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Physiological Basis of the Improvement of Movement Accuracy on the Basis of Stabilographic Training with Biological Feedback

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Abstract—Physiological parameters of hitting the ball in the unsupported position and prospects for improv-
ing spikes through training with a biological feedback were studied in volleyball players. The physiological and
3 biomechanical parameters characterizing a direct attacking shot in a supported position correlate with the
3 biomechanical specificities characterizing the performance of this short in a jump. At the same time, the
physiological ability to provide the accuracy of hitting actions is associated, first, with improving the coordi-
nation of trunk and arm movements in the flight phase, second, with the factors of intramuscular and inter-
muscular coordination of the striking arm, and, third, with a change in the pattern of motions of an athlete's
2 center of pressure. The use of a computer-based stabilographic method of training with a biofeedback con-
3 tributes to the optimization of physiological and biomechanical parameters of motor actions in the unsup-
ported position, which results in an increased accuracy of hitting the ball in a jump. The obtained results open
prospects for applying the method of computer-based stabilography for improving the performance skill of
accuracy- and target-oriented actions in unsupported positions in various kinds of sports.

Keywords: control of movements, unsupported position, stabilography, volleyball, biological feedback

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Training high-class athletes at the modern level of sports development is impossible without involving tools for objectivizing the knowledge about an athlete's functional state and without taking the physiological regularities and control mechanisms for motor actions into consideration. The problem of obtaining and interpreting this information is very important both for fulfilling the task of selecting the most promising middle-level athletes and beginners and for planning the training process at all its stages [1, 2].

A broad range of physiological control methods are now in use in sports. Information technologies are actively introduced into this area, providing a faster processing and analysis of the obtained information with a higher quality of its visualization, making it approachable not only for researchers, but also for athletes themselves [3–5].

3 The task of the integrated physiological and biomechanical approach to the study of dynamic phenomena is to determine the qualitative and quantitative relationships between the human motor system coordinative capacities, the work of skeletal muscles, and the effectiveness of motor actions in performance [6]. The contemporary physiology of sports uses a set of methodologies for this purpose: tensodynamography, stabilography, electromyography, and the digital single-frame photography of athletes' movements. These methods developed for the functional diagnostics of damages suffered by the nervous system on different levels are now actively introduced into the physiology of sports, since these methods allow us to objectively assess the nervous system functional potential for the formation of motor skills.

The accuracy- and target-oriented types of movements performed in unsupported positions are the most characteristic for sport games, such as volleyball [7, 8]. The effectiveness of these movements is defined by the rationality of their performance skills determined on the basis of biomechanical studies. The 3
main attention is given to the dynamic characteristics of movements produced by the body kinematic chains in the phase of flight [9–12].

The accuracy and significance in the performance of sports exercises are determined by the physiological mechanisms participating in the motor activity self-regulation. The physiological basis for the technique training can be considered as targeted improvements in the processes behind the control of movements crucial for the effectiveness of game-specific actions [13, 14].

At the same time, perfecting the technique of hitting actions in a jump is associated with a group of difficulties, such as the formation of abilities to coordinate body movements in the unsupported position [15–17].

The skill of sports technique depends on an athlete's capacities to manage the system of movements that are continuously improved in the course of training through their correction [18]. An athlete's self-control based on correct motor representations is important for controlling the system of movements [19, 20]. Therefore, researchers were most interested in the training methods based on a biological feedback [21–23]. One of theoretically and practically important but insufficiently developed problems of biocontrol is the adaptive properties of neuroplasticity, i.e., the capacity of neural networks to dynamically reorganize their work in accordance with changing internal or external conditions. The plasticity of neural processes is one of the most important qualities of the brain enabling us to quickly change the structure of intercentral relationships and learn new kinds of activities, which is basic for the maintenance of the body functional state and its adaptation to the environment [24].

The goal of this study was to estimate the physiological parameters of shots on the ball in unsupported positions in volleyball players and prospects for improving the effectiveness of shots through training with a biological feedback.

METHODS

The study enrolled 60 male subjects aged 18 to 22. All the subjects belonged to the basic medical group. Two groups were formed according to the training level of athletes. The first group included highly qualified volleyball players (24 subjects) engaged in volleyball for over three years, who were the participants of combined teams of departments or higher educational establishments and sub-masters of the first category. The second group (control) was composed of low-skilled volleyball players (36 subjects) engaged in volleyball for no more than half of the year and having no sports degrees.

