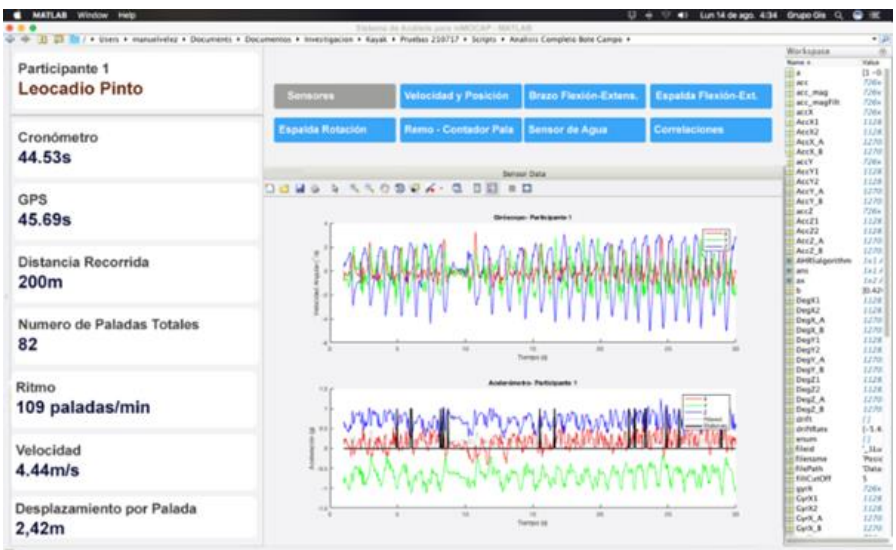

Figure 8. Data analysis software (in Spanish).

Procedure

The test was carried out in a habitual training place of the study group (cooling pools of the GENSA power plant, Paipa). The kayakers used a boat (Vanquish Nelo five L.) and a two-bladed paddle (Jantex Range L.), in a 200-meter circuit, in accordance with the distance that is implemented in national and international competitions, having a 30 cm buoy as a reference, located at the starting point of the circuit and another located at the established finish line. This distance was validated by the measurement of Garmin Forerunner 920 XT GPS. The tests began with a general and specific warm-up of the rowers, who were wearing the necessary attire of this discipline. Later the motion capture sensors were placed on their upper limbs and paddles. Some minutes before, the races were tested in short distances to calibrate the instruments. A moment was provided to the kayakers to familiarise themselves with the test and then they proceeded to the starting point of the 200-meter race and of the test, which would begin after the tests with each regatta. The tests were recorded with a video camera for posterior analysis, to compare the video with the data from the sensors and chronometers, and thus, examine the data obtained in the application of the tests.

Statistical analysis of the data

To examine the data gathered through the shot detection platform and IMOCAP, methods were used based on photogrammetric principles, such as the simultaneous video recording of three sequences in which the anatomical points that represent the axes of rotation of the shoulders, elbows, and wrists of the athletes were captured in the exercise of this sport. The values of the kinematics in 2D, left and right, regarding variables of time, length of the stroke, angles and angular velocities of the shoulders and elbows, and the inclination of the arms were compared and analysed, in addition to the calculation of the frequency of stroke and the speed of the kayak. These data were collected, taking into account the net and maximum capacity that the kayakers obtained in each stroke cycle in the 200-meter test and the advancement of the boat, thus determining data about each of the strokes.

RESULTS

The results are based on data gathered by IMOCAP during the application of the test, in which, after analysing the results of the training group, significant values were found as regards the kinematic variables (displacement, speed, acceleration and time) of each side of the boat and the technical behaviour of the athletes (flexion and extension of the arm, flexion and extension of the back, stroke cycle in the aerial and aquatic phase) during the test. The effectiveness and inefficiency of the variables under study were demonstrated. To that effect, it was registered that during the execution of the stroke cycle by the right side was efficient in contrast to the left side, this being a predominant characteristic in all the athletes, with an average of 2.2633 m of displacement per stroke in the 200-meter test. In Table 2, the reach of the kayakers during the stroke displacement throughout the circuit can be observed.

Table 2. Stroke displacement of the boat.

Sample	Maximum boat displacement per stroke on the left side (metres)	Minimum boat displacement per stroke on the left side (metres)	Maximum boat displacement per stroke on the right side (metres)	Minimum boat displacement per stroke on the right side (metres)	Average
Kayaker 1	2.624	1.574	3.149	2.387	2.387
Kayaker 2	1.826	1.462	3.090	2.285	2.285
Kayaker 3	3.242	0.762	3.651	2.118	2.118

Kinematic analysis

The average speed reached was 16.33 km/h, with a stroke frequency of 262±82 strokes/min and an average speed of the kayak of 16.3 km/h.

