Increase in efficiency of training process of weight-lifters on the basis of biomechanical control of current and reference trajectory of a bar

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Abstract. To develop methods and technical means for recording, analysis and adjustment of the exercise biomechanics. The research is based on theoretical and experimental methods: comparative analysis, system approach, mathematical modelling and theory of experiment planning. The authors developed a complex of exercises with a system for recording, analysis and adjustment of the exercise biomechanics and the common centre of mass of the biomechanical system. A series of preliminary experiments was performed. It is assumed that the research findings will demonstrate the efficiency of applying technical means with feedback, which allow setting a right stereotype of movement basing on the prompt information analysis on the movement capabilities of a sportsman.

1. Introduction

Most health and fitness methods pursue the following goals: the development of an optimal pattern of movement; maximization of a muscular effort; reduction of injuries. The development of the right stereotype of movement consists in the desire to achieve the optimal trajectory, strength and speed of the body parts’ movement in space while performing exercises.

It is known that the efficiency of both health and fitness, and training process is largely determined by the speed, completeness and correctness of information about the biomechanical system and the nature of the training load [1, 2]. The information obtained later serves for the adjustment of the training plan. Operative biomechanical control is difficult not only because of the necessity to obtain the information about kinematics and dynamics of movements as quickly as possible after completing an exercise. At present, a lot of more or less effective means have been developed to solve this problem. However, no sufficiently effective method of assimilating the obtained operational information for an adequate and rapid adjustment of the technique of performing the exercise has yet been found. The issue of increasing the efficiency of biomechanical feedback, taking into account the reduction of its influence on the training process, still remains relevant.

The purpose of the study is to develop methods and technical means for recording, analysis and adjustment of the exercise biomechanics with an effective data transfer channel.

2. Methods and organization of the research

Special complexes are being developed to improve the efficiency of physical training. There are devices...
that can keep a record of the exercise biomechanics on the basis of a fairly long processing of the results of video recording of an athlete's movements [3-6]. Alternative sets, e.g. “V-Scope VS-120” (Israel) and “Weightlifting analyzer 3.0” (Germany), have a relatively fast system for processing kinematic and dynamic parameters of the barbell movement. The employees of the Russian State University of Physical Culture, Sport, Youth and Tourism have developed a comprehensive system for recording the barbell movement and the common centre of the mass in the “weightlifter - barbell” system using the force platform and photo- and video recording [7, 8]. This system saves the obtained data in the appropriate database for the subsequent analysis of long-term training cycles, as well as the certification of physical fitness of specific individuals.

The main common drawback of these devices is the insufficient efficiency of the data transfer channel to an athlete in real time, as well as immediately after an exercise. In addition, some of these complexes are insufficiently mobile. Recording of exercise biomechanics is suitable only for healthy athletes, as there are no mechanisms to insure the barbell from falling. Moreover, it should be noted that there is a lack of the possibility to analyze the biomechanics of certain general physical exercises, as well as the possibility of correcting functional asymmetry.

The authors have developed and got a patent for the LETRON machine based on the modernized Smith machine (Figure 1). It includes hardware and software and is equipped with a system of laser emitters for recording biomechanical parameters of the barbell movement based on the analysis of which the position of the actuating barbell is corrected in real time. The barbell is adjusted in such a way that when it moves the emitters simultaneously read its position and transfer the data to a computer with the frequency of 50 measurements per second. After processing of the data the reverse signal is sent back to the barbell’s drive and adjusts the movement in such a way that kinematics and dynamics of the movement do not diverge from the optimal values. At the same time such engineered adjustment of the barbell movement is considered as resistance to the movement that initiates deviation of the body parts on the path of the least resistance. The data is transferred to the computer through wireless communication.

Before beginning of an exercise it is necessary to choose the exercise type, enter the following parameters: surname, first name, age, weight, height and the barbell weight. Then, according to the operating instructions, one should set the barbell to its initial position, mark on the computer the starting position of the body with the barbell relative to the complex and start the exercise. The countdown starts immediately after the barbell begins to move. At the end of the set, a barbell is set to the final position, which is fixed by the self-protection system. Multiple repetition of an exercise on this machine will result in a gradual memorization of the correct stereotype of movement by athlete body. The design of the machine allows an athlete freely moving a barbell in only two planes, which excludes the effect of functional asymmetry on the exercise performance. In this case, if necessary, it is possible to ensure a

![Figure 1. Scheme of biomechanical control based on the modernized Smith machine](image-url)
barbell movement in the third plane with the given amplitude, for working out the core muscles.

In order to develop the technique of performing not only basic exercises, but also most basic general physical exercises for individual muscle groups, the installation of a specially developed multifunctional bench-transformer is provided under the stands of the LETRON machine, which ensures the performance of more than 35 different exercises. The general view of the developed bench and the main types of its transformations are shown in Figure 2.

![Figure 2. Bench-transformer: a – the photo of the bench; b – the main schemes of the bench transformation](image)

A series of comparative studies on the developed complex with the use of an adjustment system with and without a drive bar allows determining how the newly developed channel for the immediate information transfer regarding the optimal exercise biomechanics influences the quality of developing the correct movement stereotype. The main factors considered in the experiment are: body length (m); body weight (kg); exercise type; exercise result (kg); maximum and minimum velocity of the centre of the barbell mass (ms⁻¹); the height of lifting the barbell (m); time of the set and exercise (s); the developed capacity of the “athlete-barbell” system (W); applied force (N); length of the trajectory (m); availability of the drive bar system. Both series of experiments are performed for several months with the participation of two groups of test persons with approximately the same anthropometric data, without discharges and special sports training. The analysis of the results of the studies with and without a drive bar allows making relative conclusions. At the end of the experiment, the final series of experiments on the machine without a drive bar is conducted with the participation of both groups of test persons. The results of the experiment are summarized.