Motion tracking. To analyze the orientation of body parts, their spatial position and their relation to the support, we used the motion tracking method. The spatial movements of the athletes' body parts were recorded using a Vision Research Phantom Mire eX2 camera. The shooting was carried out at a speed of 100 frames per second. The obtained data were treated and analyzed using the StarTraceTracker 1.1 VideoMotion software.

Electromyography. Surface electromyograms (EMGs) were recorded with a BTS FREEMG 300 electromyograph (BTS Bioengineering). The mean oscillation amplitude and frequency were evaluated in the EMG analysis.

Stabilography. The investigation was performed using a Stabilan-01-2 computer stabiloanalyzer (Russia) with a biofeedback. The stabilograph allows us to measure the parameters of the generalized center of pressure displacements during maintaining by subjects their vertical posture.

The data analysis was performed using the Statistica 6.0 for Windows software (Statsoft). The obtained data are represented as the mean ± the error of the mean ($X_m \pm m$). The Kolmogorov–Smirnov test and a visual check by the histogram method were used to determine the distribution pattern. The hypothesis of attribution of the compared independent samples to the same general population or populations with the same parameters was checked using the Mann–Whitney U test. The nonparametric Spearman's rank correlation coefficient was used to evaluate the correlation of the studied parameters.

RESULTS AND DISCUSSION

The Physiological Characteristics of the Technique of Performance of the Direct Attacking Shot in Unsupported Positions by Players with Different Qualifications

The performance characteristics of a direct attacking shot were obtained by the method of photography and building a four-bar-linkage model for an athlete's body. The angular values were assessed at the moment of hitting the ball (Fig. 1).

The obtained results evidence that low-skilled athletes had a retroflection of their upper body and a swing of the upper arm (elbow flexion) backward: the angular values ψ_3 and ψ_1 were significantly lower compared to the group of highly qualified athletes (Fig. 1, Table 1).

According to the results of biochemical analysis, the most effective is a shot in which the motion speed of the proximal component of the upper extremity (shoulder) reaches its maximum at the start of the movement and decreases by the moment of hitting the ball with the hand palm, contributing to the emergence of reactive forces that speed up both the forearm and the hand motions. These conditions are met when

Table 1. Angular values in a biomechanical model for the 3
position of an athlete's body in the unsupported phase of performing a direct attacking shot ($X_m \pm m$)

Qualification of athletes	ψ_1	ψ_2	ψ_3
Low-skilled ($n = 36$)	124 ± 9	224 ± 13	165 ± 11
Highly qualified ($n = 24$)	165 ± 11*	219 ± 12	182 ± 12*

* Significant differences between the indicators of highly qualified and low-skilled athletes, $p < 0.05$.

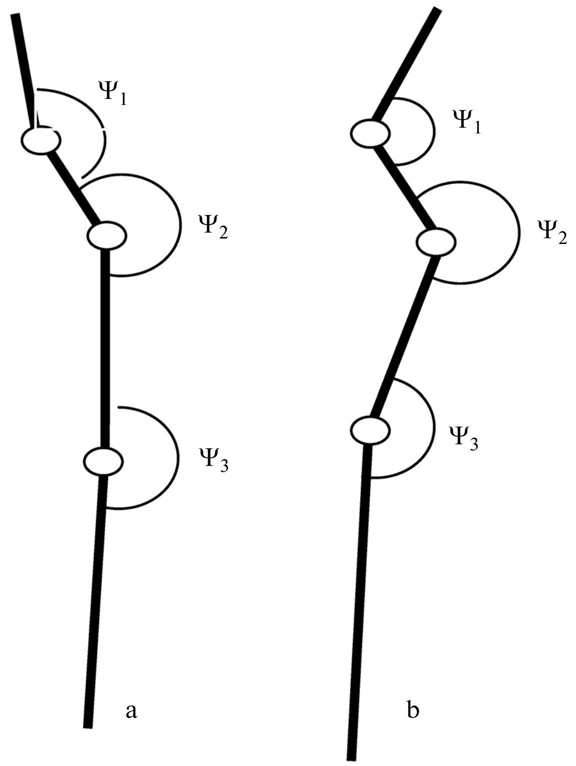

Fig. 1. A model for the position of (a) highly qualified and (b) low-skilled athletes in the unsupported phase of performing a direct attacking shot (at the moment of upward flight of the ball).

