Active posture monitoring in high performance gymnastics

Summary

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The thesis is structured in 6 chapters and 2 annexes. The first 3 chapters are introductory and supporting chapters in which the thesis is motivated, the current state of research in the field is analyzed and the notions necessary to approach the topic of the thesis are introduced. The following chapters describe the research activity carried out to monitor posture in performance artistic gymnastics. The last chapter is reserved for the conclusions and the presentation of personal contributions.

1. The importance and topicality of the research topic

By actively monitoring the posture in high performance gymnastics, the aim is detection, prevention and interventions that can be performed, due to postural changes suffered by gymnasts following the practice of this sport.

It is known that this branch is one of the most difficult sports, due to its complexity and the degree of difficulty.

Romania has accumulated about 71 medals at the Olympic Games, in women's and men's artistic gymnastics, with 26 bronze medals, 20 silver medals and 25 gold medals.

Having a decisive contribution to the development of the growing body, gymnastics is the initial stage of its physical improvement.

Like any technical-pedagogical discipline [39], gymnastics has its own theory, teaching methodology as well as its own means and forms of organizing the activity.

The key aspects of sports training are:

- energy, physical and physiological evaluation;
- training principles;
- diet, nutrition and supplements [136];
- growth and development issues;
- kinematics and dynamics;
- stress, anxiety and confrontation;

- motivation and setting goals;
- preparing mental skills for training and competition, learning psychology and performance.

The choice of the topic of the doctoral thesis is in line with the importance of this sport worldwide and the countless injuries that occur as a result of overuse. Determining the deformations, strains and stresses in athletes can lead to the prevention of more or less serious conditions.

Thus, the thesis aims to actively monitor posture in high performance gymnastics, through analytical, experimental and modeling-simulation approaches to the components of the spine as a defining element of posture during one of the most difficult elements of gymnastics, namely Danilova forward, in which case the spine is in maximum hyperextension, so it is in high demand.

Following the bibliographic analyzes performed, we did not find any references regarding the biomechanics, the states of tension and deformation that can appear as a result of performing this element in gymnastics.

The active monitoring of posture in performance gymnasts aims at:

- establishing particular biometric parameters of the gymnasts participating in the study;
- monitoring sports activities and performances;
- creating and simulating active musculoskeletal models;
- prevention of chronic occupational diseases;
- monitoring the clinical recovery of athletes;
- monitoring and improving their performance.

2. Postural analysis and postural changes that lead to ailments in artistic gymnastics

For athletes who practice sports such as swimming and gymnastics, it is necessary to assume a completely different body position compared to other sports.
The goal of good alignment / ergonomic posture is efficient and healthy coordination of blood circulation.
The obvious conclusion is to improve posture better through movement practices, rather than static body positioning.
After practicing this sport for 12 years, I can say that, indeed in the training period, in which the body and training are supported by vitamins, food supplements, supportive efforts, in which medical recovery services are offered permanently, through massage, physiotherapy and other methods of recovery, the pain in the lumbar spine is significantly reduced. When the athlete leaves the performance activity hes/shes no longer benefits from a recovery program, medical problems appear. In full knowledge of the facts and concrete evidence, I state that health problems reocure or worsen after the end of the career of a performance athlete.

One of the most demanding elements in women's artistic gymnastics in terms of spinal involvement is "Danilova before", which is part of the category of dynamic acrobatic elements with sporty difficulty and increased risk of installing spinal disorders over time. In this situation, the lumbar region (L4-L5, respectively the intervertebral disc) of the spine is the most affected due to hyperextension.

3. Biomechanical analysis of posture in artistic gymnastics

Because the most common and demanding elements in artistic gymnastics are airborne jumps and maneuvers, the present biomechanical analysis refers to these types of movements.