Table 3. Analysis of the number of strokes - time - average speed.

Sample	Total of strokes in 200 meters	Time (seconds)	Average speed (km/h)
Kayaker N1	82	45.69	15.8
Kayaker N2	88	42.22	17.1
Kayaker N3	92	44.65	16.1

After completing the 200-meter tests, important statistical registries were found among the variables of speed, stroke frequency and time, as principal indicators for the study of the stroke cycle in the different tests carried out on the analysed population. Concerning frequency, stable behaviour in the stroke rhythm was observed, with minimum differences between the participants, maintaining an average of 44.18 seconds per stroke, with the best records for speed, stroke frequency, and time obtained by athlete number 3. In Table 3**,** a rising tendency can be observed that is established between each participant as regards the available variables.

Technique analysis

It was possible to verify that the extension and flexion of the arm and the back during the stroke cycle in the aerial and aquatic phase, are fundamental actions in the study of the technique of the sport. To this end, the anthropometric capacities of each athlete during the study were established, an important aspect in order to analyse the registered information. In addition, it was observed that the position and the endurance of the athlete determine the effectiveness of the stroke, the grip, water entry and displacement of the boat, which are important factors for the success of the evaluation.

The use of IMOCAP allowed the determination of the capacities and aptitudes of the participants, as well as the flaws in their execution of the sport, which is reflected in the results, in aspects such as stroke frequency, boat displacement, speed, acceleration and times reached during the tests. Errors that affected performance were identified, which were evident in the technical and mechanical movements of each athlete during the stroke cycle in both the aerial and the aquatic phase, in addition to the physical endurance that a requires during the execution of the technique, like maintaining prescribed position and maintaining a homogenous frequency and force in the stroke, difficulties which increased even more with the effect of the humid and cold atmosphere in which this activity is practised.

The results obtained throughout the test using IMOCAP demonstrated that the athletes displayed the same technical error with regard to their performance of the activity in the moment of flexion-extension of the back and arm, rotation of back and consistency during the stroke cycle, aspects which revealed the difficulties, errors and skills of the kayakers, allowing the collection of important data for the investigation. The flexion-extension of the back and arm determines the performance, effectiveness and amplitude in order to develop the other technical gestures, since, as a whole, they allow the accomplishment of the expected results. Nevertheless, it is concluded that, when not maintaining the maximum extension and rotation of the back, the extension and flexion of the arm, and the tension of the legs during the execution, there is a reduction in the performance in aspects such as the displacement of the boat, speed, acceleration and time, as can be observed in graphs 1, 2, and 3.

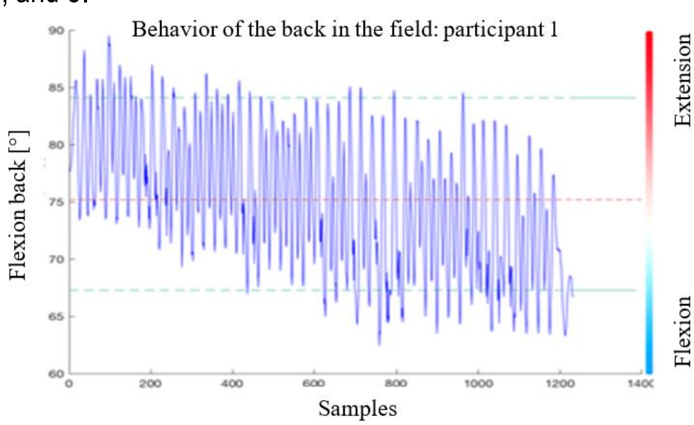

Figure 9: Behaviour of the back in the field - Participant 1.

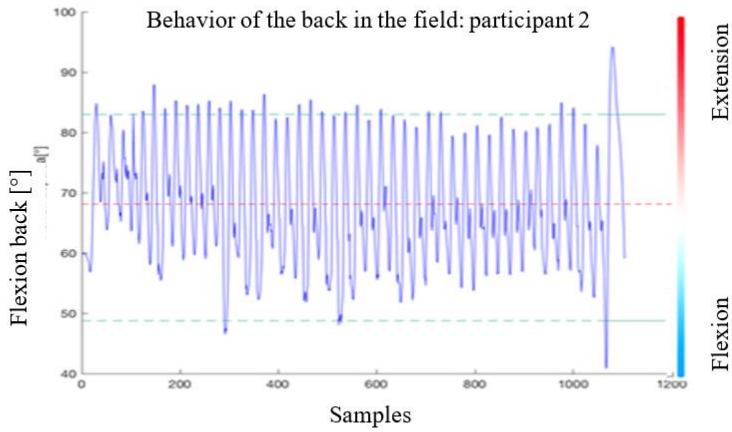

Figure 10. Behaviour of the back in the field- Participant 2.