Angles: Ψ_1—forearm–shoulder, Ψ_2—shoulder–trunk, Ψ_3—trunk–hip.

a shot is performed by a straightened arm. If the hand remains partly flexed at the elbow joint at the moment of the hand contact with the ball, the distal region motion speed and, respectively, the strength of hitting the ball decreases [25].

Such an excessive retroflection (sometimes called "running below the ball" in the sports terminology) reduces the performance accuracy of the shot. In addition, retroflection of the upper body (excessive unbending at the pelvic joint) reduces the possibility for a visual control of the ball in the final phase of a shot.

We can suggest that the afferent impulse rate from the sensory receptors of the vestibular apparatus decreases in players in the phase of flight, which leads to the suppression of statokinetic reflexes (reflective changes in the muscular tone against the preserved balance of the body at jumps and running, as well as complex reflexes, including those in the unsupported position). The sensory input from the vestibular nuclei causes not only eye movements, but also adaptive postural changes, which is mediated by commands into the spinal cord via lateral vestibulospinal tract and reticulospinal tracts. The lateral vestibulospinal tract activates the extensor muscles that support the posture [26–28].

A decreased impulse rate from the vestibular system enhances the effect of the second-type postural reflexes, namely, the tonic neck reflexes activated by the muscle spindles of cervical muscles. Upon neck flexion, the muscle spindles trigger the tonic neck reflex without the vestibular system's interference. Upon its unbending (dragging the head forward), the upper extremities are straightened and the lower extremities flex, whereas the effect is opposite at a neck flexion. Note that these effects are opposite to those provided by the vestibular system.

Since the cerebral cortex controls the activity of the brain compartments where the tonic reflex arcs are closed, tonic reflexes can be inhibited as a result of training; i.e., tonic reflexes must be suppressed while learning new movements and combinations. Protecting the body from injuries, tonic reflexes interfere with the performance of new, unusual, and complicated corporal movements.

Particularly important in this regard is the dependence of the body balance in motion on the head position relative to the trunk. An incorrect head movement causes imbalance. The untimely head motion leads to a loss of balance and disturbs the posture, such as a premature or delayed unbending or flexion of the trunk. Thus, the retroflection of the head in the unsupported position and in the conditions of decreased impulse rate from the vestibular system receptors may lead to a prevalence of tonic neck reflexes over statokinetic reflexes and the excessive retroflection and arm flexion; all this decreases the accuracy of striking actions [26–28].

It is very important, particularly when we speak about tonic postural reflexes, not to consider a reflective activity as purely automated, i.e., when a sensory input inevitably causes a motor response. In fact, a reflex is a finely controlled process that may be caused and controlled, to a large extent, by higher centers of the voluntary movement system. The automatism of tonic postural reflexes is manifested only in special cases, for example, in neonatals (due to their still not wholly formed anterior brain) or in patients with cerebral disorders. Most probably, more attention is to be paid to training the vestibular system in athletes in order to overcome these events [29].

Electromyographic Characteristics of the Performance of a Direct Attacking Shot by Volleyball Players with Different Qualifications

Significant differences have been revealed in the work organization of the hand muscles in performing a direct attacking shot on the ball by volleyball players with different qualifications (Fig. 2). All muscle groups are simultaneously involved in contraction in low-skilled athletes and the active phase of flexors and extensors differ insignificantly in duration. The sec-