The programme includes graphics of regularities of changes in velocity and trajectory of the barbell movement and the applied force. Optimal biomechanical indicators are calculated in the programme basing on the initial anthropometric data entered before the beginning of the exercise. The calculation is performed with the use of a mathematical model, which considers the interconnection of the exercise’s biomechanical parameters with the biomechanics of the barbell movement and physical fitness parameters. As a result of calculating the mathematical model, the programme allows visualizing the position of the body at any moment of the barbell movement, both in accordance with the ideal and actual trajectories without using the drive bar.

A sign of the technical performance of the exercise is the absence of speed loss and significant deviations from the standard trajectory of the barbell movement during repetitions. Taking into account
the works [4, 6, 9], it is suggested that the force when lifting of the barbell should be considered as the most important indicator of technical skill.

3. General arrangement of preliminary experiments
A series of preliminary experiments was connected with the analysis and specification of the developed principle of work and structure of the LETRON machine. The conducted studies were financed within the framework of the grant under the START-1 programme, received from the Innovation Support Fund (Bortnik Fund). The studies were carried out in a special laboratory room equipped with all the necessary measuring and training equipment. All exercises in both series of experiments were performed by one athlete. The developed machine was compared to similar technical devices in terms of quantitative indicators of the biomechanical parameters of the barbell-athlete system, taking into account the effect on the result of two functions: the method of measurement and the construction of the machine. Therefore, the experiment was divided into two parts.

The first series of experiments was connected with the estimation of the deviation of the biomechanical parameters obtained by two different methods of measuring them: the newly developed (Figure 1) and the known one (basic). The structure of the known machine [1] includes: a video camera with a shooting frequency of 50 shots per second; a nozzle with an emitter fixed to the end of the bar; a laptop with software. The measurement principle was modeled in a special mobile stand (Figure 3) developed taking into account the analysis of the known solutions [10-15] and partially repeating LETRON stands (Figure 1).

In the first series of experiments, only the basic exercises with an unloaded bar weighing 20 kg were performed: bench press, deadlift, back squats. In this case, only kinematic and dynamic biomechanical parameters were recorded, as well as the duration of the entire exercise and its individual phases and periods.

As a criterion for estimating the deviation of biomechanical parameters during the displacement of the centre of gravity of the bar, a correlation coefficient was used to show the magnitude of some statistical relationship between the two samples being compared. The closer this coefficient is to one, the more it is possible to talk about the similarity of the nature of the changes in the compared trajectories.

4. Results of preliminary experiments and their discussion
Figure 4 demonstrates some results of the first series of experiments: displacement trajectories of the gravity centre of the barbell in the sagittal plane when performing “bench press” and “back squat”.

The maximal horizontal deviation and the height of the barbell lift received from the bar displacement sensors for each exercise were transferred by the data processing programme into relative units.

The second series of preliminary experiments was aimed at revealing the influence of the machine design on biomechanics bias of general physical exercises. All the main factors and objective functions were adopted the same as in the first series of experiments. The difference was in the use of the power bench-transformer (Figure 2). Some results of the study are shown in Figure 5.

The analysis of the convergence of the curves in Figure 4 and 5 show a strong positive correlation. This indicates that there is no significant bias in the biomechanics of general physical exercises performed on the machines of the known and developed design (Figure 5), and also measured in two different ways (Figure 4). Therefore, the designed bench can serve as an effective replacement for the known exercise equipment.
Figure 3. A portable stand for recording biomechanical parameters of exercises: 1 – bar; 2 – self-protection mechanism; 3 – harnesses; 4, 11 – guideways; 5 – flexible rod; 6 – horizontal bar; 7 – binder of the inverted U-shape frame; 8 – weight plates; 9 – stand of the inverted U-shape frame; 10, 14 – slide assembly with linear bearings; 12, 13 – sensors of the barbell movement; 15 – wire; 16 – analog-to-digital coder; 17 – computer.

Figure 4. Displacement trajectories of the gravity centre of the barbell in the sagittal plane when putting it down obtained with the basic software and hardware (red curve) and the LETRON machine (black curve): a – bench press; b – back squat.
Figure 5. Displacement trajectories of the gravity centre of the barbell in the sagittal plane when putting it down obtained with the basic machine (red curve) and bench-transformer (black curve): a – seated barbell curl; b – 45-degree hyperextension; c – incline barbell bench press; d – vertical hyperextension; e – bent over underhand row on incline bench

5. Results
Thus, in the course of the analysis of experimental results, it was determined that the developed exercise complex ensures the quality of the measured biomechanical parameters of the basic exercises adopted in the measuring equipment being used. In addition, there are no significant divergences between the classical exercise machines and the developed one in terms of obtained biokinematic parameters of general physical exercises.

Considering the great positive experience of using various technical means for measuring biomechanical parameters of the exercise, their effectiveness is beyond any doubt. Based on the results of the planned research and the studies that have been performed, it is assumed to produce and introduce a prototype of the developed complex into the training programme of sports and fitness centres or specialized sports centres. In the future, the authors plan to significantly improve the software adjusted for use on Android and iOS platforms.

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