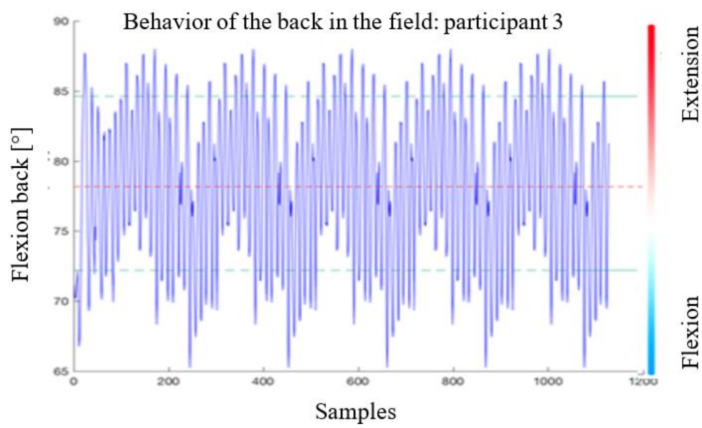

Figure 11. Behaviour of the back in the field- Participant 3.

In conclusion, the analysis of the data provided by the platform and what was observed during the tests, reflect significant deficiencies in the execution of the technique by each of the participants. Hesitancy in the stroke cycle, when committing the same technical error of the flexion and extension of the arm and back, the effort made by the legs in the rotation of the back during the stroke on both sides of the boat, affecting greatly the effectiveness of the stroke and, therefore, the displacement, seeing a reduction in the development of speed in order to later achieve an optimal acceleration that allows registering a time and significant results for this and future research.

DISCUSSION

The primary objective of the present study was to make a kinematic analysis of the stroke cycle of the kayakers using motion sensors. Characteristics and abilities of the athletes were analysed regarding the techniques of the rotation, extension, and flexion of the back and the arms, the work of the paddle in the water, among others. For the development of the investigation, the IMOCAP motion capture system was placed on the paddle and strategic parts of the body of the athlete, with the purpose of obtaining records during the 200-metre tests. These results demonstrated the effectiveness of the techniques based on the comparison of these registries with the theory.

In the samples taken using the motion sensors, the incorrect arm movement that the kayakers made when executing the stroke cycle was made evident, especially in the aquatic phase. This is a process in which the arm reaches its maximum extension, shortening the phase as a result of the flexion of the arm in its trajectory, generating constant zig-zag movement produced by the alternating entries and exits which act as a brake and delaying its re-entry into the water, reducing the constant advance necessary for the success of the test. In addition, there is no pause in the aerial phase, producing a performance reduction in the stroke cycle, generating an inefficient displacement of the boat. Besides, the results register that the kayakers work more on their left side than the right, in that the trajectory of the paddle is inferior, as a result of the pressure exerted by the right leg in comparison to that of the left.

In this way, the findings made with this study reveal the difficulties and weaknesses displayed by the kayakers from Boyacá as regards technique, such as the deficient effort made in the stroke cycle in the aerial and aquatic phases, the entry of the paddle into the water in less than maximum amplitude and the fluctuation in the control of the rhythm are elements that produce a smaller displacement of the boat after the stroke. These are essential factors for the correct development of the discipline of kayaking. The implementation of the motion analysis platform allowed the detection of deficits in force, power, speed, frequency, and time made by the kayakers during the competition.

There are few studies in the scientific literature regarding this topic. The studies published on the use of motion sensors for the evaluation of the performance and technique of the kayakers, make a theoretical contribution to the analysis and calculation of times, and not to the practical use of advanced technological systems for the measurement of the sport processes of the athletes in the field. Cêrne, et al. (2011), in their study, proposed a system for the biomechanical analysis of a paddle with an ergometer in real-time. Employing sensors of force, incremental encoders and an optical system, the data collected from the measurement of the movements of the participants, obtained in the kinematics measurement tests were stored and processed. With the implementation of a paddle ergometer and the processing of the collected data, fundamental information is provided on the performance and the technique of the athlete, becoming reliable and valid tools in the kinematic analysis.

The technologies used in previous investigations give limited and biased support to the data, considering the moment of their implementation and contrasting it with this investigation. For this, the Motion Measurement Platform for Kayakers constitutes a modern, complete and effective system that provides precise information of the upper limb movement of the human body, as well as back and paddle. It also makes a basic characterization of the kayaker's technique, which can lead to carrying out an in-depth study to detect the technical deficiencies that the boyacense athletes present in the stroke cycle. With the support of IMOCAP, the detection of technical flaws such as the lack of back rotation with a predominance of rotation on one of the sides is more precise. This flaw occurs as a result of the bad management of pressure on the legs, interrupting the incorporation of the back muscles during the cycle and the flexion of the arm when it is at its maximum extension amplitude when taking the water, causing the blade to enter at a lower angle and preventing the boat from having a better displacement. The automation technological platform, in the data collection process, perceives the necessities raised in the process of measuring time, speed, number of strokes, displacement of the boat, and the movement of the arms and the back that are important in the analysis of the stroke cycle.