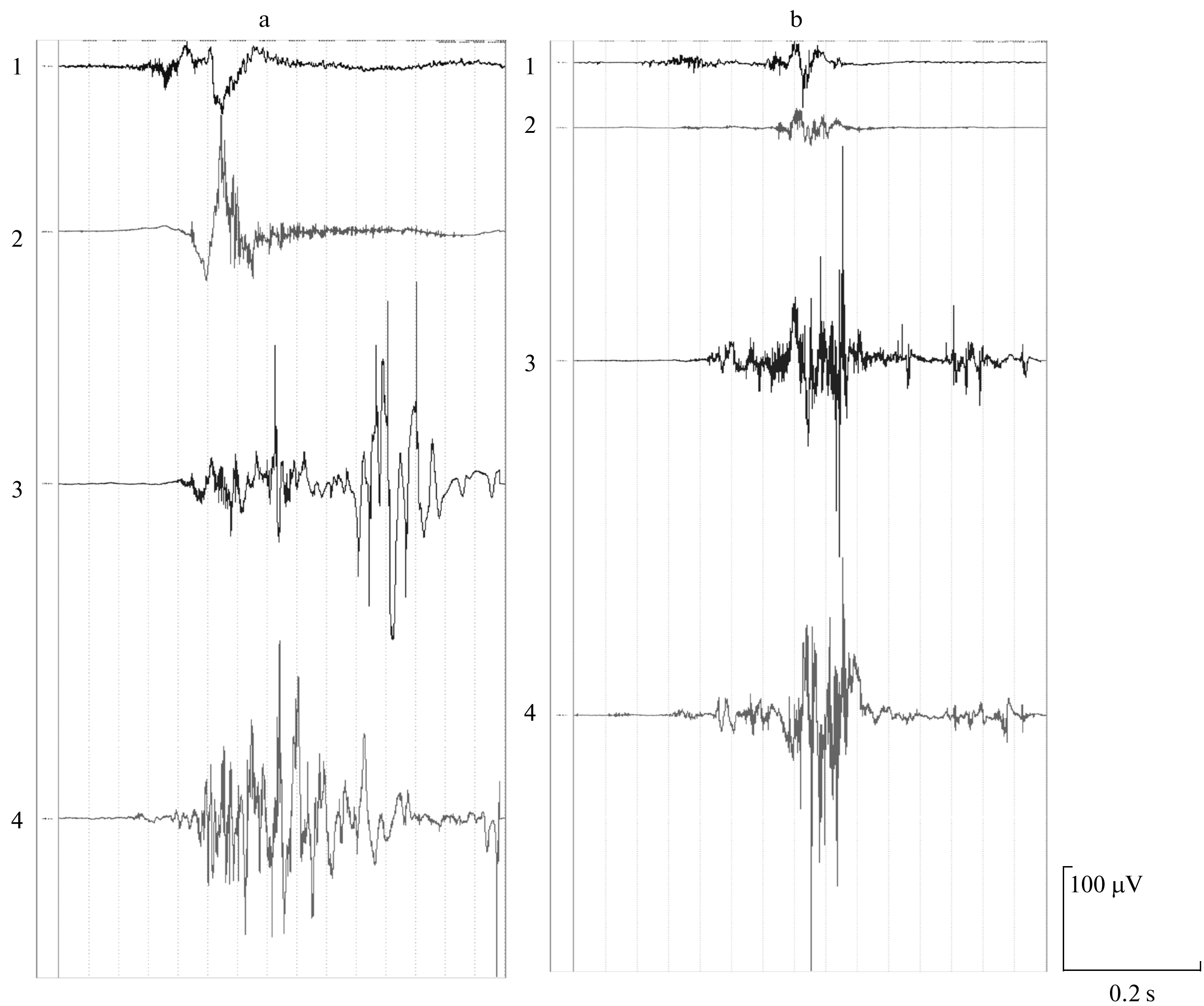

Fig. 2. The electromyogram of the striking hand's muscles in performing a direct attacking shot by (a) highly qualified and (b) low-skilled volleyball players. 1, m. biceps brachii; 2, m. extensor carpi ulnaris; 3, m. flexor carpi ulnaris; 4, m. triceps brachii. Right down, the calibrated signal and the time mark.

ond peak activity of the ulnar flexor muscle of wrist is insignificant in amplitude and duration, which evidences that the hand is mildly involved in the final phase of impact movement and the main contribution to the performance of a shot is made by unbending the ulnar joint.

The phase of activity in the triceps brachii muscle was longer in highly qualified volleyball players, and two discharges were observed on the ulnar flexor muscle of wrist, while the amplitude of the latter was higher than the former. This reflects the involvement of the hand into the final phase of impact movement. The mean amplitude of electrical activity in all muscle groups was significantly higher in qualified athletes than in the control group, while the frequency of oscillations, on the contrary, in the control group exceeded the indicators of qualified athletes (Table 2).

The obtained results allow us to state that highly qualified athletes exhibit a synchronized work of motor units and their simultaneous involvement in the performance of impact movement. The highest electrical activity is recorded on m. triceps brachii and ulnar flexor of the wrist.