The main purpose of the jump is to raise the center of mass (CM) to a certain height after the momentum phase. The athlete must take into account the beneficial effects of counter-jumping. Most people do not undertake airborne maneuvers / flight phases voluntarily because for them flying through the air is the result of an accident. However, some of the most amazing and spectacular stunts that humans are capable of can be seen in airborne maneuvers. These maneuvers are included in the gymnasts' training program.

The problem is to perform rotations while the athlete is in the air, either on a main axis or on several at the same time. Other objectives are to change both the angular velocity and the axis around which the rotation takes place. These changes are possible due to the segmented nature of the human body.

There are two major mechanical principles that cannot be violated. The first is that the angular momentum at takeoff is fixed. The second mechanical principle states that any muscular force F and joint moment M created by F will be internal to the system, so the integrals will be equal to zero.

The segmented nature of the body also facilitates the rotation of different segments and may seem to give the body angular velocity where it did not exist at take-off.

Because gravity is the only external force that acts while the body is in the air, the flight time is a function of both the height (hTO) of the CM above ground level and the vertical component of the initial velocity vi of the CM at takeoff.

In conclusion, the segments of an airborne body can rotate relative to another segment that is fixed only if there is an initial angular momentum in the system.

On one hand, gymnasts may be better at jumping than athletes, as they may adopt an arched posture around the bar with their legs outstretched in a back jump. Gymnasts can raise their weight centers to great heights to perform multiple jumps.

Compression limit load estimates for the intervertebral disc range from 2500 N to 14000 N with an average of around 5000 N.

Knowing that the area of the L4-L5 intervertebral disc is approximately 1050 mm2 for the values of the above mentioned loads, the maximum permissible value of the compressive stress of the disc can be determined to be at most 13.34 MPa.

There are also several factors related to how the load is applied to the spine that influences the tolerance of the structures in the spine. In addition, other factors such as gender, age, bone density, disc degeneration, and number of exposures have been shown to influence disc resistance. The rupture tolerance of the intervertebral disc at anterior / posterior shear forces is estimated to vary between 1400 and 2500 N while others have suggested that the discs are at risk of shear injury at loads up to 1000 N. Thus, the different structures of the spine have different levels of load tolerance and the one who gives in first will be the one who will set the tolerance limit of the spine.

4. Dynamic analysis of posture in performance gymnastics by experimental means

Methods and means of measuring / investigating postural parameters are classified according to the impact on the human body in invasive and non-invasive methods.

In this thesis, the following non-invasive methods were used: the device for tracking the fine movements of the human body (Xsens MVN Motion Tracking 3D Technology sensor suit) with inertial motion capture system and FLIR C3 WiFi thermal imaging camera.

Before the experiment began, the gymnasts performed a general warm-up for 30 minutes. When the warm-up period was over, the gymnasts were equipped with the Xsens multi-sensor suit, placed on different body segments.

After equipping the athletes with sensors, the communication between the sensors and the software was performed. The calibration of the sensors took about 3 minutes and the whole monitoring process took about 10 minutes.

The Moven sensory system is based on inertial navigation technology and consists of 18 (inertial) motion sensors that are placed on different body segments by means of strips and a special T-shirt. The content of each is: three accelerometers, one for each axis; three gyroscopes, one for each axis; three magnetometers, one for each axis.

Through computational algorithms this technology provides information on 23 segments of the human body (pelvis, vertebrae: L5- L4- T12- T8, neck, head, clavicle origin dr., shoulder dr., elbow dr., fist dr., left clavicle origin, left shoulder, left elbow, left fist, right hip, right knee, right ankle, right toe, left hip, left knee, left ankle, left toe). This device offers the possibility to measure orientation / position parameters and kinematic parameters for each segment:

- movement (position, trajectories);
- absolute or plane linear velocity (on each of the three planes of the orthogonal system xyz);
- absolute linear or plane acceleration (on each of the three planes of the orthogonal system xyz);
- absolute angles;
- angular velocities;
- Accelerate angular.