Also, Bosch, et al. (2015), conducted an investigation using inertial sensors to measure orientation in several positions of the body, by means of a simulator or ergometer. The rowers were equipped with three modules of inertial sensors located on the lower part of the leg, and the lower and upper parts of the back. With these sensors, the angles of the main posture during the movement of the kayaker were analysed, that is to say, the lower angle of the leg and the angle of the torso. The modules used sensors to measure the acceleration and rotational speed of the module. Following this, it is clear that the authors analysed the position of the body and the stroke cycle as factors that contribute to the efficient development of the kayaker's technique, also, obtaining clearer and more specific results on body posture as is an element that directly affects the competitive performance. Thus, considering the tests carried out in the present study, there is a weakness when comparing it with the investigation developed by Bosch, et al. (2015). The location and number of sensors placed on the back showed data on the angle of the position of the body of the kayakers. The sensors were not implemented in the same way in order to study the position of the back and the effort exerted by the legs. However, the two investigations highlight the inefficiency in the angle of the required posture and the incorrect execution of leg pressure; actions that affect the performance, the stroke cycle, speed and acceleration of the boat in the tests. In addition, it is possible to verify that in Bosch's study, the technologies used are presented in a simulated environment, unlike the technologies in this investigation (motion capture system IMOCAP), used in real training situations of the kayakers. This validates the results of this research and consolidates it as a practical and technological remarkable contribution for future investigations on speed canoeing in each one of its modalities.

For their part, Espinosa (2011) explains that the stroke technique in kayaking is a motion system that is analysed based on four positions that the body adopts during a stroke cycle, using methods based on photogrammetric principles of the simultaneous recording of three sequences in a video in which the anatomical points that represent the axes of rotation of shoulders, elbows and wrists, are captured. The kinematics values in 3D, left and right, were compared in relation to the variables of time, length of the stroke, angles and angular velocities of the shoulders and elbows, and the inclination of the arms, calculating stroke frequency of and the speed of the kayak. The above constitutes a valuable contribution to the study of the values, techniques, and kinematic principles present in kayaking. The platform that was used in the study of the stroke cycle displays characteristics that complement those used in the study by Espinosa since by means of the implementation of motion sensors located in specific areas, of the paddle as well as on the upper limbs and back of the kayakers, it is possible to measure more accurately the entrance angle of the paddle to the water, the route, the number of strokes and the distance covered by the boat. However, it is concluded that IMOCAP requires a sensor to measure the force applied on each stroke that the kayakers make on both sides of the boat, in order to obtain a complete analysis of the work of the paddle in the water.

CONCLUSIONS AND FUTURE WORKS

One of the contributions this investigation makes is related to the relevance of the use of new technological instruments in sport because they allow the detection of technical deficiencies in the athletes, aspects that are not observed at first sight. The use of the Motion Capture System IMOCAP with boyacense kayakers led to finding certain deficiencies they present regarding the turn of the back because of an error in the coordination of the work of the legs. The athletes evaluated exert greater pressure with one leg than with the other, limiting the turn by the opposite side causing that the rotation of the back is affected. Besides, the hip does not finish rotating forward, affecting the maximum extension of the arms and, therefore, the entrance of the paddle in the water; an effect that, when improved, guarantees a better grip and entrance angle of the paddle to achieve a lengthier displacement.

Through a comparative study of the kayakers of the sample, it was found that the distance covered by the boat in every stroke is greater on the right side, with a distance of 3,651 meters, and the minimal on the left side, with a distance of 0.762 centimetres. The smaller amount of strokes that were made in the 200-meter test was 81 strokes/minute and the best average displacement was 2,387 meters, which determines that the speed, displacement of the boat, and the number of strokes, are relevant factors for the kayakers to obtain better marks in this sport discipline.

The technological and scientific contribution of this study lies in revealing the necessity to use sensors for the kinematic analysis in the discipline kayaking, in addition to the application and analysis of other variants of the stroke cycle with a significant number of rowers of different modalities and departments. In this way, it would be possible to establish a standard of the technique in Colombia and have a considerable sample to be able to corroborate the results that were obtained in this study.

In agreement with the experience acquired and as future work, it becomes necessary that sensors to measure kinetic variables are added to IMOCAP to measure the force that the paddle exerts in the water for the displacement of the boat, as well as to be able to place a pressure sensor on the footrests of the boat to determine the force that the kayaker applies in the movement of the legs.

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