Thus, the accuracy of hitting actions in highly qualified athletes is provided by improving the intramuscular (a synchronized work of motor units) and intermuscular coordination (suppressed activity of antagonist muscles and the final explosive activity of distal branch flexor muscles of the striking hand).

The Stabilographical Characteristics of the Performance of a Direct Attacking Shot by Players with Different Qualifications

Stabilographic analysis has revealed differences 2
between low- and high-qualified athletes in shots in a supported posture. A highly qualified athlete in a pre-

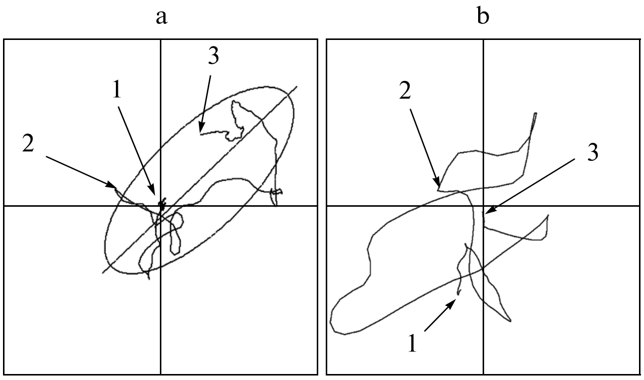

Fig. 3. A stabilogram for the performance of an attacking shot by (a) highly qualified and (b) low-skilled volleyball players. The arrows indicate: 1, the start of performing a shot; 2, the moment of hitting the ball; 3, the end of movement.

paratory phase retains the general center of pressure (GCOP) in the initial position, after which GCOP is shifted forward along the trajectory of a shot and returns back. A dextroflexion is observed only after the contact with the ball and is a consequence of a right-handed inertial movement (Fig. 3a). A beginner performs a GCOP retroflection already in the preparatory phase. The GCOP shift trajectory is flexed at performing a shot, which substantially reduces effectiveness in the performance of a movement. An athlete performs bilateral shaking movements for regaining the balance in the final phase (Fig. 3b).

The balance indicators and the dynamic characteristics of stabilograms also significantly varied in the 1
studied groups of athletes (Table 3). The GCOP displacement values and the asymmetry coefficient in the performance of a given technique action were two times lower in qualified athletes than in beginners. The integrated indicator of the quality of balance function was significantly higher in qualified athletes than in the control. The GCOP motion speed was significantly lower in qualified players in both the frontal and the sagittal planes. The asymmetry coefficients related to the linear speeds in both planes were two times higher in the control group.

The obtained results evidenced fundamental differences between the beginners and the qualified players of student volleyball teams in the skill of performing a direct attacking shot. The revealed differences are associated, first, with the coordination of the trunk and hand movements in the phase of flight, second, with the work organization of the muscles of the striking hand, and, third, with the athletes' GCOP displacement patterns.

To confirm the interconnection between the mentioned parameters, correlations were determined

Table 2. Bioelectrical activity of the striking hand's muscles in the performance of a direct attacking shot in athletes with different qualifications ($X_{av} \pm m$)

Muscles	Highly qualified athletes ($n = 24$)		Low-skilled athletes ($n = 36$)	
	mean amplitude, μV	average frequency, Hz	mean amplitude, μV	average frequency, Hz
m. biceps brachii	74.6 ± 12.5*	240.7 ± 11.4*	45.5 ± 9.3	297.3 ± 16.2
Ulnar flexor of the wrist	281.6 ± 14.1*	345.8 ± 15.6*	144.9 ± 18.7	418.3 ± 19.2
Ulnar extensor of the wrist	98.2 ± 9.2*	190.5 ± 11.5*	67.5 ± 8.7	270.03 ± 13.4
m. triceps brachii	370.2 ± 19.7*	321.5 ± 14.6*	281.4 ± 17.2	378.7 ± 12.7

Table 3. Balance indicators in the performance of a direct attacking shot by volleyball players with different qualifications ($X_{av} \pm m$)