For the phases of the Danilova element before, also presented on the basis of the data collected with the help of the Xsens Awinda MVN 3D suit for the gymnast with maximum value of the flexion / extension angle, the distributions were made (through the GraphPad Prism program) [199]

- vertical speed of the center of mass COM-Vv;
- the angle of the vertebrae L4-L5 on the flexion and extension movement- β;
- the angle of the vertebrae L4-L5 on the abduction and adduction movement - γ;
- the angle of the vertebrae L4-L5 on the internal and external rotational movement - θ;
- angular velocities at the level of the vertebrae L5, L4 - ω.

The thermographic device used in the study is a Flir B200 device that presents a technique that detects and records on film the hot and cold areas of the body by methods of detecting infrared radiation that reacts to blood circulation. The Flir B200 measures temperatures from -20 ° C to + 120 ° C. The experiment began with the heating of the spine. Thermographic data were collected both before and after the heating of the subject, as well as at the end of the execution of the Danilova element. Data analysis shows an upward trend in local temperature at rest. From a tomographic point of view, the highest value was recorded in the lumbar area of the spine L4-L5 at the end of the execution of the Danilova element before, and the value obtained shows an increase of 8.78% in the temperature in the most requested segment in the execution of the element.

The tests were performed on the components of the junior artistic gymnastics groups, respectively seniors camped at that time (2019-2020) at the High School with Sports Program "Cetate Deva". A number of 14 gymnasts with an average age of 14 ± 1 year, the average height being 149.35 ± 7.94 cm, and the weight of 40.01 ± 7.41 kg. The average duration of their training is about 30 hours / week. At the time of data collection, all the gymnasts were in good physical condition and no gymnast complained of health problems.

The gymnasts performed the Danilova element (an average of 3 jumps / gymnast) on the floor. The athletes who were introduced in our study were chosen according to their health and the possibility of performing the element we wanted to analyze.

5. 3D modeling of the lumbar spine and analysis of the state of tension and deformation of the L4-L5 intervertebral disc with the finite element method

Low back pain is a common condition in a large percentage of the world's population. Many experimental and theoretical studies have been performed to better understand the biomechanics of the lumbar spine to reduce the risk of injury or degeneration of the disc. The human spine consists of five lumbar vertebrae. Each lumbar vertebra is separated by an intervertebral disc that allows movement between the vertebrae. Their role in the spine is to act as a shock absorber. The strength of the vertebrae depends on its structure, mass and density.

The intervertebral disc (IVD) is a porous structure, very inhomogeneous and mostly avascular. IVD has very specific soft tissues: it is a heterogeneous mixture of highly hydrated core (nucleus pulposus, NP) surrounded by a dense layer of fibers (on the ring fibrosus AF) and cartilage (cartilage plate (CEP)). Thus, the intervertebral disc was considered as a hyperelastic soft tissue with a nonlinear elastic constitutive behavior. Two VBs and one IVD form the segment of movement (MS), which is the functional unit of the spine, complemented by the connection of ligaments and muscles [9].

The solid vertebral models used in this thesis were exported to the SOLIDWORKS program to assemble the three parts and create soft structures, i.e. the intervertebral discs, the end plates and the articular cartilage of the facets. Finally, this assembly was exported to the ABAQUS 3DEXPERIENCE program for the development of the finite element network and the inclusion of material properties, bonding conditions and loads.

The interactions between the components of the analyzed spine module were considered as follows:

- rigid connections between the upper surface of the disc and the lower surface of the L4 vertebra;
- rigid connections between the lower surface of the disc and the upper surface of the L5 vertebra;
- contact between disc and spinal cord;
- contact between the vertebrae and the spinal cord.

The contour conditions for the components of the finite element module analyzed are:

- fixation for the L5 vertebra;

• fixation for the lower surface of the spinal cord.

The moment was applied individually in all 6 directions that mimic the mobility of the spine or ROM (range of motion).