Stabilogram characteristics in the performance of attacking shot	Highly qualified athletes ($n = 24$)	Low-skilled athletes ($n = 36$)
Displacement, mm	4.01 ± 1.05	9.19 ± 2.12*
Coefficient of asymmetry relative to zero, %	17.3 ± 3.6	38.3 ± 6.8*
Quality of the balance function, %	19.3 ± 2.6	10.1 ± 2.2*
Mean linear velocity (frontal), mm/s	64.3 ± 3.7	73.1 ± 3.7
Mean linear velocity (sagittal), mm/s	75.8 ± 5.2	90.9 ± 6.8
Coefficient of asymmetry of linear velocity (frontal), %	2.6 ± 0.4	6.1 ± 0.8*
Coefficient of asymmetry of linear velocity (sagittal), %	0.8 ± 0.1	1.9 ± 0.1*

between the characteristics of a simulated direct attacking shot in the supported position and the performance of this shot in a jump in volleyball players. A correlation was observed between the ψ_1 angular value and the deflection value in the frontal plane (Spearman's rank correlation coefficient $r = -0.58$; $p < 0.05$), as well as between the ψ_3 angular value and the deflection value in the frontal plane (Spearman's rank correlation coefficient $r = -0.62$; $p < 0.05$).

2 Thus, the stabilographic characteristic of a simulated direct attacking shot in the supported position is
3 an adequate reflection of the biomechanical specificities in the performance of this shot in a jump. The pat-
2 tern of movements on a stabilographic platform reflects the very motions of the upper body in a flight posture.

The obtained results allow us to suggest that the
2 training using the computer-based stabilographic training method with a biological feedback will help beginner athletes to control their bodies, elaborate the motor coordination skills in the unsupported position, and raise the effectiveness of their attacking shots.

2 Stabilographic Training with Biological Feedback

The group of 36 low-skilled players was divided into two subgroups of 18 subjects each (the main and the control) to study the effect of a computer-based
2 stabilographic training with a biofeedback (BFB) on the physiological and biochemical parameters of motor actions in the unsupported position and on the accuracy of hitting the ball. Both subgroups were training under the standard program during seven months, but the training program for the main subgroup was additionally enriched by some complex for training the skills to control the GCOP displacements on a stabilograph with a biofeedback. The workouts on
2 a stabilographic training device were performed with a monthly periodicity and included 10 sessions for 10 min. Upon completing the course of training with a BFB, the physiological and biochemical parameters of motor actions using technical tools and techniques (videography and stabilography) were evaluated and the test for the accuracy of shots was performed.

The essence of the workouts with BFB was in the
2 setting volleyball players standing on a stabilographic platform visually controlled the parameters of their own GCOP deflections. The feeling of balance was worked out by the specialized (training tools) target software program that was a component of the computer-based Stabilan-01 complex.

The training tools were software programs that formed images on the monitor and were designed for using in the interactive mode with the subject. Athletes watching a GCOP deflection on the monitor learned during workouts to control their own bodies and improve their balance function.

The analysis of the video recordings with the performance of direct attacking shots showed that the

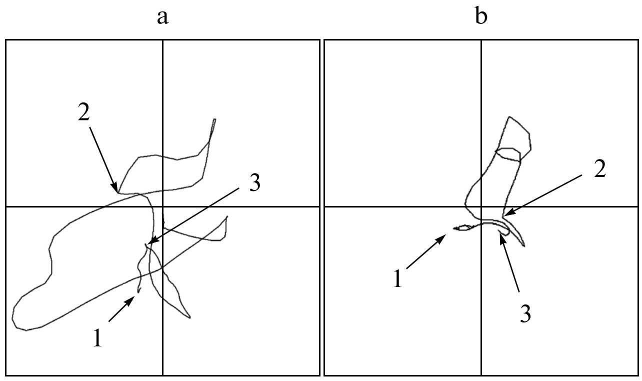

Fig. 4. Fig. 4. A stabilogram for the performance of an attacking shot by volleyball players from the main subgroup in the (a) first and (b) seventh months of training with a biofeedback. The arrows indicate: 1, the start of performing a shot; 2, the moment of hitting the ball; 3, the end of movement.

physiological and biomechanical characteristics in the 3
performance of jump shots became significantly changed over the period of investigation. It is obvious from the results shown in Table 4 that the ψ_3 and ψ_1 angular values significantly increased by the seventh month of the workouts, at the same time, the body retroflection values (angular ψ_1) did not differ from the values recorded in the group of highly qualified athletes (Table 1).

Stabilographic analysis of a shot in a supported 2
position showed that a GCOP retroflection was expressed significantly weaker in the preparatory phase (Fig. 4). The deflection value in the frontal plane by the seventh month accounted for 4.8 ± 0.5 mm, which is significantly lower compared to the indicators in the first month (8.6 ± 1.3 mm, $p < 0.05$), although it remained higher than in the group of qualified athletes (3.5 ± 0.3 mm, $p < 0.05$). There is a probability that workouts on a stabilographic platform with 2
a biofeedback improve the ability to control the body in the unsupported position thanks to the formation of

Table 4. Angular values in a biomechanical model for the 3
position of athletes from the main subgroup ($n = 18$) in the unsupported phase of the performance of a direct attacking shot ($X_m \pm m$)

Period	ψ_1	ψ_2	ψ_3
1st month	124 ± 9	224 ± 13	165 ± 11
7th month	175 ± 11*	221 ± 12	176 ± 12*

* Significant differences between the indicators of highly qualified and low-skilled athletes, $p < 0.05$.

Table 5. Accuracy of volley ball shots with a jump ($X_{av} \pm m$)

Task	The main group ($n = 18$)		Control group ($n = 18$)	
	1st month	7th month	1st month	7th month
Shots in series, % of effective shots	67.2 ± 15.3	85.4 ± 12.4*	66.4 ± 14.3	72.6 ± 10.1*#
Shots with a changed target orientation, % of effective shots	37.8 ± 21.5	66.7 ± 15.8*	38.1 ± 18.1	54.1 ± 11.7*#

* significant intragroup differences, $p < 0.05$; # significant intergroup differences, $p < 0.05$.

the skill to coordinate the movements of the body units.

The formation of such motor skills provided a higher level of accuracy in hitting the ball in a jump. As seen from Table 5, the difference between the subgroups in the effectiveness of shots was absent before taking the training course with GCOP. After having completed the training course, both subgroups exhibited an improved hitting performance; however, the effectiveness of shots in the main subgroup was higher than in the control.

The effect of interfering factors on the accuracy of shots was investigated as well. Changes in the target orientation of shots after the performance of a shot was started significantly decreased the level of accuracy in performing shots (Table. 5). As in the preceding test, there were no differences between the subgroups in the effectiveness of shots at the start of the investigation. The seventh month of training showed that the effectiveness in the performance of shots increased in both subgroups, and, to a larger extent, in the main subgroup than in the control.

CONCLUSIONS

The formation of the ability to maintain the balance and coordination of movements in volleyball players is expressed in the predominance of deflections from the vertical axis in the sagittal plane, a decreased linear speed of the general center of pressure fluctuations, and the coefficient of asymmetry.

The accuracy in the performance of hitting the ball in a jump is provided due to the increased amplitude and a decreased frequency of the bioelectrical activity of muscles, as well as due to the longer activity phase of the striking hand extensor muscles and the emergence of the second explosive activity with higher amplitude than the first activity in the ulnar extensor of the wrist. Thus, the specificity of the manifested adaptive training ability in highly qualified athletes is a result of changes in the patterns of intercentral relationships, which is reflected in changes in the amplitude and frequency parameters of the bioelectrical activity of muscles.

3 The physiological and biomechanical characteristics of a simulated direct attacking shot in a supported position in volleyball players are interrelated with the biomechanical specificities of the performance of this 3
shot with a jump. The physiological support for the accuracy of striking actions is associated, first with the improved coordination of the trunk and hand movements in the phase of flight, second, with the factors of the intramuscular and intermuscular coordination of the striking hand, and, third, with changes in the pattern of the athlete's center of pressure fluctuations.

It has been established that the application of the computer-based stabilographic training with biologi- 2
cal feedback contributes to the optimization of physiological and biomechanical parameters of motor 3
actions in the unsupported position, which, as a result, leads to a higher level of accuracy in the performance of jump shots. Thus, we can gradually improve the performance of professional and sports techniques by activating the specific patterns of the bioelectrical activity of muscles with the intermuscular coordination forms classified as optimal. The obtained results open prospects for the application of the computer-based stabilographic method for improving the perfor- 2
mance techniques in the accuracy- and target-oriented actions in the unsupported position in various sports specialties.

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SPELL: 1. stabilograms, 2. stabilographic, 3. biomechanical