For the start and end phases of the Danilova element previously performed in the Kinovea program and taking into account the maximum values of the extension angle of 16.70 degrees and applying the force of 650 N calculated at this point, the dynamic analysis of the stress and strain state was performed. intervertebral disc with the finite element method. The maximum value of the extension angle was taken into account because this movement negatively influences the behavior of the spine during the jump.

The thesis presents: the distribution of the equivalent stresses in the intervertebral disc following the load with force F and the extension angle applied in four steps and the distribution of the equivalent deformations of the intervertebral disc for the same conditions.

Analyzing the results obtained after post-processing, it can be seen that the maximum values of equivalent stresses in both the vertebrae and the intervertebral disc are concentrated towards the spinous process at the level of the curvature of the lumbar spine. The maximum value of the equivalent stress when considering only the compression of the disc has a value of 1.84 MPa, but when the angle of rotation / extension is 16,700 the value of the equivalent stress increases greatly, reaching 200 MPa.

Compared to the data in the literature, it is observed that in the case of the maximum extension phase of the spine during the execution of the Danilova element before, the values of the admissible equivalent tension are much exceeded.

According to the literature, the height of the vertebral discs in the lumbar area of the spine is about 9 mm. The maximum deformation resulting from the FEM analysis is 0.9 mm.

Given the values resulting from the FEM analysis and taking into account that a gymnast trains approximately 25,200 hours during a sports career, it is obvious that spinal disorders will occur, especially in the lumbar region, due to both exceeding the maximum values as well as intervertebral disc material fatigue.

6. Conclusions. Personal contributions. Future research directions

In this paper, the main personal contributions are: the realization of a bibliographic synthesis on postural analysis and postural changes that lead to diseases in artistic gymnastics; bibliographic analysis on pathological changes of the spine following repetitive movements in performance artistic gymnastics; the choice of the Danilova element before being one of the most demanding in terms of lumbar spine disorders due to the pronounced angle of extension; determination of biomechanics elements specific to airborne jumps and maneuvers / flight phase; establishing the analytical expressions that underlie the determination of the elements of kinematics, kinetostatics and dynamics of the Danilova element before; biomechanical modeling of the spine and the forces acting on them during the execution of the Danilova element before; comparative analysis of the biomechanical models of the spine with the specification of the optimal model in order to establish the states of tension and deformation; establishing the most affected anatomical elements, namely the lumbar area L4-L5 and the intervertebral disc of the spine; carrying out a bibliographic synthesis regarding the mechanism of diseases related to pregnancy tolerance; dynamic analysis of the posture during the Danilova element before, by non-invasive experimental means on a group of 14 gymnasts; establishing the experimental protocol for data acquisition using the Xsens MVN sensor suit; selective analysis of the experimental data obtained and their interpretation; performing the thermographic analysis of the spine in the process of performing the Danilova element and interpreting the results; prospective study of finite element models of the human spine segment L4-L5 which includes heterogeneity and anisotropy of discs; modeling the intervertebral disc as an osmo-porous-visco-hyperelastic finite element; establishing the constitutive equations of the finite element model of the lumbar area L4-L5 of the human spine under mechanical forces; realization of the geometric model of the L4-L5 vertebral module and intervertebral disc, analysis of the mobility of the spine of the limit conditions of the prescribed rotation and of the material characteristics; the use for the first time of the dynamic analysis with finite element on the mentioned module, with the determination of the tensions and deformations on the intervertebral disc and the interpretation of the results; proposing prophylactic methods to improve the process of training performance athletes in artistic gymnastics and possible recovery methods to reduce the number of postural problems;

As future research directions, the following would be of interest: determining the allowable fatigue stresses for the material of the intervertebral discs (data not existing in the literature); determination of kinematic parameters, dynamic parameters and stress and strain layers and for other anatomical segments of athletes and similar monitoring of other elements of artistic gymnastics or even other sports.

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